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Biological and Physical Characteristics of Drinking Water from Wells in Kamdini Parish, Northern Uganda.

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Abstract

Access to clean and safe drinking water is a matter of life and death in rural Uganda. Many villagers do not have access to this basic resource and are forced to consume water unfit for human consumption. As a result, many suffer from serious health problems, including water-borne diseases. The provision of clean and safe drinking water in rural Uganda is part of the United Nations Millennium Development Goals and also Uganda's Water Management Policy. In this context, this study examines the biologica, and physical characteristics of drinking water collected from open, shallow areas (i.e., open wells) and that from drilled underground wells installed by a non-governmental organization, NUDF (Northern Uganda Development Foundation). Water collection was conducted in 2008 from Kamdini Parish, Oyam District. Three NUDF wells were randomly selected for sampling as were three random open surface sources that villages have been using (or currently use) as drinking water in the same parish. Field sampling and laboratory analyses were performed according to well established protocols. In general, water samples collected from the NUDF wells had good bacteriological and satisfactory physical characteristics commensurate with Uganda potable water standards, and hence may be used for domestic consumption. The open (old) surface wells on the other hand, showed less satisfactory characteristics and therefore, require water treatment (e.g. settlement or simple filtration and disinfection) prior to direct domestic consumption.

Introduction

The need to provide clean and safe drinking water has been recognized as a priority by major world organizations and policymakers as world population increases and potable water becomes scarce (Wallace et al. 2003). Maintaining and improving the quality of water consumed by humans will become a major challenge in future for many countries since surface water and groundwater supplies are becoming depleted and/or are increasingly becoming contaminated with toxic chemicals (e.g., mercury and lead) and organisms that contribute to water borne disease (Cho et al. 2008, Gerber and Pepper 2004). Many studies (e.g., Lawrence et al. 2002; Sullivan et al. 2002) report that the quality of drinking water in developing countries is much worse than that of developed countries.

The quality of water consumed by people in most rural areas in Uganda is poor and is below the National Drinking Water Standards (UN-WATER/WWAP 2006). Access to clean and safe drinking water is an important prerequisite for improved health, and an essential investment in human capital, which has a direct and immediate beneficial contribution to the quality of life, long-term socioeconomic development of the country, and poverty eradication (UN-WATER/WWAP 2006). Many organizations have begun to focus their efforts on improving Uganda's water sector, by financing the installation of boreholes (freshwater wells). Most recently, six wells have been financed and installed by the Northern Uganda Development Foundation (NUDF), a Prince George-based humanitarian organization which has the mandate of improving the standard of living of the rural people in northern Uganda. There is an urgent need to test the quality of the water from these NUDF wells and compare it with that of the open, shallow wells that the rural people have been drinking.

The current study was conducted in July 2008, at Kamdini Parish in northern Uganda. The main research question addressed was "Is the quality of water from NUDF drilled wells better than that of open, shallow water supplies?" The study assumed that water from NUDF wells would be of better biological and physical quality than that from open sources.

The NUDF wells have been constructed in wetlands (swamps, bogs, and marshes); they have been constructed to depths of 30-33 m. These wells are located outside of densely populated areas such as trading centers or settlements located upstream of water sources and /or close proximity to on-site human excreta disposal facilities like pit latrines, which are commonly used in rural areas (UN-WATER/WWAP 2006). Open water sources are exposed to contamination from a variety of sources (eroded materials, animal excreta, etc.).

The objectives of this study were to: (1) compare the biological and physical properties of water collected from NUDF wells with that from open sources (wells); (2) discuss factors that might account for any differences in water quality; (3) determine if water from these two types of wells meet the National Standards set by Uganda, and for comparison, with the Canadian Drinking Water Guidelines; and, (4) provide appropriate recommendations in managing drinking water in this region of Uganda.

Methods

Three wells were randomly selected for sampling from a total of six NUDF wells established in Kamdini Parish, Oyam District. For comparison, three open surface wells were also randomly selected from open areas that villages have been using (or currently use) for drinking water in the same parish. All wells occur in an area with similar geological characteristics (UN-WATER/WWAP/2006).

Sample bottles were obtained from the Uganda National Water and Sewerage Corporation Central (NWSC) Laboratory in Kampala. They were pre-washed with hot, soapy water, soaked in 3% nitric acid, and were then rinsed with tap water, followed by distilled water, as outlined in the City of Boulder Drinking Water Sampling Methods (2008). Samples were collected from the site on July 15, 2008 and transported following recommended protocols (APHA AWAWA 1992). Briefly, samples were placed in the bottles, properly labeled by well source and sample number, and then packed in an ice-filled cooler and transported to the lab. Samples that required filtration were filtered immediately upon arrival back in the laboratory in Kampala, the capital city (which is about four hours drive from the sampling sites). Furthermore, samples were acid-preserved and/ or refrigerated, as required (City of Boulder Drinking Water Sampling Methods 2008).

Due to cost constraints, only six water samples (one from each well) were collected for analysis. For field blanks, laboratory millipore water was transported to the field in a sealed container. All field blank bottles were then filled from the blank water in the field as a test of sampling integrity (City of Boulder Drinking Water Sampling Methods 2008).

The analytical methods used are outlined in Table 1 and detailed in APHA AWAWA (1992).

Faecal coliforms in water were determined using Method 1604 (Oshiro 2002). This method involves membrane filtration using a simultaneous detection technique (MI) medium. Water samples (100mL) were filtered through a 47-mm diameter, 0.45µm pore size cellulose ester membrane filter that retains bacteria present in the water sample. The filter was placed on a 5-mL plate of MI gar or on an absorbent pad which was saturated with a 2-3 mL of MI broth. The plate was then incubated at 35^{o}C for 24 hours. The bacterial colonies should grow on the plate, and they are then observed for the presence of blue color from the breakdown of IBDG by CPU enzyme β-glucuronidase and fluorescence under

Table 1. Methods used in potable water sample analysis, Kamdini Parish (July 2008).

Parameter	Unit	Method
pH	-	Glass Electrode
Electrical Conductivity	µS/cm	Electrolytic
Colour: apparent	PtCo[a] scale units	Spectrophotometric
Turbidity	NTU[b]	Turbidimetric
Total Suspended Solids	mg/L	Spectrophotometric
Hardness: total as CaCO3	mg/L	Titrimetric
Faecal Coliforms	CFU[c]/100mL	Membrane Filtration

[a] PtCo scale units are a measure of apparent colour of the well water. The platinum-cobalt (PtCo) method of measuring colour is the standard, the unit of colour being that produced by 1mg platinum/L in the form of the chloroplatinate ion (APHA AWAWA 1995).

[b] NTU = nephelometric turbidity unit.

[c] CFU = colony-forming unit in 100mL of well water.

longwave ultraviolet light (366mm) from the breakdown of MUGal by TC enzyme β-glucuronidase (Oshiro 2002).

CFU (colony-forming unit in 100mL of well water) was calculated as follows (Oshiro 2002):

CFU/100 mL = [Number of fluorescence colonies + Number of blue, non-fluorescence colonies (if any)/ Volume of sample filtered (mL)] x 100

Field sampling and laboratory analysis of the water samples were done by a trained and certified technician, and the report on the results of the analysis was performed and certified by two scientists at the National Water and Sewerage Corporation in Kampala. This is in accordance with the regulations established by NWSC.

Results and Discussion

Water samples from the NUDF wells showed good bacteriological and satisfactory physical characteristics that meet the Uganda (national) and Canadian potable water standards, and hence may be used for domestic consumption. The old surface water wells on the other hand, showed less satisfactory characteristics and water, therefore, may require treatment (e.g. simple filtration and disinfection) prior to direct domestic consumption (Tables 2, 3 and 4). Results of the field blanks were not provided to the researcher. This is in accordance with the NWSC regulations.

The pH value in water is a measure of the hydrogen ion concentration. Pure water (with no dissolved species) has a pH value of 7. Water with a pH value lower than 7 is considered acidic, and with a pH greater than 7, basic (Free Drinking Water 2010, Manahan 2005). The normal range for pH in potable water is 6.5-8.5, which is equivalent to the Ugandan standard and the Canadian guideline. Water samples from old wells in Ogek Village, and both old and NUDF wells at Amaji are considered acidic (Tables 3 and 4), soft, and corrosive (Free drinking Water 2010) because their pH values are low (< 6.5). The low pH values might be partly attributed to the presence of dissolved metal ions such as aluminum, iron, zinc and manganese, in the aquifer which contribute to acidity through hydration reactions (Free Drinking Water 2010, Manahan 2005). These metal ions can cause premature damage to metal piping, and have associated aesthetic problems such as a metallic or sour taste, and staining of laundry (Free Water Drinking 2010). Low pH in water can be treated with the use of a neutralizer, such as soda ash (Manahan 2005). However, soda ash increases the sodium content of water (Free Drinking Water 2010). While the ideal pH level of drinking water should be in the range 6.5-8.5, the human body maintains pH equilibrium on a constant basis and is not harmed by consumption of waters exhibiting mild acidity (Health Canada 1995).

Water from both NUDF and Old wells had EC levels much lower than the standard (maximum EC of 1000 μS/cm) established by Uganda for drinking water. A Health Canada Guideline for maximum acceptable level of EC has not yet been established. Electrical conductivity (EC) is an indirect measure of the amount of dissolved ions in a water sample; pure water is not a good conductor of electricity, but water with a high concentration of ions (the transport medium for electrical current) will have a high EC (Lenntech 2010).

Water from both NUDF and old wells had higher (with water from old wells considerably higher) apparent colour units than the established standards (Tables 2, 3, and 4). Colour in water that contains suspended matter is defined as “apparent colour” (AP); and “true colour” is measured in water samples from which particulate matter has been removed by centrifugation (Health Canada 1995). According to Health

Table 2. Biological and physical characteristics of water samples collected from NUDF and Old wells at Kulu Aguc, Buga Village, Kamdini Parish (July 2008).

Parameter	Unit	Kulu Aguc, Buga Village, Kamdini Parish (NUDF Well)	Kulu Aguc, Buga Village, Kamdini Parish (Old Well)	Ugandan Standard for Potable Water	Canadian Drinking Water Guideline for Potable Water
WS Sample Nr	--	C-0068	C-0069		
pH	--	6.56	6.95	6.5-8.5	6.5-8.5
Electrical Conductivity	µS/cm	65.2	60	1000	n.a.
Colour: Apparent	PtCo[a] scale units	17.5	175	15	≤15
Turbidity	NTU[b]	4.1	40	5	0.3/1.0/0.1[d]
Total Suspended Solids	mg/L	3	29	0	n.a
Hardness: Total as CaCO3	mg/L	150	68	500	n.a.
Faecal Coliforms	CFU[c]/100mL	0	14	0	0

[a] PtCo scale units are a measure of apparent colour of the well water. The platinum-cobalt (PtCo) method of measuring colour is the standard, the unit of colour being that produced by 1mg platinum/L in the form of the chloroplatinate ion (APHA AWAWA 1995).
[b] NTU = nephelometric turbidity unit.
[c] CFU = colony-forming unit in 100mL of well water.
[d] Based on conventional treatment/slow sand or diatomaceous earth filtration/membrane filtration (Health Canada 2008).
n.a. = not available. Health Canada Guidelines for maximum acceptable levels of electrical conductivity (EC), total suspended solids (TSS), and hardness have not yet been established.

Canada (2008), the Canadian drinking water quality guideline for colour is an Aesthetic Objective (AO) of ≤ 15 TCU (true colour unit).

The presence of colour in drinking water may be indirectly linked to health; however, its primary importance in drinking water is aesthetic (Nova Scotia Environment 2008). Colour in well water may indicate presence of natural substances, such as dissolved organic matter (humic substances, tannin, lignin, or coal), and inorganic materials that include iron, manganese, copper, and zinc (Nova Scotia Environment 2008). Furthermore, colour in well water may also indicate insufficient water treatment, or the presence of surface or subsurface contaminants in the water supply that include surface water containing dissolved organic matter and suspended matter/industrial wastes (Nova Scotia Environment 2008). Colour in drinking water can be improved by using simple water treatment options (filtration, boiling, etc.).

Table 3. Biological and physical characteristics of water samples collected from NUDF and Old wells at Ogek Village, Kamdini Parish (July 2008).

Parameter	Unit	Ogek Village, Kamdini Parish (NUDF Well)	Ogek Village, Kamdini Parish (Old Well)	Ugandan Standard for Potable Water	Canadian Drinking Water Guideline for Potable Water
WS Sample Nr	--	C-0070	C-0071		
pH	--	6.90	5.61	6.5-8.5	6.5-8.5
Electrical Conductivity	µS/cm	68.40	45.6	1000	n.a.
Colour: Apparent	PtCo[a] scale units	16	186	15	≤15
Turbidity	NTU[b]	4	36	5	0.3/1.0/0.1[d]
Total Suspended Solids	mg/L	2	60	0	n.a
Hardness: Total as CaCO3	mg/L	50	60	500	n.a.
Faecal Coliforms	CFU[c]/100mL	0	34	0	0

[a] PtCo scale units are a measure of apparent colour of the well water. The platinum-cobalt (PtCo) method of measuring colour is the standard, the unit of colour being that produced by 1mg platinum/L in the form of the chloroplatinate ion (APHA AWAWA 1995).
[b] NTU = nephelometric turbidity unit.
[c] CFU = colony-forming unit in 100mL of well water.
[d] Based on conventional treatment/slow sand or diatomaceous earth filtration/membrane filtration (Health Canada 2008).
n.a. = not available. Health Canada Guidelines for maximum acceptable levels of electrical conductivity (EC), total suspended solids (TSS), and hardness have not yet been established.

Water from NUDF wells has turbidity levels <5 NTU (nephelometric turbidity unit), and that from old wells is much higher than 5 NTU (Tables 2, 3, and 4). Turbidity is defined as a measure of the degree to which the water looses its transparency due to the presence of suspended particulates (Lenntech 2010). Uganda establishes that the turbidity of drinking water should not be more than 5 NTU. This is also the standard that has been established by World Health Organization (WHO), which further states that the ideal standard for turbidity should be below 1 NTU (Lenntech 2010). Health Canada establishes the ideal standard for turbidity of drinking water (Health Canada 2008). The main impact of turbidity on humans is aesthetic: nobody likes the look of dirty water (Lenntech 2010). Turbidity can be reduced by simple filtration (to remove suspended particles) of drinking water. Suspended particles enhance the attachment of heavy metals and many other toxic organic compounds and pesticides, thus, increasing or decreasing the risk of exposure to these toxins (Lenntech 2010).

Table 4. Biological and physical characteristics of water samples collected from NUDF and Old wells at Amaji Tenam Village, Kamdini Parish (July 2008).

Parameter	Unit	Amaji Tenam Village, Kamdini Parish (NUDF Well)	Amaji Tenam Village, Kamdini Parish (Old Well)	Ugandan Standard for Potable Water	Canadian Drinking Water Guideline for Potable Water
WS Sample Nr	--	C-0072	C-0073		
pH	--	4.90	5.0	6.5-8.5	6.5-8.5
Electrical Conductivity	µS/cm	45.6	48.6	1000	n.a.
Colour: Apparent	PtCo[a] scale units	18	163	15	≤15
Turbidity	NTU[b]	5	32	5	0.3/1.0/0.1[d]
Total Suspended Solids	mg/L	4	20	0	n.a
Hardness: Total as CaCO3	mg/L	60	62	500	n.a.
Faecal Coliforms	CFU[c]/100mL	0	30	0	0

[a] PtCo scale unts are a measure of apparent colour of the well water. The platinum-cobalt (PtCo) method of measuring colour is the standard, the unit of colour being that produced by 1mg platinum/L in the form of the chloroplatinate ion (APHA AWAWA 1995).
[b] NTU = nephelometric turbidity unit.
[c] CFU = colony-forming unit in 100mL of well water.
[d] Based on conventional treatment/slow sand or diatomaceous earth filtration/membrane filtration (Health Canada 2008).
n.a. = not available. Health Canada Guidelines for maximum acceptable levels of electrical conductivity (EC), total suspended solids (TSS), and hardness have not yet been established.

Suspended particles might bind these toxins so that the risk is reduced, or might keep them suspended and increase the risk.

In general, levels of total suspended solids (TSS) in both NUDF and old wells are low, with NUDF wells having much lower levels than that of old wells (Tables 2, 3, and 4). Total suspended solids (TSS) refer to solids (e.g., silt, organic matter, other particulates) in water that can be trapped by a filter (Kentucky Water Watch 2010). Neither Health Canada nor US Environmental Protection Agency (EPA) provides a standard for TSS in drinking water (Murphy 2007, Health Canada 2008). In Uganda, however, a standard for TSS in drinking water is 0 mg/L. High concentrations of TSS are known to cause many problems (blocking light from reaching submerged vegetation which reduces photosynthetic rate, less dissolved oxygen, plant and fish death, reduced production and growth rates in fish and plants, etc.) for stream and aquatic life (Kentucky Water Watch 2010). The presence of TSS in drinking water for humans may affect its taste (Health Canada 1991). Total suspended solids is also linked to turbidity, so high TSS may also be an indicator of contamination from allochthonous (outside the water body) sources. Simple filtration of drinking water from these wells can remove or reduce the concentration of TSS.

Water hardness is commonly associated with dissolved minerals such as calcium, magnesium and sometimes iron. The most common observation of hard water is the precipitate formed by soap (Manahan 2005, Wilkes University 2010, Health Canada 1995). Levels of hardness of water from both NUDF and old wells are much lower than the standard used in Uganda. In Canada, a maximum acceptable level of hardness has not yet been established because public acceptance of hardness varies according to local conditions (Health Canada 1995). Hard water is not a human health risk, but a nuisance because of mineral buildup on fixtures and poor soap and/or detergent performance (Wilkes University 2010). However, water supplies with hardness greater than 200 mg/L are considered poor; and those in excess of 500 mg/L are unacceptable for most domestic uses (Health Canada 1995). Furthermore, it has been suggested that a hardness level of 80 to 100 mg/L (as $CaCO_3$) provides an acceptable balance between corrosion of well pipes and incrustation (Health Canada 1995).

Coliform bacteria are indicator organisms whose presence indicate that water borne pathogens of faecal origin may be present (Gerber and Pepper 2004). The maximum acceptable concentration of total coliforms in potable drinking water is zero detectable colonies per 100 mL (Health Canada 2008). Old wells contained unacceptable levels of faecal coliforms; while NUDF wells had no concentrations of faecal coliforms (Tables 2, 3, and 4).

Total coliforms belong to the family *Enterobacteriaceae* and have been defined in the 20th edition of Standard Methods for the Examination of Water and Wastewater (APHA AWAWA 1998) as follows: (1) all facultative anaerobic, non-spore-forming, rod-shaped bacteria that ferment lactose with gas and acid formation within 48 hours at 35 ^{o}C; (2) many facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped bacteria that develop red colonies with a metallic (golden) sheen within 24 hours at 35 ^{o}C on an Endo-type medium containing lactose; or (3) all bacteria possessing the enzyme β-galactosidase, which cleaves a chromogenic substrate (e.g., orto-nitrophenyl-β-D-galactopyranoside), resulting in release of a chromogen (ortho-nitrophenol). These definitions refer to various species of the bacterial genera *Escherichia*, *Klebsiella*, *Enterobacter*, *Citrobacter*, *Serratia*, and many others (Leclerc et al. 2001 as quoted in Health Canada 2010). A subset of total coliform group, thermotolerant coliforms (previously known as faecal coliforms), has been used as a surrogate for *E. coli* in water quality testing (Health Canada 2010). Sources of total coliform include *E.coli* (which is faecal specific), water, soil, and vegetation (Leclerc et al. 2001 as quoted in Health Canada 2010). Faecal matter contains very high concentrations of coliforms.

Testing for faecal coliforms should be conducted in all drinking water systems in Uganda. However, the number, frequency, and location of samples for faecal coliforms testing will depend on the type and size of the system and jurisdictional requirements (Health Canada 2010) treatments of water with total coliforms include boiling and disinfection of the water.

Conclusions and Recommendations

The main purpose of the study described in this paper was to investigate biological and physical characteristics of drinking water in a rural setting. Results from the study suggest that water from NUDF wells has good bacteriological and satisfactory physical characteristics that meet the Ugandan and Canadian standards for potable water, and can be used for domestic consumption. Water from old surface wells on the other hand, has less satisfactory characteristics and requires treatment (e.g. boiling or disinfection) prior to direct domestic consumption.

Access to clean and safe drinking water in rural Uganda is important. Monitoring and testing the quality of rural water in Northern Uganda should be done on regular basis, depending on available resources. Furthermore, the villagers should be educated on safe collection, handling, and storage practices of potable water from NUDF wells to avoid contamination.

References

APHA AWAWA (American Public Health Association, American Water Works Association and Water Pollution Control Federation). 1992. Standard methods for the examination of water and wastewater. 18th Edition. Maryland, USA.

APHA AWAWA (American Public Health Association, American Water Works Association and Water Environment Federation). 1995. Standard methods for the examination of water and wastewater. 19th Edition. Washington, DC, USA.

Cho, D., Ogwang, T., Opio,C. 2008.Conceptualization of principal variable selection for computing the Water Poverty Index. Proceedings of the Annual Conference of Administrative Sciiences Association of Canada, Social Responsibility. Halifax, Nova Sotia, May 24-27, 2008. Volume 29, No. 29.

City of Boulder. [Online]. City of Boulder drinking water sampling methods. (6 May 2008). http://bcn.boulder.co.co.us/basin/data/COBBWQ/SourceWater.htm

Free Drinking Water. [Online]. Color of drinking water explained in detail. (January 3, 2010). http://www.freedrinkingwater.com/water-education2/815-color-water.htm

Gerba, C.P., Pepper, I.L. 2004. Microbial contaminants. Chapter 17 in J.F. Artiola, I.L. Pepper and M.L. Brusseau (eds) Environmental Monitoring and Characterization. Elsevier Academic Press. Pp. 313-333.

Health Canada. [Online]. Significance of total Coliforms in drinking water. (January 3, 2010). http:www.hc-sc.gc/ewh-semt/pubs/water-eau/coliforms-coliforms/significance-import

Health Canada. 1995. Hardness. Ottawa.

Health Canada. 2008. Turbidity. Ottawa.

Health Canada. 1991. Total dissolved solids. Ottawa.

Kentucky Water Watch. [Online]. Total suspended solids and water quality. (January 3, 2010). http://kywater.org/ww/ramp/rmtss.htm

Lawrence, P., Meight, J., Sullivan, C. 2002. The Water Poverty Index: an international comparison. Keele Economics Research Papers, 19 October, pp.1-17.

Lenntech. [Online]. Water conductivity. (January 3, 2010). http://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm

Manahan, S.E. 2005. Environmental Chemistry. Eighth Edition. CRC Press, Boca Raton, FL.

Nova Scotia Environment. 2008. Assessed at www.gov.ns/nse/water/

Oshiro, R.K. 2002. Method 1604: Total Coliforms and *Escherichia coli* in water by membrane filtration using a simultaneous detection technique (MI Medium). EPA-821-R-02-024. U.S. Environmental Protection Agency, Office of Water (4303T). 1200 Pennsylvania Avenue, NW, Washington, DC 20460.

Sullivan, C., Meigh, J, Fediw, T. 2002. Derivation and testing of the Water Poverty Index phase I-final report. Volume 1-Overview, Joint Project by the Department for International Development and the natural Environment Research Council. Contract No: C24.

UN-WATER/WWAP. 2006. National Water Development Report: Uganda. Prepared for the 2nd UN World Water Development Report, "Water, a Shared Responsibility." UN-WATER/WWAP/2006/9 Report.

Wallace, J., Acreman, M., Sullivan, C. 2003. The sharing of water between society and ecosystems: from conflict to catchment-based co-management. Philosophical Transactions of the Royal Society of London, 358, pp. 2011-2026.

Wilkes University. [Online]. Hard water. (January 3, 2010). http://www.water-research.net/hardness.htm

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