Assessment of Microbial Quality of Surface Water Sources of Luvuvhu River Catchment, South Africa

Mailula M.A. and Gumbo JR

Abstract**—**The majority of global rural communities, including South Africa, rely on untreated surface water for human consumption. The consumption arises partly from the local municipalities' erratic supply of treated drinking water to its residents. Here we report on the microbial load of surface water sources and after simple water treatment using hand dug wells in Vhembe District, South Africa. The results of the pH were in the range 6.90 to 8.86 with the water temperature ranging from 16 to 25 ºC. The turbidity values were in the range 2.53 to 393.67 NTU which shows problem of soil erosion, rainfall runoff and wastewater discharge by upstream sewage works. The faecal coliform counts varied between 0 cfu/100 ml to > 300 cfu/100 ml, *E. coli* counts varied between 0 cfu/100ml and >300 cfu/100 ml, and faecal *Streptococci* counts between 1.5 cfu/100 ml to >300 cfu/100 ml. The microbial load in the hand dug wells was considerably lower than that of the Nandoni reservoir (due to soil filtering capacity). The existence of a high microbial load that exceeded acceptable regulatory guidelines render these water sources unsafe for human consumption. Physical conditions, such as water temperature, also enable bacterial propagation. Thus, the advent of climate change and especially the warming of surface waters may exacerbate the current condition of the use of untreated surface water sources.

Keywords **—**hand dug wells; E. coli; waterborne diseases; turbidity, riverbank filtration

I. Introduction

South Africa is a water stressed country. This condition puts our water resources at risk and creates water stress owing to the imbalance between water use and water availability. Water stress in turn affects fresh water resources' quantity (aquifer over-exploitation, dry rivers) and quality (eutrophication, organic matter pollution, and saline intrusion). Nonetheless, the quality of water is more important than quantity in water management. The objective of water management is to ensure the microbial safety of water user for domestic, industrial and agricultural purposes. Water Authorities are, therefore, doing their best to protect water sources and ensure that the water reaching the community is safe or free from any organisms or substances which are harmful to humans [1]. The common source of surface water pollution, however, is human and animals wastes. The water borne pathogens caused by these sources is of concern because there are many rural communities in South Africa that utilize unprotected sources for drinking water [2-3]. Currently, water industries are only focused on the removal of waterborne pathogens in water treatment than preventing these pathogens from entering the water environment [1].

Most communities in rural areas, such as the Dididi village in the Limpopo Province of South Africa, have limited access to municipal water and may resort to the use of nearby surface water sources that have a poor microbial quality for their daily sustenance. The use of untreated water for drinking and other domestic uses, such as food preparation, washing clothes and bathing, may be harmful to the communities. Lack of safe drinking water can lead to a number of diseases such as cholera, diarrhea and gastro-enteritis. These diseases cause high death rates per year in the World, especially with children under the age of five [4-5]. Thus, the contamination of drinking water is a serious problem in developing countries such as South Africa. Microbial pathogens have been noted as the main contaminants of most developing countries' water sources [6]. Therefore, an effective management and operation of water sources seeking to protect the source of drinking water is important. This demands action by water suppliers, environmental protection agencies, and health bodies [7]. The quality of water sources protection measures is an important component in controlling the presence of pathogens in final drinking water [8]. Diarrhea is one of the acute disease problems in many rural areas, including those in South Africa, especially those areas with no access to water source [9-10]. Village communities near the rivers and reservoirs use water from untreated water sources for drinking, laundry and recreation purposes. A study by Bessong et al. [10] notes that river water used by the Venda communities of South Africa was of poor microbial quality and unacceptable for human consumption.

Thus, to improve the microbial quality of the drinking water, some of the rural communities have resorted to hand digging of wells (Figure 1).

The hand dug wells are also commonly used in rural areas and are dug inside a river channel or along a river bank [11]. The river sand is then used to filter out pathogens as the water fills the open space inside the hand dug well [12]. The wells, which

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J.R. Gumbo is with the University of Venda, Department of Hydrology & Water Resources (e-mail: jabulani_gumbo@yahoo.co.uk; jabulani.gumbo@univen.ac.za).

M.A. Mailula was with the University of Venda, Department of Hydrology & Water Resources as Honours student. (e-mail: tshego1avrol@yahoo.com).

are usually quite shallow, typically 0.3 m to 0.6 m deep, are very important to rural communities, especially in areas where surface water is scarce. Nonetheless, these wells are easily prone to contamination. The major objective of the study was to assess the microbial quality of surface water sources in both the Luvuvhu River catchment and hand dug wells that are dotted along the Nandoni Dam, Vhembe district of the Limpopo province of South Africa.

II. MATERIALS AND METHODS

A. Location of the Study Area

The study area is the Luvuvhu river catchment (Mvudi river is a tributary of the Luvuvhu River flows into Nandoni dam), Vhembe district in Limpopo Province (Figure 1).

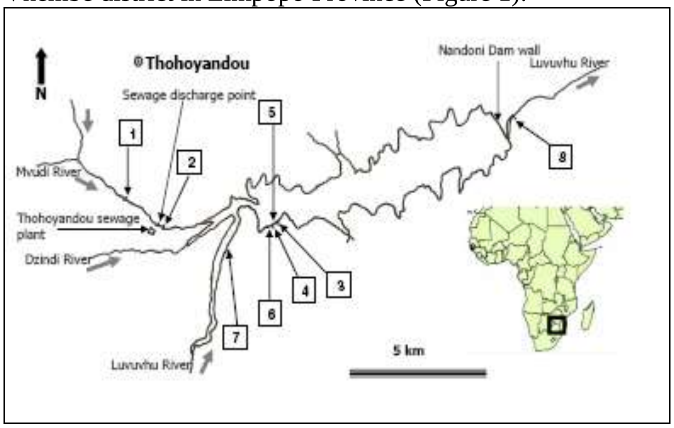

Fig 1: The location of sample sites in the Luvuvhu river catchment

B. Sample Collection and Onsite Physical Measurements

The water samples (Table 1) were collected monthly from August to November, 2009.

TABLE 1: DESCRIPTION OF THE SAMPLING POINTS

Site #	Site Name	Description
1	Mvudi River	Upstream of Thohoyandou sewage plant
2	Mvudi River	Downstream of Thohoyandou sewage plant
3	Hand dug well #1	A shallow well approximately 30 cm deep and 5 m from edge of Nandoni dam
4	Nandoni dam	Nandoni dam water close to hand dug wells
5	Hand dug well #2	A shallow well approximately 30 cm deep and 1 m from edge of Nandoni dam
6	Hand dug well #3	A shallow well approximately 30 cm deep and 10 m from edge of Nandoni dam
7	Luvuvhu River	Upstream and is just before the confluence of Dzindi and Mvudi Rivers
8	Luvuvhu River	Downstream of Nandoni dam well

Water samples were collected for microbiological analysis in sterile 250 ml glass bottles, transported in a cooler box to the laboratory and analyzed within 24 hours. The onsite measurements, in triplicate, were pH and water temperature (a pH meter (Multi 340! /set Instruments, Germany) Supplied by Wissenschaftlich-Technische werkstatten GMBH) and turbidity (portable 2100P turbidity meter supplied by LABTEC, South Africa). The pH meter was calibrated according to the manufacturer's guidelines using pH buffers of four and seven.

C. Microbiological Analysis

Water samples were analyzed for *E. coli*, faecal *Streptococci*, total coliform and faecal coliform and determined using the membrane filtration method [13]. The water samples were tested in duplicate with the media prepared according to the instruction of the manufacturer. The media used was Chromogenic, Slanetz and Bartley and the agar that was used were Nutrient and Bile aesculin (Oxoid) while mFC (Labretoria).

D. Climate Data

The climate data on rainfall and air temperature was obtained from the South African Weather Station at Thohoyandou.

E. Data Analysis

The Microsoft Office Excel 2003 was used for both the data analysis and drawing of graphs. The results on water collection from surface water sources were summarized using average and standard deviation in triplicates for physical water quality and duplicates for microbial water quality. The differences in water quality parameters between upstream and downstream for each sample point were analysed using one way ANOVA with MS Excel 2014. The level of significance for the tests was set to $p<0.05$. The correlation was used to determine of the water quality parameters with climate data on rainfall and air temperature.

III. RESULTS AND DISCUSSION

A. The Effects of Physical Parameters on the Microbial Growth of Organisms

The water pH at all sites was in the range 6.90 to 8.86 (Tables 2 to 4). According to Makhera et al. [14] pH values ranging from 3.0 to 10.5 could favour the growth of both indicators and pathogenic micro-organisms.

TABLE 2: THE PHYSICAL PARAMETER DATA FOR THE MVUDI SAMPLING SITE

	Mvudi upstream			Mvudi downstream		
Months	**pH**	**Turbidity (NTU)**	**Water temp oC**	**pH**	**Turbidity (NTU)**	**Water temp oC**
Aug-09	8.4±0.3	11.6±0.9	16±0	7.9±0.1	10.7±0.3	18±0
Sept-09	7.5±0.0	10.5±0.3	18±0	7.2±0.2	17.4±0.3	20±0
Oct-09	8.3±0.4	3.5±0.3	21±0	7.7±0.2	11.8±0.9	22±0
Nov-09	6.9±0.3	17.6±0.6	19±0	7.2±0.3	28.3±0.6	21±0

TABLE 3: THE PHYSICAL PARAMETER DATA FOR THE NANDONI DAM AND HAND DUG WELLS

	Nandoni reservoir			Hand dug well #1		
Months	**pH**	**Turbidity (NTU)**	**Water temp oC**	**pH**	**Turbidity (NTU)**	**Water temp oC**
Aug-09	8.1±0.1	34.7±2.1	20±0	7.6±0.5	2.5±0.3	22±0
Sept-09	7.7±0.1	37.7±0.6	23±0	7.1±0.1	39.0±1.0	20±0
Oct-09	8.7±0.6	113.8±4.4	21±0	7.6±0.9	12.6±1.8	20±0
Nov-09	8.5±0.5	13.6±0.9	21±0	8.4±0.5	3.0±0.4	20±0

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TABLE 4: THE PHYSICAL PARAMETER DATA FOR THE LUVUVHU SAMPLING SITE

	Luvuvhu upstream			Luvuvhu downstream		
Months	**pH**	**Turbidity (NTU)**	**Water temp oC**	**pH**	**Turbidity (NTU)**	**Water temp oC**
Aug-09	8.4±0.1	13.2±2.6	20±0	8.1±0.0	6.3±0.3	17±0
Sept-09	8.5±0.1	11.3±0.1	25±0	8.0±0.1	5.6±0.1	19±0
Oct-09	8.9±0.1	8.8±1.6	24±0	7.9±0.2	7.8±0.1	19±0
Nov-09	7.9±0.4	16.6±0.8	20±0	8.4±0.3	8.9±0.1	19±0

In addition, microorganisms are affected differently in the water sources due to the changes of pH and temperatures of water sources [11,15]. Nevertheless, the pH of the study sites was within the South African Water Quality Guidelines standard limits and WHO guideline values [16-17].

All the pH values were within the acceptable the South African Water Quality Guidelines Standard limits (6.0 to 9.0) for domestic use and have no effects to human health, irrigation of crops and watering of livestock, aquatic ecosystem, as well as recreation such as bathing and swimming [16]. A similar study by Zamxaka et al. [4] found the pH range of 6.8 to 8.3 and is thus in agreement with this study (6.90 to 8.86) and indicates that the pH levels may promote the growth of bacteria.

The values of turbidity at all sites ranged from 2.53 NTU to 393.67 NTU (Tables 2 to 3). The increase in turbidity levels between Mvudi upstream and downstream was probably due to rainfall, for there is a positive correlation between rainfall and turbidity levels (Table 5). The high values of turbidity are influenced by rapid erosion of surface soils into the rivers due to high heavy rain such as that received in November 2009. This is supported by the study of Abanyie et al. [18] who found that the turbidity in surface water sources increased during the wet seasons and may be associated with microbial pathogens. The Thohoyandou sewage plant may also contribute to the high levels of solids discharged at the Mvudi downstream but this was ruled out since there was no difference between upstream and downstream (p>0.05).

TABLE 5: CORRELATION BETWEEN THE CLIMATE DATA AND PHYSICAL PARAMETER OF THE MVUDI SAMPLING SITE

	Average Air Max Temp (°C)	Total Rainfall (mm)	Turbidity (NTU) upstream	Turbidity (NTU) downstream	Water Temp(°C) downstream	Water Temp(°C) upstream
Average Air Max Temp (°C)	1.00					
Total Rainfall (mm)	0.13	1.00				
Turbidity (NTU) upstream	-0.43	**0.77**	1.00			
Turbidity (NTU) downstream	0.22	**0.93**	0.78	1.00		
Water Temp(°C) downstream	**0.97**	0.33	-0.27	0.38	1.00	
Water Temp(°C) upstream	**0.95**	0.19	-0.46	0.16	0.96	1.00

There was, however, a significant difference (p< 0.05) in the turbidity levels for the sample points from the Luvuvhu upstream and downstream. In between these two sample points, Luvuvhu upstream and downstream likes the giant Nandoni Reservoir, which may account for the low turbidity levels downstream of Nandoni dam, since the suspended materials may silt in the Nandoni Reservoir? Most of the turbidity values were above the South African water Quality Guidelines Standard limits (1 to 5 NTU) for domestic use [16]. High turbidity with more than 10 NTU is associated with high pathogens counts [18].

The water temperature for all sampling sites was between 16ºC and 25ºC during the sampling time (Tables 2 to 4). There was a positive correlation between water temperature and air temperature (Table 5). The recommended standard limits which carry no risk are temperatures less than 24ºC for domestic use. The water temperature measurements noted in this study were of no significant effects on domestic use. Several studies noted that water temperature plays an important role in the survival of microorganisms [15,16, 19]. The recommended limits of surface water temperature varied between 18 ºC to 24 ºC [16]. The temperatures' impact on surface water could explain the high coliform counts observed in this period at almost all sites in this study and was also confirmed in studies by Fatoki et al. [19] and Zamxaka et al. [4]. Thus our research findings showed that the temperature range may also promote the growth of bacteria in surface water sources

B. Microbiological Water Quality of Surface Water Sources in the Luvuvhu River Catchment

The study observed a great variation in the microbiological water quality of the surface water sources at all sites (Tables 6 to 8). The poor microbial quality of the water sources highlights the public health concerns for communities living near these sources. The study showed that human and animal activities at the water collection sites may affect the water quality greatly.

The quality of water that was collected from Mvudi River was microbial poor. The faecal coliform in the upstream of Mvudi River varied between 52 to >300 cfu/100 ml (Table 6) and 0 to >300 cfu/100 ml in downstream of Mvudi River in August, September and October. The maximum limits for no risk for faecal coliform is 0 cfu/100 ml [16]. This situation showed that the faecal coliform in the upstream was extremely higher than the recommended limits. These high counts of faecal coliforms in the river indicate that the river was probably contaminated by discharge from the Thohoyandou sewage plant [17] but this was ruled out since there was no difference between upstream and downstream (p>0.05). A positive correlation between faecal coliform and rainfall (0.80) was also observed and this implies that animal and human wastes were washed into the Mvudi River after a rain event, such as the one that occurred in November 2009 during the study.

TABLE 6: THE MICROBIAL QUALITY (CFU/100 ML) DATA FOR THE MVUDI SAMPLING SITE

	Mvudi upstream			Mvudi downstream		
Months	**Faecal coliform**	***E. coli***	**Faecal streptococci**	**Faecal coliform**	***E. coli***	**Faecal streptococci**
Aug-09	185±5	7±6	192±29	>300	>300	>300
Sept-09	169±11	0	263±15	>300	27±4	85±6
Oct-09	52±10	0	80±7	>300	0	>300
Nov-09	>300	5±7	266±4	0	0	87±16

The data for the upstream exceeded the recommended limits only in November and in the downstream section in August and September. The high levels of total coliforms in surface water sources were the result of the high rates of contamination from faecal and environment wastes [15]. These high coliform counts are associated with waterborne diseases caused by pathogenic organisms such as *Shigella spp*, *Vibrio cholerae*, *Salmonella spp* and pathogenic *E. coli* [20].

The levels of *E. coli* counts ranged between 0 to 7 cfu/100 ml and 0 to >300 cfu/100 ml for the upstream and downstream sites, respectfully. The high levels observes on the upstream section were not within the recommended DWAF limits. The levels of *E. coli* increased downstream of the Thohoyandou sewage plant in comparison with the upstream section during the dry months of August and September. Thus the high levels of *E. coli* on the downstream section are attributed to the discharge of treated effluent from the Thohoyandou sewage plant. The analysis observed a positive correlation between *E. coli* and turbidity (0.80) and a weak association with rainfall (0.45), which implied that the *E. coli* levels originated from the Thohoyandou sewage plant. There are other studies, such as those by Fatoki et al. [19] and Fatoki et al. [21], which also implicate sewage outflows as the likely candidates of point sources of microbial pollution.

The faecal *Streptococci* results in both the upstream and downstream are of poor quality because all the counts were above the recommended limits (0 cfu/100 ml) for human consumption and (0- 30 cfu/100 ml) for recreation. The faecal *Streptococci* varied from 80 to 266 cfu/100 ml and 85 to >300 cfu/100 ml for the upstream and downstream sites. The high levels of faecal *Streptococci* counts could be due to faecal contaminants from animals and human waste from the surface [15]. There was positive correlation between faecal *Streptococci* and turbidity (0.86) and a weak association with rainfall (0.49), thus implying that the faecal *Streptococci* levels originated from the Thohoyandou sewage plant.

C. Microbiological Water Quality of the Nandoni Reservoir Water and Hand Dug Wells

The microbial quality of the hand dug wells (Figure 2) and Nandoni Reservoir water was different, with the latter was highly contaminated than that from the hand dug wells (Table 7).

Fig 2: The location of hand dug wells along Nandoni dam

Most of the counts for faecal coliform, *E. coli* and faecal *Streptococci* were higher than the recommended limits with no risk for human consumption of 0-130 cfu/100 ml for *E. coli* and 0-30 cfu/100 ml for faecal *Streptococci* in recreation that were set by DWAF[22]. The low levels of microbial counts in the hand dug wells in comparison to Nandoni reservoir water were probably due to effective riverbank filtration. The contamination in hand dug wells arose from the fact that the wells were not protected from animals and surface waste. The Nandoni Reservoir water was highly polluted during both the dry and wet months. This may be attributed to human activities such as fishing, washing clothes, and making bricks which occur in both wet and dry months [24]. There was a positive correlation between *E. coli* and rainfall (0.96) and faecal *Streptococci* and rainfall (0.83) at the Nandoni reservoir, which implies that animal and human waste was washed into the reservoir after a rain event such as the one that occurred in November 2009 during the time of the study.

TABLE 7: THE MICROBIAL QUALITY (CFU/100 ML) DATA FOR THE NANDONI RESERVOIR AND HAND DUG WELLS

Site no.	Site Name	Months	cfu/100ml limits			
			Total coliform*	Faecal coliform**	*E. coli***	Faecal *streptococci***
3.	Hand dug well no.1	August	0 ±0	0 ±0	0 ±0	44±1
		September	12 ±0	0 ±0	12±5	5±0
		October	0 ±0	17 ±3	0 ±0	42±3
		November	95 ±21	0 ±0	0 ±0	9±0
		Range	0— 95	0— 17	0— 12	5— 44
4.	Nandoni lake water	August	9 ±0	39 ±13	9±0	7±1
		September	36 ±7	43 ±3	36±7	181
		October	72 ±24	16339	72±24	52±4
		November	>300 ±0	0 ±0	205±50	46±16
		Range	28— >300	03— 40	9— 205	7— 46
5.	Hand dug well no.2	August	4 ±6	6 ±1	2±1	2±2
		September	3±0	150 ±212	3±0	284±0
		October	ND	ND	ND	ND
		November	50±0	>300 ±0	5±7.07	175±50
		Range	3— 50	6— >300	2— 5	2— 175
6.	Hand dug well no.3	August	11 ±5	277 ±34	10±6	100±6
		September	8 ±5	84 ±22	8±5	63±8
		October	ND	ND	ND	ND
		November	235 ±92	55 ±7	6 ±0	260±42
		Range	8— 235	55— 277	0— 10	63— 260

***no risk 0-10 cfu/100ml is based on DWAF guidelines**
****no risk 0 cfu/100ml**
ND – not done because the wells were dry (no water found)

The levels of *E. coli* counts varied from 9 to 205 cfu/100 ml (Table 7) and these were higher than in the hand dug wells. The levels of faecal *Streptococci* counts were above the recommended limits, the count which ranged from 7 to 181 cfu/100 ml (Table 7), was higher than in the hand dug well # 1.The above level of faecal *Streptococci* counts may have been caused of human pollution. This may be attributed to the filtering capacity of the soil. A weak correlation between *E. coli* and rainfall (-0.33) and faecal *Streptococci* and rainfall (-0.51) in the hand dug well #1 was also observed, thus implying that the low microbial levels in the hand dug well were due to effective soil filtering capacity.

D. Microbiological Water Quality of the Luvuvhu River Upstream and Downstream

The microbiological water quality of Luvuvhu River was relatively poor (Table 8). The levels of microbial contamination in the upstream were higher than in the downstream and this was probably caused by human activities such as fishing, washing clothes, swimming and brick making. The levels of faecal coliform counts were between 5 to 67 cfu/100 ml in the upstream section and lower in the downstream section. The levels of faecal coliform counts in the upstream and downstream of Luvuvhu River were greater than the acceptable recommended limits (0 cfu/100 ml). The high levels of faecal coliforms are associated with the waterborne disease caused by high pathogens levels which were present in the water sources.

TABLE 8: THE MICROBIAL QUALITY DATA FOR THE LUVUVHU SAMPLING SITE

	Luvuvhu upstream			Luvuvhu downstream		
Months	**Faecal coliform**	***E. coli***	**Faecal streptococci**	**Faecal coliform**	***E. coli***	**Faecal streptococci**
Aug-09	25±70	7±1	6±1	1±0	2±0	13±1
Sept-09	20±2	11±6	64±4	12±6	3±1	26±6
Oct-09	67±24	113±29	61±9	21±6	10±6	21±7
Nov-09	5±7	0	4±2	5±7	0	29±6

The levels of *E. coli* and faecal *Streptococci* counts in the Luvuvhu River were variable but much lower in the downstream section. The standard recommended limit for no risk human consumption is 0 cfu/100 ml and 0 to 130 cfu/100 ml for recreation. During the dry months, all animals and human get water from the surface water sources which are nearby and this increases the chances of high levels of contaminants in surface water sources. The high count of microbial levels in the river indicate that the river was probably contaminated by sewage waste discharged from Thohoyandou sewage plant [23] but this was ruled out since there was no difference between upstream and downstream (p>0.05). There was also a weak correlation between faecal *Streptococci* and rainfall (0.66), which implied that animal and human waste was washed into the Luvuvhu River after a rain event such as the November 2009 witnessed during the time of the study.

IV. CONCLUSION

The contamination of water sources in the Luvuvhu River catchment resulted from the discharge from the Thohoyandou sewage plant and washing of animal and human wastes into both the Mvudi and Luvuvhu Rivers after a rainy event that was experienced in November 2009. The microbial quality of the simple hand dug well was better than that of the Nandoni Reservoir as the soil had filtered the water in the hand dug well. The high microbial load which exceeded the acceptable regulatory guidelines renders these water sources unsafe for human consumption. Nevertheless, physical conditions such as water temperature are also contributed to bacterial propagation. The simple hand dug well was thus able to filter water that was marginally better for human consumption than drinking untreated surface water sources.

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REFERENCES

[1] Luyt, C. D., Tandlich, R., Muller, W. J., & Wilhelmi, B. S. (2012). Microbial monitoring of surface water in South Africa: an overview. *International journal of environmental research and public health*, *9*(8), 2669-2693.

[2] Fosso-Kankeu, E., Jagals, P., & Du Preez, H. (2008). Exposure of rural households to toxic cyanobacteria in container-stored water. Water SA, 34(5), 631-636

[3] Rananga, H. T., & Gumbo, J. R. (2015). Willingness to pay for water services in two communities of Mutale Local Municipality, South Africa: a case study. Journal of Human Ecology, 49(3): 231-243.

[4] Zamxaka, M., Pironcheva, G., & Muyima, N. (2004). Microbiological and physico-chemical assessment of the quality of domestic water sources in selected rural communities of the Eastern Cape Province, South Africa. Water SA, 30(3), 333-340.

[5] Bulled, N., Poppe, K., Ramatsisti, K., Sitsula, L., Winegar, G., Gumbo, J., ... & Smith, J. (2017). Assessing the environmental context of hand washing among school children in Limpopo, South Africa. *Water International*, 1-17.

[6] Meybeck M, Chapmans DV and Helmer R, (1989). Global freshwater quality: A first assessment. Environment/ Pollution. Blackwell Reference. Oxford, London

[7] Howard G and Schmoll O, (2006). Water safety plan: risk management approaches for the delivery of safe drinking –water from groundwater sources. IWA. London, UK.

[8] WHO, (2004). Guideline for Drinking Water Quality, Recommendations. 3rd edition. Volume1. WHO. Geneva.

[9] Madzivhandila TL, (2007). The bacterial pathogenicity of source waters based on enterovirulent *Escherichia coli* as model pathogens. University of Johannesburg, BioTechnology. Hons thesis, unpublished.

[10] Bessong, P. O., Odiyo, J. O., Musekene, J. N., & Tessema, A. (2009). Spatial distribution of diarrhoea and microbial quality of domestic water during an outbreak of diarrhoea in the Tshikuwi community in Venda, South Africa. Journal of health, population, and nutrition, 27(5), 652.

[11] Nkansah, M. A., Boadi, N. O., & Badu, M. (2010). Assessment of the quality of water from hand-dug wells in Ghana. Environmental health insights, 4, 7

[12] Ray C, (2003). River Bank Filtration: understanding contaminant biogeochemistry and pathogens removal. North Atlantic Treaty Organization Science Affairs Division. 14. Book.

[13] APHA, (1998). Standard methods for the examination of water and wastewater. Washington DC. American Public Health Association

[14] Makhera M, Gumbo JR, Chigayo K, (2011). Monitoring of microcystin-LR in Luvuvhu River catchment: Implications for human health. African Journal of Biotechnology, 10(3), 405-412.

[15] Potgieter, N., Becker, P. J., & Ehlers, M. M. (2009). Evaluation of the CDC safe water-storage intervention to improve the microbiological quality of point-of-use drinking water in rural communities in South Africa. Water SA, 35(4), 505-516.

[16] South African water quality guidelines. Volume 1, Domestic Water Use. 2nd Edition. Pretoria, South Africa.

[17] WHO, (1996).Guidelines for drinking water quality: Health and other supporting criteria. 2nd edition. Volume 2.WHO. Geneva

[18] Abanyie, S. K., Boateng, A., & Ampofo, S. (2016). Investigating the potability of water from dug wells: A case study of the Bolgatanga Township, Ghana. *African Journal of Environmental Science and Technology*, *10*(10), 307-315.

[19] Fatoki, O. S., Muyima, N. Y. O., & Lujiza, N. (2001). Situation analysis of water quality in the Umtata River catchment. Water SA, 27(4), 467-474.

[20] Onuigbo, A. C., Onyia, C. E., Nwosu, I. G., & Oyeagu, U. (2017). Impacts of bacterial pollution on hand-dug well water quality in Enugu, Enugu State, Nigeria. *African Journal of Environmental Science and Technology*, *11*(6), 331-338.

[21] Fatoki, O. S., Gogwana, P., & Ogunfowokan, A. O. (2003). Pollution assessment in the Keiskamma River and in the impoundment downstream. Water SA, 29(2), 183-188.

[22] Department of Water Affairs and Forestry, (1996b). South African water quality guidelines. Volume 2, Recreational Water Use. 2nd Edition. Pretoria, South Africa.

[23] Gumbo, J. R., Dzaga, R. A., & Nethengwe, N. S. (2016). Impact on Water Quality of Nandoni Water Reservoir Downstream of Municipal Sewage Plants in Vhembe District, South Africa. *Sustainability*, *8*(7), 597.

Professor Jabulani Ray Gumbo graduated with a PhD in Water Resources Management from University of Pretoria in 2007. He was awarded the second best student poster price at the 12th International Conference on Harmful Algae in 2006 and the study was then published in the prestigious conference proceedings after a rigorous peer review process. This author became a Member (M) of International Society for the Study of Harmful Algae; International Mine Water Association; Water Institute of Southern Africa; Microscopy Society of Southern Africa and South African Council for Natural Scientific Professions. In 2008, he was appointed as a senior lecturer at University of Venda and in 2016 he was appointed as Associate Professor. He is the first or second author of more than 47 peer reviewed papers, conference proceedings and co-authored a chapter in a book. He acts as a reviewer for NRF in the fields of cyanobacteria and has been invited to be a reviewer for Ohio Sea Grant Proposal (USA); Journal of Applied Phycology (Australia); Bioresource Technology Journal (BITE) (USA); Journal of Freshwater Ecology (Britain); South African Journal of Science (SAJS) (South Africa) and African Journal of Biotechnology (AJB) (Nigeria). He lectures students at undergraduate and postgraduate levels in the fields of water treatment; water quality management; water law and institutions; rural water supply and sanitation; data information systems and water quality principles and he supervises several Honours, Masters and PhD students in the fields of water quality management; aquatic ecotoxicology and limnology and water treatment. In 2016 he and two other colleagues registered a patent on Defloridation of ground water rich in fluoride.