

Water quality from hand-dug wells and boreholes in Micheweni District of Pemba Island, Zanzibar

Abstract

This study focuses at determining physicochemical and microbial properties, some selected heavy metals, anions and coliform bacteria in hand-dug wells and boreholes drinking water sources in Micheweni- district of Pemba Island, Zanzibar. Water samples were collected from 24 hand-dug wells and boreholes during dry season (December, 2015) and wet season (April, 2016) and analyzed for physicochemical parameters including pH, electrical conductivity, total dissolved solids, turbidity and heavy metals and anions analyzed were Cd, Fe, Pb, NO₃⁻, SO₄²⁻, PO₄²⁻ and Cl⁻. Total coliform and fecal coliform were analyzed. The analysis was done according to standard methods for water examination and reported based on the WHO prescribed limit for drinking water and TBS standard. The range of levels of parameters for boreholes and hand-dug wells respectively were: pH: 6.8 to 8.3 and 6.9 to 8.3; temperature: 27.3 to 30.1°C and 27.1 to 30.1°C ; EC: 179 to 1751µS/cm and 74 to 1667µS/cm; TDS: 38 to 901mg/L and 33 to 855mg/L; turbidity: 0.7 to 48.9NTU and 1.31 to 11.2NTU; nitrate: BDL to 12.2mg/L and BDL to 6.3mg/L; phosphate: 0.11 to 4.1mg/L and 0.11 to 2.18mg/L; sulphate: 4.81 to 77.4mg/L and 4.8 to 87mg/L; chloride: 14.2 to 513mg/L and 12.1 to 711mg/L; iron: 0.246 to 0.84mg/L and 0.11 to 1.09mg/L; faecal coliform: Nil to 32 and 5 to 32cfu/100mL; total coliform: 2 to 94 and 15 to 92cfu/100mL. The analysis of some parameters such as iron, chloride, EC, turbidity, fecal and total coliform were found to exceed WHO and TBS maximum limit. Thus, consumption of water from sampled groundwater sources without proper treatment might cause serious ill effects. Therefore, there is a need of attention for the ZAWA and other stakeholders to undertake regular checking sources of water used for drinking purposes to protect public health.

Keywords: borehole, hand-dug well, water quality, Micheweni district, total and faecal coliform

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Introduction

Water is one of the earth's most precious natural resource for all life forms.¹ It is regarded as the necessity for survival and extremely essential for proper body functions of all living organisms.² The majorities of the population in developing countries is inadequately supplied with portable drinking water, and are thus forced to resort to the use of water from other sources like groundwater, particularly shallow wells and boreholes.

Similarly, majority of the water supply in Zanzibar is provided by traditional sources, such as open wells and springs.³ According to the United Nations, eleven percent of the global population (783 million people) remains without access to an improved source of drinking water. The majority of these are in Asia (20%) and sub-Saharan Africa (40%).⁴

However, these groundwater sources are found to have potential contamination and may therefore provide unsafe water for domestic and drinking purposes.⁵ About 80% of all diseases that are spreading in developing countries are carried by contaminated fresh water, and that 25,000 people die every day because of unhygienic freshwater.⁶ Cholera, diarrhea, and other waterborne diseases have been estimated to cause 2.2 million deaths.⁷

Biochemical contamination in groundwater might be enhanced by anthropogenic activities, such as improper disposal of used electronic devices (e-wastes), tires, and other waste materials. In addition, the application of fertilizers, pesticides, and metal-containing paints play

a significant contribution in the perspective of groundwater pollution. These activities enhance the changes in groundwater. Also water sources are threatened by contamination due to increased urbanization; poor wastewater drainage and other environmental pollution caused by the lack of proper garbage collection, pit latrines, waste disposal and water from unprotected wells can easily get contaminated through ropes and buckets.

Therefore, contaminated groundwater is likely a key source of many health problems in Zanzibar Island, which may lead serious environmental impact for the domestic water consumers in the island. For example, lead (Pb) in groundwater has been assessed by Mohamed et al., 2016 and was found to be higher 0.0054mg/L at Kiwengwa-cairo. It has been established as toxic for human health, and at higher levels, it can cause ill effects such as, vomiting, loss of appetite, anemia, intestinal colic, headaches, double vision, mental disturbance, anxiety, convulsions, coma, muscular weakness, loss of memory, and damage of brain, liver and kidney.^{8,9}

Therefore, the assessment of groundwater quality is vital, and its consequences can be connected with non-communicable diseases such as cancer. Thus, the present study basically focused in examining the water quality at Micheweni District-Pemba with particular emphasis on the levels of total coliform, fecal coliforms, physical parameters (pH, temperature, conductivity, TDS and turbidity), chemical parameters (Pb, Fe, Cd, PO₄³⁻, NO₃⁻-N, Cl⁻ and SO₄²⁻) from hand-dug wells and boreholes so as to ascertain the safety of water for consumption in accordance with the standards set by the World Health Organization and Tanzania Board Standard (WHO and TBS).

Materials and methods

Study sites

Pemba Island is forming part of the Zanzibar Archipelago situated of the coast of Tanzania, East Africa in the Indian Ocean. The island lies between 40°52' and 60°31' South of equator, approximately 50km to the north of the main Island of Unguja. It had a population of 406,808 in 2012.

In general, the climate of Pemba is shaped very much by the trade winds of the tropical Monsoon system and movement of convergence zone. It is characterized by tropical climate. The average annual temperature 26°C and average annual rainfall varies between 000 - 2250mm. The soil of Zanzibar is generally very permeable owing to sand and coral type of soil.¹⁰ Therefore any waste materials discharged into the ground without treatment can easily leach to groundwater. The study was conducted in six wards of Micheweni district. These include Konde, Msuka, Shumba Viamboni, Makangale, Tumbe and Maziwa Ng'ombe. Both these wards are found in Northern part of Pemba. Micheweni-district located at 5° 2' 0"S, 39° 45' 0"E. It had a population of 103,861 in 2012 with annual growth rate 5% which is greater than the national average of 3.1%.¹¹

Samples collection

Water samples were collected from from six locations of Micheweni-district of Pemba Island during dry season (December 2015) and wet season (April 2016). Four wells were selected from each of the six words for sampling, which gave a total of twenty four samples. All the wells found in Konde were designated KO, MS for wells in Msuka, SH for wells in Shumba Viamboni, MA for wells in Makangale, TU for wells in Tumbe and KM for well in Maziwa Ng'ombe. In order to collect fresh and representative samples, the boreholes were pumped on the average 5 min before the samples were collected. The samples were collected into sterilized cleaned 1L polyethylene bottles, tightly covered by caps. All the samples were kept in an ice box and transported to the Chief Government Chemist Laboratory Agency (CGCLA)-Zanzibar, stored in a refrigerator at a temperature of about 4°C until biochemical analysis was completed. Immediately after collection, electrical conductivity, temperature, turbidity and pH were measured in situ using Multi-parameter meter.

All laboratory analyses on the samples were carried out using appropriate certified and acceptable international procedures outlined in the Standard Methods for the Examination of Water and Wastewater.¹²

Sample analysis

The analysis was done according to standard methods for water examination and reported based on the WHO prescribed limit for drinking water and TBS standard. Total and faecal coliform were enumerated using the membrane filtration technique. Some physico-chemical parameters (pH, conductivity, turbidity, TDS) were determined using multiparameter water quality meter. Phosphate, chloride, nitrate and sulphate were also measured using bench photometer method and heavy metals (Cd, Pb and Fe) were analyzed using atomic absorption spectrophotometer (AAS).

Results and discussion

SPSS version 16 was used for the data analysis. The summary of the descriptive statistics of the analyzed parameters in water samples were presented in Figure 1.

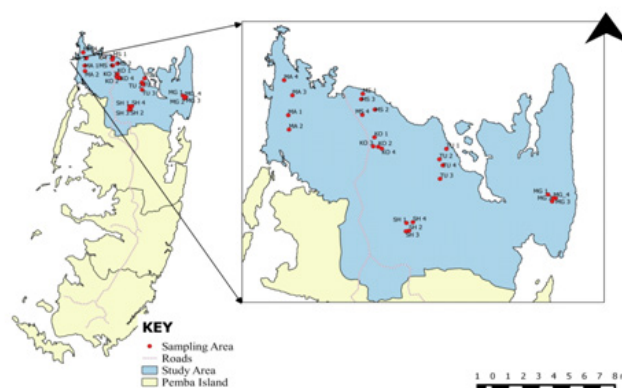


Figure 1 Sampling sites at Micheweni–district in Pemba Island.

Physical parameters

pH: The level of pH in the water sample was of 6.8 to 8.3 for bore holes and 6.9 to 8.3 for hand-dug wells water respectively. The minimum level of pH was found at Maziwa ng'ombe kandahari sample site and maximum level of pH were found at Makangale jiwe moja area (Table 1). In present study, all boreholes and hand dug wells water analyzed had pH value within the recommended limit for TBS and WHO (2008) drinking water standard, and hence not capable causing significant health problems.

Table 1 Sampling sites and nature (type) of the well

Wards	Well ID	Sampling sites	Type of well
KONDE	KO1	Chanjaani	BHW
	KO2	Minazini	BHW
	KO3	Shaurio	HDW
	KO4	Micheweni	HDW
MSUKA	MS1	Taponi	BHW
	MS2	Ungi	BHW
	MS3	Sebleni	HDW
	MS4	Kichaka	HDW
S/VIAMPBONI	SH1	Gombe	BHW
	SH2	Nguuni	BHW
	SH3	Nguuni	HDW
	SH4	Mihogoni	HDW
MAKANGALE	MA1	Sokoni	BHW
	MA2	Tondooni	BHW
	MA3	Jiwemoja	HDW
	MA4	Kijijini	HDW
TUMBE	TU1	Kaliwa	BHW
	TU2	Mtemani	BHW
	TU3	Pwepweu	HDW
	TU4	Chwaka	HDW
M/NG'OMBE	KM1	Kandahari	BHW
	KM2	Rahaleo	BHW
	KM3	Mbokoni	HDW
	KM4	Kibagoni	HDW

Electrical conductivity (EC): The level of EC in the water sample was of 179 to 1751 $\mu\text{S}/\text{cm}$ for boreholes and 74 to 1667 $\mu\text{S}/\text{cm}$ for hand-dug wells water respectively. The minimum level of EC was found at Konde shaurio sample site and maximum level of EC were found at Msuka taponi area (Table 2). In present study, all borehole and hand dug wells water analyzed had EC value below the maximum

permitted limit of 1000 $\mu\text{S}/\text{cm}$ recommended by the WHO and TBS except for sample of Msuka taponi, Tumbeki kaliwa, Maziwa ng'ombe kandahari, Maziwa ng'ombe rahaleo, Maziwa ng'ombe mbokoni and Maziwa ng'ombe kibagoni (Table 2 respectively), the EC values are above 1000 $\mu\text{S}/\text{cm}$.

Table 2 Physical parameters in boreholes and hand-dug wells

Parameter	Borehole				Hand-dug well				P-Value	TBS	WHO
	Min	Max	Mean	SD	Min	Max	Mean	SD			
EC	179	1751	834.2	492.8	74	1667	677.9	383.9	0.227	1000	1000
pH	6.8	8.3	7.6	0.4	6.9	8.3	7.67	0.4	0.593	6.5-9.2	6.5-8.5
TDS	38	901	382.1	240.9	33	855	331.1	194.2	0.423	1000	1000
Temp	27.3	30.1	29.1	0.7	27.7	30.1	28.9	0.8	0.582	-	-
Turbidity	0.7	48.9	6.17	12.7	1.3	11.2	4.6	3	0.568	25	5

Turbidity (NTU), EC ($\mu\text{S}/\text{cm}$), temperature ($^{\circ}\text{C}$) and TDS (mg/L)

Total dissolved solids (TDS): The level of TDS in the water sample was of 38 to 901 mg/L for bore holes and 33 to 855 mg/L for hand-dug wells water respectively. The minimum level of TDS was found at Konde shaurio sample site and maximum level of TDS were found at Msuka taponi area (Table 2). In present study, all borehole and hand dug wells water analyzed had TDS value within the recommended limit for TBS and WHO (2008) drinking water standard, and hence not capable causing significant health problems. A health-based value has not been proposed by the WHO, however, a TDS above 1,000 mg/L may be objectionable to consumers,¹³ therefore the only water samples with TDS values below 500 mg/L were considered safe for drinking. The high TDS values in the study area might be a result of dissolution of weathered materials from the rock formation in the study area or from pollution through leaching from pit latrines into the hand dug wells due to the un-protective nature of the hand dug and borehole wells.

Temperature: The level of temperature in the water sample was of 27.3 to 30.1 $^{\circ}\text{C}$ for bore holes and 27.7 to 30.1 $^{\circ}\text{C}$ for hand-dug wells water respectively. The minimum level of temperature was found at Shumba gombe site and maximum level of temperature were found at Msuka sebleni area (Table 2). In present study, all boreholes and hand dug wells water analyzed had temperature value within the recommended limit for both TBS and WHO (2008) drinking water standard, hence not capable causing significant health problems. Although, both TBS and WHO have not defined temperature values for drinking water, all the values exceeded the normal room temperature of 22 $^{\circ}\text{C}$. This can be acceptable because it could be due to the weather condition of the area at the period of sample collection.

Turbidity: The level of turbidity in the water sample was of 0.7 to 48.9 NTU for bore holes and 1.31 to 11.2 NTU for hand-dug wells water respectively. The minimum level of turbidity was found at Shumba nguuni sample site and maximum level of turbidity were found at Msuka taponi area (Table 2). This is due to poor filtration process of water supplies as well as human activities including logging, agriculture, which contributed to periodic pulse or chronic levels of suspended sediment in water may affected the wells sampled. Also the plausible explanation for high turbidity is the use of a hand pump resulting from corrosion. Corrosion may cause permeability of the hand pump such that soil particles seep into the water, therefore

causing high turbidity levels.¹⁴ In present study all water samples were within TBS and WHO (2008) standard except for Konde ya micheweni, Tumbeki chwaka, Makangale jiwe moja, Maziwa ng'ombe mbokoni, Shumba mihogoni and Msuka taponi (Table 2). The value of turbidity from analyzed samples range from 1.16 to 25.6 NTU respectively higher turbidity levels than the WHO recommended guidelines.

Chemical parameters

Chloride: The level of chloride in the water sample was of 14.3 to 513 mg/L for bore holes and 12.1 to 711 mg/L for hand-dug wells water respectively. The minimum level of chloride was found at Konde shaurio sample site and maximum level of chloride were found at Maziwa ng'ombe kibagoni area (Table 3). Large amounts of chloride in these sampling site is due to natural processes such as the passage of water through natural salt formations in the earth by intrusion most these wells are near to the sea or it may be an indication of pollution from sea water, It is quite evident from the study that there are evident signs of saltwater intrusion in the coastal aquifers. In present study, the chloride values for all samples analyzed were within the permissible limits of 250 mg/L and 200 mg/L set by TBS and WHO except for site of Msuka taponi, Tumbeki kaliwa Maziwa ng'ombe kandahari, Maziwa ng'ombe rahaleo, Maziwa ng'ombe mbokoni and Maziwa ng'ombe kibagoni.

Nitrate: The level of nitrate in the water sample was of BDL to 12.2 mg/L for bore holes and BDL to 6.3 mg/L for hand-dug wells water respectively. The minimum level of nitrate was found at Konde minazini sample site and maximum level of nitrate were found at Konde chanjaani. The high values could be attributed to the presence of manure spill, fertilizer application, wastewater, sludge and septic tank systems, which are the main contributors to nitrate concentration in water. Also due to this well being located in close proximity pit latrines. Nitrate concentration in most water sampled is below WHO guidelines. However, the TBS recommend 10-75 mg/L as the maximum permissible limits for the nitrate concentration in drinking water (Table 3). The results showed that only 10% of the total samples had the concentrations exceeding WHO limit however none of the samples was above the TBS limit. In higher concentrations of nitrate may cause methemoglobinemia or blue baby syndrome, a condition found especially in infants less than six months and pregnant women.¹⁵

Table 3 Nutrients parameters in boreholes and hand-dug wells

Parameter	Borehole				Hand-dug well				P-Value	TBS	WHO	
	(mg/L)	Min	Max	Mean	SD	Min	Max	Mean				SD
Cl-		14.2	513	150.8	165.9	12.1	711	129.4	176.4	0.667	200-800	250
NO3-		0	12.2	2.8	4	0	6.3	1.8	2.1	0.287	10.0-75	50
PO43-		0.1	4.1	0.9	1	0.1	2.2	0.6	0.54	0.247	1	1
SO42-		4.8	77.4	29.6	24.2	4.8	87	33.9	27.6	0.6	200-600	250

Phosphate: The level of phosphate in the water sample was of 0.11 to 4.1mg/L for boreholes and 0.11 to 2.18mg/L for hand-dug wells water respectively. The minimum level of phosphate was found at Shumba gombe sample site and maximum level of phosphate were found at Makangale tondooni (Table 3). Most of farmers sample site as other Tanzanian farmers use organophosphates insecticides including malathion, diazinon and parathion.¹⁶ These chemicals may get washed by rain water and reach shallow well water through agricultural runoff. Phosphate values for all samples analyzed were within the WHO and TBS permissible level of 1.0mg/L except for site Msuka taponi Msuka ungi, Shumba nguuni, Makangale tondooni, Makangale sokoni.

Sulphate: The level of sulphate in the water sample was of 4.81 to 77.4mg/L for bore holes and 4.8 to 87mg/L for hand-dug wells water respectively. The minimum level of sulphate was found at Konde shaurio sample site and maximum level of sulphate were found at Maziwa ng'ombe kibagoni (Table 3). The results obtained revealed that the sulphate concentrations in all the water samples from hand-dug well and boreholes were below the maximum limit of 250mg/L

and 200-600mg/L recommended by TBS and WHO (2008). The sulphate levels might be due to low levels of sulphate minerals found in the soil type of the area, which might include magnesium sulphate, sodium sulphate and calcium sulphate, which occur naturally in soil and in rock formation. Water with elevated levels of sulphate can cause diarrhea and dehydration. Infants are often more sensitive to sulphate than adults. Since the levels were below the WHO permissible limits, the water could be used for domestic purposes.

Heavy metals in groundwater

Iron: Iron was the only heavy metal family detected in the water sample analysis. The level of iron in the water sample was of 0.246 to 0.84mg/L for boreholes and 0.11 to 1.09mg/L for hand-dug wells water respectively. The minimum level of iron was found at Shumba nguuni sample site and maximum level of iron were found at Maziwa ng'ombe kibagoni (Table 4). Iron concentration in majority of both hand-dug well and boreholes were beyond the recommended guidelines WHO and TBS of 0.3mg/L. However, the heavy metals like lead and cadmium were not detected in the water quality samples.

Table 4 Heavy metals parameters in boreholes and hand-dug wells

Parameter	Borehole				Hand-dug well				P-Value	TBS	WHO	
	(mg/L)	Min	Max	Mean	SD	Min	Max	Mean				SD
Cd		BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	*	0.03	0.003
Fe		0.3	0.8	0.5	0.1	0.1	1.1	0.5	0.2	0.22	1	0.3
Pb		BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	*	0.1	0.05

Microbial in groundwater

Total coliform: The minimum level of total coliform was found at Makangale sokoni sample site and maximum level of total coliform were found at Shumba nguuni (Table 5). According to the WHO standards no coliform should be detected at all in any 100mL of drinking water. However, the TBS recommend 10cfu/100mL as the maximum permissible limits for the total coliform concentration for safe drinking water quality in Tanzania. In this present study the results of water samples showed that 22/24 (90%) of hand-dug well and boreholes are with values above 10cfu/100mL and 0cfu/100mL TBS and WHO which are not safe for drinking. The major source of contamination was suggested to be septic tanks/ pit latrines. The contamination was contributed by several correlating factors, such as the depth of the well, the separating distance from a septic tank to a well and the number of septic tanks surrounding a well. The results showed that shallow dug wells are highly contaminated than deep dug wells and boreholes. The results also depict that the well close

to septic tank showed the highest number of coliform contamination. The distance of majority wells is only 3 meters from latrine which indicates that contamination could be caused by polluted groundwater. Another possible cause of microbial contamination is the depth of the borehole.^{17,18} Also it was observed that buckets and gallons used in drawing water from the wells were often placed on the ground.

Faecal coliform: The level of faecal coliform in the water sample was of Nil to 32cfu/100mL for boreholes and 5 to 32cfu/100mL for hand-dug wells water respectively. The minimum level of faecal coliform was found at Makangale sokoni and Shumba nguuni sample site and maximum level of faecal coliform were found at Makangale tondooni and Konde chanjaani (Table 5). In this present study the results of water samples showed that 22/24 (90%) of hand-dug well and boreholes are with values above 0cfu/100mL (beyond TBS and WHO limits) which are not safe for drinking. The results depict that the well close to pit latrines showed the highest number of coliform contamination. The distance of majority wells is only 3 meters

from latrine which indicates that contamination could be caused by polluted groundwater. The groundwater table in that area was rather high, only few meters below the surface, so transportation of bacteria from latrine to the groundwater and then to the well was possible. The nearness (averagely 13.7 meters) of pit latrines to hand dug

wells which is below the recommended value of 50 meters,¹⁹ could influence the contamination levels of the wells. Leaching of human excreta from latrines may be said to be responsible for the presence of fecal matter from this wells in this study.

Table 5 Microbial parameters in boreholes and hand-dug wells

Coliform Type	Borehole				Hand-dug well				P-Value	TBS	WHO
	Min	Max	Mean	SD	Min	Max	Mean	SD			
(per 100mL)											
Faecal coliform	0	32	12.5	10.5	5	32	14.5	7.6	0.454	0	0
Total coliform	2	94	42.7	31.7	15	98	47.5	22.2	0.547	0-10	0

Conclusion

Generally, the results of the above work showed that most of the physicochemical parameters such as pH, TDS, temperature, sulphate, nitrate were respectively within the acceptable limits of WHO and TBS recommended. However turbidity, EC, phosphate, chloride, iron, total and fecal coliform were mostly found to exceed the maximum permissible limit as recommended by WHO and TBS at some study sites. Again the majority of hand-dug well analyzed in this study contained high microbial indicator counts which were considered. This implies that, water from these sources is not suitable for drinking without treatment. In this regard, it is critical to take the precautionary measures and to establish good and sustainable water-management program.

Acknowledgments

None.

Conflicts of interest

The author declares that there is no conflicts of interest.

References

- Nafees M. Groundwater quality Assessment in different villages of Bara Tehsil, Allahabad, U.D. *International Journal of Scientific Research*. 2015.
- Patil PN, Sawant DV, Deshmukh RN. Physico-chemical parameters for testing of water-A Review. *International Journal of Environmental sciences*. 2012;3(3):1194–1207.
- Cholera outbreak response in Pemba, 2006 and Pertinence of using Oral Cholera Vaccines for control Mission report Zanzibar*. WHO. 2006.
- https://www.who.int/water_sanitation_health/dwq/en/Welsh
- Guidelines for drinking-water-quality*. World Health Organisation. Switzerland: Geneva; 2011:541.
- Global water supply and sanitation assessment, 2000 report*. World Health Organization. New York: UNICEF; 2000.
- Mohamed AAJ, Kombo MA, Rahman IA, et al. Chemical Assessment in Shallow Wells at Mtoni and Kilima-Hewa Zanzibar: A Comparative Study. *Int J Exp Spectroscopic Tech*. 2016;1(1):002.
- Mohamed AAJ, Sara A Khamis, Miza Ali Kombo. Monitoring the Levels of Essential and Trace Metals in Groundwater along Fuoni Area in Zanzibar. *Journal of Water Resources and Ocean Science*. 2016;5(3):37–46.
- Bellinger DC. Lead neurotoxicity and socioeconomic status: Conceptual and analytical issues. *Neurotoxicology*. 2008;29(5):828–832.
- FINIDA. *Zanzibar Urban Water Supply Developmental Plan 1991-2015*. Placenter Ltd. 1991.
- A comprehensive multiyear plan Zanzibar Tanzania*. Revolutionary Government of Zanzibar (RGoZ). 2013.
- Water Environment HYPERLINK “http://www.worldcat.org/search?q=au%3AWater+Environment+Federation.&qt=hot_author”Federation. American Public Health Association. Washington: APHA-AWWA-WEF; 2005.
- Amoako J, Karikari AY, Ansa-Asare OD. Physico-chemical quality of boreholes in Densu Basin of GHANA. *Applied Water Science*. 2011;1(1-2):41–48.
- Ibe SN, Okpleny JI. Bacteriological Analysis of borehole water in Uli, Nigeria. *African Journal of Applied and Environmental Biology*. 2005;7:116–119.
- Nkansah MA, Owusu Boadi N, Badu M. Assessment of the quality of water from hand-dug wells in Ghana. *Environ Health Insights*. 2010;4:7–12.
- Ngowi AVF, Mbise TJ, Ijani ASM, et al. Pesticides use by smallholder farmers in vegetable production in Northern Tanzania. *Crop Prot*. 2007;26(11):1617–1624.
- Seth ON, Tagbor TA, Bernard O. Assessment of chemical quality of groundwater over somerock types in Ashanti region, Ghana. *Am J Sci Ind Res*. 2014;5:1–6.
- Moyo NAG. An analysis of the chemical and microbiological quality of ground water from boreholes and shallow wells in Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*. 2013;66:27–32.
- Duah AA. *Groundwater contamination in Ghana*. In: Xu Y, Usher BH, editors. Netherlands: Taylor and Francis; 2006.