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Factors affecting distribution of coliforms bacteria in semi-arid groundwater sources- Tanzania

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Abstract

Groundwater sources are highly depended for domestic purposes in semi-arid regions of Tanzania. However, most of them are prone to contamination from natural and anthropogenic sources which affect their quality for drinking purposes and may result in the eruption of water-borne diseases. This study aimed at identifying and quantifying the total coliform (TC), fecal coliform (FC) and *Escherichia coli (E. coli)* concentrations and establish the possible cause of their distribution in groundwater sources of Singida Urban and Manyoni Districts in Tanzania. A total of 58 randomly selected boreholes and shallow wells were sampled and analyzed using the Membrane Filtration Technique during dry and wet seasons. Overall results showed that the concentrations of all coliforms decreased significantly with an increase in depth ($n=58$, $p\leq 0.05$). Increase in temperature and turbidity showed significant increase in FC counts ($n=53$, $AdjR2 = 0.66$, $p \leq 0.01$). Significant higher microbial contamination was on unpiped wells and those without protective covers in comparison with piped and protected ($n =15$, $p\leq 0.01$) and uses buckets ($n=14$, $p\leq 0.01$) to withdraw water from the source. Moreover, higher microbial contaminations observed in shallow wells during the wet season could be linked with increased surface runoff from the heap of poultry manure, vegetable farms or livestock feces that infiltrate into groundwater sources situated in the vicinity. Proper covering of wells mouth and use of water pumps to withdraw water instead of buckets are highly recommended to prevent further microbial contamination.

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Introduction

Access to clean and safe drinking water is a fundamental human right that enables a sustainable socio-economic development of any community (Prasanth, *et al*., 2012: WWAP, 2014) . In Sustainable Development Goals (SDG) of 2015- 2030, water has been included because of its critical importance for human beings. However up to 2017, more than 884 million people Worldwide lack access to a clean and safe water supply source (WHO and UNICEF, 2017). This lack has led to the use of drinking water of unknown quality from unprotected and untreated sources such as dams, springs, river and uncovered wells (Kanyerere, *et al*., 2012: WHO/UNICEF, 2015). Fifty percent of the Worldwide diseases affecting people are water-borne or water-related diseases such as cholera, diarrhoea, dysentery and typhoid (Aller, *et al*., 2013; Kihupi, *et al*. 2016). Specifically in Tanzania, about 90% of deaths are attributed to poor water, hygiene and sanitation conditions. The 2014 census, showed that almost 5,800 cases were of cholera and 18,500 children under the age of five were reported to die from diarrhoea annually (URT, 2014b).

Globally, groundwater sources are heavily depended for domestic purposes and in Tanzania, they contribute to more than 25% of the domestic water supply including drinking purposes, and are considered to be the primary water source in most of the semi-arid and arid regions including Singida, Dodoma, Manyara, and Shinyanga (Kashaigili, 2010). However, most of them are easily susceptible to contamination from natural (rock, soil type) and anthropogenic sources (agricultural activities, domestic sewage and industries), which cause changes in their physico-chemical (pH, temperature, dissolved oxygen, turbidity, nitrate, sulphate, phosphate and chloride) and biological characters (Tredoux, *et al*., 2009; Palamuleni and Akoth, 2015). Despite of the existing threats, most sources used for drinking purposes are of unknown physico-chemical and microbial quality (Mato, 2002). Most research on groundwater contaminations mainly focused on determining the sources and levels of microbial contamination especially the coliform bacteria in the drinking sources (Kanyerere *et al*., 2012; Mdoe and Buchweishaija, 2014; Elisante and Muzuka, 2016; Kihupi, *et al*., 2016). And few studies focused on identification of the relationship between physical-chemical parameters and coliform concentrations in relation to groundwater pollution. Such studies are the bottleneck for the protection of groundwater sources.

Singida is a semi-arid region in Tanzania where groundwater is highly depended for domestic purposes. Moreover, majority of the population use on-site sanitation facility such as pit latrines that pause contamination risk to groundwater source through waste infiltration especially during wet season. Furthermore, data from the Internal Drainage Basin office in Singida reveals that most of the groundwater sources have high levels of sulphate and nitrate which may signify the contamination by physical-chemical parameters or faecal matters from natural or anthropogenic sources (Frisbie, *et al*., 2008). Moreover, data from Singida District Health Information Software (dhis) showed that water-borne diseases were among the top three reported diseases by outpatients in the years 2014, 2015 and 2016 consecutively (http://dhis.moh.go.tz). Early 2015 and late 2016 data showed that Singida was among the regions affected by the massive cholera outbreak in Tanzania (Mahali, 2017).

Therefore, based on these evidences, this study aimed at (i) determining the coliform levels in selected groundwater sources which are used for drinking purposes (ii) identifying the key environmental parameters influencing the concentrations of coliform bacteria (iii) finding the existing relationship between coliform and the physical-chemical parameters using multiple regression analyses so as to lay a foundation for proper intervention and effective improvement of the water quality management.

Materials and methods

Study Area

The study was conducted in Manyoni and Singida Urban Districts which are located in central zone of Tanzania (Fig. 1). The region covers a total area of 49,438km^2. According to Tanzania National Census of 2012, the population of Singida Region was

1,370,637 with a population growth of 2.3% per year (NBS, 2013). Singida Urban and Manyoni Districts had a population of 150,379 and 296,763, respectively. The main source of livelihood in this region includes livestock keeping and farming. It is estimated that 10.1% households lack toilet facility. This amount is higher than the national average level of 7.8% (URT, 2014b). Lack of toilet facility favour open defecation which might increase a threat to groundwater sources through run-off and leaching especially in wet season. Also, Singida has no sewerage system, most people depend on on-site sanitation facilities and when they are full, the waste water is collected from the households and dumped in an open area which is situated about 4 kilometres from Lake Kindai and 9 kms from Singida Town.

Meteorologically, Singida region is classified as a semi-arid zone with an average of 650 mm of annual rainfall. The area experiences a unimodal type of rainfall from December to March while sometimes goes to April (Davies, 2005). The region lack piped water supply and the whole population rely totally on boreholes and shallow wells. However shallow wells are commonly available because they are relatively cheaper to construct as compared to boreholes.

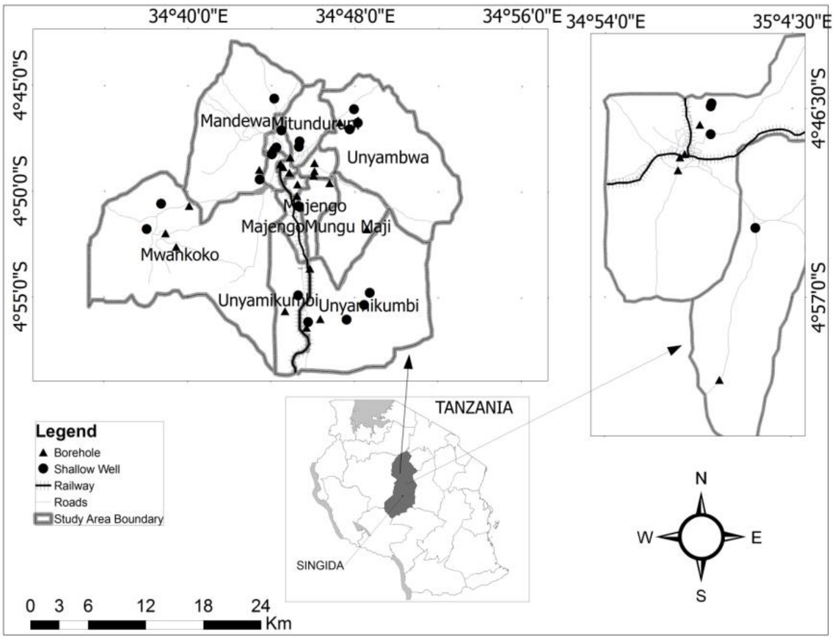

Fig. 1. A map of Singida and Manyoni district showing the sampling locations.

Groundwater Classifications

Groundwater sources of the study area were classified as shallow wells with a depth of 1- 20m and boreholes from 21 m and above. Most of the sampled sources were located in urban and fewer in peri-urban **(**Fig. 1**).** Most of the sampled wells are not disinfected except for shallow well 6 (Yugo), which is chlorinated twice a year and the two major boreholes including other two vendor kiosks (Appendix).

Sampling Sites

Water samples were collected from 12 selected wards (Fig. 1) that depend on groundwater sources for their daily domestic needs. Singida Urban District has two major boreholes Mwankoko and Erao (CT 1 and CT 2). Both tanks contained underground tank with a capacity of 2.5 million litres and an elevated tank of 0.5 million litres. They both receive water from three boreholes each with a depth of >100m. These two boreholes (BH2 and BH7) are the main supply of water to the population of Singida town. However, these two supplies are inadequate for the entire population hence, most of the inhabitants depend on private owned boreholes and wells which their status on water quality in terms of microbial concentrations is unknown. Groundwater sources were identified from Singida groundwater sources list provided by Singida Regional Water Engineering Department.

Private owned wells and boreholes were accessible through information obtained from local people and ward officers. A total of 28 (i.e. 23 and 5) shallow wells and 30 (i.e. 15 and 11) boreholes from Singida Urban and Manyoni were sampled, respectively (Appendix 1).

Sample Collection

Water samples were collected during dry (September-October 2015) and wet (April 2016) seasons. Sample location points were fixed using Etrex Geographical Positioning System (GPS), with an accuracy of ±3 meter. Water samples were pumped from boreholes and wells, for at least two minutes before sampling so as to ensure the collected water has not overstayed in pipe rather fresh from aquifer. For the shallow wells without lid and pump, special buckets were used to collect water. Water samples were collected in sterile 250mL glass bottles that were rinsed thoroughly with sample water and finally filled to the beam. A total of 58 water samples were collected from shallow wells and boreholes during dry and wet season respectively. All collected water samples were stored in ice-packed cool box and transported to Water Quality laboratory at Internal Drainage Basin office in Singida for analysis of TC, FC and *E. coli* bacteria. Features associated with sampling site such as well head height from ground, lateral distance from pit latrine or any potential contaminants, disinfection status, depth, types of cover and water collection mechanisms were also documented. Samples for NO_3^- and NH_4^- were collected using a 500 mL prewashed, high density polyethylene (HDPE) bottles while those for PO_4^{-3}determination were collected in 500 mL amber glass bottles.

Microbiological Analysis

The collected water samples were analysed for TC, FC and *E. coli* at the Singida Water Quality Laboratory by using membrane filtration technique (APHA, 2005.). M-Endo agar, M-FC Agar and HiCrome Agar were prepared as per manufacturer instructions and used for incubating TC, FC and *E. coli,* respectively. Twenty millilitres of each sample was drawn and diluted to 200mL using double distilled water. The resulting amount was divided into two equal aliquots ready for membrane filtration. Each aliquots was filtered using Millipore 0.45μm nitro-cellulose filters, followed by incubation into the respective agar plate. TC and *E. coli* samples were incubated at 37°C and FC at 44°C for 24 hours. The viable colonies were counted and recorded as colony forming units (CFU) per 100mL of the original sample. Results were averaged to reduce any error related to measurements. In addition, 100mL of double distilled water used for dilution was filtered followed similar procedures for incubation as control.

Measurement and Analysis of Water Quality Parameters

Water quality parameters such as temperature, pH and Dissolved Oxygen (DO) were measured *insitu* using Multiparameter HACH DR 2008. Turbidity was also measured using Turbidity Portable Meter (HI 98703). All collected water samples were stored in ice-packed cool box and transported to Water Quality laboratory in Internal Drainage Basin office in Singida for TC, FC and *E. coli* analysis. Determination of concentrations of NH_4^- and PO_4^{-3} were done using HACH spectrophotometer (Model DR 2800, USA) with powder pillow reagent methods. Chloride concentrations were determined using standard methods suggested by American Public Health Association (APHA, 2005).

Statistical Analysis

All statistical computations were done using STATISTICA StaSoft version 10.1 and multiple regression analyses were performed using Sigma Plot Version 10.1. The multiple regression analysis were verified by using the p-value, Variance Inflation Factor (VIF) and adjusted R^2 value. The independent variables were independent when VIF was less than 10. Significance of the relationship was based on *p*-value ≤ 0.05. Manny Whitney Test was done to determine the relationship between microbial quantities during dry and wet season.

Results and discussion

Microbial Occurrence in Groundwater Sources

The analysis of groundwater quality from selected boreholes and shallow wells in Singida Urban and Manyoni- Tanzania, showed that all sources were contaminated with TC during dry and wet seasons with the concentrations ranged of 6-1 CFU0100 mL in boreholes and 8-9 CFU0100 mL in shallow wells, respectively (Table 1). Higher TC contamination observed during the wet season, could be attributed by the movement of pollutants present in the soil and the surrounding environment into groundwater source by run off (Mato, 2002; Mdoe and Buchweishaija, 2014; Elisante and Muzuka, 2016). Despite of the disinfection to some sources shallow wells (SW) 6, boreholes (BH) 1, 6, 7, 15, 16 and boreholes(BH2 and BH7: Appendix 1) (CT 1 and 2: Appendix 1), they still indicate positive for coliform suggesting the possibilities of poor or delayed re-disinfection process (Lin, *et al*., 2010; Water, 2007). Therefore, timely and proper disinfection must be emphasized in order to decrease microbial contamination. Study by Sobsey, *et al*., (2003), showed microbiologically improvement of water quality through proper chlorination, similar disinfection process can be adopted in this case.

FC contaminations were recorded in 14% and 33% of all boreholes during dry and wet seasons respectively, with the maximum record of 49 CFU/100mL, whereas in shallow wells the maximum record of FC was 618 CFU/100 mL (Appendix 1), with contamination of 47% and 63% during the dry and wet seasons respectively. Higher FC counts observed in shallow wells was due to most of them being poorly constructed and situated at a short distance from pollutants sources such as pit latrine, farms and sanitary facilities which may allow leakage or seepage (Appendix 1) (Mdoe and Buchweishaija, 2014; Elisante and Muzuka, 2016). For example wells 46, 47 and 48 were situated at a lateral distance of < 10m below pit latrine, a distance which is less than the recommended standard from Tanzania Bureau of Standards which requires 50m from any sanitary facilities (TBS, 2005).

The short distance to pollution sources threaten the ground water source due to possibilities of horizontal movement of contaminants to the water source. Studies by Adekunle *et al.* (2007), Joseph and David (2011), Kiptum and Ndambuki (2012) and Tairu *et al.* (2015) also reported higher FC counts in groundwater sources situated in a short distance from sanitary facilities. On the other case, the FC contamination of boreholes 6, 7 and 14 could be linked with poor water storage facilities as water were pumped into roof tanks which lack lids or covers, hence easy to receive contamination from different sources including flying birds.

Table 1. Descriptive statistics of TC= total coliform, FC= faecal coliform and *E. coli*= *Escherichia coli* counts for shallow wells and boreholes during dry and wet seasons. Values presented as CFU/100mL. Abbreviations: BH= boreholes; SW= shallow wells.

Coliform Bacteria	Water Source	Min		Max		Mean		Median		STD Deviation	
		Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season
TC	BH	6	14	100	200	32	66	26	67	25	38
	SW	8	12	350	900	87	298	67	241	85	259
FC	BH	0	0	17	49	1	5	0	0	11	5
	SW	0	0	53	618	17	90	14	35	15	143
E. coli	BH	0	0	6	24	0	1	0	0	2	5
	SW	0	0	98	250	14	43	5	13	22	65

E. coli contamination were observed in 7% and 8% of all boreholes during the dry and wet seasons, respectively with the highest record of 24 CFU/100mL, while in shallow wells *E. coli* contamination was recorded in 57% and 78% of all wells during the dry and wet seasons, with maximum counts of 250 CFU/100mL. Results showed that all sources contaminated with *E. coli* were also contaminated with FC (Appendix 1 and 2), signifies the possibility of pollution being originated from the same source, either septic system, domestic sewage or animal faecal matter as most of them were at proximity to them (Water Aid, 2007). Furthermore, FC and *E. coli* pollution of boreholes 1, 9, 28 and 30 were likely due to lack of lids on their roof storage tank thereby allowing easy access of contaminants into the tanks as some were situated under tree (field observations). Likewise, Sobsey, *et al.*, (2003) reported on FC and *E. coli* contamination from storage containers in 84% of all sampled water sources. The overall results of coliform counts showed a significant difference such that, higher microbial contaminations were in shallow wells than in boreholes in both seasons (*n= 58, p=0.001*) due to the use of buckets as withdrawing mechanism and lack of lid covers (Table 2). Also, this higher microbial contamination is not accidental given the poor sanitation of the surroundings (Plate 1) and most being placed very close to sanitary facilities and human settlements. At the same time, most of the settlements lack proper domestic waste discharge and pit latrines are commonly used hence their discharge may interfere with the underground aquifer thus leads to increased pollution in water sources.

Relationship between microbial quantities and groundwater features

A number of groundwater features were analysed in order to assess their influence/impact on microbial pollution in the selected water sources. Features investigated included depth, types of covers, well mouth/lid, wellhead elevation and water withdrawing mechanisms (Appendix 1). Results showed that, the uncovered or partially covered well-mouth and covers with gaps had significantly higher coliform contamination (*n=15, p=0.01*) than the completely (concrete covers) in both seasons. Likewise, wells which uses bucket as a means of water withdrawing had significantly higher TC (*n=14, p=0.01*), FC (*n=14, p=0.01*) and *E. coli* (*n=14, p=0.01*) than wells where motor or hand pump were used (Table 2) in both seasons. Four types of covers were commonly used in shallow wells, concrete, fractured metal sheets, wooden lid and mixture of fractured metal sheet with wood cover (Plate 1).

Study by Mdoe and Buchweishaija, (2014) in assessing the quality of groundwater from wells in squatter and non-squatter settlements in Dar es Salaam City- Tanzania, linked improperly covered wells with high colour values in shallow wells due to dissolved organic debris. Also study by Elisante and Muzuka, (2016), associated 84% of wells with gaps on their cover/lid with high microbial contamination from storm water and dust surrounding environment. Uncovered wells situated under trees increase possibility of getting faecal contamination from different sources such as flying birds or tree leaves which can easily introduce organic matters into the water source which in turn increases turbidity levels and favours easy attachment of microbes to suspended particles (Elisante and Muzuka, 2016; Mdoe and Buchweishaija, 2014).

A study by Tairu *et al.* (2015) in South-western Nigeria reported high bacteria counts on uncovered wells (9.2±0.49 log CFU/mL) compared to the properly covered (1.40±0.16 log CFU/mL). Moreover, poor sanitary condition of most of the wells such as lack of fence provides opportunity for domestic animals such as cows, dogs, goats and sheep to drink and defecate around the water source.

Despite the recommendation by Tanzania Bureau of Standards (2005) on the importance of fencing water sources and prohibiting animal defecation around 50m radius from the water source, still most ground water sources in the study area did not adhere to that regulation.

As such this may enhance bacterial contamination to the water sources in case there is a crack or break in a well slab (CAWST, 2013). Concrete covers prevent the ground water sources from receiving external contaminants such as surface runoff, windblown substances which may be carrying faecal matters from the surrounding environment. Therefore, much emphasis has to be placed in improving the types of covers and conditions of the wells surroundings in order to improve water quality conditions. Similarly, wells that used buckets to withdraw water had a significantly higher coliform contamination compared to hand /motor pump wells (n=14, p=0.01).

In shallow wells, the main water withdrawing mechanisms were: hand pumps (46%), buckets (43%) and motor pumps (11%) (Appendix 1). Use of a common bucket favour microbial contamination from the surrounding environment depending on the hygienic condition of a place a bucket is kept (Cronin, *et al.,* 2006; Kanyerere *et al.,* 2012).

For example wells 20, 21, 22, 23, 32, 33, 34 and 46 which used bucket to withdraw water recorded highest FC (> 100 CFU/100 mL) and E.coli (>30 CFU/100mL) counts during both dry and wet seasons (Appendix 1 and 2). Extreme mode of water collection was observed in well (SW) 33 (Plate 1a) during the peak of dry season when water well decreased such that an individual had to enter inside the wells to collect water. Such behaviour contributed higher microbial contamination to the source (TC= 80 CFU/100mL and E.coli= 44CFU/100mL) due to re-introduction of microbes from each person entering the well and from their individual buckets.

Plate 1. Type of covers and well condition observed from the study area: (a) fractured metal cover (b) uncovered wells with poor well-head elevation, lack fence and possess unhygienic surrounding.

Table 2. Relationship between microbial quality and covers/lids and the mechanism of drawing water from shallow wells in the dry and wet seasons. Abbreviations: TC = total coliform; FC = faecal coliform and *E.coli* = *Escherichia coli*; n = number of samples; z = value of Mann-Whitney; p = statistical significance.

Season	Factors	TC					FC					*E. coli*				
		n	Rank	*U*	*z*	p value	n	Rank	*U*	*z*	p value	n	Rank	*U*	*z*	p value
Dry	Lid cover: Uncovered/ partially covered/ lid with gaps	15	10.7	96.5	3.8	0.0	15	12.3	53	5.2	0.0	15	14.2	77.5	5.9	0.0
	Completely covered	43	18.3				43	17.2				43	16.3			
	Water pumping: Motor/hand pump	44	13.0	70	2.4	0.0	44	17.8	43	5.2	0.0	44	17.6	31.5	6.1	0.0
	Bucket pulley	14	7.1				14	11.7				14	11.9			
Wet	Lid cover: Uncovered/ partially covered/ lid with gaps	14	10.2	108	3.2	0.0	14	11.6	35	4.9	0.0	14	11.8	23.5	5.5	0.0
	Completely covered	38	16.3				38	14.9				38	14.7			
	Water pumping: Motor/hand pump	39	17	104	3.1	0.0	39	15.7	37	4.7	0.0	39	16.6	94.5	4.2	0.0
	Bucket pulley	13	9.5				13	10.8				13	11.4			

Relationship between coliform bacteria and water quality parameters

The physico-chemical parameters are important for monitoring the quality of drinking water and contribute to microbial quality (WHO, 2004). Pearson correlation indicated strong positive correlations between TC and FC (*n=52, r=0.75*), FC and *E. coli* (*n=52, r=0.58*), FC and turbidity (*n=52, r=0.50*), and *E. coli* and PO_4^{3-} (*n=52, r=0.50*), Also a negative correlation were observed between depth and TC, FC and *E. coli* (*n=52; r=-0.45, -0.39, -0.42)* respectively during the wet season. While in the dry season strong positive correlation were between; *FC* and turbidity (*n=58, r=0.62*), FC and *E. coli* (*n=58, r=0.52*) and the negative correlation were observed between depth and TC, FC and *E. coli* (*n=53; r=-0.29, -0.59, -0.40). Also,* moderate positive correlation were observed between; TC and FC (*n=58, r=0.3*), TC and *E. coli* (*n=58, r=0.23*) (Table 4 and 5).

The multiple regression analysis results showed the main water quality parameters with significance influence on coliform contaminations in the study area were depth, temperature, turbidity, pH and DO (Table 3). Increase in depth produced significant decrease on TC (*t=-3.0, AdjR²=0.2, p=0.001*) and (*t=-3.3, AdjR²=0.2, p=0.001*); FC (*t=-3.0, AdjR²=0.78, p=0.001*); (*t=-6, AdjR²=0.66, p=0.001*); and *E. coli* (*t=-4.2, AdjR²=0.51, p=0.001*); (*t=-4.9 AdjR²=0.59, p=0.001*) during dry and wet seasons respectively. The significant decrease in TC, FC and *E. coli* due to depth could be explained by the fact that shallow depth (1-20) m sources are normally closer to soil surface and most were situated closer to potential contaminants such as pit latrine, poultry manure or vegetable farm hence easy inflow of materials and surface runoff especially in wet season (Kelly and Stephani, 2016). Moreover, high contaminations were observed in wells lacking cover lids and situated closer to potential contaminants such as pit latrine, poultry manure or vegetable farm (Table 3).

Similar results of high coliform contamination due to shallow depth were reported by other studies in other regions (Elisante and Muzuka, 2016; Kelly and Stephani, 2016).

Table 3. Multiple regression results between coliform and physico-chemical parameters during dry and wet seasons at Singida Urban and Manyoni Districts.

Seasons	Microbial Factor	Phyico-chem Variables	t-value	p-value	Adjusted Rsqr	Global p-value	VIF
Dry	TC	Depth	-7.40	0.01	0.20	0.04	2.39
	FC	Temperature	3.99	<0.001	0.78	<0.001	2.39
		DO	2.62	0.01			1.43
		Depth	-3.00	<0.001			1.66
	E. coli	Depth	-4.22	<0.001	0.51	<0.001	2.39
WET	TC	Depth	-3.27	0.02	0.20	0.03	1.82
	FC	pH	-2.01	0.05	0.66	<0.001	1.84
		Depth	-5.97	<0.001			1.82
		Turbidity	2.27	0.03			2.45
	E.coli	Depth	-4.91	<0.001	0.59	<0.001	1.82

Furthermore, the increase in temperature caused an increase in FC count during dry season (t=3.99, AdjR²=0.78, p=0.001). The mean temperature of the study area was 25.6 °C during dry season but temperature above 23°C tend to decrease survival rates of fecal bacteria (Reddy *et al.*, 1981; Gerba and Bitton, 1984). Review compiled by Reddy, *et al.*, (1981) found that the die off rates of faecal coliform approximately doubled with an increase in temperature to>23°C. High temperature tends to affect the physical, chemical and biological processes in groundwater which affect the rate of chemical processes including the decrease of the solubility of gases such as oxygen. This eventually decrease the growth of coliform bacteria (Kumar, *et al.*, 2014).

In addition to that, higher temperature were experienced more in shallow wells with wide mouth, lack lid-cover with shallow depth hence capable to receive direct sun light which make water warm easily compared to boreholes which are deep and therefore their water remain cool.

Furthermore, increase in turbidity ($p<0.05$) cause a significant increase in FC during wet season ($p\leq0.05$) (Table 3), probably due to soil erosion and increased surface run-off which brought suspended materials into the source during rainy season (Pritchard, *et al.*, 2007; Mdoe and Buchweishaija, 2014; Elisante and Muzuka, 2016). Also, things like lack of cover lids, possession of poor well head elevation (Plate 1 and Appendix 1), altogether favor easy inflow of materials and surface run-off that carries sediment bound nutrients such as nitrogen and phosphorus that affect the odor, color, taste of water hence increase turbidity levels (Prakash and Somashekar, 2006). Similar conditions were reported to favor higher turbidity in groundwater sources in slopes of Mount Meru by Elisante and Muzuka (2016) also Mdoe and Buchweishaija (2014) reported on the same case from squatter and non-squatter settlement in Dar es Salaam City-Tanzania.

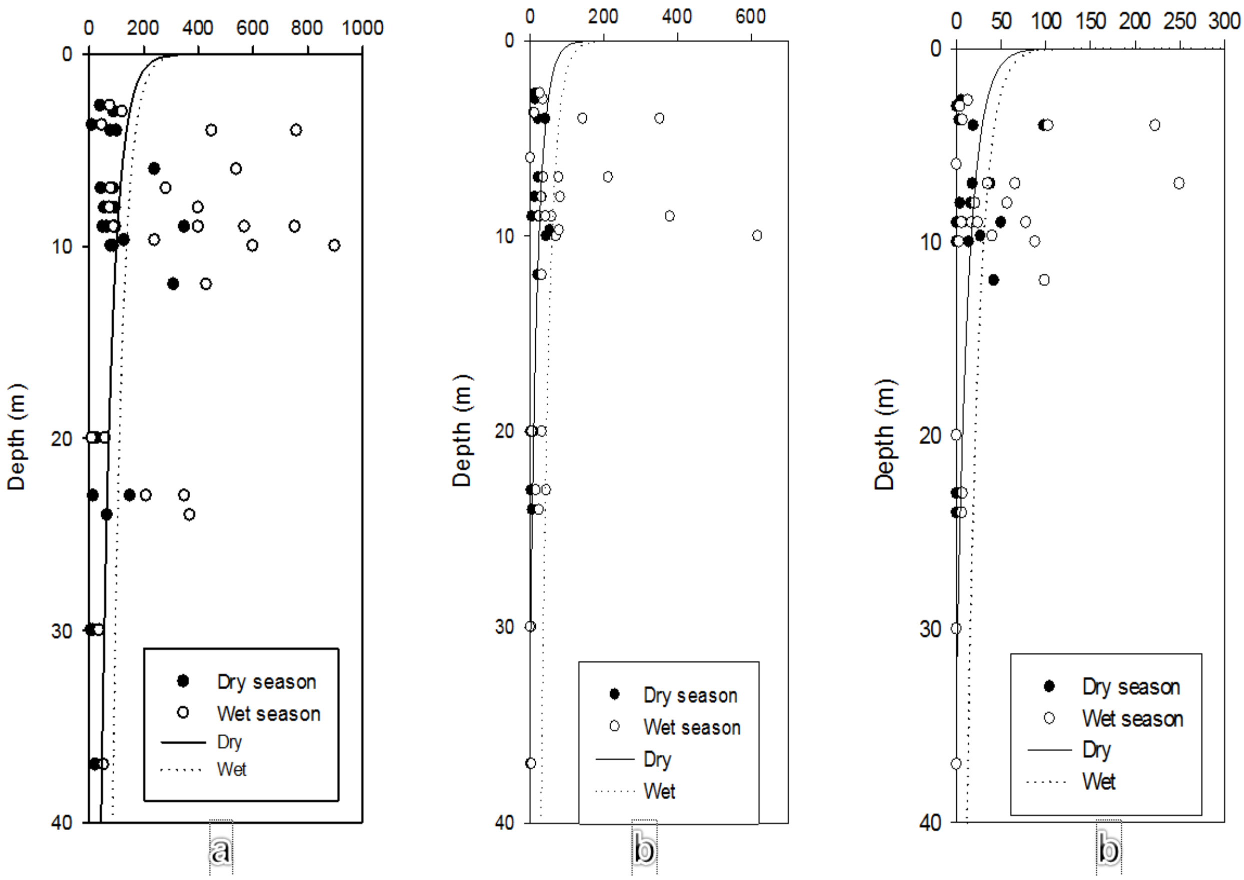

Fig. 3. Scatter plot showing variations of coliform counts with shallow well depth: (a) TC (b) FC and (c) *E. coli*

Furthermore, the decrease of pH in wet season and DO in dry season caused a decrease in FC counts (Table 3), because FC are pH sensitive and pH 6 to 7 appear to be optimal for survival for most of them (Reddy, *et al.*,1981; Trivede, 2010).

The 28% and 48% of all sources had pH values below the recommended standard by TBS and WHO (i.e. < 6.5), hence slightly acidic condition that do not favor growth of coliform bacteria (Gerba and Bitton, 1984). Sjogren, (1994), found that coliform bacteria survived longer at a neutral to alkaline soils pH than acidic pH of similar texture and organic matter content. Decrease in DO in the dry season could be due to lack of rapid water mixing from rainfall hence decrease of FC (Wang, *et al.*, 2013).

Table 4. Pearson correlation coefficient between total (TC), faecal coliform (FC), *Escherichia coli* (*E. coli)* in (CFU/100mL*)* and physico-chemical water quality parameters during wet season. Abbreviations: Turb = turbidity (NTU), depth in m, Temp= temperature (°C). All other values were in mg/l.

Variables	Depth	TC	FC	*E. coli*	Temp.	pH	DO	Turb.	PO_4^{-3}	NH_4^{-}	Cl^{-}
Depth	1.00										
TC	-0.45	1.00									
FC	-0.39	0.75	1.00								
E.coli	-0.42	0.43	0.58	1.00							
Temp.	0.41	0.34	-0.46	-0.43	1.00						
pH	0.30	-0.14	-0.30	-0.33	0.15	1.00					
DO	0.44	-0.19	-0.27	-0.17	0.24	0.23	1.00				
Turb.	- 0.31	0.33	0.50	0.31	-0.31	-0.33	-0.30	1.00			
PO_4^{-3}	-0.19	0.14	0.11	0.50	0.02	-0.23	-0.10	-0.02	1.00		
NH_4^{-}	-0.14	-0.08	0.00	0.06	-0.19	-0.04	-0.11	0.15	-0.01	1.00	
Cl^{-}	0.08	-0.01	-0.18	-0.15	0.18	0.13	0.14	-0.24	-0.03	0.16	1.00

The degree of correlation between total coliform and water quality parameters during wet season was ranked in the following order FC >*E. coli* >Temperature >Turbidity >DO> pH >PO_4^{-3} >NH_4^{-} >Cl^{-}. Rank for faecal coliform and water quality factors were; *E. coli* > Turbidity > Temperature > pH > DO > Cl^{-} > PO_4^{-3} > NH_4^{-} > Degree of correlation between *E. coli* and water quality parameters were: PO_4^{-3}>Temperature > pH >Turbidity > DO> Cl^{-}. The degree of correlation between total coliform and water quality during dry season were ranked in the following order; Depth>Temperature> FC>*E. coli*> DO>Turbidity > NH_4^{-}> Cl^{-}> *PO_4^{-3}*. Rank for faecal coliform and water quality factors were; Turbidity>pH> *E. coli* > Turbidity > NH_4^{-}> Cl^{-}.

Table 5. Pearson correlation coefficient between total (TC), faecal coliform (FC), *Escherichia coli* (*E.coli) in* (CFU/100mL*)* and physico-chemical water quality parameters in the dry season. Abbreviations: Turb = turbidity (NTU); depth in m, Temp= temperature (°C). All other values were in mg/L

	Depth	TC	FC	*E. coli*	Temp.	pH	DO	Turb.	*PO_4^{-3}*	NH_4^{-}	Cl^{-}
Depth	1.00										
TC	-0.29	1.00									
FC	-0.59	0.30	1.00								
E. coli	-0.40	0.23	0.52	1.00							
Temp.	0.28	-0.44	-0.04	-0.10	1.00						
pH	0.57	-0.07	-0.60	-0.31	0.05	1.00					
DO	0.30	0.08	-0.08	-0.21	-0.34	0.30	1.00				
Turbidity	-0.34	0.07	0.62	0.09	0.01	-0.44	0.11	1.00			
PO_4^{-3}	-0.23	-0.01	0.01	0.24	-0.09	-0.16	0.00	0.11	1.00		
NH_4^{-}	-0.22	0.06	0.32	0.17	-0.01	-0.08	0.02	0.00	-0.31	1.00	
Cl^{-}	0.50	-0.04	-0.32	-0.07	0.14	0.37	0.06	-0.32	0.00	-0.03	1.00

Conclusion

This study assessed the seasonal concentrations of coliform bacteria in selected groundwater sources in the Singida region and the factors affecting them. The main water quality parameters found to influence the coliform concentrations were depth, temperature, DO and turbidity. However the principal factor that found to affects the survival of all coliforms in this semi-arid area were depth. Shallow wells of (1- 20)m showed higher microbial contaminations as compared to boreholes due to most of them being poorly constructed, situated in proximity to pollution source and lack proper well cover which favour easy access of contaminants from external environment. In addition, use of buckets to withdraw water contributed to higher microbial contaminations because buckets contribute to re-introduction of microbes from external environment thus deteriorate the water quality. Also, poultry manure and livestock faeces may have contributed to FC profusion in groundwater sources because heap of poultry manure were dumped closer to water source and livestock keeping is the main livelihood activity in the study area.

Basically, result from this study has shed light on the sources and factors facilitating TC, FC and *E. coli* contaminations which may lead to the increase of water borne disease. Since, faecal contaminated water, may contain pathogens that may cause cholera, dysenteries, diarrhoeal diseases or enteric fever (CAWST, 2013), and diarrhoea was among the leading in occurrences in Singida Region in the year 2014, 2015 and 2016 (http://dhis.moh.go.tz).

It is therefore recommended to disinfect water sources as currently most of the individuals in Singida do not practice it. Also maintaining of clean and hygienic environment around the sources must be emphasized in order to minimize contamination.

In addition, construction of new wells should adhere to the rules and regulations instituted by the respective authority so as to minimise chances of contaminations hence prevention of water borne disease.

Conflict of interest

The authors declare that there is no conflict of interest regarding publication of this paper.

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