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Impacts of Pit latrines on Groundwater Quality in Squatter Settlements in Zanzibar

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Abstract
Groundwater is the major source of drinking water in Zanzibar. Most of the people in squatter settlement rely on shallow groundwater due to insufficient supply of treated water. In these areas, shallow wells are located close to pit latrines, the condition which increasing the risk of contamination. This study aimed to assess the impact of pit latrines on groundwater quality in five sub-urban areas of squatter settlements in Unguja Island. Water samples were collected from twenty shallow wells and analyzed for the microbiological and physio-chemical parameters. The Ordinary Least Square (OLS) regression model was used to assess the influence of distance from pit latrine to the groundwater sources. The data revealed that nitrate and chloride concentrations increases when the distance between the shallow wells and the nearest pit latrine decreases. In contrary, faecal coliform counts shows that for every unit increase in the distance from pit latrine to the shallow wells the counts decreased by 42 CFU/100 ml. However, OLS regression model did not show significant relationship of total coliform and distance from the well. This study suggests that there are other factors that may accelerate the total coliform bacteria in water wells. These results illustrate that public health risks associated with waterborne diseases could be ranked high at densely populated squatter settlement. Thus, the study recommends that routine monitoring of shallow wells is required as well as application of low-cost technologies such as raised and lined pit latrines in order to minimize potential risk of groundwater pollution.

Keywords: Groundwater Quality; Squatter Settlement; Pit Latrines; Water Wells; Zanzibar.

1. Introduction
The peri-urban areas of Zanzibar is suffered with inadequate treated water supply service, although the government efforts in provision of tap water through the Zanzibar water Authority [1]. This has made groundwater to be a major source of water supply for domestic and other purposes. Over 90 percent of the population in squatter settlement areas in Zanzibar relies on shallow well groundwater due to insufficient tape water supply [2]. Groundwater contemplated to be cleaner and safer, relative to the surface water owing to its natural soil benefits act as natural filter for variety of the contaminants [3]. However, the use of pit latrine without considering building construction guidelines may lead to groundwater contamination. The needs for both pit latrines and groundwater resources in developing country like Zanzibar is greater due to poverty levels and unstable economy. Pit latrines are characterized by harmful coliforms and high level of chemical nutrients that may change the groundwater quality [4]. Human feces contain a large amount of microbes, including bacteria, viruses, microbial eukarya and potentially *protozoa* [5,6]. The poor sanitation is a major factor facilitating to the ongoing high rate of diarrhoeal disease and cholera in third world countries [7]. Travel distance of microbes and contaminants from latrines to groundwater well varies due to a number of factors including the seepage flow, the size of soil particles, soil pH and temperature. In pit latrines, there is absence of the physical barrier, such as concrete, between stored excreta and groundwater aquifer [8, 9]. Hazardous chemicals and microbial bacteria can enter to the groundwater as effluent from sewage treatment or run off from pit latrines, water flows through the ground and seeps down in the soil; it will eventually reach the groundwater zones. The movement of bacteria and nutrients in the groundwater is affected by the pores in the soil; permeable soil has larger pore and more space between particles. So that, due to the soil infiltration (leaching) as well as surface overflows there may be a potential danger of bacteria and chemical nutrients in groundwater contamination through pit latrines excreta, particularly in heavily populated areas [10].

Studies on groundwater in Zanzibar have been mainly focused on groundwater quality degradation due to salt water intrusion in Zanzibar municipality [11], risk assessment on trace metals in groundwater and spring in urban environment of Zanzibar Island [12], quality of groundwater from open wells in rural and Peri urban areas of Unguja Island, Zanzibar [13]. Little is known about the impact of pit latrines on groundwater quality in squatter settlement areas of Zanzibar. Therefore, this study aims to assess the impacts of the pit latrines on groundwater quality. Specifically, we need to understand (i) levels of physio-chemical parameters and fecal coliforms bacteria in groundwater wells vicinity to the pit latrines, (ii) how the variation of distance from the pit latrine to the well could affect the groundwater quality.

2. Materials and Methods

2.1 Study area

The study was conducted in Urban West Region of Unguja Island, Zanzibar, comprises sub-urban villages of Fuoni, Kinuni, Mtopepo, Munduli and Mwera (Figure 1). Among the five villages selected for this study Mwera was selected particularly for comparison with other areas due to its characteristics of less populated and low building density. The island is approximately north-south oriented, with about 85 km long and 35 km wide. The total area of the island is approximately 1530 km2. It's situated adjacent to Tanganyika (mainland Tanzania). The northern angle of Unguja Island is located at 5.72oS, 39.30oE; with the southernmost tip at 6.48oS, 39.51oE. The island is separated from the Tanzanian mainland by a canal (waterway), which at its narrowest point is 36.5 km across. The climatic changes of the study area are greatly influenced by the Migratory Inter-Tropical Convergence Zone (ITCZ) characterized by monsoon winds. The climatic regime favors the existence of a bimodal rainfall pattern with the long rain season occurring from March to May and the short rains occurring from October to December. The area has a tropical climate, with temperatures ranging from 24 to 32oC and a mean annual temperature of 25.7oC. The mean annual precipitation is 1,124 mm, with a mean yearly potential evapotranspiration of 2300 mm. The topography of the study area is mostly a low lying terrain, with only minor relief on the northwestern side, where the Masingini Ridge rises about 100 m above mean sea level [14].

2.2 Hydrogeological Characteristics of the Study Area

The geology of Zanzibar (Figure 1) is based on the works of [14] followed by [15, 16]. The stratigraphic sequence (Table 1), present a schematic cross-section from several lithological logs and hydrogeological significance of wells taken from ZAWA archive. Zanzibar is underlain by mainly Lower Miocene rocks consisting of deltaic sandstone associated with marls and minor reef limestone. Based on borehole data drilled by British Petroleum Company Ltd during 50's, the cross sections show that the logs are primarily consisted of mainly Miocene rocks [14]. Fringing the Island and covering mostly the east and south-eastern parts of the Island are raised Quaternary Coral reef terraces (Fig 1a). The main part of the island consists of coralline limestone formations of Pleistocene age [14]. These formations contain fresh groundwater that derived from rainfall, and stored in less efficient aquifers, the consisting fresh water lenses hovering on the underlying sea water [17]. In many limestone islands including Zanzibar, renewable water resources are now over exploited or approach crisis [18]. The consequences of over utilization can include the lowering of groundwater table, land subsidizing and weakening/ fading groundwater quality and salt water invasion [19, 20]. Based on infiltration characteristics (Figure 1b), soil texture of Zanzibar determines a number of physical and chemical properties of soils. These affects the infiltration and retention of water, soil aeration, absorption of nutrients, microbial activities, tillage and irrigation practices [21].

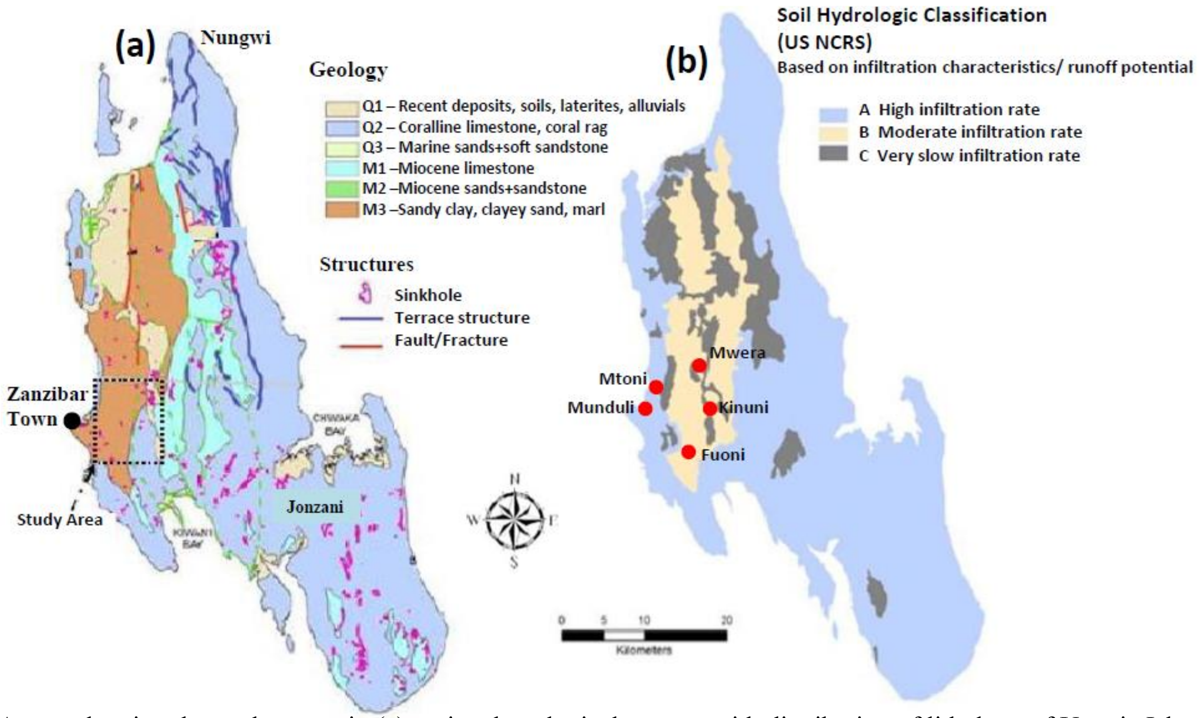

Figure 1: A map showing the study areas, in (a) regional geological context with distribution of lithology of Unguja Island, Zanzibar, and in (b) distribution of soil hydrologic groups and location of villages marked in red where groundwater samples were collected. Modified from Tanzania coastal map after [14] and geology of Zanzibar after [16].

Table 1: Stratigraphic sequence

Age	Geology	Lithology/Description	Hydrogeological significance
Quaternary	Q1 – Recent sediments	Soils, laterites, beach sands and gravel	Laterites are minor aquifer. Clays sometimes form an aquitard.
Quaternary	Q2 – Coralline Reef Limestone (Coral Rag)	Limestone	Main aquifer material in corridor zones.
Quaternary	Q3 – Quaternary Sands	Sands	Main aquifer material in corridor zones.
Miocene	M1 –Miocene Limestone	3 Kinds: crystalline; sandy limestone and reef limestone; detrital limestone	Aquifer in the coral rag areas, underlying the thin Q2.
Miocene	M2 –Miocene Sands and Sandstone		This most often underlie the Q3 sands and together they form an aquifer.
Miocene	M3 – Miocene Clayey Sands, Marls and Clays		Aquitard, the base of the aquifers in the corridor zones.

Furthermore, infiltration characteristics is an indicator of some other related soil features such as type of parent material, homogeneity and heterogeneity within the profile, migration of soil particle and intensity of weathering of soil material or age of soil [22]. Over a very long period of time, the processes such as erosion, deposition, eluviation and weathering can change the textures of various soil horizons [23].

Quality of soil affects transportation of water through soil. Coarser soils have high percolation. Soils with higher clay or organic matter content hold water and dissolved chemicals longer. Highly permeable soils allow dissolved chemicals to be carried along with water and are likely to reach groundwater zones [24]. Shallower the depth to the water table, the less soil to function as a filter. Areas of high water tables are more susceptible to contamination. High rainfall and permeable soils will allow water to percolate to the groundwater within a few days. The permeability of the geologic layers between the soil and groundwater also affects the probability of groundwater pollute. Leachate from refuse dumps seeps through the soil and carries with it soluble chemicals.

Generally, the soil of Zanzibar is very absorbent due to the nature of the soil taxonomy [25] and mostly the parental rocks of Zanzibar are limestone ($CaCO_3$) therefore pit latrines excreta can be easily flow to the groundwater zones.

2.3 Sampling and chemical analysis

Four wells were selected from each site (as described in section 2.1) based on availability of pit latrines close to the well. A GPS device was used to determine the geographic positions and elevations of the wells and pit latrines. The distance from pit latrine to the vicinity of each well were also measured (Table 2). In total, twenty groundwater samples were collected for this study during dry seasons of February 2018. General procedures for water sampling, preservation, transportation, and chemical analyses were conducted according to ISO standards as outlined by [26]. Well purging was performed using either bailer sampler or water pump at depths of 5 to 22 m. Samples for chemical analysis were collected in 250 mL high-density polyethylene (HDPE) bottles, after passing through 0.45 lm membrane filters. Temperature, electrical conductivity (EC), pH, oxidation–reduction potential (Eh) and dissolved-oxygen concentration (DO) were measured in situ using portable meters [27] prior to filtration. Chlorides were analyzed by using silver nitrate titrant standard method 4500-CH-D using a 50 ml water sample [28]. Nitrate was determined by using the Jenway ion meter-3205.

2.4 Microbiology analysis

Samples for microbiological analysis were taken in sterile, wide mouthed, glass stoppered, 250 ml bottles. The bottles were then quickly raised and stoppered. The samples were iced and transported to the University of Dar es Salaam Laboratory for analysis. In the laboratory the samples were vigorously shaken to ensure equal distribution of the organisms present. The Most Probable Number (MPN) method were used for microbiological tests [28]. Total coliform and faecal coliform tests were drawn by a series of three tests constituting the standard method of water analysis. Such tests are; presumptive test where McConkey broth was used to detect total and fecal coliform that were incubated at 37 ºC and 44.5 ºC for 24 to 48 hours, followed by confirmed test and finally the completed test. All tests were performed in triplicates. In the confirmatory test, EMB media was employed where by E. coli colonies appear bluish- black by transmitted light and have green metallic sheen by reflected light and Brilliant Green Lactose-bile (BGLB). It should be noted that, these colonies were counted with MPN table and converted to represent a count per 100 ml [29]. These results were recorded in Table 2.

2.5 Statistical analysis

Statistical analysis was performed using one-way randomized analysis of variance (ANOVA) under 95 % level of confidence. The results were used to test and explain the effect of each area from the wells on the levels of the bacteriological and chemical parameters measured. Moreover, Ordinary Least Squares (OLS) regression model were used to test the effect of distance from pit latrines to the shallow wells and the levels of bacteriological and chemical parameters measured.

3. Results and Discussions

3.1 Pit latrines and wells settings in the study area

The distances of the borehole-wells or dug wells from nearest pit latrines (Table 2) shows that wells were sited between 8 and 38 m from nearby pit latrines. The conducted disinfection survey showed that more than half of the boreholes were covered with either a metallic or a wooden lid. It was also observed that some of the wells had their inside walls lined with concrete (kalbi) and over 30% were having their immediate surroundings paved with concrete. The results show that the mean distance recorded between household latrines and wells was 18.8m. The data revealed that 11 (55 %) wells were located on a lower elevation than the household latrine, while 8 (40 %) of the household had their latrines on a lower elevation to the wells and only 1 (5 %) had its latrine and well occupying the same elevation (Table 2). It was also observed that most of the people in the study area deviates from the Zanzibar Water Authority (ZAWA) Act/ Regulation No. 3(1) which states that "person should not drill wells nearby the pit latrines, septic tanks, dumping areas, and any possible sources of pollution and their boundary. Furthermore, the Act state that all wells must be at minimum distance of 100 m (government borehole) from all leaching field set back 25 m from surface water or drainage culverts and set back 75 m from all lots lines. If a placement is necessary within 75 m but not closer than 20 m (this applied by household well) and standard released form should be signed by authorities owner". [30] has found an improvement of groundwater quality when distance apart between pit latrine and groundwater source is 25m or more. Most of the wells in the study are located close to the pit latrines in low elevation area, the location which is easily to be contaminated with pollutants especially during the high rainfall where down slope materials directly enter the wells. [31], pointed out that groundwater sources usually polluted by pit latrines when the secure distances between a water point and pit latrines is inadequately maintained.

3.2 Groundwater physical parameters

The results of groundwater samples collected from five selected squatter areas of Zanzibar are presented in Table 2. The data revealed that turbidity ranged from 0.43 to 16.2 NTU, while dissolved oxygen (DO) range from 3.46 to 7.61 mg/l. This show that 90% of the presented data for turbidity and DO were within the desirable standards of TBS and WHO guidelines for drinking water quality. Moreover, water temperature in the sampled wells ranged from 26.9 ^{o}C - 32.9 ^{o}C, where the highest and lowest temperatures were found at MTW2 (32.9 ^{o}C) and at MTW1 (26.9 ^{o}C). This reflected that the collected water samples are potentials for coliform bacteria to survive [32]. reported that coliform bacteria (total coliform and E. Coli) can survive at temperature range of between 25℃ and 45℃. According to [33], the higher temperature is ideal by low counts of bacteria and vice as versa for water samples.

Electrical conductivity reported in this study ranged from 326 to 1208 µS/cm which are within the standard set by WHO and TBS drinking water standards (Table 3). Most of the presented water pH values was in permissible range of WHO and TBS standards for drinking water, which ranged from 7.3 to 8.68. Oxidation-reduction potential (ORP) ranged from -5 to -77.7 mV, indicating an anoxic condition in the groundwater well due to the mineralization of organic matter either due to water passing through organic-rich surface layers in the recharge zone or by oxidation of dissolved organic matter brought down with the percolating soil water as agreed by [34].

3.3 Distribution of chemical contaminants

Nitrate and chloride concentration are presented higher in Mtopepo and Mondule, respectively (Figure 2). The chloride concentration ranged from 17.8 - 133.0 mg/l (Table 2). The lowest values of chloride concentration were found at KW-2 (17.7 mg/l), and highest value in this study was found in MUW-4 (133 mg/l). The results are within the limits of TBS and WHO standards. Nitrate concentration ranged from 11.49 to 235 ppm, with the lowest found at MWW-3 (11.49 ppm), and highest at MTW-1 (235 ppm). Indeed, nitrate concentration for most of the groundwater wells were exceeding the permissible level (50 mg/L) set by WHO and TBS standards for drinking water quality. This is probably due to the closeness of groundwater well and pit latrines. The only station having permissible value of nitrate concentration for drinking water was found at MWW-3 (11.49 ppm). This is probably due to the fact that the area (Mwera) is less density populated and the pit latrine is located far away (38m) from the groundwater well. These results are in agreement with [3] which reported that, nitrate concentration in groundwater and surface water is usually low but can reach higher levels because of contamination from human or animal waste due to oxidation of ammonia, leaching or run-off from agricultural land and similar sources. Further results show that the observed mean NO3- concentrations of 78.1, 27.6, 98.5, 141 and 123 ppm were found in groundwater source of Fuoni, Mwera, Kinuni, Mtopepo and Munduli, respectively (Table 3). This results indicate that the investigated areas are prone to waterborne diseases.

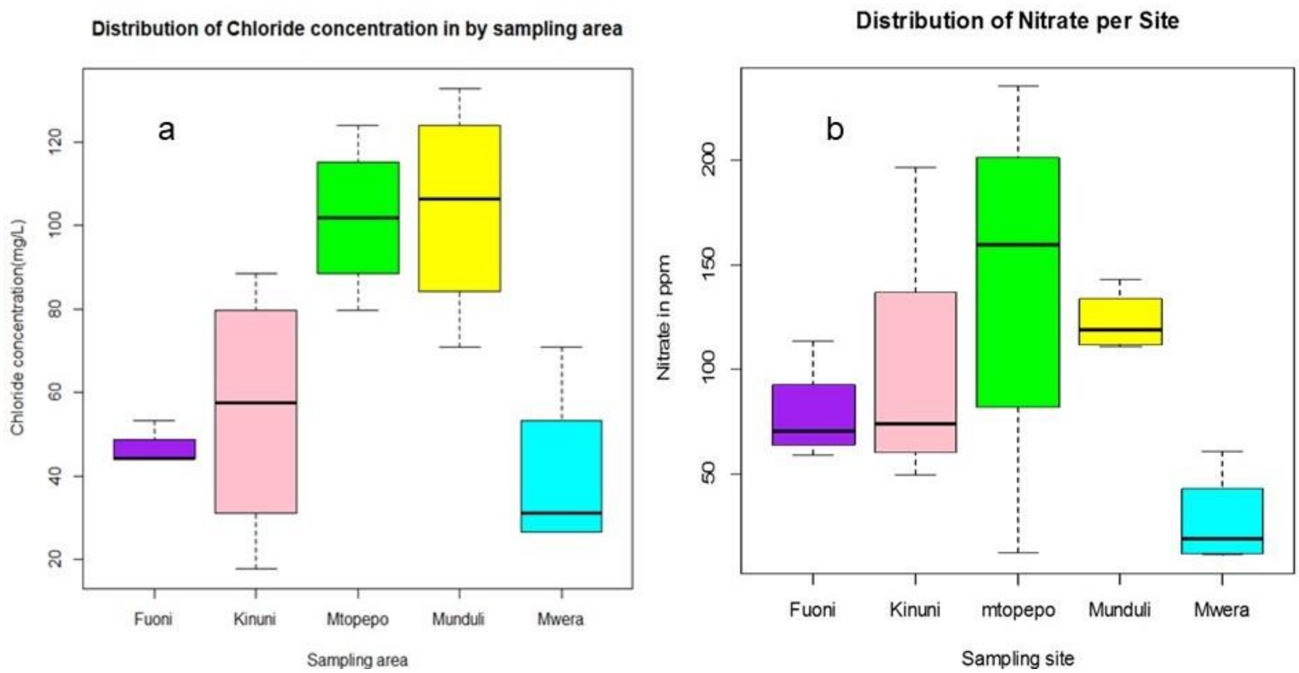

Figure 2: Present the distribution of Chloride per sampling site (a), and Present the distribution of Nitrate in by sampling site (b).

Table 2: Characteristics of groundwater wells and pit latrines, along with analyzed results of biological- and physiochemical-parameters of the groundwater wells at the study area.

Sampling point	Well depth (m)	Distance from pit latrine (m)	well elevation a.m.s.l (m)	Pit latrine elevation a.m.s.l (m)	Total Coliformm (cfu/100 ml)	F.C (cfu/100 ml)	Turbidity (NTU)	Salinity (‰)	DO (mg/L)	Temp. (°C)	pH	E.C (µS/cm)	ORP (mV)	Chloride Cl^- (mg/l)	Nitrate $NO3^-$ (ppm)	Type of well
MUW-1	13	18	39	35	1100	1100	0.67	0.43	6.16	29.2	8.1	952.0	-47.9	70.9	111	Borehole
MUW-2	11	10	32	34	0	1100	0.45	82.1	6.32	28.4	8.0	1109	-41.5	97.5	113	Borehole
MUW-3	13	18	44	46	4	4	1.19	0.54	6.01	29.0	7.9	1172	-33.3	115	143	Dug-well
MUW-4	13	17	26	28	0	0	0.52	0.55	7.02	29.3	8.0	1203	-34.4	133	124	Dug-well
MTW-1	13	8	27	34	460	1100	0.65	0.54	6.28	26.9	8.1	1194	-6.28	106	235	Dug-well
MTW-2	17	15	29	33	460	460	0.76	0.50	7.09	32.9	8.0	1199	-40.5	97.5	151	Borehole
MTW-3	20	24	26	35	7	7	5.99	0.48	3.81	34.0	8.0	1186	-38.8	79.8	12.2	Borehole
MTW-4	11	14	36	40	7	1100	0.43	0.54	6.24	30.3	8.0	1208	-38.1	124	168	Dug-well
KW-1	20	23	34	35	1100	7	1.14	0.20	6.38	28.9	8.3	460.0	-58.3	70.9	77.3	Borehole
KW-2	10	15	45	40	0	0	1.04	0.14	6.10	28.8	8.0	326.0	-40.0	17.7	49.3	Borehole
KW-3	10	13	36	34	1100	1100	0.47	0.31	6.30	28.3	7.6	697.0	-15.5	88.6	196	Dug-well
KW-4	22	16	40	39	7	9	0.53	0.25	6.43	28.8	7.4	572.0	-5.00	44.3	71.0	Dug-well
MWW-1	8	23	30	29	93	93	0.86	0.27	5.96	28.6	8.3	598.0	-53.5	26.6	12.5	Borehole
MWW-2	5	17	30	33	9	9	1.22	0.16	3.46	28.3	7.9	367.0	-35.5	70.9	60.8	Dug-well
MWW-3	10	38	36	35	0	0	0.52	0.24	7.61	29.0	8.3	548.0	-57.1	26.6	11.5	Dug-well
MWW-4	11	12	36	19	23	460	0.74	0.24	7.00	28.1	8.5	539.0	-67.4	35.5	25.6	Borehole
FUW-1	6	25	25	21	93	4	4.18	0.29	5.57	28.5	8.7	656.0	-77.7	44.3	59.0	Dug-well
FUW-2	6	27	20	20	460	7	0.59	0.30	6.81	30.4	8.3	686.0	-56.9	44.3	71.5	Dug-well
FUW-3	7	24	21	23	1100	23	0.66	0.30	6.49	30.6	8.2	690.0	-52.4	44.3	68.7	Borehole
FUW-4	7	18	21	25	1100	460	16.2	0.35	6.74	31.4	8.1	807.0	-55.4	53.2	113	Dug-well

Note: MUW = Munduli well, MTW = Mtopepo well, KW = Kinuni well, MWW = Mwera well and FUW = Fuoni well

Table 3: Comparison of mean concentration obtained from this study with World Health Organization (WHO) and Tanzania Bureau of Standards for drinking water supplies.

Parameters	Units	TBS (2005)	WHO (2011)	Average value obtained from this study				
				Monduli	Mtopepo	Kinuni	Mwera	Fuoni
pH	-	5.5 - 9.5	6.5-8.5	7.99	8.25	7.82	8.25	8.33
Turbidity	NTU	5 - 25	< 5	0.70	1.96	0.80	0.84	5.40
Nitrate, NO_3^-	(mg/L)	45	50	123	142	98.5	27.6	78.1
Conductivity	µS/cm at 20oC	2500	< 1 380	1109	1196	514	513	710
Dissolve Oxygen	mg/L	-	> 5	6.38	5.86	6.30	6.01	6.40
Total coliform	CFU/100ml	0- (1-3)	0	276	234	552	31.3	688
Faecal coliform (*E.Coli*)	CFU/100ml	0	0	551	667	279	141	124

Note:

TBS **=** *Tanzania Bureau of Standards for drinking water supplies (TBS860:2005).*

WHO **=** *World Health Organization- Drinking water guideline (2011).*

3.4 Distribution of Bacteriological contaminants

Total and faecal coliform ranged from 0 to 1100 CFU/100 ml. The maximum total coliform and faecal coliform bacteria were found in the water samples collected from Kinuni and Mtopepo villages (Figure 3). The data (Table 2) showed that proximity of pit latrines to shallow wells in these areas contributed highly to the bacteriological contamination to groundwater sources. Nevertheless, the possibility of contamination is less with the groundwater sources which are allocated relatively far from the pit latrines (Table 2 and Figure 3). In all five villages collected for water samples, Mwera village were found to have lowest mean value of faecal coliform probably due to less populated and low building density surrounded in the area. Our finding is in agreement with the study carried out by [30] who reported that, the high coliform count could be attributed to the proximity of the wells to pollution sources such as open defecation, pit latrines and waste dumps which encouraged quick migration of contaminants, especially those located upstream of the shallow wells. Similarly, in study conducted in two peri-urban areas of Kisumu in Kenya [35] reported that latrine and building density have been found as a potential determinant for faecal pollution in domestic wells.

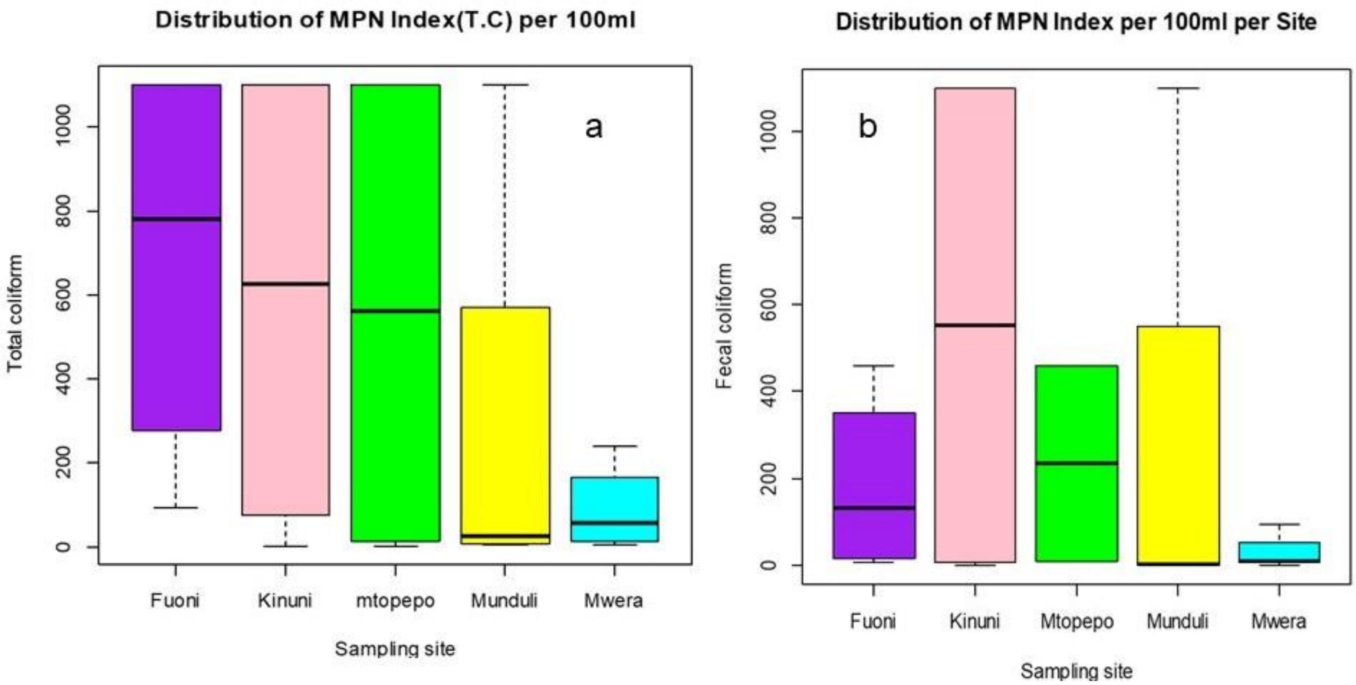

Figure 3: *Distribution of MPN Index of total coliform per sampling (a), and Distribution of MPN Index of fecal coliform per sampling (b).*

3.5 The influence of the distance between pit latrines and groundwater quality

3.5.1 Chloride concentration

The results of the OLS regression presented in equation (i), revealed that if there is 0 distance from the well to pit latrine the parameter estimate for Cl- concentration is 114.310. Since the value of coefficient of determination (R-square) from the model is 0.115, indicating that about 11.5 % of total variability in chloride concentration is explained by distance between pit latrines to the well. In addition to that, the parameter estimate of the variable distance between pit latrines to the well is -2.366; this implies that, for every one unit decreases in distance from dug well to pit latrines, Cl- concentration increases by magnitude of 2.366. The test of significance was 0.03 (at $p \leq 0.05$), confirms that the distance between the dug-wells and the nearest pit latrine has significant effect on the Cl -concentration.

Cl^{-1} $-2.4X+114.3$............. (*i*) , where X is the distance from the pit latrine to the well.

This reflect that when the chloride concentration increases the distance between pit latrine and well decreases. This results are similarly with Ahmed et al., (2002)[36] who was found the increasing of chloride concentration in the groundwater well when distance between pit latrine and groundwater source decreases.

3.5.2 Nitrate concentration

Results from the OLS regression equation 2, revealed that if there are 0 distances (i.e. x = 0) from the well to pit latrine the parameter estimate for NO3- concentration is 196.315 (equation ii).

$NO_3^- = -5.4X + 196.3$ .... (ii) , *where X is the distance from the pit latrine to the well.*

Since the value of coefficient of determination (R-square) from the model is 0.382, indicates that only 38.2% of total variability in nitrate concentration is explained by distance between pit latrines to the well. In addition to that, the parameter estimate of the variable distance between pit latrines to the well is -5.432; this implies that, for every one unit decreases in distance from dug well to pit latrines, NO_3^- concentration increases by magnitude of 5.432. The test of significance gave a significant p value of 0.004 (i.e. $p \leq 0.05$), confirms that the distance between the dug-wells and the nearest pit latrine has significant effect on the NO3- concentration. Our study findings were in agreement with the study of [37] who found the decrease of nitrate concentration in groundwater sample as the distance from the pit latrines to groundwater source increased from 15 to100 m. [38] demonstrated that the highest nitrate concentrations in groundwater were associated with the highest population and pit latrine densities within the settlement.

3.5.3 Total coliform counts

Results of the OLS regression model (*equation iii*) for the amount of total coliform in the dug wells indicates that, if there is a 0 distance from the dug well to pit latrines yield the estimate value 616.697 with a p-value 0.082 (not significant).

$CT = 9.2\,X + 616.7$ .... (*iii*) , where X is the distance from the pit latrine to the well.

Moreover, for every unit decrease in distance the amount of total coliform increases by 9.222 with p-value of 0.586 (not significant), this indicates that the effect of distance on the amount of total coliform is not significant. The measure of proportionate of the variability of total coliform explained by distance from pit latrines to well is equal to 1.7%. Additionally, t-test results of -0.555 suggest that there is inversely relation between total coliform and distance that shows there is other factors accelerate the total coliform bacteria in wells. For instance, ropes tied to gallons or buckets to draw the water from the well may lead to pollute the water. Our results of no significant association between the distance from the pit latrine and total coliform contaminants is also agreed by a number of studies including [36, 39, 40]. All of them found no positive association between coliform contamination (water quality) and proximity to latrine pits.

3.5.4 Faecal coliform

From the OLS regression model (*equation iv*) if there are 0 distances from the well to pit latrine the parameter represents the estimate value of 1146.621.

$FC = -42.4\,X + 1146.6$......................(*iv*) , where X is the distance from the pit latrine to the well.

The estimate constant p-value of > 0.0001 shows that this value has a significant effect on the amount of faecal coliform in the dug-wells. Since the value of coefficient of determination (R-square) from the model is 0.386, about 38.6 % of total variability in chloride concentration is explained by distance between pit latrines to the well. Also, the coefficient of the variable distance of -42.372, shows that every unit increase in the distance from pit latrine to the dug wells decreases the amount of faecal coliform by an amount of 42.372 CFU/100 ml. The test of significance gave a p-value of 0.003; which confirms that the distance between the pit latrines and the nearest well has significant effect on the amount of faecal coliform. The similarity results of the study carried out by [30] showed that pit latrines were microbiologically impacting groundwater quality up to a distance of 25 m from the groundwater source, while [41] observed that microorganisms travel up to 3m in the route of groundwater flow and they reduce with distance.

4.0 Summary and Conclusions

This study assesses the impacts of the pit latrines on groundwater quality in five sub-urban area of squatter settlement in Zanzibar. Physio-chemical and bacteriological parameters were measured from groundwater wells allocated nearby pit latrines. Most of the physical parameters of the water well were in the range of WHO guidelines and TBS standard limits for drinking water quality, except for turbidity and dissolved oxygen which are relatively high. Nitrate and Chloride concentrations were found to be impacting on the groundwater quality probably due to its high concentrations in excreta and its relative mobility in the subsurface. The data revealed that, over 57% of nitrate and chloride concentration measured in water samples were above the WHO and TBS standard set for drinking water quality. Among five sub-urban villages conducted on this study, the maximum coliform counts in water well were recorded at Munduli (1100 CFU/100ml), where population density is higher and pit latrines were located close to groundwater wells. Furthermore, Ordinary Least Square (OLS) regression model reveals that for every one unit decreases in distance from shallow well to pit latrine, NO - and Cl- concentration increases by magnitude of 5.432 and 2.366, respectively. This indicate that the distance between the shallow wells and the nearest pit latrine has significant effect on NO - and Cl- concentrations. In contrary, faecal coliform counts show that for every unit increase in the distance from pit latrine to the shallow wells the counts decreased by 42 CFU/100 ml. However, OLS regression model did not show significant relationship of total coliform and distance from the well. This suggest that there are other factors that may accelerate the total coliform bacteria in water wells e.g. ropes tied to gallons or buckets during water abstraction. These results illustrate that public health risks associated with waterborne diseases could be ranked high at densely populated squatter settlement. Thus, this study recommends that (i) routine monitoring and management of shallow wells is required as a proper solution to decrease the waterborne diseases in squatter areas in Zanzibar. (ii) The concerned authority to provide construction guidelines for those new construction development together with application of low-cost technologies such as raised and lined pit latrines in order to minimize potential risk of groundwater pollution. (iii) Use of household water treatment techniques like chlorine based substances is recommended in the area where groundwater is exposed to faecal coliform contamination [42].

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