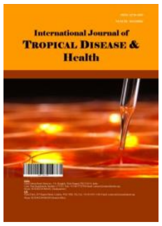

International Journal of TROPICAL DISEASE & Health

42(4): 30-45, 2021; Article no.IJTDH.67547
ISSN: 2278–1005, NLM ID: 101632866

Seasonal Assessment of Quality of Groundwater from Private Owned Wells in Unguja Island Zanzibar

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Authors' contributions

This work was carried out in collaboration among all authors. Authors HM, MRH and WJO designed the study, wrote the protocol and the first draft of the manuscript. Authors HM and CJO managed the analyses, statistical studies and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJTDH/2021/v42i430449
Editor(s):
(1) Dr. Giuseppe Murdaca, University of Genoa, Italy..
Reviewers:
(1) Yogesh V. Ushir, SMBT Institute of D. Pharmacy, India.
(2) Patel Mona Rajendrakumar, Gujarat Technological University, India.
(3) Khushbu.K.Birawat, Global Academy of Technology, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67547

Original Research Article

Received 28 January 2021
Accepted 03 April 2021
Published 06 April 2021

ABSTRACT

The Assessment of seasonal changes in groundwater quality is an essential aspect for evaluating pollution level which can be a reflection of the source environment and the activities of man, including the use and management measures. This study examined the effect of seasonal variation on the physical, chemical, and biological properties of groundwater in the Bububu constituency which is located in the West district within the Urban –West region of Unguja Island. The study was conducted using cluster sampling. Four clusters with a large number of wells were selected for further analysis. The number of wells from each cluster was sampled for physicochemical and bacteriological contamination levels. Samples were collected in two different seasons (Wet and Dry) to allow comparison between the two seasons. Analysis of water samples (N= 52) indicated that the sources are very vulnerable to microbial contamination particularly during the wet season at which 78.85% of the analyzed samples were contaminated with fecal coliform and unfit for human

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consumption. However, all measured physicochemical parameters were within the acceptable range except the levels of nitrate during the wet season in some samples taken at Kibweni and Sharifumsa which exceeded the recommended level by WHO. There is a need for adequate treatment of water particularly during the wet season as well as serious monitoring and proper regulation by the appropriate authorities to curb the menace and safe guard the lives of people to prevent a possible epidemic.

Keywords: Seasonal; groundwater; bububu; unguja.

1. INTRODUCTION

Peri-urban communities are growing rapidly in line with global trends in urbanization around the world. These are communities that are not yet well understood and often disregarded and characterized by increasing marginalization and environmental degradation [1]. Peri-urban areas exist at the geographical and economic fringe of cities, exhibiting features of both the urban and rural context [2]. Whereas these areas were once viewed as a stepping stone on the road to more 'modern' urbanity, they are now seen as an independent category from either traditional rural or urban institutions [3]. Peri-urban communities have unique characteristics by being situated in the center of what is known as the health risk transition from traditional diseases, which are associated with a rural lifestyle and modern urban diseases [4]. Their position on the outer edges of urban society may put them at risk of contracting modern diseases, as the areas have no protection infrastructure. The growing and highly dense populations of peri-urban areas frequently depend on locally available sources of water, as there is often a lack of water-providing infrastructure by government or private sector actors [1]. Unprotected dug groundwater wells, which are considered highly susceptible to contamination with pathogenic organisms, are often the water source of choice in peri-urban communities because they are inexpensive and easy to construct. Contamination of these wells can occur from surface by flooding, the introduction of pathogens on dirty buckets, or accidental dropping of waste or other items into the water. It can also occur from below ground contamination of the aquifer itself through leaching of wastewater from landfills, on-site wastewater treatment, or rivers contaminated with waste nearby. Contamination from above may be caused by unhygienic usage of wells without covers and nearby poor sanitary practices such as disposal of human excreta in open spaces close to water sources [5]. Peri-urban areas often have disproportionately high numbers of poor people, driven into these informal settings by demolishing of slums and migration from impoverished rural areas [6]. Groundwater is a crucial source of drinking water in peri-urban areas but the water is vulnerable to different sources of pollution. As populations grow and the distribution of settlements change, the risk of contamination increases. Increasing amounts of waste above ground in peri-urban areas is one factor at play. It is common for informal settlements to be located close to polluting infrastructures, such as factories, dumps, and waste treatment plants. Most peri-urban areas have no necessary sanitation infrastructure to manage household solid waste and sewage, a situation that gives an additional burden and heightens the existing health risk [7]. Pollution of groundwater sources in urban areas is also commonly attributed to septic tanks' proximity to wells and floods [8]. In areas where water is obtained from underground sources, pit latrines are not recommended unless the groundwater table is very deep or specific known characteristics of the soil prevent migration of contaminants [5]. The problem can be mitigated by increasing distances between wells and on-site sanitation systems; however, this may not be feasible in the case of informal settlements, as space is at a premium, and there is rarely adequate or effective regulation of development. The level of contamination is impacted by several factors, including speed and quantity of movement of contaminants from outside sources into groundwater, type of surrounding soil, depth of water table, and proximity of the sources. Seasonal variations in stream flow, standing water, and distribution of pathogens by surface runoff and flood waters can also have dramatic and immediate impacts on levels of pathogens in water resources. On the other hand, temperature plays a role in these variations, as it may alter growth rates for many bacteria, protozoa, viruses and helminthes, increasing the spread of contamination in water resources in warm climates [9]. Level of contamination seems to be seasonal and therefore determination of water quality in different seasons of the year is vital to check the suitability of water for various domestic consumptions. The study on variations in water quality around Stone Town in Zanzibar showed strong relationship between levels of precipitation and levels of contamination in coastal waters caused by flooding of streets that carried rubbish, agricultural runoff, and sewage into the bay [10]. Similar variations in contamination levels could be expected in groundwater, as the same flooding that carries sewage into the bay may also contaminate surface waters with the potential to leach into subsurface aquifers. Under normal environmental conditions (absence of heavy rain), microorganisms are retained efficiently by the soil and are only detectable in trace amounts in groundwater. Serious weather events, such as high-intensity rain or drought, can greatly influence the water quality, contributing to the dissemination of pathogenic microorganisms to geographic areas in which they were previously absent. Recent climate changes have led to an uneven rainfall distribution throughout the year with large and intense rains in certain regions. The safety of groundwater resources by being free from different forms of pollution is vital to avoid direct health impacts. The diseases associated with biological or microbial contamination of drinking water such as cholera, diarrhea, and dysentery are considered to have more and immediate health effects compared to diseases emanated from physical and chemical contamination [11]. Diarrhea kills 2,195 children every day—more than AIDS, malaria, and measles combined [12]. According to a report, about 88% of diarrhea-associated deaths are attributable to unsafe water, inadequate sanitation, and insufficient hygiene [13]. Studies have shown that outbreaks of water-related diseases have both spatial and temporal variations. The outbreaks are more common in peri-urban areas with unplanned housing compared to urban and villages [14]. Similarly, waterborne disease outbreaks are very high in wet seasons and rarely occur in dry seasons. According to Tanzania Demographic and Health Survey in 2010, the prevalence of diarrhea in Tanzania varies regionally and by season, with the highest rates usually occurring around the rainy season. The situation becomes worse in regions with a poor management approach [15]. The provision of safe, adequate water depends on several issues such as availability of good and safe water sources, efficient distribution network, and appropriate institutional arrangements that can effectively govern public water supply. Lack of adequate safe water in a particular community will force the community residents to look for other sources regardless of their safety. Zanzibar peri-urban areas are characterized by water shortage, and the communities within the areas have responded by establishing their private wells. The wells were established with low or minimum technical expertise such that many of these water sources are very close to source of pollution or are covered by runoff during heavy rains. Bububu constituency is among the areas faced with this situation. The knowledge on the quality of water from these wells is very scanty. This study was therefore conducted to assess the quality of water from these private wells within four villages (shehias) of Bububu constituency.

2. MATERIALS AND METHODS

2.1 Study Site

The reported study was conducted in Bububu constituency located in the West district within the Urban –West region of Unguja Island of Zanzibar, Tanzania. The study area has four administration units (shehias) namely, Sharifumsa, Kibweni, Mwanyanya, and Bububu (Fig. 1). The constituency covers an area of 10.31 km^2 with a total population of about 51,578 people (*Census*, 2012) but due to the rapid population growth rate (6.6%), the population has doubled to 110,600 inhabitants in 2015. The current daily water demand for inhabitants within the constituency is estimated at 3262m^3/day and is increasing significantly to meet the demand of ever-increasing population.

2.1.1 Climate condition of the study area

The study area experiences the same climate as Unguja Island, which is equatorial and humid. Zanzibar has two main rain seasons, the more extended rain period (Masika) from March to June and the short rain period (Vuli) that begins in October to December. The humidity is high ranging from 900mm to 1000 mm during the heavy rainy season and from 400mm to 500mm during the short rainy period. This is because of two rainfall peaks, and Zanzibar is usually green throughout the year. The remaining period of the year is almost dry, particularly from January to March. The study area experiences temperatures fluctuation of 20 – 35 °C.

2.2 Data Collection

The study used a combination of data collection methods, including Survey/Observation, Geographic Information Systems (GIS) coordinates, and laboratory analysis.

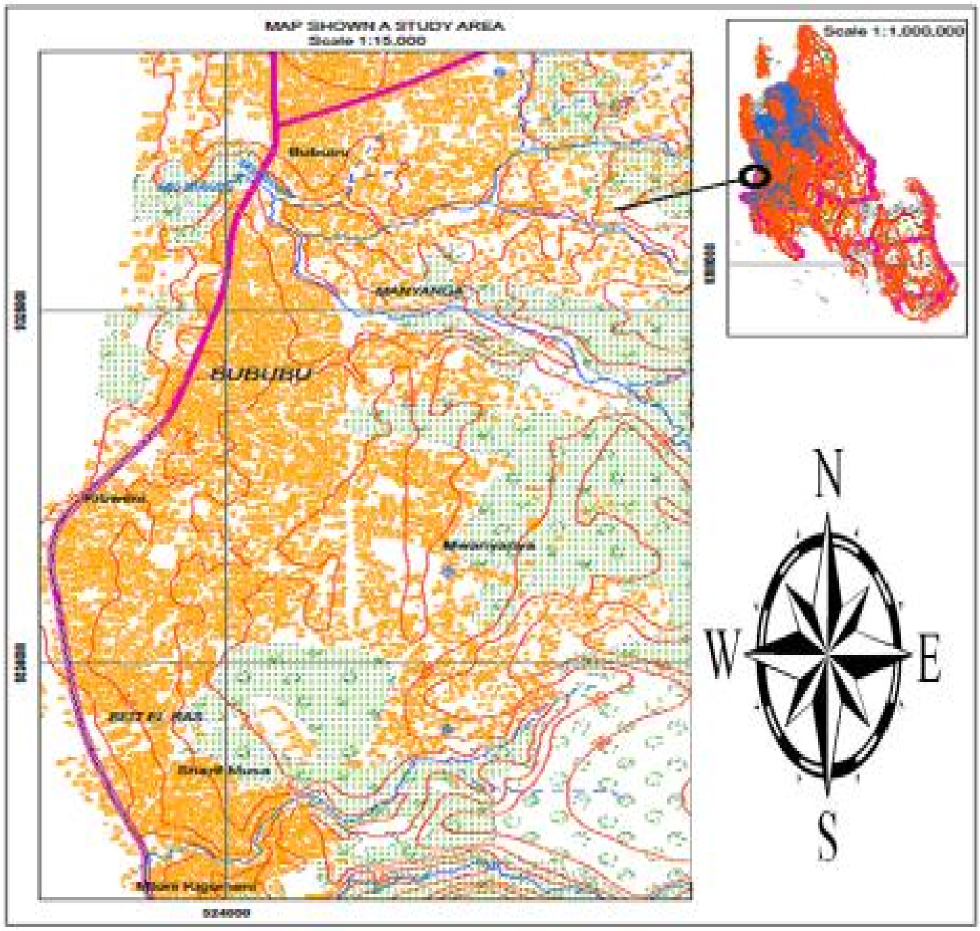

Fig. 1. A map of Unguja Island with study site created by Haji Mwevura and Moh'd R. Haji

2.2.1 Survey /observation and GIS coordinates

Both domestic and community wells were surveyed and inspected using an inspection checklist to collect the required information. GPS readings of water sources as well as nearby potential pollution sources were recorded. Garmin GPS 60 was used to obtain geographic coordinates, and ESRI ARC GIS version 9.3 was used to map the study area and sampling points in the Bububu Constituency

2.3 Collection of Samples for Water Quality Parameters

The study was conducted using cluster sampling. Four clusters with a large number of wells were selected for further analysis. The number of wells from each cluster was sampled for physicochemical and bacteriological contamination levels. Samples were collected in two different seasons (Wet and Dry) to allow comparison between the two seasons. Water samples for physicochemical analysis were collected in the pre-cleaned 1 litre plastic bottles, while the bacteriological analysis samples were collected in sterilized glass bottles. The use of sterilized glass is by the protocol of water sampling to avoid contamination during bacteriological analysis. Bacteriological samples were then analyzed in the laboratory immediately after being collected [16].

2.4 Laboratory Analysis of Water Quality Parameters

2.4.1 Temperature and pH measurement procedures

The pH and temperature were measured using digital pH – Meter (Wagtech). These instruments were calibrated before using them for measurement. The water samples' pH and temperature were then measured by dipping the electrode of the calibrated instrument into samples and allowed to stabilize to give a reading. The electrode was then rinsed with deionized water before being used to measure the other samples.

2.4.2 Total Dissolved Solids (TDS) and Electrical Conductivity (EC) measurement procedures

EC and TDS values were measured using the (Wagtech) digital conductivity meter. The instrument was firstly calibrated. The electrode of the calibrated device was used to measure EC and TDS by dipping into the sample and allowed enough time to give a stabilized reading. Similarly, the electrode was rinsed with distilled water before transferring to another sample.

2.5 Analysis of Nitrate

Nitrate was measured using a Colorimeter (HACH, DR/850). The instrument sample cell was filled with 10ml of water sample to mark until adding a level spoonful of Nitrate Powder. Similarly, a sample cell was filled with 10ml of the water sample, but the blank was without the nitrates powder. The screwcap was replaced, and the tubes were shaken well for one minute, respectively. The tube was allowed to stand for one minute then gently inverted three or four times to aid flocculation. The tube with nitrates powder was allowed to stand for two minutes or longer to ensure complete settlement. The screw cap was removed, and the top of the tube was wiped with clean tissues and allowed to stand for 10 minutes to allow for full-color change. Amber color developments showed the presence of nitrate. There was no color change in the blank. The steps were repeated according to the number of samples.

2.6 Bacteriological Analysis

Microbial analysis for both total coliform and fecal coliform bacteria was conducted using Advanced Portable Meter Kit (Wagtech). The technique used was the membrane filtration technique (MFT) as described in ISO (1990). All apparatus and materials involved in all stages of bacteriological analyses were sterilized to prevent cross-contamination. During analysis, the membrane filtration unit was sterilized between analyses of consecutive samples by rinsing the inside part of the sampling cup with methanol as much as possible. A cigarette lighter was used to ignite the methanol and then left for 15 minutes to ensure complete sterilization. Petri dishes were sterilized using an autoclave/Pressure Cooker at 121°C. Further sterilization was done by wiping the contact area with methanol using clean, soft tissues and then left to dry. This sterile unit was then used for sample filtration. Before sample filtration, membrane Lauryl Sulphate Broth (MLSB) was prepared by adding 10 spoonfuls of culture media into a sterilized measuring tube with boiled water. The tubes were then placed in a media measuring device sterilized at 121°C for at least 10 minutes. While closing the tube lids, the content was shaken to dissolve all the powder to give a bright pink colour. About 2.5 ml of the prepared nutrient medium was dispensed on absorbent pads placed in a sterile petri dish. Sample filtration was performed by using a sterile membrane filter and vacuum filtration system. The sterile membrane filter was carefully removed from its package, placed in the sterile filtration apparatus. Water samples were then thoroughly mixed by inverting its container several times. A volume of 100 ml water samples was measured and poured into the filter funnel and then filtered by applying a vacuum to the suction flask and draw the sample through the filter. The membrane filter was carefully removed from the filtration apparatus using the sterile forceps and placed in the previously prepared Petri dish onto the pad, starting at one edge to avoid trapping air bubbles. The Petri dish was then covered with a sterile lid of the Petri dish.

The Petri dish was then immediately incubated at a temperature of 37^{o}C for 18hours for total coliform determination. The development of yellowish colonies on the filter paper indicates the presence of total coliform. For Fecal coliform determination, membrane filtration of the same samples was followed by incubation at 45^{o}C for 18 hours. Similarly, the formation of a yellowish spot on the filter paper indicated the presence of fecal coliform. The formed-colonies were then counted and the results expressed as a number of colonies per 100 ml of sample. Where smaller volumes have been done the results were normalized to a number of colonies per 100 ml of sample.

To confirm the membrane results for total coliforms, a representative number of colonies were sub cultured to tubes of lactose peptone water and incubated at 35 °C for 48 hours. Gas production within this period confirms the presence of total coliforms. The confirmation of fecal coliforms was performed by sub-culturing a representative number of colonies to a tube of lactose peptone water and a tube of tryptone water and incubated at 44 °C for 24 hours. Growth with the production of gas in the lactose peptone water confirmed the presence of fecal coliforms.

3. RESULTS

3.1 Seasonal variation of Physical and Chemical Parameters

These include the mean pH, TDS, EC and Nitrate values

4. DISCUSSION

The pH results are in agreement with a decrease in pH values from dry to wet season, as reported by other workers [18]. Variations in pH could be attributed to the geology of host rock and other human activities [19]. In areas with heavy anthropogenic activities where acidic gases' emission is pronounced, acidic rain will lower the pH of both soil and groundwater. Thus the lower pH values in the study areas, which were statistically significant during the wet season, were likely attributed to rainwater which increased acidity during recharging of the groundwater. Our study recorded a pH value slightly higher than those measured in groundwater (6.47 – 7.27) from south Pemba [20]. A pH range of 6.5–8.5, however, is considered suitable for drinking water [17], and therefore, all pH values measured in water from the study areas are within the acceptable range recommended by WHO. The highest levels of TDS at Sharifumsa could be attributed to the influence of seawater intrusion on the groundwater sources in the area indicated verbally by all water source owners from the Shehia. According to them, as the day goes on, the water became too salty. However, the influence of organic dissolved matter associated with anthropogenic activities cannot be ruled out.

These levels measured in this study, however, compared well with the levels (108 – 431 mg/l) reported in groundwater water South Pemba regions (Mohamed et al. 2016) but significantly lower than those TDS levels (7 – 6,380 mg/l) found in groundwater from Chukwani Zanzibar [20].

In contrary to these findings, some workers [21] reported higher TDS values in the wet season (0.39 to 7.11mg/L) compared to the dry season (0.00 to 2.11mg/L). The increase in TDS during the rainy season was attributed to the different forms of leachate during the rainy season. It is known that groundwater contains some dissolved solids, and may be naturally high in TDS in some settings, such as geothermal and arid areas of groundwater discharge. In addition to the natural sources, TDS can enter groundwater through recharge of water that has been degraded by human use, such as wastewater or runoff from human settlement [22]. Based on TDS groundwater can be classified as fresh, if the TDS is less than 1,000 mg/L; brackish, if the TDS is between 1,000 and 10,000 mg/L; saline, if the TDS is varied from 10,000 to 1,000,000 mg/L; and brine, if the TDS is more than 1,000,000 mg/L [23]. High concentrations of TDS in groundwater used for water supply make the water less acceptable to consumers because TDS can cause an objectionable taste or odor [23]. However, based on the TDS values reported, the quality of groundwater in the present study area is still classified as fresh and within the WHO recommended levels for drinking water [17]. In principle, EC is highly connected to TDS as, in most cases, conductivity is attributed by TDS. The overall seasonal variations for EC though significantly reduced in the dry season in the present study, are still within the WHO recommended ranges of EC (500-800μS/cm) for drinking water and therefore qualify for human consumption [17]. The higher variation of nitrate in the wet season, as reported in the study, has also been reported in waters from dugout well located with tropical savannah environment of Ghana [24,25]. Although the overall mean values are within the WHO recommended standard, it is still a source of worry because they are within the upper reference range of the normal. In agricultural areas application of nitrogen-rich fertilizers has been considered as a major source of nitrate in groundwater however for non-agricultural environments principal sources are improper disposal of human and animal waste as well as wastewaters and runoff from municipal or dump areas [26]. As the reported study was conducted in non-agricultural areas, the possible nitrate source could be associated with lack of sanitation infrastructure and septic tanks found close to water sources. An increase in nitrate concentration during the wet season was likely attributed to septic tanks leachate and residential runoff as it has been reported in another study that leachate of septic tank is the primary source of nitrate in groundwater during heavy rains [22]. Nitrate is one of the groundwater contaminants of

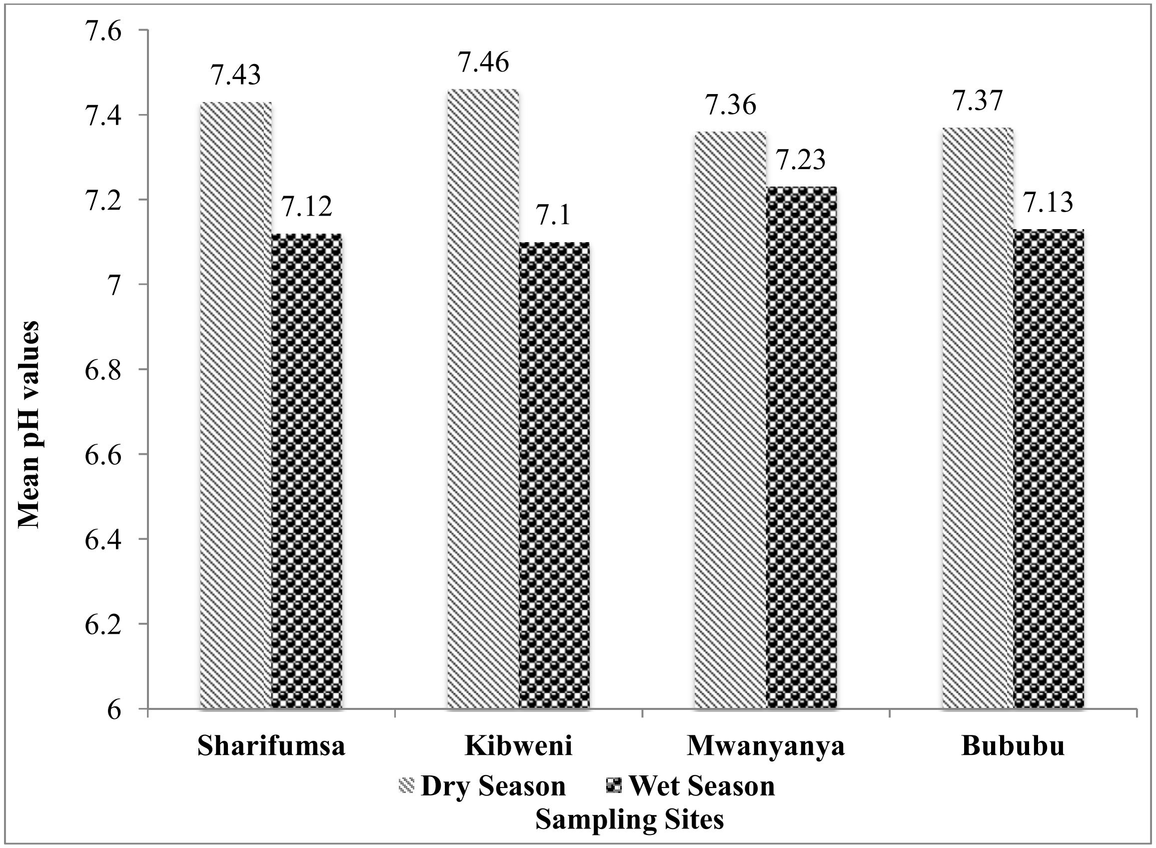

Fig. 2. Seasonal variations of mean pH values of groundwater

The mean pH values measured in water collected from each Shehia are presented in Fig. 2. The values varied between 7.10 and 7.23 during the wet season and between 7.36 and 7.46 in the dry season. Water samples from Kibweni recorded the highest pH mean value of 7.46, while Mwanyanya had the lowest pH mean value of 7.36 during the dry season. On the other hand, the highest mean pH in the wet season was measured in water from Mwanyanya at 7.23, while Kibweni recorded the lowest mean pH value of 7.1

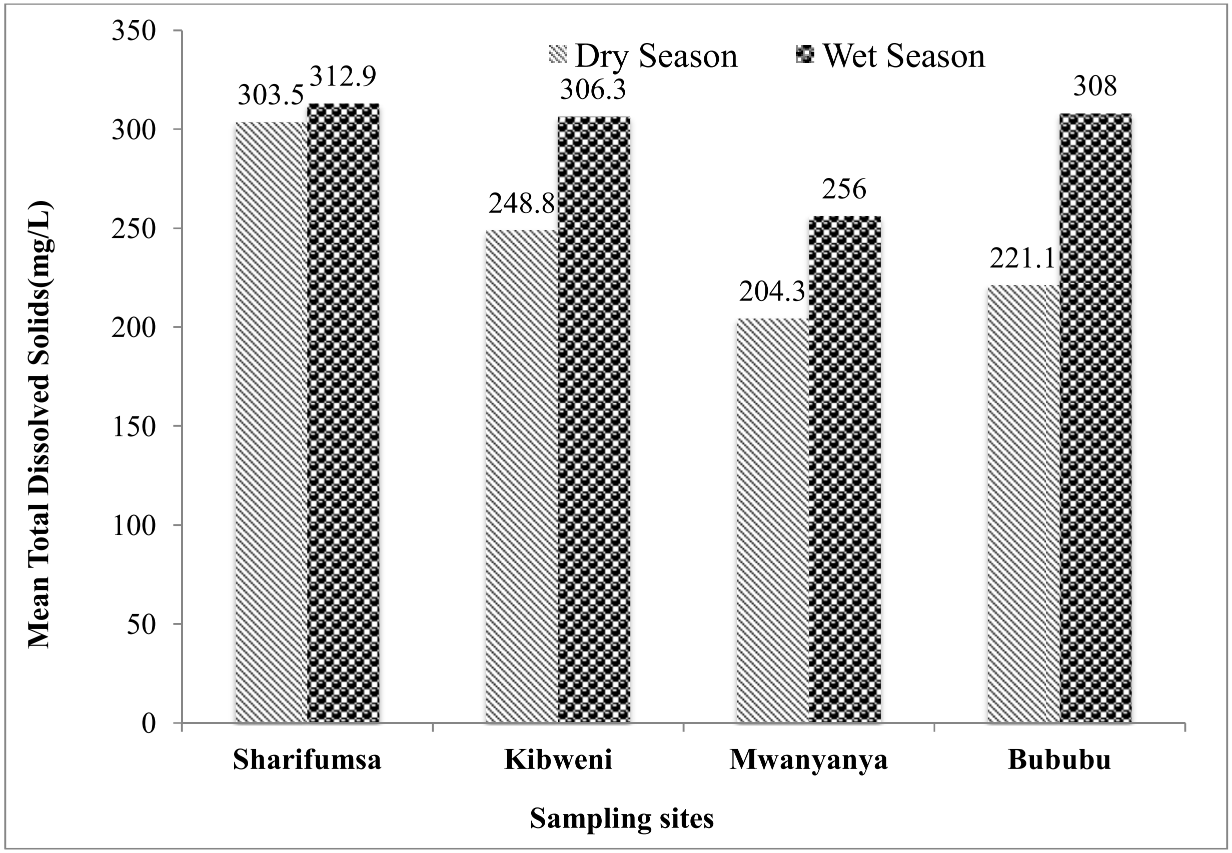

Fig. 3. Seasonal variations of the mean TDS measured in the ground among the sites

The highest values of mean TDS (dry =303.3mg/L and wet = 313mg/L) were recorded in wells from Sharifumsa Shehia, while the lowest in the dry and wet seasons of 204.3 mg/L and 256 mg/L respectively were found at Mwanyanya

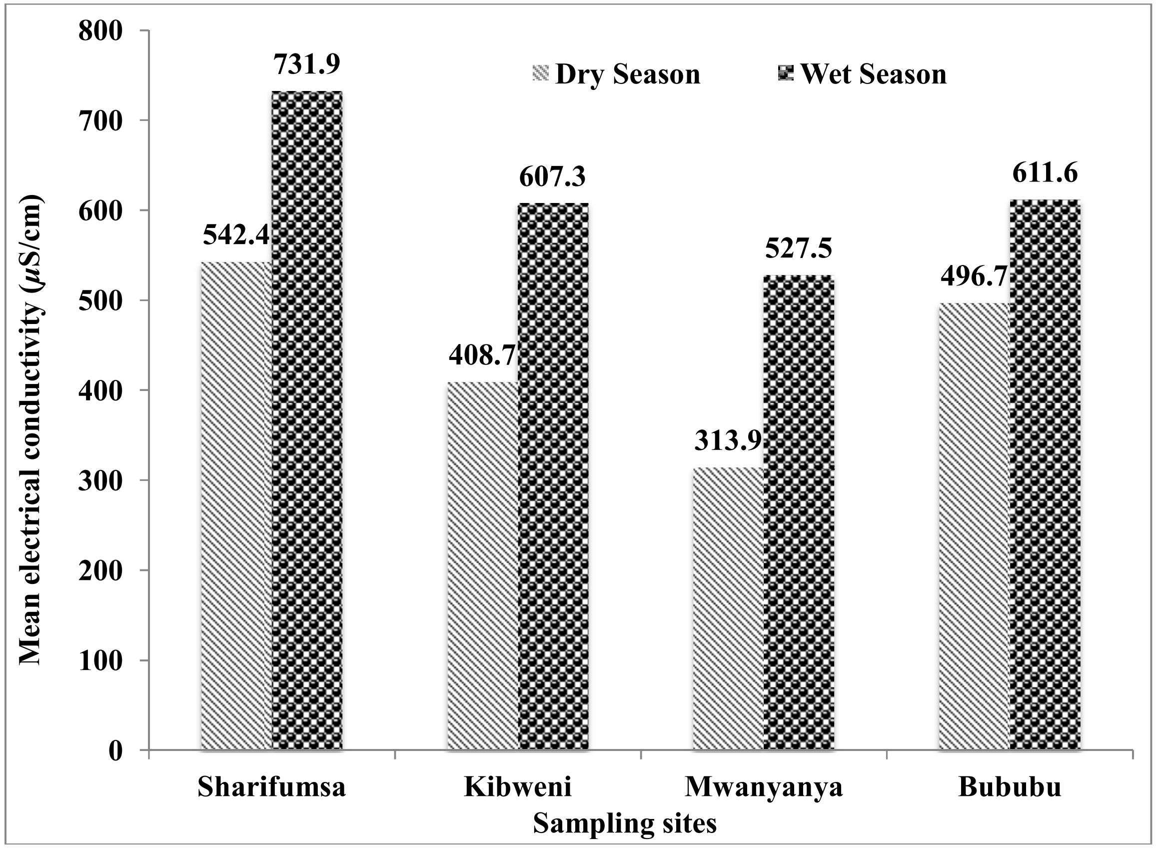

Fig. 4. Seasonal variations of mean electrical conductivity (EC)

The highest mean EC values of 542.4 microS/cm and 731.9 microS/cm for both dry and wet seasons, respectively, were recorded at Sharifumsa while the lowest in the dry and wet seasons of 313.9 microS/cm and 527.5 microS/cm respectively were found at Mwanyanya

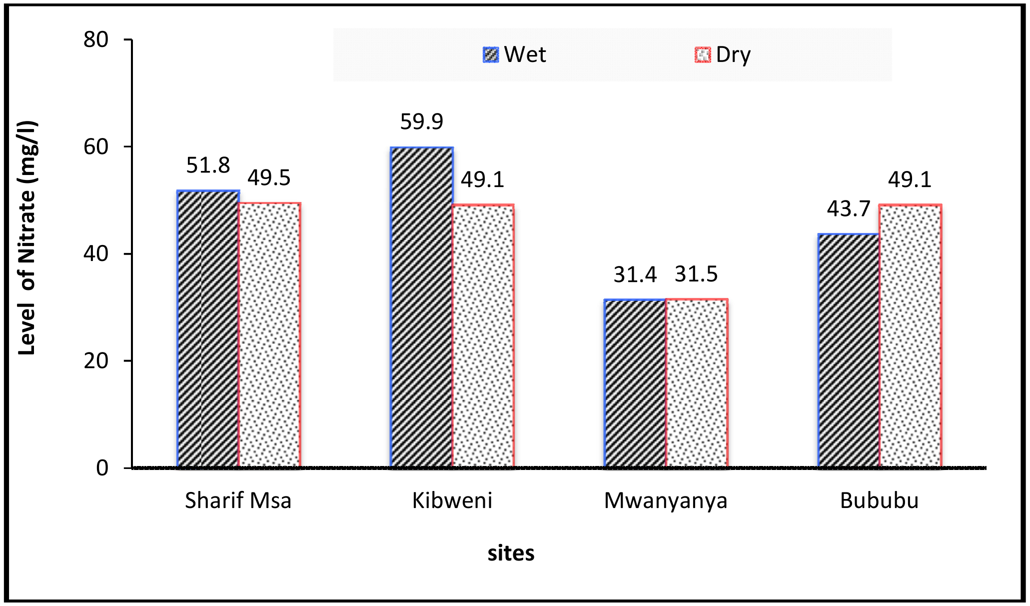

Fig. 5. The seasonal variations in nitrate concentrations among the study sites in different shehias

Nitrate was detected in all water samples collected from the study sites. These nitrate concentrations had average ranges of 31.4 mg/L - 59.9 and 31.5 - 49.5mg/L in the wet and dry seasons. Kibweni showed the highest concentrations of nitrate during the wet season, while in the dry season, the highest concentration was measured at Sharifumsa. On the other hand, the lowest concentrations of nitrate during both seasons were found at Mwanyanya

Table 1. Statistical comparison of seasonal variations of physicochemical parameters among the four study sites

Location	Physicochemical Parameters	Total No of Wells	Dry season	Wet season	X^2	P-value
Sharifunsa Kibweni Mwanyanya Bububu	pH	52	7.405±0.048	7.145±0.058	t=12.452	P < 0.0001
Sharifunsa Kibweni Mwanyanya Bububu	TDS	52	244.425±43.45	295.8±26.68	t=3.633	P = 0.0013
Sharifunsa Kibweni Mwanyanya Bububu	EC	52	440.43±100.96	650.27± 70.729	t=6.138	P < 0.0001
Sharifunsa Kibweni Mwanyanya Bububu	NITRATES	52	46.7±12.16	44.8±8.87	t=0.455	P = 0.6531

There were statistically significant differences when the values (Mean ± SD) of pH, TDS, and EC were compared between the wet and dry seasons (p< 0.01)

Table 2. Summary of physicochemical parameter of drinking water [17]

Parameters	Season	Ranges	WHO Standard
pH	Dry	7.36-7.46	6.5-8.5
	Wet	7.12-7.34	
Temp (Celsius)	Dry	29.3-32.3	Ambient
	Wet	27.5-30.9	
TDS (ppm)	Dry	256-313	500-2000
	Wet	204.3-303.5	
EC (uS/cm)	Dry	527.5-731.9	500-800
	Wet	408.7-607.9	
Nitrate (mg/L)	Dry	31.5-49.5	50
	Wet	31.4-59.9	

Table 3. Microbial contamination during the wet season

Sharifumsa			Kibweni			Bububu			Mwanyanya		
Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)	
	Total	Fecal		Total	Fecal		Total	Fecal		Total	Fecal
SM1	15	2	KB1	Nil	Nil	BB1	3	nil	MN1	15	2
SM2	37	6	KB2	35	7	BB2	Tnc	30	MN2	12	1
SM3	7	2	KB3	10	3	BB3	15	1	MN3	35	3
SM4	1	Nil	KB4	25	5	BB4	26	7	MN4	nil	Nil
SM5	6	3	KB5	5	Nil	BB5	23	4	MN5	50	5
SM6	27	4	KB6	11	3	BB6	85	14	MN6	44	6
SM7	4	Nil	KB7	6	1	BB7	tnc	15	MN7	5	2
SM8	nil	Nil	KB8	4	Nil	BB8	tnc	30	MN8	40	9
SM9	25	3	KB9	6	1	BB9	tnc	35	MN9	4	3
SM10	tnc	15	KB10	25	4	BB10	40	22	MN10	31	12
SM11	2	Nil	KB11	22	5	BB11	30	10	MN11	20	11
SM12	20	5	KB12	nil	Nil	BB12	50	28	MN12	47	27
SM13	5	Nil	KB13	tnc	40	BB13	60	41	MN13	tnc	35

From the table, 92.38% (N=48) of the analyzed samples were contaminated with total coliform during the wet season, and 41 samples, equivalent to 78.85% of the samples were detected with fecal coliforms. The levels of bacterial contamination ranges were nil to tnc (too numerous to count) cfu and nil –41 cfu for total coliforms and fecal coliforms, respectively. Water collected in wells within Bububu shehia was most contaminated compared to other shehias

Table 4. Microbial contamination during the dry season

	Sharifumsa			Kibweni			Bububu			Mwanyanya	
Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)		Sample	coliform (cfu/100ml)	
	Total	Fecal		Total	Fecal		Total	Fecal		Total	Fecal
SM1	14	1	KB1	Nil	Nil	BB1	Nil	Nil	MN1	16	1
SM2	10	Nil	KB2	Nil	Nil	BB2	Tnc	12	MN2	Nil	Nil
SM3	10	Nil	KB3	10	Nil	BB3	2	Nil	MN3	25	6
SM4	nil	Nil	KB4	14	Nil	BB4	32	2	MN4	nil	Nil
SM5	40	4	KB5	Nil	Nil	BB5	18	3	MN5	30	3
SM6	15	Nil	KB6	Nil	Nil	BB6	55	3	MN6	15	4
SM7	30	2	KB7	15	2	BB7	19	2	MN7	22	2
SM8	nil	Nil	KB8	10	Nil	BB8	nil	Nil	MN8	9	Nil
SM9	nil	Nil	KB9	Nil	Nil	BB9	21	4	MN9	4	Nil
SM10	20	1	KB10	Nil	Nil	BB10	7	Nil	MN10	nil	Nil
SM11	nil	Nil	KB11	Nil	Nil	BB11	nil	Nil	MN11	35	3
SM12	3	Nil	KB12	nil	Nil	BB12	24	4	MN12	4	Nil
SM13	nil	Nil	KB13	6	Nil	BB13	17	1	MN13	5	Nil

In the dry season, about 63.46% (N= 33) of the analyzed samples were detected with total coliforms at contamination level ranging between nil to too numerous to count (tnc) cfu. The contamination by fecal coliforms was detected in 36.54% (N=19) of the analyzed samples. Similarly to the wet season, the Bububu Shehia was leading with the highest levels of contamination of both total and fecal coliforms followed by Mwanyanya. On the other hand, samples from Kibweni and Sharifumsa were only found to be contaminated with total coliforms but not fecal coliforms

Table 5. Seasonal comparison of microbial contamination; The table shows a high statistically significant seasonal difference in both faecal coliforms and total coliforms ($p<0.01$)

Location	Biochemical Parameters	Total No of Wells	Dry season	Wet season	X^2	P-value
Sharifunsa Kibweni Mwanyanya Bububu	Faecal Coliform	52	19 (36.54%)	41 (78%)	9.630	0.0019
Sharifunsa Kibweni Mwanyanya Bububu	Total coliform	52	33 (63.5%)	48 (92.3%)	10.232	0.0014

concern and is regulated in drinking water because it is associated with various health effects, including infant methemoglobinemia [27], hemorrhaging at the spleen [28], and cyanosis or asphyxia in infants [29].

In general, total and fecal coliforms significantly increased from dry season to wet season. This increase is likely to be attributed to the flooding and seepage of runoff [30]. In some cases, microbial contamination could also be associated with the overflow of septic tanks. In both seasons, the highest microbial contamination was recorded at Bububu, followed by Mwanyanya. The contamination levels at Kibweni and Sharifumsa were relatively low, with only one (7.69%) and four (30.76 %) among the analyzed water sources at Kibweni and Sharifumsa respectively contaminated with fecal coliforms. The difference in contamination among shehias is likely attributed to their closeness with pollution sources as the two shehias had the shortest average distance between well and potential. Furthermore, Bububu and Mwanyanya had a larger number of wells located within flood-prone areas, and the wells may have been filled by runoff during heavy rains.

5. CONCLUSION

Fecal coliforms are indicators of pathogens, and thereby, understanding their fate and transport in surface waters is important to protect drinking water sources and public health. A comprehensive study of the levels and sources of these pathogenic bacteria in the wells or water collection depots in a vast number of Shehias is necessary for developing a management plan for reducing these bacteria pollution in waters meant for drinking. Above all, guidance on seasonally representative water quality monitoring by the national water quality agencies could lead to improved assessments of access to safe drinking water.

CONSENT

It is not applicable.

ETHICAL APPROVAL

Permission was sought and granted from the Second Vice President's office, the responsible institution for all research conducted in Zanzibar. Approval was also gotten from the Zanzibar Water Authority.

ACKNOWLEDGEMENT

This study was conducted with funding from the NORHED V3R-Pwani Project at the State University of Zanzibar. Kassim H. Ame and Shehia heads gave valuable support during field work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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