Analysis of Spatial Bacteriological Quality Variation of Domestic Water Source Points in Mbarali District, Tanzania

[1]Gislar E. Kifanyi*, [2]Hildegard Kasambala, [3]Rosemary Kavishe, [4]Moses Moyo

[1]Department of Civil Engineering
[2]Department of Earth Sciences
[3]Department of Architecture and Art Design
[4]Department of Construction Management and Technology
[1,2,3,4] Mbeya University of Science and Technology, P.O. Box 131, Mbeya, Tanzania

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ABSTRACT

This study assessed the bacteriological quality of water source points for domestic use. The study was conducted at Mbarali District, which is found in the Mbeya region of Tanzania. Eight wards were selected for water sampling, which were Mawindi, Ubaruku, Rujewa, Chimala, Ihahi, Mapogoro, Igurusi, and Mahongole. The eight wards were chosen because their waters are highly polluted. All samples were properly sampled and transported the same day to the TARI Uyole Laboratory for chemical and biological analysis. In-situ physical parameters were tested in the field using multiparameter equipment. Using GIS software, a spatial bacteriological quality variation of domestic water source points was analyzed and presented. For testing Escherichia coli (*E. coli*), Total Coliform, and Total Heterotrophic Bacteria (THB), 60 samples of water were taken from 8 wards and put through a membrane filtration method. 75% of the water source points found to be less than 20 meters away from residential areas were observed to be associated with bacterial contamination. The mean concentrations of *E. coli,* total coliforms, and THB were 2.5 CFU/100 ml, 10.36 CFU/100 ml, and 70 CFU/100 ml, respectively. There was a significant difference between CFU of total coliforms in samples collected ($p = 0.026$). About 80% of the samples collected and analysed for water quality parameters did not conform to the TBS and WHO drinking water quality guideline value of no detection per 100 ml. The study concludes that domestic water point sources found in Mbarali District are located less than 20 meters away from residential areas, with significant unpaved areas and the presence of septic tanks and pit latrines that may lead to water pollution. Unsafe drinking water in Mbarali District is the primary route for waterborne disease transmission. Therefore, we recommend treating the water from dug wells and rivers/streams in Mbarali District before drinking it.

*Corresponding author's e-mail address: gislakifanyi@gmail.com (Kifanyi, G.E.)

1.0 Introduction

Water is the primary concern and the foundation for any socioeconomic development. Access to safe water and sanitation is recognised as a human right and has long been central to international development policies and targets (UNCESCR, 2003; UNGA, 2010). However, in Sub-Saharan Africa, the percentage of people who received piped water on their premises has decreased by 8% from 42% to 34% (WHO/UNICEF, 2014). Moreover, most of the Sub-Saharan African countries have adopted a cost-sharing approach (Kessy, 2016). The affordability is a key issue to ensure that the least disadvantageous population segments can gain access to a safe and clean water supply (Bayliss, 2011; Mats, 2012).

Many successful water supply projects in Sub-Saharan Africa (including Tanzania) use fresh surface water sources over gravity-driven water supply, but when this option is not available in other communities, pumping of either available ground or surface water sources is preferred (Lufingo, 2019). Unfortunately, the cost for pumping, treating, and supplying water is unaffordable to low-income earners living in rural areas (Chumbula, 2016; Chumbula, 2018). Water quality is another criterion for freshwater source suitability in domestic use (Lufingo, 2019). Nowadays, groundwater is largely preferred over surface water due to a general perception that it is of excellent water quality (Kooy *et al*., 2018; Ngasala, 2018), despite the potential existence of chemical pollutants (Chacha, 2018; Elisante, 2016; Figoli, 2016; Goeller, 2017).

The water sector in Tanzania has been evolving rapidly in past years given the priority it has received in the development agenda, at least since the inception of poverty reduction strategies, where this sector was one of the priorities for poverty reduction (Kessy, 2016). In Tanzania, the water sector has been reformed several times to meet important goals (Chumbula, 2016; Kessy, 2016; URT, 2002). For example, in 2000 and 2015, safe water supply service coverage increased from 51% to 68% in rural areas and from 90% to 95% in urban areas (Kessy, 2016; URT, 2012).

Despite the government's initiatives to improve the water sector's performance, over the past two decades, access to safe and clean water in rural and urban areas of Tanzania has not shown significant improvement (Dzimiri, 2010; Kessy, 2016; Twaweza, 2014). The share of rural households with access to safe and clean water has only changed from 45% in 2004/05 to barely 57% in 2011/12 (Kessy, 2016). The challenges facing the water sector include water quality, drying off of water sources as a result of climate change, malfunction of water points, inequitable budget allocations, and late disbursement of funds (Kessy, 2016; Marandu, 2012).

Access to safe drinking water is crucial for improved health and human welfare in general, and it is regarded as a basic human right. Given its importance, providing adequate and safe drinking water is one of the indispensable components of the Tanzania National Water Policy of 2002 (URT, 2002). The same has been reflected in several national development plan documents, including the Tanzania Vision 2025 and Five Year Development Plans 2018–2022 (URT, 2018). Water quality is a primary concern in all water projects in Tanzania, and the improved health and human well-being are the major expected benefits (Lufingo, 2019; URT, 2018). From the planning to implementation stages of water projects, as well as from source selection to the choice of maintenance technology, the quality factor must be the top priority (URT, 2018).

Regardless of the origin of the domestic water source (groundwater or surface water; public or private), excellent water quality is a prerequisite criterion due to its suitability (Gudaga *et al*., 2018; Lufingo, 2019). It should be understood that contaminants in groundwater are encountered in environmental settings because of their geological conservation (Gudaga *et al*., 2018). On the other hand, human development has encouraged the contamination of surface water sources with chemical and microbial pollutants in various ways. These include (i) the application of fertilisers in irrigation water, which interacts with aquifers or is transported downstream for domestic applications; (ii) the harvesting of rainwater through various roof materials; and (iii) the corrosion of metallic-based water supply networks (Elumalai, 2017). It should be noted that groundwater is like surface water; it is also prone to pollutants. Therefore, switching from using surface water to groundwater due to the belief that it is pollution-free could potentially shift the problem from visible to invisible resources (Kabote, 2018; Lufingo, 2019). Evidence suggests that different parts of Tanzania (including Mbarali District) experience different challenges in relation to water quality issues (Lufingo, 2019).

The Mbarali district is characterised by commercial and small-scale irrigation activities for paddy production. In many cases, paddy production uses different types of agrochemicals, which cause water pollution problems. Currently, the surface water source in Mbarali district is diminishing due to high water demands for irrigation activities; consequently, a significant number of people are relying on groundwater resources, including both deep and shallow wells, for socio-economic activities. Most of the shallow wells (dug wells) are poorly constructed and unprotected (Kabote, 2018). Unless water source points are protected for human consumption, its water may become hazardous for human health and transmit some waterborne diseases. The main sources of contaminants in these water sources in urban and rural areas are pit latrines, wastewater from residential areas, animal waste, and effluent from sewage systems (Lukubye & Andama, 2017). As a result, people use water from questionable sources, putting them at risk of waterborne diseases. Analysis of the bacteriological quality of drinking waters is important in determining the sanitary quality of domestic water sources. Indicator bacteria are used to evaluate the quality of drinking water because it would be next to impossible to accurately enumerate all pathogenic organisms that are transmitted through contaminated water (Desalegn *et al.*, 2013). The use of indicator bacteria as a means of assessing the quality of drinking water has been critical in protecting people's lives from waterborne diseases. The principle here is that the selected bacteria indicate either contamination or deteriorating water quality, upon which protection of public health from waterborne diseases has been developed. Therefore, the study aimed to determine the bacteriological quality of drinking water sources, specifically focusing on dug/deep wells, springs, rivers, and streams in the Mbarali District.

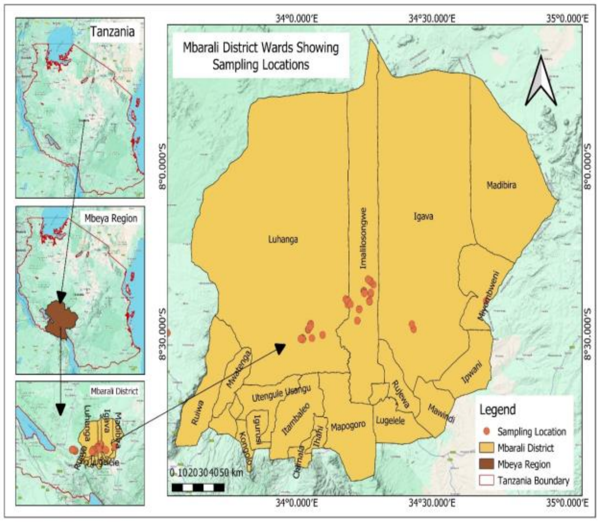
2.0 Materials and Methods

2.1 Study Area

The Mbarali District covers an area of 16,632 square kilometres and has a population of 300,517 (URT, 2014). It is located at latitude: 8° 51' (8.85°) South, longitude: 33° 51' (33.85°) East. Altitude is almost low, ranging from 1000 to 1800 meters above sea level (Kangalawe *et al.*, 2012). The minimum temperature is 19°C (June-July), while the maximum is 35°C (August to December) (Kangalawe *et al.*, 2012). Administratively, the district is divided into 20 wards with a total of 99 villages. The Mbarali District boasts primary soil features. The district's water resources, including groundwater, are located in the Great Ruaha River Catchment, which is one of the country's four sub-basins of the Rufiji River Basin.

The average rainfall is 600 mm per year, which falls between December and April, and hence the district is vulnerable to water scarcity (Kayombo, 2016; Sirima, 2016). This explains the need and high importance of groundwater use, which is extracted from shallow wells and deep boreholes (Pavelic *et al.*, 2012). Figure 1 displays a map of Mbarali District, including study wards and sampling locations.

Figure 1
Map of Mbarali District Showing Study Wards and Sampling Locations Characterisation and Mapping of Domestic Water Source Sampling Points



Human beings and other animals discharge a large number of intestinal bacteria into stool and urine. Hence, bacteria appear in drinking water when the water source is contaminated with stool or urine. Intestinal bacteria, which are normal intestine flora, are not pathogenic, whereas other bacteria cause serious disease when they are present in drinking water. Pathogenic bacteria include Salmonella, Shigella, Vibrio cholera, and Yersinea enterocolitica. The potential threats and pathways of contamination of domestic water source points were identified based on observed human activities in close proximity to domestic water source points. This was accomplished during field study visits to 20 water source points found within 8 wards of Mbarali District.

2.2 Sample Collection and Preparation

A total of 60 water samples were collected from 20 water source points. Samples were collected aseptically in sterilized 500-ml sterile plastic bottles, then transported to the TARI Uyole Mbeya water quality laboratory for analysis. Before transportation of water samples, the sampling bottle stoppers were shielded with aluminium foil in order to avoid any form of hand contamination and adhere to aseptic techniques. All samples were assigned identification numbers, as well as the location of the source name and corresponding ward/village. Samples were analysed within 24 hours after collection to avoid unpredictable changes in the bacterial population.

2.3 Bacteriological Analysis

In accordance with APHA (1981), the membrane filtration method, which involves direct plating for coliform detection and estimation, was used. This method of analysis involved filtering 100 ml of water sample through a 0.45μm Millipore filter membrane that retained total coliform (TC) and Escherichia coli. For the heterotrophic bacteria count, 1 ml of sample was filtered according to the same procedures as for total coliforms. The funnel unit was carefully positioned over the filter support assembly and locked in place. Samples were poured into the funnel assembly, then filtered through the membrane filter by applying a vacuum pump. Finally, the culture dishes were put in an incubator for 24 hours at 37˚C, 24 hours at 44˚C, and 48 hours at 37˚C to find out the total coliform *E. coli* and Total Heterotrophic Bacteria (THB) counts. Upon completion of the incubation period, typical coliform colonies were seen on the membrane filter. Using a magnifying lens (APHA, 1981), all colonies were counted.

2.4 Analysis of Spatial Bacteriological Quality Variation of Domestic Water Source Points

Water quality management is a core component of water resources management. The Geographical Information System (GIS) helps to manage an area's water quality. It can be a powerful tool to develop solutions related to water resources quality problems on a local (Hossen *et al.*, 2018) or regional scale (Rahmati *et al.*, 2015; Youssef *et al.*, 2011). The study's primary goal is to estimate bacteriological water quality in the study area and thematically represent water quality parameter variation using GIS software. Geo-information technology has played a critical role in helping to understand the present scenario at a glance. Analysis of water quality in a particular area is of prime importance and requires monitoring and assessment to formulate preventive measures against health hazards. The variation in water quality at a location is determined by physicochemical and biological parameters (Ministry of Urban Development, 1999). Water quality monitoring aims at providing regular feedback to guarantee compliance with national and international water quality standards, efficiency, and effectiveness in law enforcement by different natural resource custodians (Muhoyi *et al.*, 2022).

3.0 Results and Discussion

3.1 Characterisation of Domestic Water Source Points

The potential threats and pathways of contamination of domestic water source points were identified based on observed human activities in close proximity to domestic water source points. This was accomplished during the field study visit to 20 water source points in Mbarali District. The study findings revealed that 16 (80%), 15 (75%), and 11 (55%) of the water source points sampled were situated less than 20 m away from residential areas, toilet/pit latrines, farming, and banana plantations, respectively. Building toilets or pit latrines in close proximity to drinking water increases the risk of faecal contamination. A study conducted by Sivaraja & Nagarajan (2014) reported that many rivers in urban areas were loaded with coliform bacteria attributable to raw sewage. Moreover, high concentrations of microbes in drinking water sources located in close proximity to pit latrines (<20 m) were reported (Naser *et al.*, 2019). Furthermore, construction of residential houses in proximity or upstream to drinkingwater sources poses a threat to water contamination through the leaching of contaminants. Photos 1(a) and 1(b) below show protected and unprotected dug wells near households.

Photo 1(a)
Unprotected Dug Well

Photo 1(b)
Protected Dug Well

As depicted in Photos 1(a) and (b), we found water source points situated approximately 5 meters adjacent to the residential area. It was further observed that wastewater was flowing from the residential area into the water source points. For example, the direct deposition of feces into the water body increases the survival rate of pathogens due to the rapid sorption of contaminants onto bed sediments (Goss & Richards, 2008). According to a study by Liu *et al.* (2019), animal manure and feces are key sources of fecal contamination of drinking water sources in the agricultural watershed. Farming was also another observed activity around water springs that were studied. Crops such as beans, potatoes, vegetables, and bananas were planted in close proximity to water source points. The study revealed the uncontrolled application of agricultural inputs such as fertilizer and pesticides. Animals were also observed in close proximity to water source points. Given the seemingly high groundwater table in some parts of Mbarali District and the potential for surface runoff and sediment transport, these are potential threats to the water quality of source points. Photos 2(a) and 2(b) below show unimproved, unprotected dug wells unfenced and unimproved dug wells fenced with shrub thorns, respectively.

Photo 2(a)
Unimproved Unfenced Unprotected Dug Well

Photo 2(b)
Unimproved Unprotected Fenced with Shrub Thorns

It should be noted that most of the dug wells found in the study area were unprotected and highly polluted, smelling odd. The dug wells were observed to contain high turbidity and sedimentation (see Photos 2(a) and 2(b)). Shrub thorns were used to protect the dug well from cattle and wild animals.

3.2 Bacteriological Quality of Domestic Water Source Samples

Water samples from 20 domestic water sources in eight Mbarali District wards were tested for *E. coli*, total coliforms, and heterotrophic bacteria. All of the samples were positive for these bacteria.

3.2.1 Total Coliform

Total coliforms in water are often used as a proxy for the potential presence of faecal contamination and the risk of waterborne diseases. Total coliform counts ranged from 1 to 22.93 CFU/100 ml (Fig. 2). Compared to any other water source points, some parts of Luhanga and Imalilosongwe recorded the highest total coliform counts, ranging from 20.50 to 22.93 CFU/100 ml. Compared to other studied water sampling points, the high groundwater table, high population density, local pit latrines, and shallow dug wells have a significant impact on Luhanga and Imalilosongwe water source points. The lowest total coliform counts recorded ranged from 1 to 3.44 CFU/100 ml (Fig. 2). The mean total coliform value was 10.36 CFU/100 ml. This level is lower than those reported by Davino *et al.* (2015) in an urban beach in tropical northeastern Brazil. This pattern of total coliform count indicates that water has come in contact with materials like human faeces, soil manure, and plants, among others. Furthermore, their presence suggests the possibility of faecal contamination, which may contain harmful pathogens such as Salmonella or Shigella (WHO, 2011).

3.2.2 Thermotolerant E. coli

When thermotolerant *E. coli* was looked at, samples had *E. coli* counts that ranged from 1 to 7.83 CFU/100 ml. The highest thermotolerant *E. coli* levels were found in the Luhanga and

Imalilosongwe wards, at 7.83 CFU/100 ml. Moreover, the study found that 15% of the water samples collected were free from thermotolerant *E. coli.* The mean value for thermotolerant *E. coli* was 2.5 CFU/100 ml. The high level of thermotolerant *E. coli* recorded in this study may be attributed to the high degree of contamination of the water sources due to unhygienic practices in close proximity to water source points and the closeness of pitlatrines to the water source points. According to WHO (2004), *E. coli* is a subgroup of the faecal coliform group. Most thermotolerant *E. coli* bacteria are harmless and exist in the intestines of warm-blooded animals and people. However, some strains can cause human illness. The presence of *E. coli* in a drinking water sample is usually indicative of recent faecal contamination (Farenhorst *et al.,* 2017). *E. coli* O157: H7 strain is known to cause most outbreaks (WHO, 2011). The water samples reported with *E. coli* do not necessarily mean that O157:H7 is present. It suggests recent faecal contamination.

3.2.3 Total Heterotrophic Bacteria

The total heterotrophic bacteria (THB) count concentration varied from 1 to 126.89 CFU/100 ml. The mean value for THB was 70 CFU/100 ml. Several studies (Azizullah *et al.*, 2011; Haydar *et al.*, 2016; Jain *et al.*, 2010) have found that bacterial contamination of water sources in rural and urban areas is caused by an intermittent water supply that lets any wastewater into the distribution system, water sources that are close to pit latrines and sewer lines, and sewers and sewage channels that are overloaded and usually stay blocked. Using the paired samples T-test, we discovered a significant difference between the CFU of total coliforms in water samples from Luhanga and Imalilosongwe wards ($M = 10.36$, $SD = 10.12$; $t(13) = 2.5$, $p = 0.026$). The number of CFU of heterotrophic bacteria in water samples from Luhanga and Imalilosongwe wards ($M = 126.89$, $SD = 120.11$) and Itambaleo, Ihahi, and Mawindi wards ($M = 21.5$, $SD = 20.51$; $t(13) = 3.5$, $p = 0.004$) was very different. Researchers found no big difference in the amount of *E. coli* CFU found in water samples from the wards of Mwatenga, Igurusi, Utengule Usangu, Itambaleo, Luhanga, Imalilosongwe, Igava, Madibira, and Miyombweni ($M = 2.21$, $SD = 2.08$; $t(13) = 2.0$, $p = 0.062$). It was also revealed that total coliforms and heterotrophic bacteria are abundant at water source points in the Luhanga and Imalilosongwe wards. This is due to the high groundwater table in these wards and the proximity of most water source points, especially the shallow dug wells, to pit latrines within a 20-meter radius.

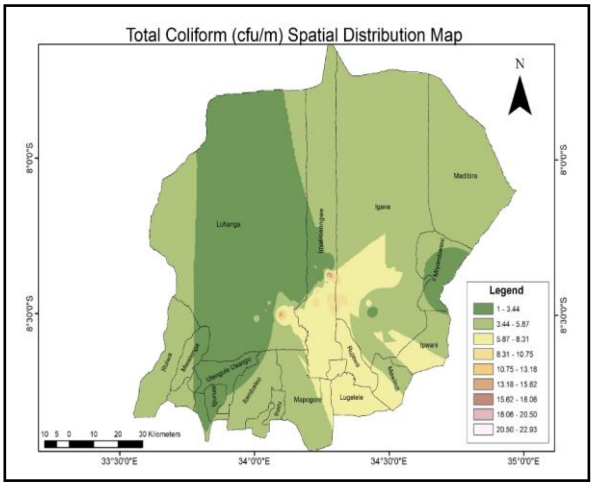
3.3 Spatial Bacteriological Quality Variation of Domestic Water Source Points

The study was carried out to determine bacteriological water quality parameters and spatial variation within the Mbarali District water source points, which are 40 km from Rujewa town. A total of 60 samples (from both surface water and groundwater (deep and shallow wells) source points) were collected and analysed for bacteriological quality parameters. To determine their spatial variation, the results were interpolated using statistics and an Inverse Distance Weighting (IDW) tool embedded in a Geographical Information System (GIS) environment.

3.3.1 Total Coliform Spatial Variation

Following the bacteriological analysis of the collected samples, a GIS tool was used to interpolate the water quality prediction in each area. Following that, GIS software generated a spatial distribution map of the total coliform bacteriological parameter. The reclassification process was carried out in accordance with the drinking water standards set by the Tanzania Bureau of Standards (TBS) to create the spatial distribution map. Figure 2 depicts the generated Mbarali District Total Coliform Spatial Distribution Map.

Figure 2
Map showing Total Coliform Spatial Distribution in the Mbarali District Wards



From Figure 2, it can be observed that all samples tested for the Total Coliform parameter showed positive results, and hence, the water from these wards did not meet the TBS as well as the WHO drinking water prescribed standards of no CFU detection per 100 ml. Most of the wards covered by the study had lower Total Coliform counts, ranging from 1–5 CFU/100 ml (*see Figure 2).* However, water from these wards needs to be treated before domestic use to avoid health problems for the people living in these wards of the Mbarali District. Figure 2 depicts the generated Mbarali District Total Coliform Spatial Distribution Map.

3.3.2 Thermotolerant E. coli Spatial Variation

Following the thermotolerant *E. coli* analysis, a geostatistical tool interpolated the water quality prediction in various areas. Thereafter, a spatial distribution map of thermotolerant *E. coli* bacteriological parameters was generated using GIS software. To generate the spatial distribution map, the reclassification process was carried out in accordance with the Tanzania Bureau of Standards (TBS) drinking water standards. Figure 3 shows the thermotolerant *E. coli* spatial distribution map of wards in Mbarali District.

Figure3
Map Showing Thermotolerant E. coli Spatial Distribution in theMbarali District Wards

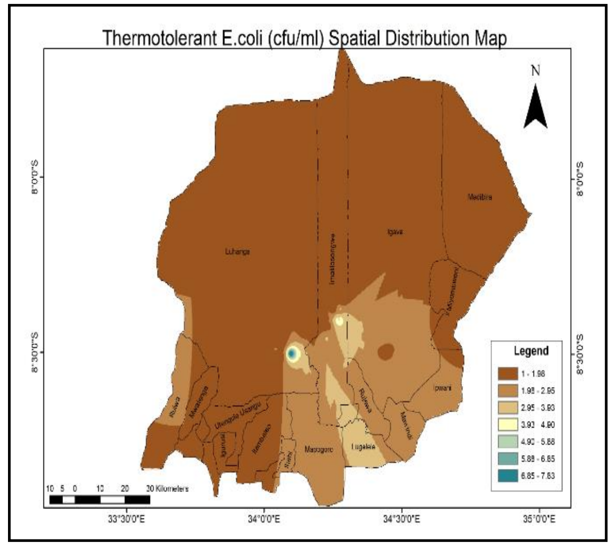
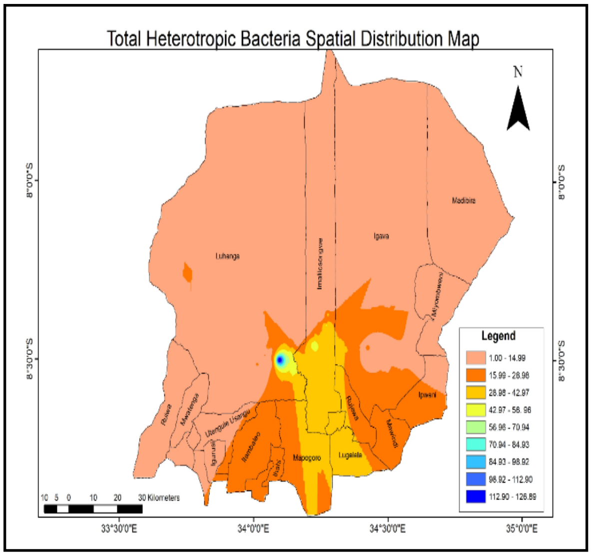


Figure 3 indicates that the highest level of thermotolerant *E. coli* distribution occurred in some parts of Luhanga and Imalilosongwe wards, ranging from 6.85 to 7.83 CFU/100 ml. In more than 95% of the Mbarali District, the amount of thermotolerant *E. coli* was low, ranging from 1 to 2.95 CFU/100 ml. This was seen in most of the Mwatenga, Igurusi, UtenguleUsangu, Itambaleo, Luhanga, Imalilosongwe, Igava, Madibira, and Miyombweni districts. It should be noted that most thermotolerant *E. coli* bacteria are harmless and exist in the intestines of warm-blooded animals and people. However, some strains can cause human illness. The presence of *E. coli* in a drinking water sample is usually indicative of recent faecal contamination (Farenhorst *et al.,* 2017). *E. coli* O157: H7 strain is known to cause most outbreaks (WHO, 2011).

3.3.3 Total Heterotrophic Bacteria Spatial Variation

After analyzing the collected samples, a geostatistical tool interpolated the water quality prediction in each area. The spatial distribution map of total heterotrophic bacteria was generated using GIS software. To generate the spatial distribution map, the reclassification process was carried out in accordance with the Tanzania Bureau of Standards (TBS) drinking water standards. Figure 4 shows Mbarali District's total heterotrophic bacteria spatial distribution map.

Figure4
Map Showing Total Heterotrophic Bacteria Spatial Distribution in the Mbarali District Wards



According to Figure 4, the highest level of Total Heterotrophic Bacteria distribution occurred in Luhanga ward and ranged from 112.90 to 126.89 CFU/100 ml. More than 95% of the wards in the Mbarali District had very low levels of Total Heterotrophic Bacteria, which ranged from 1 to 14.99 CFU/100 ml. This was found in the Mwatenga, Igurusi, UtenguleUsangu, Itambaleo, Luhanga, Imalilosongwe, Igava, Madibira, and Miyombweni wards.

4.0 Conclusions and Recommendations

4.1 Conclusions

In the study area, 75% of the water source points were constructed less than 20 meters away from residential areas. The mean concentrations of *E. coli*, total coliforms, and THB were 2.5 CFU/100 ml, 12.67 CFU/100 ml, and 70 CFU/100 ml, respectively. There were significant differences between CFU of total coliforms and HTB in samples collected in the study area ($p = 0.026$). The study concludes that: Results indicate that Luhanga and Imalilosongwe wards had abundant total coliforms and heterotrophic bacteria in water source points. This is due to the high groundwater table in these villages, where most water source points, especially shallow dug wells, are unprotected and situated in close proximity to pit latrines and cattle sheds, typically within a 20-meter radius. About 80% of the water samples collected and analysed for total coliforms from all of Mbarali district's wards did not conform to TBS standards or the WHO drinking water quality guideline value of no detection per 100 ml. Anthropogenic activities such as farming, pit latrines, and animal wastes, which were constructed less than 20 meters away from the selected drinking water source points, compromised the quality of the water. The majority of water source points (80%) are located less than 20 meters away from residential areas with significant unpaved areas, in the presence of septic tanks and pit latrines.

4.2 Recommendations

The study's findings inform the following recommendations for government policymakers, local government leaders, CBOs/NGOs, and household dwellers in Mbarali District. (1) Due to high bacteria concentrations, water should be treated before drinking, which makes it unsafe for consumption. The responsibility to improve household drinking water must generally fall on individual households. (2) To prevent possible water contamination, the government and CBOs/NGOs should play an active role in ensuring that residential areas are constructed at a distance greater than 20 meters from domestic water source points. (3) Realise that there are affordable water testing methods available nowadays to assess the bacteriological quality of water. Local people should always be involved in testing the bacteriological quality of water before use.

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introduced us to the wards and village leaders, who guided us through the locations of domestic water sources in their respective wards and villages within the Mbarali District. We extend our gratitude to the wards and village leaders, as well as to the local villagers, who warmly welcomed us to their areas during field data collection.

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7.0 Conflicts of Interest

The authors declare no conflict of interest.

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