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Geospatial Analysis of Water Sources Accessibility: A Case Study from Tanzania

Juma Lungo[a,1], Ramadhani Mohamedi[b]

[a]*Department of Computer Science and Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania*
[b]*Department of Information Systems and Technology, University of Dodoma, Dodoma, Tanzania*

[1]Corresponding author
Email: jlungo@udsm.ac.tz

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Abstract

The government of Tanzania uses Water Points Mapping (WPM), a practice that utilizes GIS technologies, as the main tool for monitoring rural water supply. Data from WPM is used to report the functionality status of the water points, a proxy indicator (a measurable substitute) for water access. Access to water sources is crucial for strategically constructing water points to improve access to clean and safe water. This study employed cost-distance geospatial analysis methodology to establish routes to water sources from nearby villages where the construction of water points could take place. The research took place in the Kilimanjaro region in Tanzania where the researchers conducted interview sessions with household members and district water engineers. Data were also collected by reviewing water point records. The study found that inaccessible water sources exacerbated the scarcity of water as they limit the possibilities of constructing more water points. The study demonstrated a better approach to establishing routes to water sources from water point construction areas through the use of cost-distance geospatial analysis. The study recommends the use of geospatial analysis to establish access routes to water sources as it increases the possibilities of enabling water sources to serve multiple water points.

1. Introduction

Water accessibility is one of the global agendas articulated in the Sixth United Nations Sustainable Development Goal (SDG 6) aimed at eliminating poverty, improving human wellbeing, and conserving the environment by 2030 [1]. The target of the sixth SDGs is to achieve worldwide accessibility to clean and safe water, as well as to achieve sustainable management of water resources [1]. Since the UN set this target in 2015, governments in developing countries have been taking initiatives to ensure that their citizens have increased access to clean and safe drinking water

[2]. However, the accessibility of clean and safe water remains a problem in many Sub-Saharan countries [3]. One of the problems contributing to the delay in achieving universal water accessibility in many Sub-Saharan countries is the lack of proper analysis of water source accessibility. Many studies have only partially analyzed the geographical accessibility of water sources, as they often lack geospatial analysis [4].

In this paper, a water source refers to a natural resource of water, which is either surface water or groundwater, potentially useful as a source of water supply. Often the term water source is used interchangeably with water point, although they are different when it comes to water accessibility. A water point is a location where people can draw water for domestic use and to a lesser extent, for watering animals [5]. We refer to a water point as a place where people can draw water for their household needs. The main difference between a water source and a water point is that a water source is the body of water, while a water point is the place where water is accessed.

The emergence of Geographical Information Systems (GIS) has provided a scientific tool for the proper analysis of geographical accessibility of water [6] and other land degradation issues. For example, a study in Zanzibar investigated the impact of mining activities by using geospatial technology to identify the extent of land degradation issues [7]. Geographical accessibility is usually referred to as a spatially complex relationship between the geographical distributions of water sources relative to population distribution [8]. As water accessibility is examined by availability, acceptability, affordability, distance, quality, capacity, reliability, and convenience [5], GIS is an efficient tool capable of comprehensively analyzing such aspects of water accessibility. Spatial accessibility of water sources in Tanzania has been a problem [9]. However, details regarding this issue, particularly spatial analysis, are still inadequate due to the poor application of modern tools like GIS [10].

Although Tanzania is striving to construct water points widely in rural areas to increase water availability, various water sources have not been identified and analyzed in terms of their accessibility [10]. It seems logical to claim that a study of geospatial analysis to evaluate water accessibility for domestic use is important to improve domestic water accessibility. The country, through the Ministry of Water, emphasizes training programs on applying geospatial analysis of water accessibility to increase sustainable management of water resources and improve water availability [11]. Water source availability is a particular area of attention in order to increase domestic drinking water access as well as other domestic uses, thereby reducing the time people spend in fetching water [12].

The main objective of this study is to conduct geospatial analysis of water source accessibility to determine routes that would address water scarcity challenges. The specific objectives are (i) to assess the spatial distribution of water sources in Same District; and (ii) to determine the least-cost path for water distribution from identified water sources using geospatial techniques.

2. Literature Review

Accessibility of fresh water in Tanzania remains a problem in many areas despite the country being endowed with numerous water sources, including both surface water bodies and groundwater aquifers [13]. Tanzania is riparian, consisting of nine water basins: Lake Victoria Basin, Lake Tanganyika Basin, Lake Nyasa Basin, Ruvuma and Southern Basin, Wami Ruvu Basin, Pangani Basin, Internal Drainage Basin, and Rufiji Basin [14]. The most commonly available and utilized water source in Tanzania is surface water, which is often affected by a long dry season that typically extends from July to October [16]. Other factors contributing to the shortage of fresh water supply include climate change, uneven spatial-temporal distribution of sources of water, a shortage of fiscal resources to invest in water supply, population growth with increasing socio-economic activities, inadequate water security infrastructures, water use conflicts, and diminishing water resources [17].

Like in other parts of Tanzania, Same district faces a problem of water scarcity [15] despite the region having many water sources located within the Pangani River basin. The main challenge in Same is to identify reliable water sources for easy distribution of water to nearby water points. A study using spatial identification of alternative routes to water sources has not been done. Furthermore, access to spatial data on water sources as well as water points is limited.

Geographical Information System (GIS) is among the approaches globally used to measure water sources' accessibility due to its powerful capability to measure distance and identify routes. It is a special type of information system that combines data and maps to analyze and understand the world around us. GIS uses computer hardware and software to store, manage, and visualize geographic data [19]. GIS is widely utilized for spatial analysis of freshwater resources distribution. For instance, a GIS was applied to map different sources of fresh water to determine freshwater accessibility in schools in Pakistan and USA [20, 21]. In GIS, a cost distance analysis or cost path analysis is a method for determining one or more optimal routes of travel through unconstrained (two-dimensional) space [13].

In Tanzania, the Water Points Mapping System (WPMS) project was used to elucidate methodological challenges in water access [12, 18]. However, a study by Mwiturubani in 2017 concluded that the use of GIS would improve access to fresh water sources and alleviate the increased walking distance to the fresh water sources, as well as reducing water prices [9]. Despite its important role in informing policymakers and water resources practitioners to improve water accessibility and supply, the technology is not well-applied.

Digital Elevation Models (DEMs) are raster files with elevation data for each raster cell. DEMs are being used for calculations and manipulations of an area, and more specifically, analysis based on the elevation [31]. ArcGIS Map 10.3 has several built-in functions that are relatively easier to use and will turn the DEM into a derivative map. This study utilized DEM analysis to determine water availability based on the landscape of the area.

The Tanzanian government has been taking initiatives to improve water accessibility and ensure equitable sharing of water resources in both rural and urban areas [22]. In 1991, for example, Tanzania adopted its National Water Policy, which, among other issues, focused on technological improvement to facilitate water accessibility and supply to both urban and rural areas [22]. A legislative framework of 1991 was developed to support the policy; however, it was inadequate in considering technological development in water supply and management of water resources [23].

In 2002, a revised National Water Policy [24] was launched to rectify all the shortfalls of the 1991 water policy. Additionally, the government was mainstreamed to implement one of the objectives of the Millennium Development Goals (MDGs) at that time, which was to improve water supply to the lowest levels [23]. The policy preparation also embraced the agreement of the Dublin conference aimed at improving water accessibility and sustainable management [22]. The Dublin conference consisted of four principles: water is a finite and vulnerable resource; a participatory approach; the role of women; and water as an economic and social good [22].

The implementation of the new water policy was guided by the National Strategy for Growth and Reduction of Poverty (NSGRP) [14], which is informed by the aspirations of Tanzania's Development Vision (Vision 2025) for high and shared growth, high quality livelihood, peace, stability and unity, good governance, high quality education and international competitiveness [14]. One of the priority areas is to improve water supply and accessibility for poverty eradication. Tanzania has taken a practical and phased approach to improve water resources management, participation, and accessibility. After a detailed nationwide assessment of water resources management, supply, and accessibility, the government prepared the National Water Sector Development Strategy (NWSDS) [23].

The preparation of NWSDS followed the production of Water Sector Development Program (WSDP) for the period 2006 - 2025, which was to be implemented in three phases, each lasting five years [23]. The WSDP consists of four components: Water Resources Management; Rural Water Supply and Sanitation; Urban Water Supply and Sewerage; and Institutional Development and Capacity Building. Through this program, the government aimed to improve water supply, accessibility to the citizens, and water management through information technology [25].

Furthermore, the government reviewed the legislative framework, including the Water Resources Management Act No. 11/2009 [26] and the Water Supply and Sanitation Act No. 12/2009 [27]. These laws support the government, among other objectives, to improve water supply and management for development.

3. Materials and Methods

This study was conducted in Same District, which is one of the seven districts in the Kilimanjaro region covering approximately 5,186 square kilometers. The district is located at latitude 4˚0’– 4˚5' S and longitude 37˚5' – 38˚5' E (Figure 1). Specifically, the study focuses on five wards: Kisima, Mwembe, Same, Stesheni, and Ruvu. These wards are located within the Pangani basin.

Data collection was designed in three stages. In the first stage, all water sources were mapped using handheld Global Positioning System (GPS) devices to collect coordinate points. Second, the collection of Landsat 8 satellite imagery of Same District and Digital Elevation Model (DEM) was done through downloading from the online databases of United States Geological Survey (USGS). Before downloading the Landsat 8 imagery, cloud coverage was set at 10% to enhance atmospheric correction. Thirdly, the location of households and all water points in the study area were obtained from the office of the District Water Engineer (DWE). Other spatial data, such as Same District ward boundaries and road shape files, were obtained from the National Bureau of Statistics (NBS) website [28].

To complement the spatial data, non-spatial data were collected through a questionnaire guide that was administered to household members.

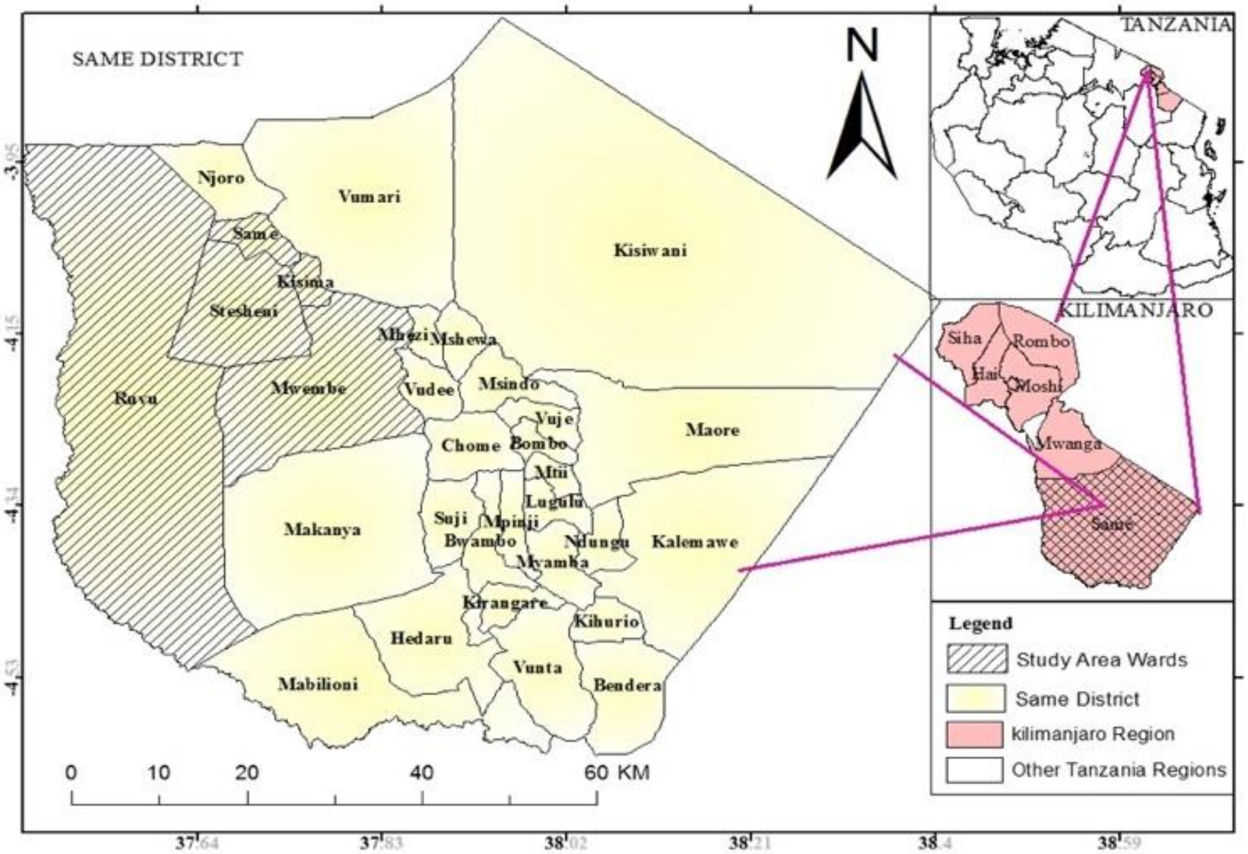

Figure 1. Location of the studied area.

A structured interview data collection method was conducted with 50 randomly selected household members to collect data on water accessibility, reliability, availability, acceptability, and the distance people walk to access domestic water services. A modified Expanded Program of Immunization (EPI) was used to create clusters in five wards using ArcGIS Map 10.3 software [12, 29]. The survey randomly selected households from each sub-ward cluster, considering their proportionate sizes. The households were surveyed systematically from the center of each cluster outwards along a chosen direction until the desired sample size of 50 households was reached, using questionnaires.

The study also collected data from key informants. The Key Informant Interviews (KII) were conducted to collect data from the Water Supply Authority (e.g., District Water Engineer), community leaders (i.e., Ward Executive Officers, Village Executive Officers, and Village Chairpersons), as well as a few individuals, mostly elders, with extensive knowledge on water sources in their respective areas.

Spatial data analysis was conducted using GIS to determine the distance households had to walk to fetch water. In this case, buffers of specified thresholds of 400 meters and 1,000 meters, as recommended by [15] and [16] respectively, were created to determine the households falling within and outside the coverage. Households falling outside the buffer were termed as underserved, while those falling within the buffer zone were termed as having satisfactory access to water.

The collected GPS coordinate points of water sources were compiled and added to the ArcGIS

Map 10.3 software to determine the spatial distributions of water sources. A Modified Normalized Difference Water Index (MNDWI) was generated to determine the presence or absence of water moisture among the wards in the study area. This provided insight into why some of the wells lacked or had enough water. Equation 1 illustrates the calculation of MNDWI. For the spatial distribution of water quality in the selected wards, the pH data of water sources were collected from the office of the District Water Engineer (DWE) and then added to ArcGIS Map 10.3 Software to produce a map. The coordinates of the water source points and household points were used to determine and understand the distance people covered to access water.

$$MNDWI = \frac{GREEN - SWIR}{GREEN + SWIR} \quad (1)$$

Equation 2 illustrates the calculation of distances to water sources. By considering two points, namely household P1(x_1 , y_1) and water source P2(x_2 , y_2), the Near geoprocessing tool in ArcGIS Map 10.3 software was used to calculate the distance between the two points. Equation 2 presents the formula used to find the distance between two points, which is an application of the Pythagorean theorem.

$$D(P1, P2) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2)$$

Lastly, the route from a reliable water source was generated using ArcGIS Map 10.3 Model Builder. The dataset input parameters used included slope, land use map, road cost surface, and cost distance. These parameters were obtained after conducting intermediary analysis from Landsat 8 imagery and DEM datasets. The DEM datasets have the following characteristics: Tile Size 3601 x 3601 (1 x 1); Pixel Size 1 arc-second; Geographic Coordinate System (latitude and longitude); DEM Output Format GeoTIFF, in units of vertical meters; Referenced WGS84/EGM96 geoid and Resolution of 30m.

The accuracy analysis was done using systematic random sampling in ArcGIS Map 10.3 software. The overall accuracy of the classification output was observed to be 88.87%. This complies with the minimum accuracy of 85.00%, as reported by USGS.

4. Results

4.1 Distribution of water sources and water points

A total of 51 water sources were identified and mapped. The identified water sources are of two categories: surface and groundwater. These water sources are of four types: wells, rivers, river-canals, and springs, where 35 (69%) were deep wells, 5 (10%) were shallow wells, 7 (13%) were springs, and 4 (8%) were rivers and canals (Figure 2a). These findings are consistent with a study from Ghana [5], which found that rural areas water sources include boreholes, rivers, and constructed surface water points.

A total of 133 water points were distributed across five wards (i.e., Kisima, Mwembe, Ruvu, Same, and Stesheni) (Figure 2(b)). Mwembe ward had the highest number of water points (57), followed by Same and Stesheni wards, each with 22 water points. Ruvu ward had 21 water points, and Kisima ward had 11 water points. The distribution of water sources varied among all five wards (Table 1). The majority (53%) of the water sources were privately owned, while 47% were publicly owned. Mwembe and Kisima wards had the most water sources, each with 15 water sources. However, Kisima ward had 5 publicly owned and 10 privately owned water sources. Mwembe had 8 public water sources. In Stesheni ward, only one water source was found, owned by Joyland Girls Secondary School. All available water sources also served as water points, providing access to water for domestic use.

4.2 Water quantity and availability in the water sources

Although Same district has many water sources, only a limited number of water sources can be tapped to supply water to the water points. Most of the sources do not have enough water to be tapped for domestic supply. In many areas, the fresh water available from surrounding water sources is minimal compared to the demand. The main water source capable of supplying water to many water points in the study area is in Kisima ward (Figure 3). Similarly, there is one water source (borehole) in Stesheni ward which is capable of supplying water to the Stesheni community only. Overall, the water supplied from the water sources was inadequate. It was further found that some water points were connected to water sources outside the study area (Figure 3). During the KII data collection, one respondent commented that "*Generally, we have a big number of water sources, but unfortunately, very few sources are capable of being tapped to serve many people. Currently, tapped water sources have insufficient quantities of water to cater for our needs. However, some other privately owned water sources like deep and shallow wells play a significant role in domestic water accessibility in our community*" (KI_ID 18, Mahuu village, 3rd April, 2021).

Furthermore, this study found that most of the wells in areas without surface water had little or no water. For example, in Mwembe ward, wells with water were found along Mlulu River contact zones. Similarly, in Hedaru ward, potential water point zones were found in the Pangani River flood plain. A similar situation was observed in Stesheni, Same, and Kisima wards where water points were found near the zone of groundwater. Figure 4 shows a map of the modified normalized difference water index (MNDWI), representing areas with little or no surface water with negative values. These areas lack constructed wells. For example, in Stesheni ward, there is only one functioning well as the ward falls in areas with negative values indicating little or lack of surface water. Areas like Same, Ruvu, and part of Mwembe are located in areas with positive values indicating the presence of surface water; hence, many functioning wells are found in these areas. Other studies such as that of Gain were known to have used the modified normalized difference water index (MNDWIS) [30].

Based on the DEM analysis, it was found that the availability of water in many wells in the Same district is influenced by the elevation of the area. For instance, Stesheni ward is highly elevated, approximately 782 meters (m), compared with Kisima and Same wards which are approximately between 588-650 meters (Figure 5). Thus, a well found in Stesheni ward is deeper than a well found in other wards.

The study found that, availability of water quantity in both surface and groundwater decreases during the dry season and increases in the wet seasons. During a key informant interview, one of the interviewees in Stesheni ward stated that "*There is one potential public deep well in this area from which water is pumped to the community. In the rainy season, the water quantity is high and therefore pumping is not a problem. In the dry season, pumping water to the users' water point becomes difficult. When we force pumping, we mostly end up pumping a lot of mud to the consumers*" (KI_ID 15, Stesheni ward, 1st March, 2021).

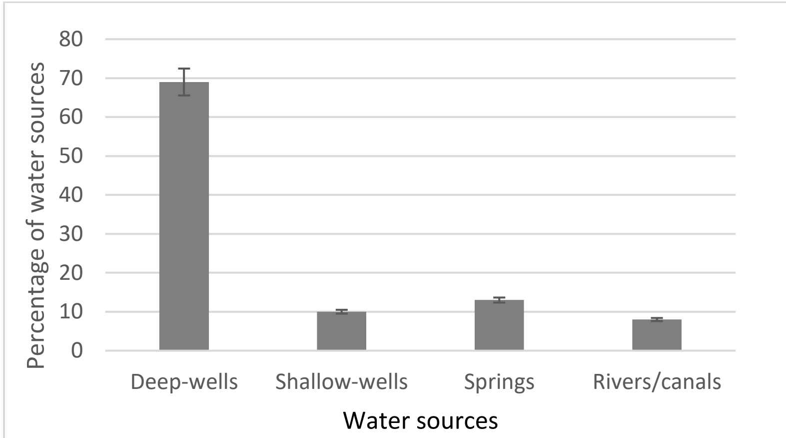

Figure 2a. Types of water sources in same district.

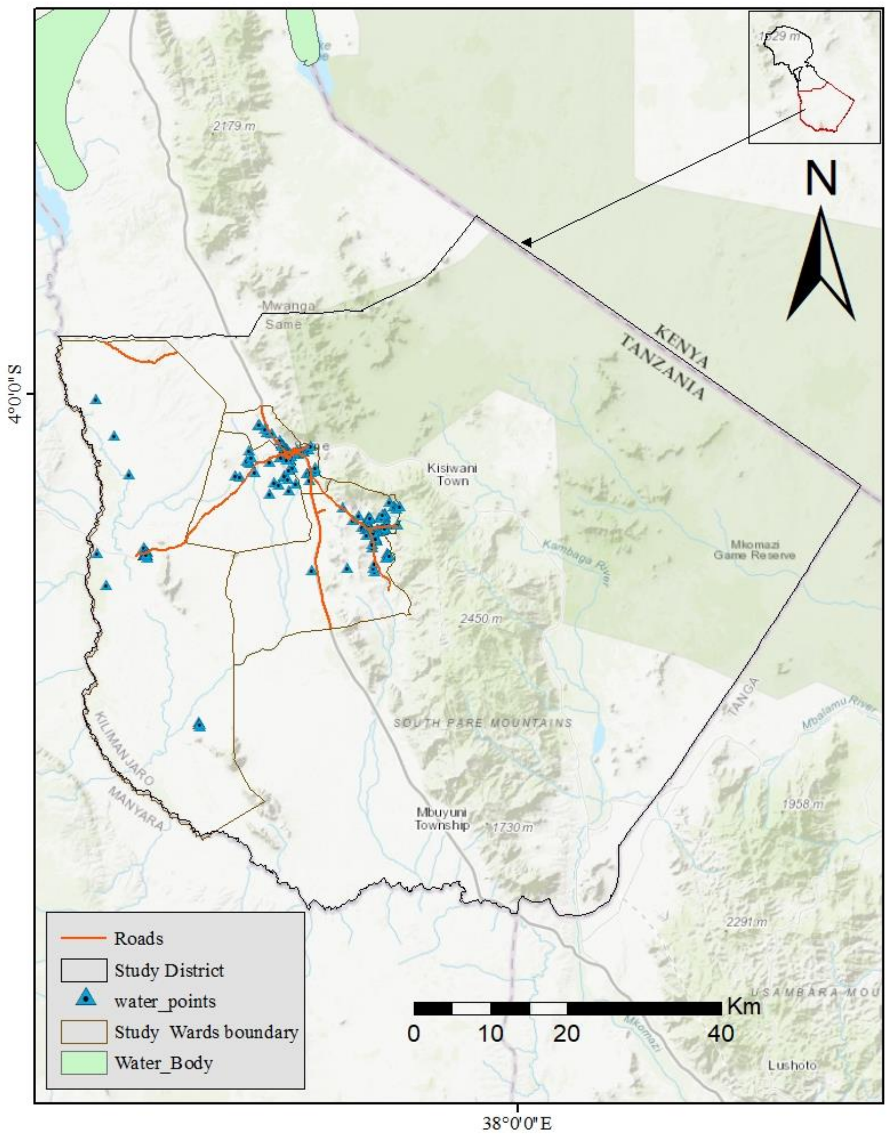

Figure 2b. Distribution of water points in same district.

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Table 1. Distribution of water sources in the study area by ward.

S/N	Ward	Number of water sources	Public water sources	Public (%)	Private water sources	Private (%)
1	Ruvu	13	7	53.85	6	46.15
2	Same	7	4	57.14	3	42.86
3	Mwembe	15	8	53.33	7	46.67
4	Kisima	15	5	33.33	10	66.67
5	Stesheni	1	0	0.00	1	100.00
	TOTAL	51	24	47	27	53

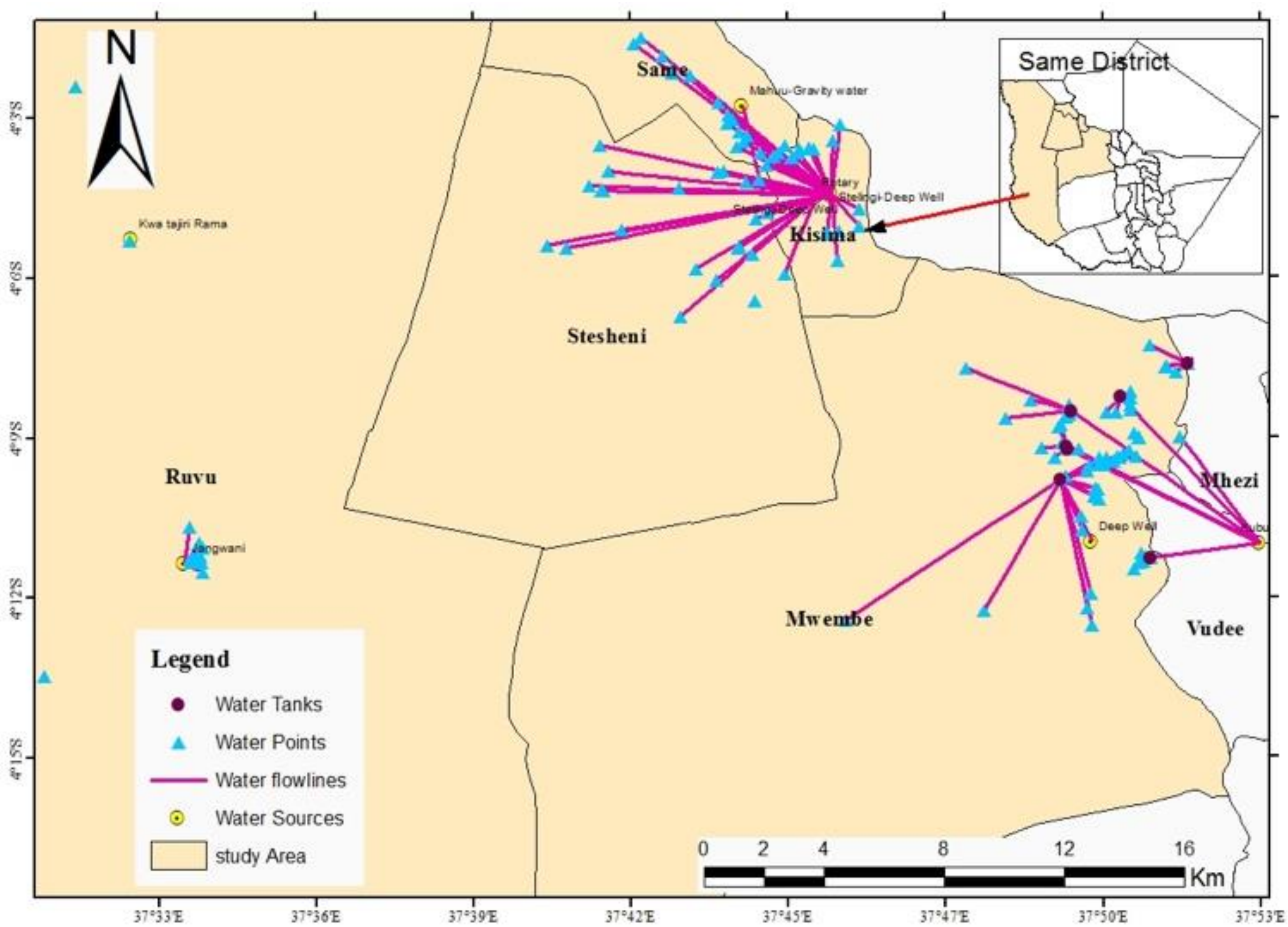


Figure 3. Flowline map indicating connectivity from water source to water points.

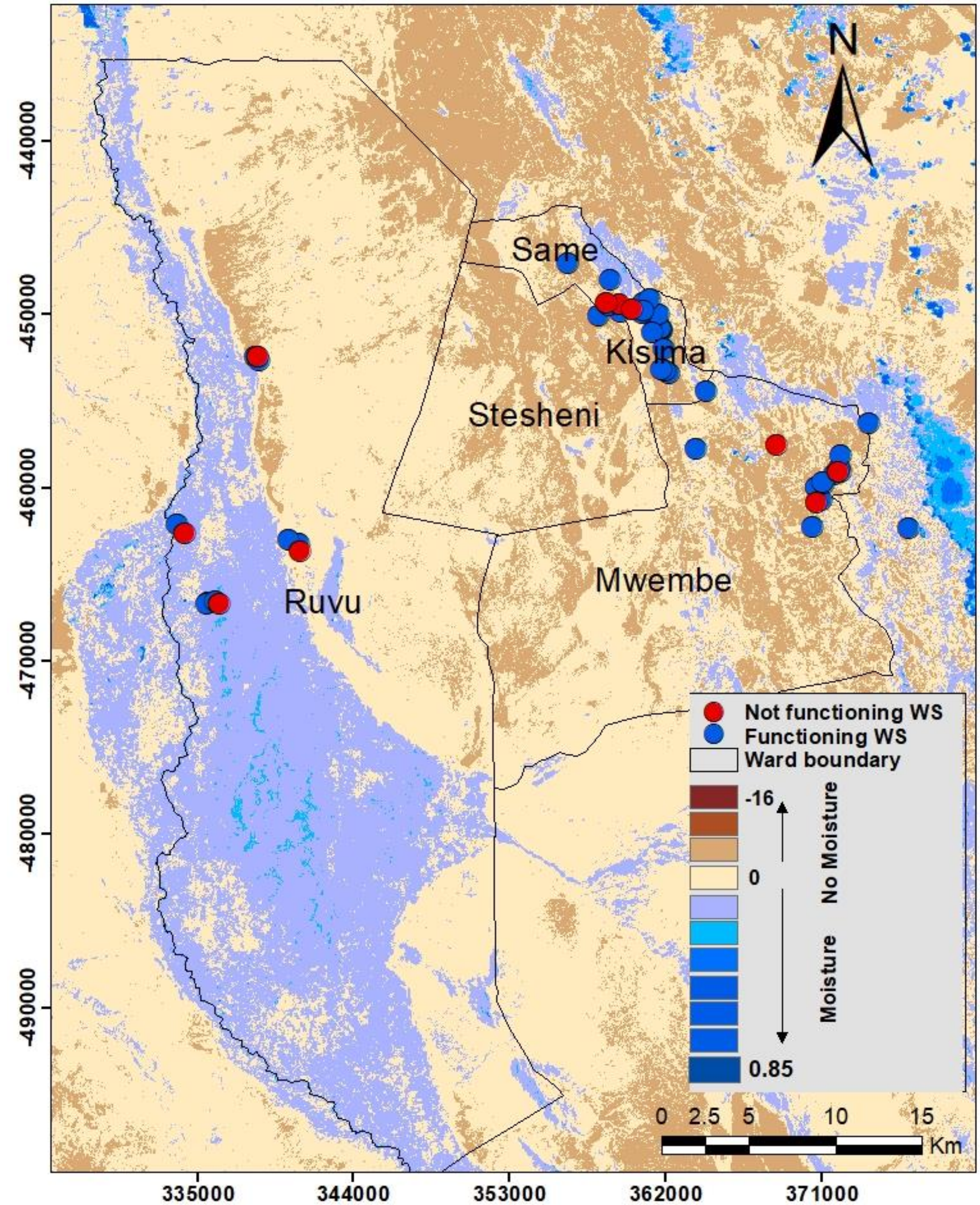


Figure 4. Modified normalized difference water index.

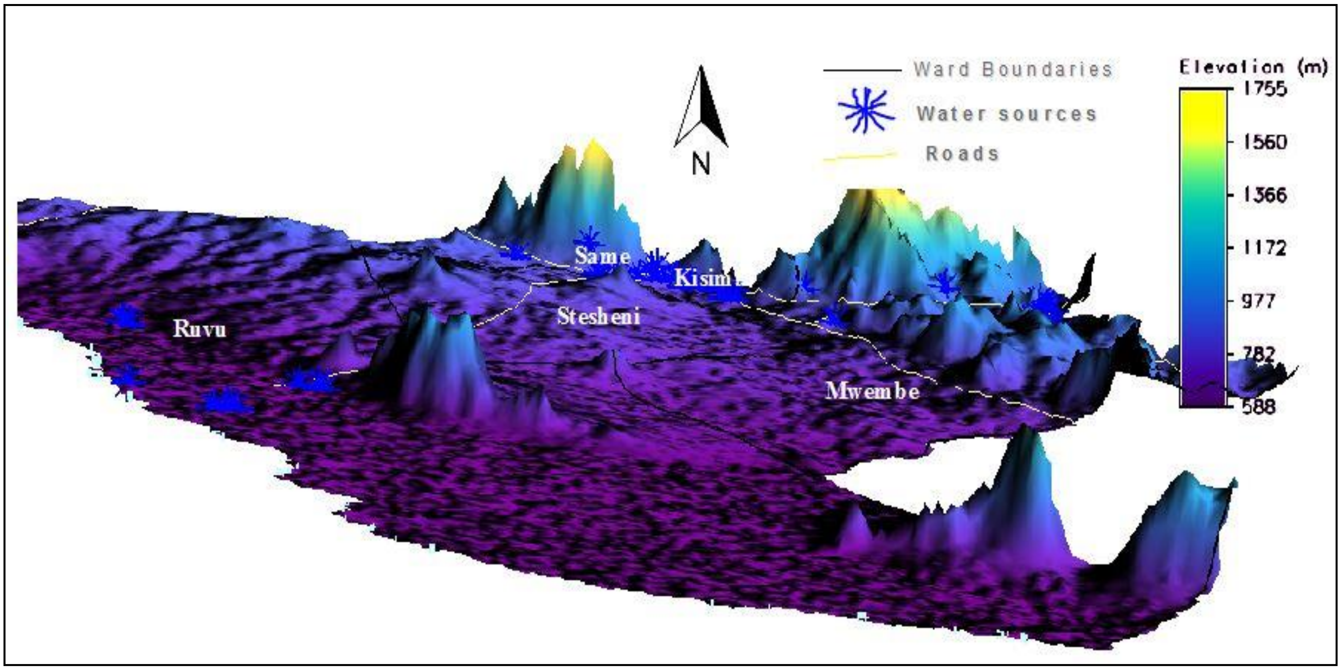


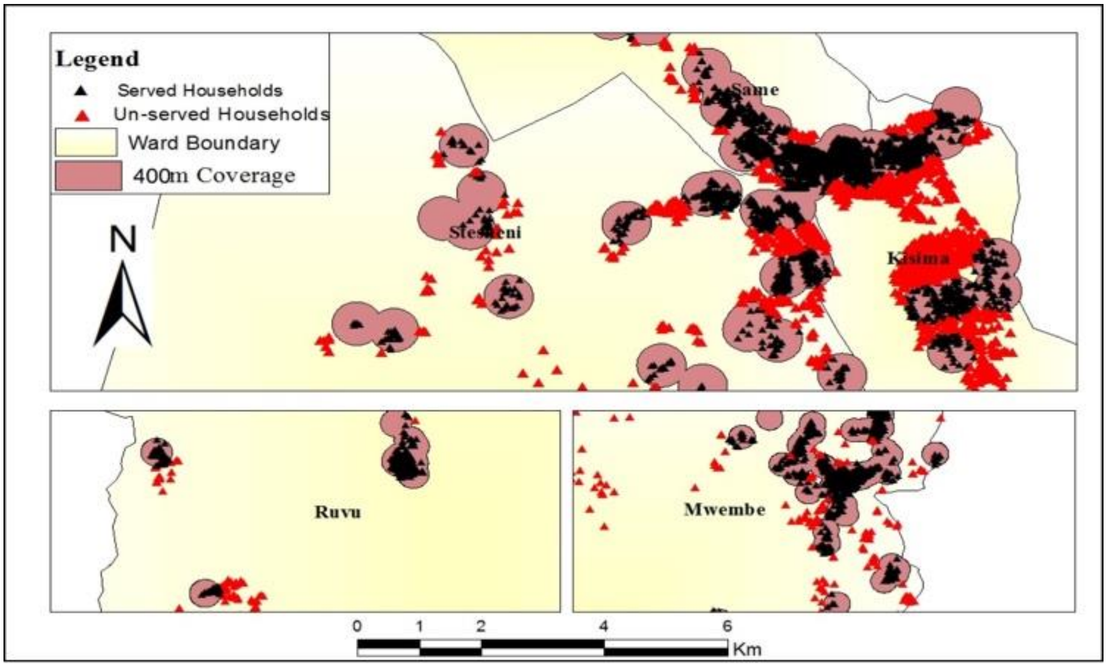
Figure 5. Dimensional landscape of the study area.

4.3 Proximity of water sources

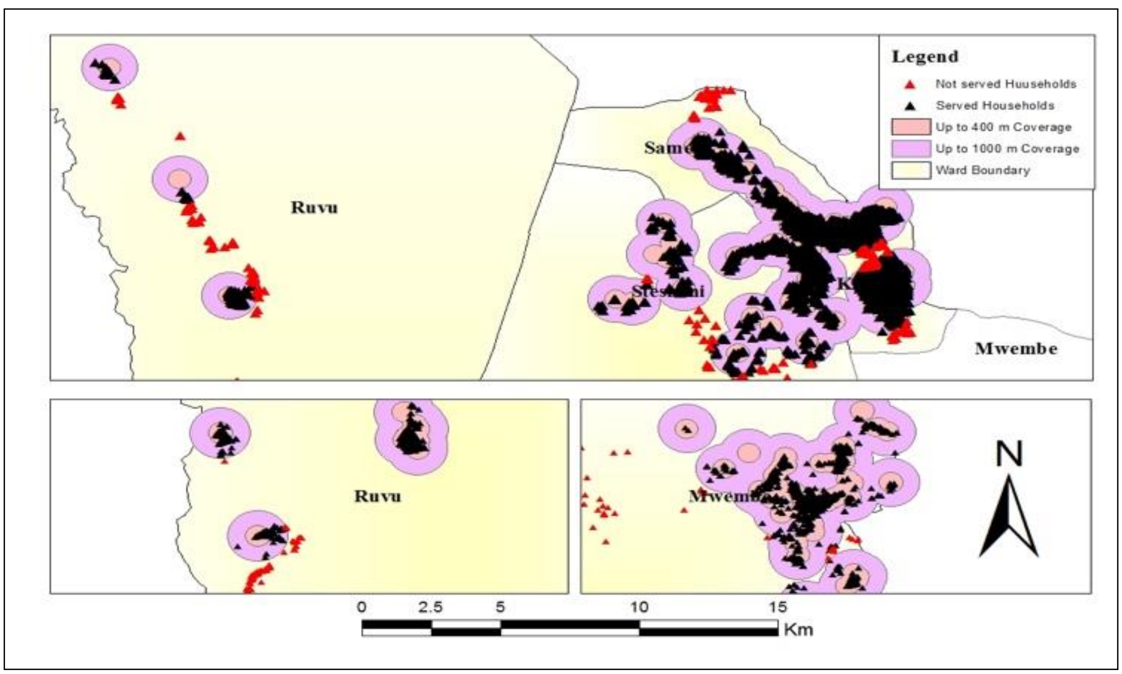
Based on a criterion of 400 meters, Figure 6a shows that 50.40% of the households are served, while 49.60% are underserved. For the case of 1,000 meters coverage, Figure 6b shows that 68.34% of the households are served, while 31.65% are not served. In the same district, particularly in the selected wards, many citizens have to walk a long distance to access water. Household surveys indicate that 46% of the respondents walk within 400 meters, 32% walk between 400 meters and 1,000 meters, and 22% walk over 1,000 meters to fetch water.

The findings are supported by one of the Key Informants (KIIs) who stated, "*In our village, most of us fetch water from Kubu River and Chemka Spring. The distance to Kubu River is about 500m to 700m, while the distance to Chemka Spring is more than 2 kilometers from Nasuro village*" (KI_ID 24, 29th March 2021, Mwembe ward).

The study found further that the preference and attitudes of individuals toward a specific water source contribute to the long distance walked. Some people believe that certain water sources provide better quality of water, while other water sources are deemed unsuitable due to their color, taste, or odor. For instance, in Mwembe ward, Chemka Spring and Kubu River in Mhezi ward are the most preferred sources of drinking water because of their good quality in terms of taste, color, and odor. Consequently, many people choose to walk a long distance to access water from these water sources.



(a)



(b)

Figure 6. Distance to water sources (a) (up-to 400 m) coverage. (b) (up-to 1,000m) coverage.

4.4 Reliability of water sources and water points

There were numerous complaints regarding the time (hours) spent by respondents and the number of days water services were available from constructed water sources and water points. The household survey findings indicate that 34% of the respondents reported spending more than 30 minutes to obtain water; 38% spent between 1 and 20 minutes; and 28% spent between 20 and 30 minutes. When analyzed by wards, approximately 62.5% of households in Mwembe and 57.1% in Stesheni reported spending more than 30 minutes to access water. In contrast, in Kisima and Same wards, 60% of the households reported spending less than 20 minutes to access water for domestic use (Table 2). In various areas in Sub-Saharan countries, particularly rural areas, household members spend a significant amount of time searching for water. For instance, a study in Ethiopia found that women and girls spend 3 to 4 hours per day fetching drinking water [32].

Table 2. Reliability in terms of time (go and return) spent to get water.

Wards	1 - 20 minutes		20 - 30 minutes		More than 30 minutes		Total	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Kisima	6	60	1	10	3	30	10	20
Mwembe	2	25	1	12.5	5	62.5	8	16
Ruvu	3	21.4	8	57.1	3	21.4	14	28
Same	7	63.6	2	18.2	2	18.2	11	22
Stesheni	1	14.3	2	28.6	4	57.1	7	14
TOTAL	19	38	14	28	17	34	50	100

The household survey results indicated that 48% of households reported that water services are available only twice a week. Additionally, 52% of households reported that water services are available for only 2 hours per day, with 14% receiving water for only 8-12 hours.

Wards such as Mwembe, Kisima, and Stesheni are supplied with water for only two (2) days per week for a maximum of 4 hours. This was confirmed by a key informant who stated, "*We spend a lot of time to get water for domestic use because it is supplied for only 2 days within a week. In each day, it is discharged for only four (4) hours, after which it is stopped until the next day or after a week again*" (KI_ID 23, Same ward, 10th April, 2021). Another key informant mentioned that, "*We get water for only 2 hours within a day on every selected two days of the week. This limits us to fetch much water due to a long queue*" (KI_ID 21, Msalaka village, 2021).

The limited number of days water is supplied each week, along with the restricted daily hours, has resulted in insufficient water supply to households.

4.5 Water acceptability

The acceptability of water depends on its quality, which is determined by factors such as taste, color, odor, and chemical as well as biological characteristics. Regarding the color and odor, most water sources from the studied wards were found to be of good quality. However, when it comes to taste, the majority of households (76.47%) reported that the water has a salty taste, while only 23.53% said it has a good taste.

Regarding the chemical characteristics of the water sources, only the pH level was examined in this study. Most of the water sources were found to have a pH level within the specified range of 6.5 to 8.5 [16] except for a few sources that had a pH below 6.5 (Figure 7).

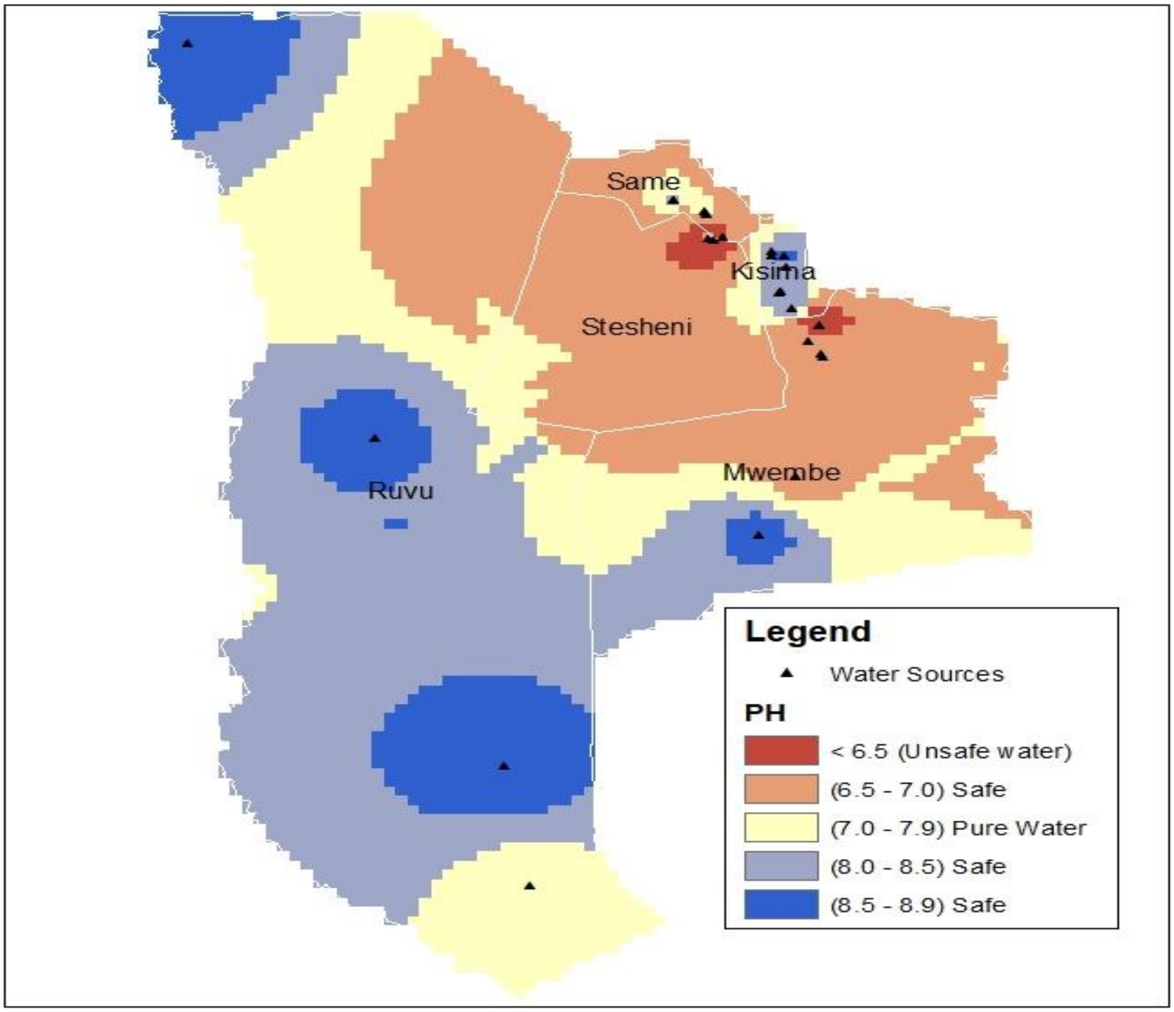


Figure7. The pH distribution in sampled water sources.

5.0 Discussion

The Same district has various water sources, including wells, rivers, and springs. The majority of these water sources are boreholes, making groundwater the primary source for domestic use. Groundwater is a crucial freshwater resource, satisfying a variety of human needs in many areas of the world [33]. To enhance water supply in Same district and achieve SDG number 4, there are ongoing collaborative efforts between the government, NGOs, and private/individual stakeholders. Both privately and publicly owned water sources exist in the area, with a significant contribution from private stockholders. About 53% of the available water sources are privately owned, with these stakeholders having developed various water points. There is a growing acknowledgement that access to fresh and clean water for domestic use is a fundamental human right and a critical factor in achieving various SDGs [32, 34].

The quantity and availability of water from water sources and water points are crucial factors in determining water accessibility [5]. Despite the large number of water points in Same district, the area faces water scarcity because not all water sources and water points can provide a reliable supply of water. The mere presence of numerous water sources does not ensure sufficient water for domestic use as some sources may not yield enough water for tapping. The quantity of water in these sources and points is influenced by factors such as rainfall, groundwater and surface water, and altitude [33]. The water quantity in the study area fluctuates with climate variability. Most of the dependable water sources are not consistently reliable throughout the year, leading to acute water crises during the dry season. This situation mirrors the challenges faced by many Sub-Saharan communities, which often lack reliable water sources [35].

The topography of Same district has contributed to water shortages in some wards. The high elevation of certain areas has led to a lack of groundwater that can be tapped for domestic use. The location and elevation of a borehole can significantly affect water availability, as drilling a deep well to reach an aquifer for groundwater can be costly. For example, the shortage of wells in Stesheni ward is due to its elevation, which is approximately 782 meters compared to Kisima and Same wards, which are at elevations of approximately between 588 meters and 650 meters. Drilling a well in Stesheni ward is very costly due to its high elevation. This study found only one well has been drilled. In Kisima, Same, and Mwembe wards, many wells have been constructed along lineament fractures, indicating the presence of groundwater in these areas [36]. Wells were found along Mlulu River contact zones in Mwembe and Pangani River floodplain in Hedaru, indicating that the presence of rivers and springs has been used as indicators for well construction.

Water accessibility in Same district, especially in the sampled wards, is a significant problem in terms of distance. In general, a large number of households in the studied wards have to walk long distances to fetch water, exceeding the recommended limits of 400 meters [37] and 1000 meters [38]. Despite the presence of various water sources, nearly half (49.60%) of the households are considered underserved according to the threshold of 400 meters [37]. Additionally, about 31.65% of the households are classified as not served based on the [16] threshold of 1000 meters. According to WHO and Florence [1], the water coverage trends in rural areas in Tanzania in 2015 was 50%. The long distances that many households must walk to fetch water are not only due to a shortage of water from nearby sources, but also because some individuals having negative attitudes towards well water. This attitude leads them to seek water from rivers or springs, which they believe to be of better quality, even if it means traveling long distances.

Furthermore, the water problem has become more critical due to the limited number of days and hours per week during which water is available. Having water services for only two days out of seven, during specific daytime hours, is insufficient for households to obtain an adequate water supply. This situation forces many people to spend more time fetching water than the recommended 30 minutes, which has significant implications for economic growth and the development of households as it reduces production time [39]. The impact of the water crisis is more severe for women and girls, as many households assign them the responsibility of fetching water [3].

A significant number of people receive an insufficient amount of water for domestic use due to the limited hours each day that water is available in their areas. Additionally, many households reported receiving less water than they actually need. This shortage is also highlighted by Hellar et al. [40], who stated that the available quantity of water in water sources in Same district is 1,368 cubic meters per day (m3/day) while the actual demand is over 3,500 m3/day.

Water from many sources in the area was reported to have a salty taste, leading many household members to dislike such water. As a result, people have opted to travel long distances to find palatable water. According to the [16] the rejection of water sources by consumers is often due to the bad taste. Regarding the pH level of the water, only a few sources had a pH below 6.5. Most of the sources had a pH level that is considered suitable for human health [38].

The quality of water and people's attitudes towards accepting water are crucial factors in analyzing water accessibility. According to WHO guidelines, water is safe for drinking if its pH level falls within the range of 6.5 to 8.5. These metrics are recognized by the United Republic of Tanzania through the Tanzania Bureau of Standards (TBS) as well [17].

6. Conclusion

This study utilized cost distance spatial analysis to establish optimal routes to water sources from the villages. The study concludes that water accessibility can be improved in the district by utilizing more water sources through the identification of routes to the water sources using GIS. It was further found that a significant number of households are located beyond the recommended distance from the water sources, leading to underserved communities. Furthermore, most of the available water sources (boreholes) have water with a salty taste, calling for the need to use GIS technologies to increase accessibility to water sources. Since the majority of the mapped wells were found to have acceptable pH levels, indicating they are safe for human consumption, if the available water sources could be made accessible through optimized access routes, the problem of water accessibility could be addressed.

The study recommends the use of GIS technologies to gather detailed information on water sources, facilitating informed decision-making in water supply to households, and identifying optimized routes to water sources, which would drive costs down related to water point construction and reuse of water sources to serve many nearby villages.

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CONTRIBUTIONS OF CO-AUTHORS

Juma Lungo	[ORCID: 0000-0001-6803-0757]	Conceived the idea, wrote the paper, conducted review, language editing, and coordinated reviewers' comments.
Ramadhani Mohamedi	[ORCID: 0000-0002-1276-154X]	Conducted data collection, provided methodological inputs and conducted Geospatial analysis.

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