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Assessment of Human Health Risks Emanating from Underground Water Quality Based on Selected Physicochemical Parameters

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ABSTRACT

This study was designed to assess groundwater pollution from four borehole samples commonly used at Kibaha district informal settlements. This was achieved using grab sampling with three replications. The samples were tested for physicochemical groundwater quality. The maximum temperature was recorded at Msufini borehole sample, reaching 28.81ºC, while the minimum temperature was observed at Kikongo, registering 26.31ºC. There were variability pH levels, with mean values ranging from 6.55 at Msufini/Boko Kibaoni to 7.21 at Ruvu Darajani. The lowest mean total hardness was found at Boko Kibaoni borehole samples (24.14 ± 2.48 mg/L), whereas the highest was detected at Ruvu Darajani borehole samples (147.20 ± 1.01 mg/L). The highest nitrate concentration, reaching 3.85 mg/L, was observed at the Ruvu Darajani borehole sample, while phosphate concentrations ranged from 0.02 to 2.41 mg/L at the Kikongo and Ruvu Darajani boreholes, respectively.The Hazard Index (HI) via oral intake for adults ranged from 44.8 at Kikongo to 3,447.1 at Ruvu Darajani, while for children, it varied from 44.8 to 5,389.0 at Kikongo and Ruvu Darajani, respectively. A high Hazard Index for both adults and children via oral intake signals a notable risk to human health, warranting prompt action to mitigate exposure and address contamination sources. This may entail implementing water treatment measures to borehole water sources, enhancing wastewater management practices, and enforcing regulations to safeguard the safety of borehole drinking water supplies.

Keywords: *Groundwater, Hazard index, water pollution, Human health, Kibaha*

INTRODUCTION

Water is the very essence of life. The safety and abundance of water are crucial for our prosperity and the realization of our full potential. Deprived of it, we spiral into diminished well-being, poverty, hunger, and heightened conflict. According to Prüss-Ustün *et al.* (2014), the Millennium Development Goal 7, focusing on access to safe drinking water, aimed to reduce by half the proportion of the global population lacking sustainable access to safe water. However, the target wasn't met by the 48 least developed countries. Nevertheless, significant advancements have occurred, with 42% of the present population in these nations gaining access to enhanced sources of drinking water since 1990 (Mehari *et al.* 2023). In Africa, a staggering third of her population lack access to pure water, and nearly two-thirds lack clean sanitation. This dire situation leads to widespread suffering from diseases like malaria, typhoid, dysentery, and numerous others. Beyond the immediate health impacts, the productivity setbacks caused by water-related illnesses stifle our advancement (Fuller *et al.* 2016).

The suitability of water for different purposes is significantly influenced by its quality (Nyangi and Sibomana, 2023). Ensuring access to safe drinking water is crucial for supporting good health and fostering socio-economic progress (Laiser, 2020). Contaminants like bacteria, viruses, and excessive levels of physical and chemical elements have polluted water supplies (Adesakin *et al.* 2020).

Africa's population surged by more than 1 billion, rising from 228.7 million in 1950 to 1.341 billion in 2020 (Kaba, 2020). This growth distributed across various regions as follows: 431 million in Eastern Africa, 404 million in Western Africa, 247.5 million in Northern Africa, 193.5 million in Middle Africa, and 64.5 million in Southern Africa (Kaba, 2020). However, the absence of secure water and sanitation systems hampers her economic progress at a rate twice as fast. Tanzania has notably elevated its aspirations and deepened its dedication to broadening access to water supply, sanitation, and hygiene (WASH). This is evident through its embrace of the Sustainable Development Goals and the expansive scope of the ongoing Water Sector Development Program (URT, 2022; WB, 2018).

Assessing the country's water sector involves evaluating various aspects such as water resource management, water quality control, rural and urban water supply, sanitation services, and the sector's institutional capacity. Tanzania is estimated to possess water resources suitable for human consumption, averaging 126 BCM annually (Katonge and Makupa, 2023). Of this, approximately 105 BCM are in the form of surface water, while around 21 BCM are accessible as groundwater. Factoring in Tanzania's population projection for 2019, this equates to the amount of water available per person per year is approximately 2,250 m^3 (Kashaigili, 2012). The available amount totals approximately 2,250 m^3, surpassing the international recommended minimum of 1,700 m^3 person per year (URT, 2022). Falling above this threshold signifies that the country is not considered water stressed.

For various purposes such as domestic, irrigation, industrial, and environmental, Tanzania annual water requirement is estimated at around 47 billion m^3 (BCM), accounting for 37.3% of the yearly renewable water resources. This demand is projected to rise to about 80 BCM annually by 2035 (URT, 2022). This suggests that the nation's water resources currently suffice for socio-economic advancement. However, to prevent potential water stress stemming from increased catchment degradation and escalating water needs, it's crucial to bolster the management and development of water resources (USAID, 2022).

In mainland Tanzania, slightly more than half (54%) of all households rely on an improved water source as their primary drinking water supply. In urban areas, three out of four households (74%) have access to clean and safe water, whereas in rural areas, this proportion drops to just under half (46%) (WB, 2023). The country has a high Infant mortality rate, with water borne diseases such as cholera and diarrhea having been identified as the main causes of infant mortality (WHO/UNICEF, 2020). About 38% of Tanzanians rely on piped water, while 34% use non-piped improved sources. In terms of drinking water service levels, a total of 13% of the population relies on surface water, 15% on unimproved sources, 11 % on limited sources and 61 % on basic sources (USAID, 2022).

While piped water infrastructure is a positive step forward, it's equally essential to ensure that those who don't have access to piped water can still rely on safe and improved sources. Options like protected wells or boreholes can serve as viable alternatives, particularly in areas where establishing piped water systems might be challenging or costly (URT, 2022a). Diversifying water sources ensures a more comprehensive approach to providing clean and safe water to all communities, ultimately improving the quality of life for everyone.

Kibaha district has implemented several initiatives in collaboration with the Ministry of Water and Irrigation and DAWASA to tackle the water supply challenge. Despite these endeavors, the issue persists (URT, 2006). Residents along the Coast area like Dar es Salaam, Kibaha, and Bagamoyo residents living in an area with access to the municipal fresh water supply was 85% and the proportion of residents connected to the sewage system was 10% (EWURA, 2018). Poor operational and maintenance practices contribute to a 20% non-functioning rate among rural supply systems, and Kibaha town council faces similar challenges (Mbwette, 2010). In swiftly growing urban areas such as Kibaha council, most individuals depend on boreholes or shallow wells to fulfill their daily water requirements due to the lack of a sufficient piped water network by the authorities. Unfortunately, inadequate wastewater disposal practices have resulted in groundwater contamination, subsequently causing waterborne diseases to spread (Adelodun *et al.* 2021). This situation raises significant concerns about the safety of water sourced from shallow wells.

Given the projected growth of Kibaha town and the expected increase in demand for this scarce resource, coupled with potential climate changes in the area, understanding water quality becomes crucial. This study aimed to extensively assess the quality of water in boreholes, commonly relied upon as water sources in Kibaha's peri-urban and informal settlements. This study encompassing physicochemical parameters and predict human health risk to consumers. The primary goal was to safeguard human health and the balance of aquatic ecosystems by conducting a comprehensive evaluation.

MATERIALS AND METHODS

Study Area

Kibaha district is among of nine administrative districts of Pwani region which located between latitude 6.8º in the

South and longitude 38.2º and 38.5º in the East, the district is 40km away from Dar es Salaam along Morogoro road. The district covers an area of 1,502km^2 with population of 123,367 (URT, 2022b).

Most community members in Kibaha district depend on hand-dug wells or sometimes using available boreholes, placing the primary responsibility of fetching water on women. Water scarcity is a prevalent issue, necessitating extra efforts to safeguard water sources. Consequently, the Kibaha rural district employs various methods like open wells, rainwater tanks, household water storage units, hand pumps, and tube wells to preserve and store water.

Data Collection Method

Sixteen water samples were obtained from four boreholes over a one-week interval, spanning from June 1st to June 30th, 2022. These boreholes were situated in informal settlements within the Kibaha district, catering to the regions of four wards: Ruvu, Kikongo, Soga, and Bokomnemela. The samples underwent testing at the Tanzania Water Institute Laboratory. A non-probabilistic method was chosen specifically for assessing the existing boreholes and examining the quality of groundwater.

The method included four rounds of grab sampling from every borehole. Before processing, the samples were collected in 1L polyethylene (PE) bottles that had been rinsed with deionized water and rinsed three times with water sample. To ensure convenience, sampling occurred in the morning, independent of peak or off-peak hours. Purging before sampling was omitted as the boreholes remained active. After collection, a series of physicochemical analyses were conducted to assess the water's overall quality and to identify specific characteristics in each sample, including temperature, pH, electrical conductivity, hardness, BoD, alkalinity, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-} and total dissolved solids (TDS). Moreover, each sample was triplicated and evaluated in the laboratory to gauge various parameters for determining optimal drinking water quality. Post-analysis, these samples were cross-referenced with guidelines endorsed by the World Health Organization (WHO, 2011).

Data Analysis

To prevent degradation, the water samples were carried in a cooler box with ice cubes to the SWSC laboratory kept at 4 ºC, to assess the physical, chemical, and bacteriological quality of the samples. The data were analyzed using Microsoft excel computer software and compared against drinking water standards (APHA, 2005).

Onsite analysis

Some variables were measured in the field, very soon after the sample has been collected, those variables include pH, Temperature, Conductivity. Temperature, pH and electrical conductivity tests were conducted on-site using calibrated standard instruments following the established protocols outlined (Nollet, 2000; Jeyashanthi, et al., 2023). A pH meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.) was utilized to measure the pH of the water samples. Prior to data collection, the pH meter underwent calibration using three standard solutions (pH 4.0, 7.0, and 10.0). After submerging the pH sensor in the water sample and allowing it to stabilize, the reading for each sample was recorded. To prevent any contamination between samples, the probe was cleaned with deionized water after each analysis.

The samples' conductivity was gauged utilizing a conductivity meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd). The probe underwent calibration using a standard solution with a known conductivity before being immersed in the water sample. The reading was captured once the stability indicator vanished, and after each sample measurement, the probe was cleansed with deionized water to prevent potential contamination among the different samples according to the APHA (1998) guidelines.

Determination of total hardness, BOD, total dissolved solids and alkalinity

The analysis of water samples for total hardness and total alkalinity and total dissolved solids employed the standard method (Ma, *et al*. 2020; Khodapanah, et al., 2009). The determination of total hardness utilized complexometric EDTA titration with the aid of Eriochrome black T. (EBT). Total alkalinity (TA) was determined through titrimetric methods using phenolphthalein and methyl orange as indicators. For measuring total dissolved solids (TDS), the filtered sample underwent evaporation in a hot oven at 180 ± 2°C. Following complete evaporation, the dish was cooled, and the final weight was measured and compared with the initial weight, as outlined by Mohammed and Nur (2013). The BOD was determined using Winkler method (Young et al., 1981) by titrating $MnSO_4$, alkali-iodide, azide solution and 1 mL conc. H_2SO_4 then allowed to settle for about 5 minutes after formation of brown ppt. The iodide ions produced react with any remaining oxygen to form iodine which will be titrated with a standardized sodium thiosulfate ($Na_2S_2O_3$) solution.

Determination of nitrate

The determination of nitrate in water samples followed the methodology outlined in Ma, *et al.* (2020). For each water sample, 10 cm^3 was introduced into meticulously cleaned sample containers. A single reagent powder pillow containing NitraVer 5 Nitrate was then added to each sample. After sealing the containers and shaking them vigorously for 1 minute, the sample concentrations were measured at 500 nm using a portable Data Logging Spectrophotometer (HACH DR/2010) after a 5-minute incubation period. The recorded values were subsequently multiplied by a conversion factor of 4.427, as specified by APHA (1998).

Determination of phosphate

The analysis of phosphate in wastewater samples followed the procedure outlined in Ma, (2020). Under acidic conditions, orthophosphate ions reacted with ammonium molybdate, forming a yellow complex compound known as ammonium phosphomolybdate. This complex was then subjected to reduction using tin (II) chloride solution in glycerol. The yellow complex transformed into a blue-colored compound due to the formation of molybdenum blue, as detailed in the APHA (1998) protocol.

Determination of sulphate

A pristine sample container was filled with 10 cm^3 of each water sample. To each borehole sample, the contents of a sulphate reagent powder pillow were added and swirled to facilitate dissolution. The cell was then left undisturbed for 5 minutes. Subsequently, the concentration was measured at 450 nm using a portable Data Logging Spectrophotometer. Blank samples underwent the same treatment, following the procedure outlined (APHA, 2017; Jeyashanthi, *et al.* 2023)

Determination of chloride

The chloride ion concentration was determined by using Mohr's method (precipitation titration) titrating each sample against 14 M silver nitrate solution using 1 ml of 5% potassium chromate as an indicator (WHO,1993; APHA 2017).

Nutrient Pollution Index (NPI)

Nutrient Pollution Index (NPI) and human health risks were computed to evaluate water pollution and potential health hazards associated with using the water for domestic activities. The NPI was determined using the formula presented in Eq. (1).

$$NPI = \frac{C_N}{MAC_N} + \frac{C_P}{MAC_P} \qquad (1)$$

Where $C_{N/P}$ is the mean concentration of nitrate and phosphate in the borehole sample, $MAC_{N/P}$ is maximum allowable concentration taken from WHO to be 50 mg/L and 5 mg/L for nitrate and phosphate in surface water respectively.

The classification for NPI is categorized as NPI of <1 (no pollution), $1 < NPI \leq 3$ (moderate polluted), $3 < NPI \leq 6$ (considerable polluted) and NPI > 6 (very high polluted).

Chronic Daily Intake (CDI)

Humans may be exposed to nitrate and phosphate in surface water by two means via ingestion or oral and dermal route when they come in contact with the water. Therefore, health risks were computed from these two pathways. The oral and dermal route risks are estimated from the chronic daily intake (CDI) per unit weight as expressed in Eqs. (2) and (3)

$$CDI_{oral} = \frac{C_{N/P} * IR}{BW_{Ad/Ch}} \qquad (2)$$

$$CDI_{Derm} = \frac{C_{N/P} * K_i * SA * EV * CF}{BW_{Ad/Ch}} \qquad (3)$$

$C_{N/P}$ is mean concentrations of nitrate and phosphate (Table 3); IR is the rate of ingesting the water which is 2 L/d for adults (Ad) and 0.67 L/d for children (Ch), BW is body weight for adult (Ad) and children (Ch) i.e 70 kg and 15 kg respectively, K_i is the dermal permeability coefficient in water (0.001 cm/h for both adult and children), SA is the surface area of contactable skin (1700 and 3416 cm^2 for adult and children respectively), EV is Frequency of bathing (2 times/d), CF is the conversion factor (0.002 L/cm^3) (Yu et al., 2020).

Hazard Quotient

The hazard quotient (HQ) associated with the use of the borehole water for domestic activities is estimated using Eq. (4). The reference doses were taken from USEPA, (2003) as 0.36 mg/kg.d oral and 0.18 mg/kg.d skin nitrate nitrogen (Yang *et al.* 2012; Yu *et al.* 2020) while 0.00002 mg/kg.d oral for phosphate while for skin was not found (USEPA, 1993).

$$HQ_{oral/Dermal} = CDI_{Oral/Dermal} \Big/ RFD_{Oral/Dermal} \qquad (4)$$

The hazard index (HI) were computed as the summation of HQs and expressed in Eq. (5).

$$HI_{Oral/Dermal} = HQ_N + HQ_P \qquad (5)$$

RESULTS AND DISCUSSION

Physicochemical Parameters

Seven water quality parameters were selected for analysis, these being: pH, BOD, alkalinity, electrical conductivity (EC), total dissolved solids (TDS), and water hardness, were analyzed and outlined in Table 1. The values obtained for these physicochemical parameters can serve as indicators to assess the fertility or pollution status of the well water in the study area, particularly when compared to the international standards set for water considered suitable for drinking.

Table 1: Analyzed data for Physical Parameters of Selected Boreholes

Sampling site	Range	Parameter						
		Temp (ºC)	pH	EC (µS/cm)	TDS (mg/L)	Total Hardness (mg/L)	BOD (mg/L)	Total alkalinity (mg/l)
Msufini	Max.	29.52	7.29	461.53	221.31	48.12	7.05	101.12
	Min.	27.81	6.09	404.71	216.07	42.89	6.62	96.08
	Mean	28.81	6.55	437.02	219.32	45.21	6.89	98.12
	STD (±)	0.893	0.647	29.202	2.836	2.664	0.24	2.655
Boko Kibaoni	Max.	29.14	7.19	227.84	114.21	26.82	6.43	60.12
	Min.	27.23	6.12	222.72	112.32	21.92	6.22	57.12
	Mean	28.19	6.55	225.07	113.08	24.14	6.32	58.15
	STD (±)	0.955	0.565	2.586	0.996	2.483	0.11	1.704
Ruvu darajani	Max.	26.98	7.46	1029.12	432.67	148.23	9.58	329.34
	Min.	25.87	6.89	1018.68	431.42	146.22	6.72	327.22
	Mean	26.52	7.21	1024.34	432.08	147.20	8.07	328.04
	STD (±)	0.58	0.29	5.28	0.63	1.01	1.59	1.14
Kikongo	Max.	27.11	7.51	492.65	208.35	37.12	7.13	103.08
	Min.	25.65	6.52	489.39	203.22	35.08	5.51	101.13
	Mean	26.31	6.92	491.27	205.94	36.14	6.25	102.12
	STD (±)	0.739	0.523	1.688	2.578	1.022	0.82	0.976
WHO (2007)			6.5-8.5	2500	600	500	< 5.0	20-200
TBS (1997)			6.5-8.5	3000	500-600	500-600	6.0	NA

Temperature serves as an indicator of the average kinetic energy of water molecules, measured on a linear scale in degrees Celsius. Monitoring water temperature is crucial for assessing water quality, offering crucial insights into the dynamics and health of aquatic ecosystems (Sarr *et al.* 2023). This monitoring aids in identifying potential stressors, contributing to the effective management and conservation of water resources. The highest value recorded at Msufini with 28.81 ºC while the lowest recorded at Kikongo borehole with 26.31 ºC. However, these values, when compared to findings from other studies, were notably lower. For example, in a study (Kiruthika *et al.* 2012), which examined the groundwater quality in Tiruchirappalli District the recorded temperature ranged from 27°C to 29°C.

However, values are higher than the one detected in shallow wells elsewhere (Kipchumba, 2015), ranged from 11.82 °C to 18.32 °C.

The pH level plays a crucial role in shaping the conditions necessary for life, serving as a measure of the acidity or alkalinity of water-soluble substances (Sarr *et al.* 2023). It is well-established that the pH of water significantly affects the availability of micro-nutrients and trace metals (Barrow and Hartemink, 2023). In the case of the boreholes examined in this study, the pH values varied, with mean levels ranging from 6.55 for borehole Msufini/Bokokibaoni to 7.21 for borehole Ruvu Darajani. Notably, the mean pH value observed in this study is lower than the previously reported findings (Vilane and Dlamini, 2016), where the pH levels for all studied boreholes ranged from mean levels of 7.06 to 7.89.

Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. The measured electrical conductivity in the examined samples spans from 225.7 to 1024.34 µS/cm. These results demonstrate a higher range compared to a previous study conducted by Rahmanian *et al.* (2015), which reported values ranging from 69.7 to 269.3 µS/cm, with an average value of 102.1 µS/cm. In the context of water, electrical conductivity refers to the medium's ability to conduct an electric current (Sarr et al., 2023). This conductivity arises from the presence of dissolved ions, whether metallic or non-metallic, such as calcium, chloride, sulfate, magnesium, and others within the water samples (Thomas, 2011).

Evaluating water alkalinity is essential for comprehending its ability to resist pH changes, maintaining pH stability, supporting aquatic ecosystems, preventing corrosion, and ensuring adherence to water quality standards. This assessment offers valuable insights for the sustainable management and safeguarding of water resources. In the examined sample, Ruvu darajani exhibited the highest mean at 328.04 ± 1.14 mg/L, while Boko Kibaoni recorded the lowest at 58.15 ± 1.704 mg/L. These values align with recent findings by Mengstie et al. (2023), ranging from 40.88 to 239.17 mg/L.

There is no health-based limit for Total Dissolved Solids (TDS) in drinking water, and TDS concentrations in drinking water typically fall well below levels considered harmful. Water with TDS levels below 100 mg/L is generally deemed good for palatability. In the study area, the mean concentration of TDS in water samples varied from 113.08 ±0.996 to 432.08 ± 0.63 mg/L. While these values exceed the mean TDS concentration reported in a recent study (Mengstie *et al.* 2023), ranging from 67.3 to 190.9 mg/L, the health risks remain minimal. This is because the observed TDS values are significantly lower than the maximum permissible limits set by the World Health Organization (WHO, 2011) (500 – 1000 mg/L) and the Tanzanian Bureau of Standards (TBS, 1997) (500 – 600 mg/L).

Total Hardness denotes the total amount of calcium and magnesium ions present in the body. The highest permissible limit of total hardness as $CaCO_3$, according to the WHO (2011) is < 500 mg/L while TBS (1997) is ranging from 500 – 600 mg/L. The lowest mean total hardness was detected at Boko

Kibaoni (24.14 ± 2.48 mg/L and the highest was detected at Ruvu darajani (147.20 ± 1.01 mg/L). The detected values are lower than the one detected earlier (Abubakar and Sa'id, 2022), where the total hardness ranged from 51.200 ± 3.200 to 609.467±11.085 mg/L. According to WHO standards, the degree of hardness borehole water supply is moderately soft, which is not harmful to users. The high level may be as a result of the presence of excess amounts of insoluble metals and salts which rendered it to be not suitable for other purposes such as washing.

Biochemical Oxygen Demand (BOD) quantifies the dissolved oxygen required by aerobic biological organisms to decompose organic matter within a specified water sample, considering a particular temperature and duration. Table 1 reveals that the lowest average BOD was observed at Kikongo borehole, registering at 6.25 ± 0.82 mg/L, while the highest was noted at Ruvu Darajani, measuring 8.07 ± 1.59 mg/L. The BOD levels in all analyzed samples surpassed the acceptable limits set by both WHO (2007) and TBS (1997), which are <5.0 and 6.0 mg/L, respectively. Notably, these values exceed those reported in a previous study (Edet et al. 2020), where the BOD ranged from 5.35 ± 0.003 to 6.85 ± 0.001 mg/L. Elevated BOD values observed in all examined samples signify the existence of significant quantities of biodegradable organic substances, including sewage, wastewater, or industrial effluents, within the study area.

Concentration of Non-metals in Water Samples

Nitrate is present in groundwater due to the leaching of nitrate with percolating water. Contamination of groundwater can also occur from sewage and other waste sources rich in nitrates (Sirajudeen and Mubashir 2013). While nitrate is a natural component of groundwater, elevated concentrations may be linked to animal and human waste, open septic or sewage systems, and agricultural fertilization (Akaahan *et al.* 2010).

The highest nitrate concentration, reaching 3.85 mg/L, was detected at the Ruvu Darajani borehole water source, whereas the lowest concentration of 0.06 mg/L was observed at the Kikongo borehole water supply (Figure 1). Excessive levels of NO_3^- in drinking water can lead to various disorders, including methemoglobinemia in infants, gastric cancer, goiter, birth malformations, and hypertension (Majumdar and Gupta, 2000).

Phosphate may be present in groundwater due to factors such as domestic sewage, detergents, and agricultural effluents containing fertilizers (Letshwenyo and Sima 2020; Murhekar, 2011). Typically, groundwater maintains a low phosphorus level because of the low solubility of native phosphate minerals and the soil's capacity to retain phosphate (Devendra *et al.* 2014).

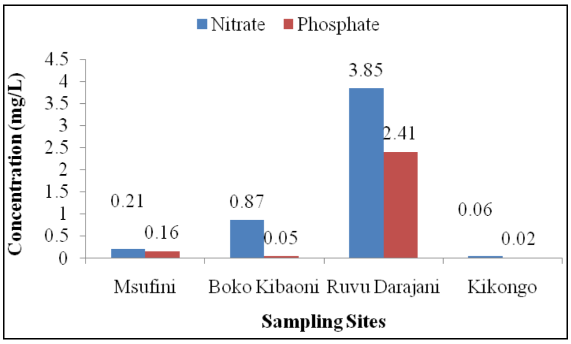

Figure 1: Nitrate and Phosphate Levels

In the study area phosphate concentrations varied from 0.02 to 2.41 mg/L at the

Kikongo and Ruvu Darajani boreholes respectively (Fig. 1). These values surpass those reported earlier (Dagim *et al.* 2017), which ranged between 0.30 mg/L and 0.16 mg/L. While phosphates are essential nutrients, excessive intake through drinking water can pose health risks, including associations with kidney problems, cardiovascular diseases, and other health issues (Vranić *et al.* 2023). Moreover, a higher intake of phosphorus is positively correlated with serum phosphorus, femur bone mineral content, and femur bone mineral density, exhibiting a similar pattern in gender-specific analyses (Fulgoni *et al.* 2022). Additionally, specific phosphate compounds may contribute to the leaching of heavy metals into the water, introducing additional health hazards.

Sulfate naturally appears in water through leaching from gypsum and other common minerals. Its concentration tends to increase due to the discharge of industrial wastes and domestic sewage (WHO, 1999). In the research area, sulfate concentrations ranged from 119.65 mg/L at the Kikongo borehole water source to a minimum of 46.33 mg/L at the Boko Kibaoni borehole water source (Fig. 2). These findings align with a recent study conducted in Tanzania (Sibomana, 2022), which reported sulfate concentrations ranging from 15.1 mg/L to 195.5 mg/L. Nevertheless, these levels fall within the Tanzanian Standard (TBS, 1997) of 600 mg/L and the WHO (2011) recommended standards of 450 mg/L.

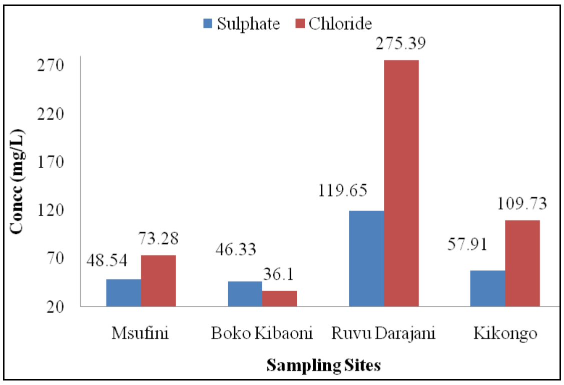

Figure 2: Concentration of sulfate and Chloride in Different Sampling Sites

Nutrient Pollution Index (NPI) and Human Health Risks

The general nutrient index (NPI) for the ground water considers possible summation effect of nitrate and phosphate on environmental health (Table 2). This help to quickly estimate the overall quality of surface waters.

Table 2: Nutrient Pollution Index of Ground Water Samples

Sampling Point	Msufini	Boko Kibaoni	Ruvu Rarajani	Kikongo
NPI	0.036	0.027	0.559	0.006

In this study, the NPI was calculated to assess the influence of anthropogenic activities, such as the application of fertilizers containing nitrogen and phosphorus nutrients, on the groundwater in the study area. Nitrogen and phosphorus compounds in groundwater primarily originate from anthropogenic sources, including organic matter, municipal wastewater, sludge, septic tanks, and fertilizers rich in nitrate-phosphate-potassium (Tokatli 2021; Onyemesili *et al.* 2022).

The outcomes of the applied NPI for drinking groundwater resources are presented in Table 2. The NPI values, which integrated parameters such as NO_3^-

and PO_4^{3-}, indicated a 'no pollution' status of water quality for the investigated borehole water samples, ranging from 0.060 to 0.559. A similar outcome was recently reported in Anambra State, Nigeria (Egbueria *et al.* 2023), where the NPI ranged from 0.060 to 0.745.

However, the NPI analysis led to the formation of two distinct clusters, as outlined in Table 2. Cluster I consist of water samples exhibiting the lowest NPI values (< 0.04), while Cluster II is predominantly composed of samples with NPI values exceeding 0.04. The presumption is that groundwater locations within Cluster I may become more susceptible to nutrient pollution compared to those in Cluster II, especially with a continual rise in anthropogenic activities in the region. The NPI results indicate a relatively low anthropogenic influence in terms of nutrient enrichment in the groundwater.

A similar observation was reported in Turkey by Tokatli (2021). While the current study area encompasses urban clusters marked by intense human activities, the primary factor contributing to the low NPI scores observed in this investigation is believed to be the hindrance of organic contaminant migration into the aquifer systems due to the presence of clayey geological units and the soil structure in the study area.

HUMAN HEALTH RISK ASSESSMENT

Chronic Daily Intake (CDI)

Humans may encounter nitrate and phosphate in surface water through ingestion or oral ingestion and dermal contact when they interact with the water. Consequently, health risks were assessed based on these two exposure pathways. The Chronic Daily Intake (CDI) of nitrate and phosphate for both adults and children in the waterbody via ingestion/oral and dermal/skin pathways is depicted in Table 3.

Table 3: Chronic Daily Intake of Nitrate and Phosphate

Site	**Age**	**CDI Ingestion**		**CDI Dermal**	
		NO_3^-	**PO_4^{3-}**	**NO_3^-**	**PO_4^{3-}**
Msufini	Adult	6.00×10^{-3}	4.60×10^{-3}	2.04×10^{-4}	1.55×10^{-4}
	Child	9.40×10^{-3}	7.2×10^{-3}	1.91×10^{-3}	1.46×10^{-3}
Boko Kibaoni	Adult	2.49×10^{-2}	$1.4. \times 10^{-3}$	8.45×10^{-4}	4.86×10^{-5}
	Child	9.40×10^{-3}	2.20×10^{-3}	7.93×10^{-3}	4.56×10^{-4}
Ruvu Darajani	Adult	1.10×10^{-1}	6.89×10^{-2}	3.74×10^{-3}	2.34×10^{-3}
	Child	1.72×10^{-1}	1.08×10^{-1}	3.51×10^{-2}	2.20×10^{-2}
Kikongo	Adult	1.70×10^{-3}	6.0×10^{-4}	5.83×10^{-5}	1.94×10^{-5}
	Child	2.70×10^{-3}	9.00×10^{-4}	5.47×10^{-4}	1.82×10^{-4}

CDI values for nitrate and phosphate when exceeding 1 consistently indicate chronic intake and associated risks. In adults, CDI via ingestion revealed nitrate concentrations ranging from 1.7×10^{-3} (Kikongo borehole) to 1.10×10^{-1} (Ruvu Darajani borehole). A similar pattern was evident in children, with ranges from 2.70×10^{-3} (Kikongo borehole) to 1.72×10^{-1} (Ruvu Darajani borehole). These figures are lower than those previously reported (Isiuku and Enyoh, 2020), where nitrate CDI for adults ranged from 0.38 to 1.05 and for children ranged from 0.59 to 1.63.

The CDI for phosphate ranges from 6.0 x 10^{-4} to 6.89 x 10^{-2} for adults and 9.0 x 10^{-4} to 1.08 x 10^{-1} for children. These values are lower than the one detected earlier (Isiuku and Enyoh, 2020) where for adults' ranges from 0.06 to 0.28 and for children ranges from 0.10 to 0.44. Nevertheless, this indicates that continuous consumption of nitrate and phosphate into the body isn't detrimental and might not result in significant health consequences.

The dermal route typically exhibited minimal chronic intake (Table 3). Findings from the research indicated that children generally experienced higher overall intake compared to adults. Numerous studies have echoed similar findings for various water pollutants (Ibe *et al.* 2020; Jehan, *et al.* 2020), attributing them to the smaller body size and less developed organs of children.

Hazard quotient (HQ) and index (HI)

The analysis of non-carcinogenic hazard quotient and index across various pathways for both children and adults is detailed in Table 4 and Figure 3.

Table 4: Hazard Quotient of Nitrate and Phosphate for both Children and Adults

Site	**Age**	**CDI Ingestion**		**CDI Dermal**	
		NO_3^-	**PO_4^{3-}**	**NO_3^-**	**PO_4^{3-}**
Msufini	Adult	1.67 x 10^{-2}	2.29 x 10^{2}	1.13 x 10^{-3}	-
	Children	2.61 x 10^{-2}	3.57 x 10^{2}	1.06 x 10^{-2}	-
Boko Kibaoni	Adult	6.90 x 10^{-2}	7.14 x 10^{1}	4.70 x 10^{-3}	-
	Children	2.61 x 10^{-2}	1.12 x 10^{2}	4.40 x 10^{-2}	-
Ruvu Darajani	Adult	3.06 x 10^{-1}	3.44 x 10^{3}	2.08 x 10^{-2}	-
	Children	4.78 x 10^{-1}	5.38 x 10^{3}	1.95 x 10^{-1}	-
Kikongo	Adult	4.76 x 10^{-3}	2.86 x 10^{1}	3.24 x 10^{-4}	-
	Children	7.44 x 10^{-3}	4.47 x 10^{1}	3.04 x 10^{-3}	-

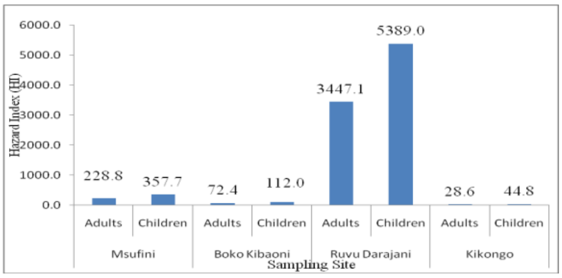

Figure 3: Hazard index for Adults and Children via Oral Intake

When HQ and HI surpass the value of 1, it signals potential adverse health effects of a chemical on adults and/or children through diverse intake routes. Moreover, HI values exceeding 1 signify potential concerns regarding non-carcinogenic risks associated with chemical intake by either adults or children (Enyoh *et al.* 2020). Notably, both nitrate and phosphate displayed notably high HQs and HI, indicating substantial risks of non-carcinogenic health hazards. Findings from the study highlight those children generally exhibited higher HI values compared to adults. Excessive nitrate consumption in children can result in methemoglobinemia, potentially leading to mental retardation if the child survives. Additionally, nitrate in the body can be converted to nitrite (NO_2^-), which reacts with amines to generate nitrosamines, known carcinogens (Moshoeshoe and Obuseng, 2018).

CONCLUSION AND RECOMMENDATIONS

Residents living in the peripheral area of Kibaha, primarily rely on groundwater for their domestic needs due to the lack of connection to the piped water supply system from the Upper Ruvu treatment plant. Analysis of borehole water samples revealed that the physicochemical parameters fell within the recommended range of TBS and WHO values, indicating the absence of physico-chemical contaminants in the water. The comprehensive findings of this study have demonstrated that anthropogenic influences on groundwater physicochemical characteristics are minimal. This research is valuable as it equips decision-makers with a convenient tool for promptly identifying individuals exposed to physicochemical contamination in the research area based on the study's results and findings.

Despite these strengths, the study acknowledges certain limitations that warrant consideration in future research endeavors. Notably, the study did not account for the potential impact of seasonal variations over an extended period. Therefore, future research efforts are encouraged to address this aspect. Additionally, there is a limitation in the number of water sites included in the study. Hence, it is recommended that future studies encompass a broader range of urban clusters and water stations within the Kibaha district to enable more detailed, comprehensive, and comparative analyses. Lastly, water management authorities in the region should strive to enhance their management strategies to safeguard groundwater from human-related impacts, particularly in light of the anticipated increase in the human population in the area.

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