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Assessment of Spatial Distribution of Excreta Contaminants in Groundwater from Onsite Sanitation Facilities at Kibondemaji Ward, Dar es Salaam

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ABSTRACT: The study assessed underground spatial distribution of excreta contaminants from on-site sanitation facilities in terms of groundwater quality at Kibondemaji ward. Twenty (20) water samples from wells were collected. Physicochemical and biological parameters like pH, TDS, electrical conductivity, Nitrate (NO_3), Ammonia (NH_3-N), Phosphate, and Fecal coliform were analyzed. A pollution index was used to determine the gross water quality of the wells. ArcGIS, using Inverse Distance Weighting (IDW), was used to visualize pollutants concentrations and interactions in relation to onsite sanitation facilities. Kibondemaji and surrounding areas' groundwater exhibited excreta contaminants (FC) exceeding WHO and Tanzania (TZS 789:2008) standards. Kibondemaji B had the highest contamination rate (43.7%) due to large number of shallow wells easily contaminated by onsite sanitation facilities. In some wells, Ammonia and Electrical conductivity were relatively high, suggesting that the water had been contaminated by fresh excreta matter emanating from onsite sanitation facilities. The water quality indices for BH8, BH3, BH6, BH9, BH10, SW5 and SW9 ranged between 0-50 indicating good to excellent water for consumption, whereas the rest (mostly shallow wells) with WQI > 51 were not suitable for consumption due to pollution from the onsite sanitation facilities.

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Introduction:

Most human activities that use water, produce wastewater (Connor *et al.*, 2017). The generation of wastewater has become an increasing environmental and public health problem everywhere in the world, particularly in developing countries (Massoud *et al.*, 2009). The fast urbanization due to rapid population and informal natural settlement cause poor management of generated waste water resulting to water born disease and loss of peoples' lives (Akoteyon *et al.*, 2011). Groundwater contains over 90% of fresh water resource and is an important reserve of good quality water, its chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation and for industrial and other purpose (Aragaw and Gnanachandrasamy, 2021). Therefore, monitoring and ensuring the quality of water is important because clean water is necessary for health and reliability of both terrestrial and aquatic ecosystem (Babiker *et al.*, 2007). On site sanitation facilities are common human excreta disposal system in low-income countries (Chinyama *et al.*, 2012), and their use is on the rise as countries aim to meet the sanitation-relate target of the millennium development goals. However, discharge of chemical and microbial contaminants from onsite sanitation facilities to groundwater may negatively affect human health. Besides, due to high demand of groundwater resources in low- income countries, on site sanitation facilities are likely to cause human and ecological health

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impacts associated with microbiological and chemical contamination (Van Ryneveld and Fourie, 1997), through leach into the resource. Moreover, groundwater sources are often contaminated by on site sanitation facilities when the safe distance from on site sanitation facilities are not adequately maintained (Islam *et al*., 2016). On site sanitation facilities encompass contaminants like pathogenic bacteria, viruses, protozoa and helminths which may filtrate through the ground (unsaturated and saturated) and ultimately reach the groundwater (Luby *et al*., 2008). The spatial distribution of these contaminants in groundwater are influenced by the proximity of the facilities to water table, the type of soil present, and the presence of fractures or other pathways for contamination (Humphrey *et al*., 2014). Given the aforementioned factors, excreta contaminants can migrate from onsite sanitation facilities posing high risks to groundwater resources. Given the importance of the groundwater resource, it is important to assess the spatial distribution of excreta contaminants in groundwater in order to identify areas of potential risks and implement appropriate management measures to prevent further contamination of groundwater. The consequences of the use of onsite sanitation facilities have potentially distributed excreta contaminants to groundwater sources (Lutterodt *et al*., 2023); their large numbers especially in developing countries have triggered serious contamination to the sources (Rahman *et al*., 2009). There are numbers of water born diseases cases reported in Dar es salaam, Tanzania due to consumption of contaminated groundwater; for instance, about 815 people were affected and 13 people lost their life due to waterborne diseases in September 2015 according to Tanzania ministry of health and social welfare report (WHO, 2015). Kibondemaji's residents at Mbagala, Dar es Salaam depend on shallow wells and borehole waters that, most of which, are close to on site sanitation facilities. However, the level of contamination of the wells and the risks of consuming such water are not known. Therefore, this study assesses the underground spatial distribution of excreta contaminants and establishes the current situation in term of groundwater quality against on site sanitation facilities in selected areas at Kibondemaji ward. The study's findings rise awareness to other researches and decision makers on the current spatial distribution of excreta contaminants in Kibondemaji's groundwater. Besides, the findings trigger a call for regulatory bodies to ensure that sanitation facilities are designed and constructed in a way that they do not pose potential risks groundwater consumers.

Groundwater occurrence and the emergence of springs depend on the lithology of geological materials, regional geological structure, geomorphology of landforms and availability of recharge sources (Rajaveni *et al*., 2017). Groundwater resource is any aquifer or portion of an aquifer regardless of it's current use (Kanmani & Gandhimathi, 2013). Infiltration of rainfall and flow of groundwater in an aquifer toward a discharged area are governed by physical laws describing change in groundwater energy (Hiscock, 2014). Recharge to groundwater depends on the process of infiltration and percolation. The recharge may result from natural and artificial water on the surface of ground. Natural sources are rainfall, snow, melt, streams and lakes. Artificial sources are leakage from reservoirs, conduits, septic tanks etc. Precipitation (the main sources groundwater (Williams *et al*., 2007)), and surface water recharge groundwater through downward movement into the soil mantle or rock surface. Groundwater occurrence is influenced by 1. hydraulic properties governing water storage and transmission, including pores, lava tubes, solution cavities, bedding planes, faults, unconformities, and intrusive contracts; 2. gemological frameworks including topography, types of geology formation, physical and chemical characteristics of unconsolidated deposit overlaying bedrocks; 3. climate, for example in area having sufficient amount of rainfall the level of groundwater will rise due to the water which percolates into the ground (Singhal & Gupta, 2010). The type of well depends on the quantum of water required, economic consideration, geologic and hydrologic condition (Akoteyon *et al*., 2011). The commonly constructed wells are dug well, borehole, tube wells, dug-cum-bore wells and filter point wells. Groundwater quality varies due to different geological formation (Ojoawo & Adagunodo, 2023). The quality of groundwater in shallow aquifer water changes due to human activities. However, the water is less susceptible to bacterial pollution than surface water because the soil and rocks through which ground water flows screen out most of the bacteria. Bacteria, however, occasionally find their way into ground water, is sometimes in dangerously high concentrations (WHO, 2006). Being free from bacterial pollution alone, does not mean that the water is fit to drink - many unseen dissolved mineral and organic constituents might be present in the groundwater at various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic (Onyango *et al*., 2018). Besides, the quality of groundwater can be affected by a number of factors, including chemistry of soil and geologic layers, depth of aquifer from ground level, biological activities, and domestic and industrial waste if the source is near houses or industries (Abanyie *et al*., 2023).

Several chemicals and various synthetic products we use today are usually the main causes of groundwater pollution. To assess the groundwater quality, it is important to know various ways resulting to groundwater pollution. The pollutants in groundwater can be due to waste disposal, saline water intrusion, pollution under natural condition and leachate generation (Mato, 2002). Besides, ground-water-flow system constitutes geologic deposits, interactions with surface water, pumping, and other stresses on movement of water controlling advective transport of contaminants (Zhou *et al*., 2023). Groundwater vulnerability is a major concern, indicating the possibilities of contamination of underlying aquifers due to activities on the land surface. Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface, and it is low, if natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation (Harter and Walker, 2001). Groundwater vulnerability assessment can be conducted through 1. the assessment of intrinsic vulnerability,depending only on the characteristics of the aquifer - usually suitable for natural systems (Fisher *et al*., 1993) 2. the assessment of specific (or integrated) vulnerability, which is a combination of intrinsic and the potential or the actual source of contamination (Kumar *et al*., 2013).

Groundwater vulnerability assessment can be coupled with spatial analysis to express the spatial distribution of vulnerabilities in the assessed area. The assessment uses various techniques with the aid of statistics and geographical information systems (GIS). GIS facilitates attribute interaction with geographical data in order to enhance interpretation accuracy and prediction of spatial analysis (Gupta, 2017). The spatial analysis that is involved in GIS can build geographical data and the resulting groundwater data/information become more informative.

MATERIALS AND METHODS

Description and selection of the study area: Kibondemaji ward is located at -6.877112 Easting and 39.253135 Northing within Temeke municipal Council in Dar es salaam Region – Tanzania. Kibondemaji ward is not fully supplied by tap water from the Dar es Salaam Water Supply and Sewerage Authority (DAWASA) - the main water service provider in the city. Therefore, the ward consists of several underground water sources including boreholes and shallow wells used for human consumption such as cooking, bathing and washing. The sources are predominant in the area; however, in most cases they are in proximity with on-site sanitation facilities.

Site reconnaissance and interviews: The site reconnaissance involved site visitation identify the on-site sanitation facilities, assess the current types of on-site facilities, and evaluate the presence of wells and their locations in the study area. This was followed by interviews for vulnerability of the water sources based on the community opinions at Kibondemaji wad. A purposeful sampling of interviewees was used to identify heads of households who resided in the area for a long time and are knowledgeable of the any impacts that had happened due to consuming groundwater in the area.

Water sample collection: Twenty (20) water samples were collected (7 from Michikichini sub-ward, 3 from Majimatitu sub-ward, and 10 from Kibondemaji B sub-ward) by using one litre sampling bottles. Similarly, 21 samples from onsite sanitation facilities were collected across the three sub-wards. Random sampling technique was used to select wells to be analyzed. The samples were taken to Ardhi University Environmental Engineering Laboratory for analysis. It was ensured that samples had to be analysed within six hours to avoid bacteriological or chemical changes that might have occurred when samples stay for a long time without analysis

Laboratory Analysis: Parameters like pH, total dissolved solids (TDS), electrical conductivity (EC), Ammonia, nitrate ($\boldsymbol{N-NO_3}$) and Faecal coliform (FC) were analysed to determine the possible contamination from on-site sanitation facilities to groundwater. The analysis was conducted based on the Standard Methods for the Examination of Water and Waste Water, 20th Edition (APHA, 1998). pH was analyzed by electrometric method using pH meter (tens ion 378). The same method was applied for TDS and EC using a multi-parameters instrument. Nitrates were analyzed be a reduction method using Spectrophotometer (DR 400) equipment. Moreover, bacteriological analysis was conducted to determine faecal count in the water. The analysis embraced the Pour Plate Counting method using Standard Method for Fecal Coliform determination. A pollution index was used determine the aggregated concentration of pollutants from each well and excreta contaminants. The weighted additive excreta contaminants pollution index (Kumar and Alappat, 2005; Umar *et al*., 2010; Lukhabi *et al*., 2023; Aralu *et al*. 2022) was used as indicated in equation 1, a similar equation was used by Aralu *et al*. (2022) for water quality index quantification. The values of the indices were described based on Lingswany and Saxena (2016) and

Aralu *et al*. (2022) from Alum *et al*. (2021), as indicated in Table 1.

$$EPI = \frac{\sum_{i=1}^{m} W_n Q_n}{\sum_{i=1}^{m} W_n} \text{…………………}(1)$$

Where; EPI = is the weighted additive excreta contaminants pollution index; m = is the number of pollutant parameters for which data is available; W_n = is the weight for *i*th pollutant variable; Q_n = is the sub index score of the *i*th excreta contaminants pollutant variable

Table 1: Description of the pollution index values

Water quality index	Water quality grading	Water quality status
0-25	A	Excellent
26-50	B	Good water quality
51-75	C	Poor water quality
76-100	D	Very poor water quality
>100	E	Unfit for consumption

(Source: Lingswany and Saxena, 2016)

Spatial distribution analysis: Geographical Positioning System (GPS) was used to record coordinates of the water points including shallow wells and boreholes, this went hand in hand with water levels determination using water deeper equipment. Other important information included the distances of the wells from the on-site sanitation facilities, and the descriptions of wells and on site sanitation facilities. ArcView GIS software (version 10.4) was used for spatial analysis (ESRI, 2016) through the Inverse Distance Weighting (IDW) Model. The spatial data (digital Kibondemaji map layers –urban ward, main roads, streams, pipeline and landforms) and the non-spatial database (boreholes number, rig number, testing results, casing type and locations, screens, lithology and water quality) were linked by the spatial location (geographical coordinates) of boreholes in the GIS.

RESULTS AND DISCUSION

Description of wells and on-site sanitation facilities: Based on the coordinates taken for wells and on-site sanitation facilities at kibondemaji by using GPS, the case study is characterized by shallow wells and boreholes depending on the nature of the area - lower land areas were characterized by several shallow wells (about 70%) due to higher water table; whereas, most boreholes (about 60%) were found in highland due to lower water table. The distance between wells and on-site sanitation facilities ranged from 2m – 17m, and the maximum number of sanitation facilities surrounding a well was four (4). That means, most wells and sanitation facilities fall under the restricted distance of 50ft as stated by US EPA. Location of wells and onsite sanitary facilities shown in Fig. 1.

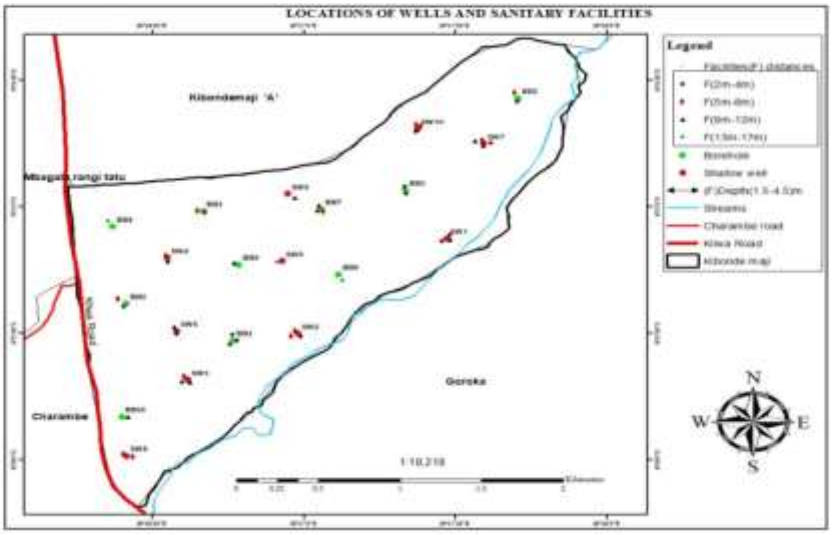

Fig. 1: Location of wells and on-site sanitation facilities

Out of 21 sampled on-site sanitation facilities 51% were pour flush latrine, 27% pit latrines and 22% were septic tanks. All sanitation facilities were unlined thus indicating the possibility of seepage of excreta contaminants to reach the ground water source and contaminate the water.

Groundwater characterization: For water analysis there where twenty (20) wells sampled for three selected sub-wards, where at Mchikichini seven (7) wells were taken, three (3) wells were taken from Majimatitu and ten (10) wells from Kibondemaji B. The laboratory analysis results are presented in Table 2 and 3.

Table 2: Laboratory results for water sampled from shallow wells at Kibondemaji.

WELLS	**Unit**	**SW 1**	**SW2**	**SW3**	**SW4**	**SW 5**	**SW6**	**SW7**	**SW8**	**SW9**	**SW10**
pH		6.42	6.70	6.32	6.36	6.89	7.09	6.22	6.77	6.52	6.45
E.C	µs/cm	2450	2359	1222	2720	1826	2510	1890	2964	2360	1176
TDS	Mg/l	1189	1179	635	1360	913	1134	915	1482	1180	588
Temperature	℃	22.1	21.7	22.0	21	21.2	21.8	22.3	24.7	24.7	24.1
Nitrate	Mg/l	6.6	6.4	7.2	8.6	7.9	5.4	6.7	6.2	5.8	5.9
Ammonia	Mg/l	0.6	1.52	1.86	2.88	0.23	0.392	1.20	0.35	0.18	1.65
Phosphate	Mg/l	6.2	7	9.2	12	3.4	6.2	7.3	6	6.5	11
Fecal coliform	Count/100ml	7	11	15	23	5	4	12	7	3	11

Table 3: Laboratory results for water sampled from boreholes at Kibondemaji.

WELLS	**Unit**	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**	**BH7**	**BH8**	**BH9**	**BH10**
pH		6.46	6.62	6.64	6.35	6.78	7.32	6.52	7.01	6.56	7.21
E.C	µs/cm	1518	2134	1465	2960	1683	2181	2223	1360	1233	1470
TDS	Mg/l	759	1067	733	1587	842	1047	1111.5	680	617	735
Temperature	℃	23.8	23.7	23.9	22.2	24.7	21.7	23.8	24.9	24.4	22.4
Nitrate	Mg/l	5.4	5.7	5.8	6.0	5.3	4.8	5.5	4.8	6.3	0.8
Ammonia	Mg/l	0.41	1.67	0.14	2.88	0.46	0.14	2.59	0.05	0.15	0.16
Phosphate	Mg/l	4.2	5.4	5.5	8.3	6	4.3	5.8	4.6	5.3	4
Fecal coliform	Count/100ml	1	5	1	8	4	0	4	0	2	0

The pH of most waters ranged from 6.0 – 9.2 (TZS 789:2008 and WHO). The results show pH variation for sampled wells from Majimatitu, Kibondemaji B, and Mchikichini. The variations are independent, for Majimatitu it varies from 6.52 to 6.77, for Kibondemaji B pH varies from 6.22 to 7.32, and for Mchikichini pH varies from 6.45 to 7.12. The highest values of pH exhibited at BH3, BH6, BH4, and SW6. This indicates a trend were boreholes are likely to encompass higher pH than shalow wells, and this is due to the possible rock formations in the deep aquifers which are not susceptible to anthropogenic contaminant that can influence pH. On the other hand, the lowest pH were mostly found in shallow wells such as SW1, SW3, SW4, SW7, SW10 - despite having one borehole (BH8) with lower pH, general findings suggest that the shallow wells had the lowest pH than boreholes. This suggests the possibility of contamination from onsite sanitation facilities. Fig. 2 shows the variation of pH at sampled wells around Kibondemaji ward.

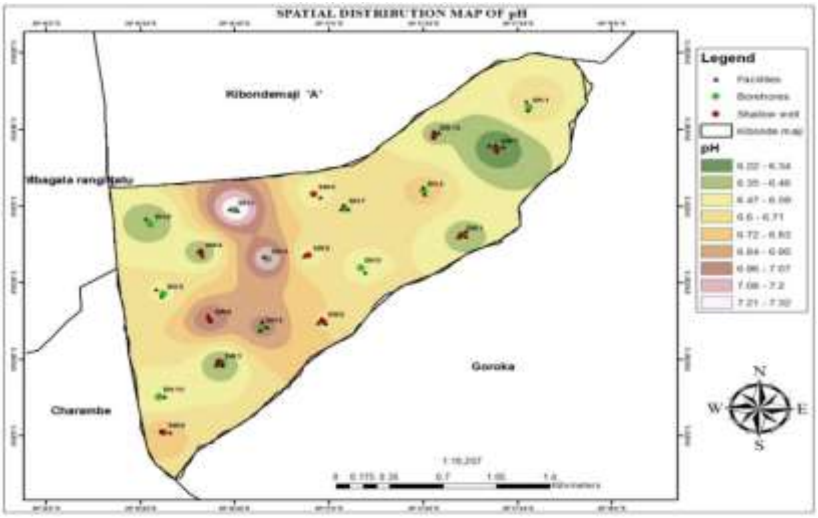

Fig. 2: Spatial distribution of PH in wells around Kibondemaji

Electric Conductivity varied across the sub-wards where at Majimatitu it varied from 2223 µs/cm to 2964 µs/cm, at Kibondemaji B varied from 1222 µs/cm to 2985 µs/cm, and at Mchikichini varied from 1176 µs/cm to 2134 µs/cm. The variation is illustrated by a spatial distribution map in Fig. 3. Similar observations can be found where shallow wells (SW1, SW2, SW5, SW6, SW8, and SW9) were dominant in having higher

EC with only two boreholes (BH8 and BH9) that have high EC. Besides, BH 8, SW 8 and SW 5 had higher EC values exceeding the portable water standard (Min 1500 µs/cm - 2500 µs/cm max) (TZS 789:2008- Portable Water Specification, Tanzania). Higher EC in shallow wells is highly likely to be contributed by dissolved salts emanating from onsite sanitation facilities, most of which are not lined allowing free movement of contaminants to the wells.

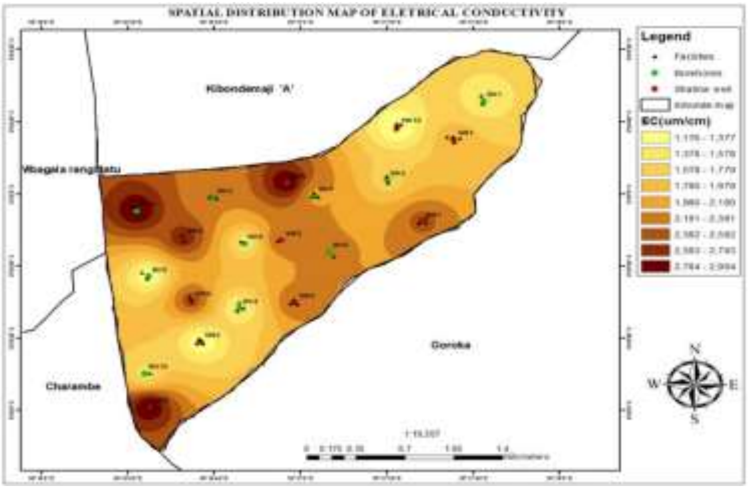

Fig. 3: Spatial distribution of Electric Conductivity in wells around Kibondemaji

Total dissolved solids (TDS) varied across the sub-wards, at Majimatitu it varied between 1111 mg/l and 1482 mg/l, at Kibondemaji B varied between 635mg/l and 1492mg/l, and at Mchikichini varied between 588mg/l and 1067mg/l. TDS expressed mixed behaviour across the sub-wards, it was unclear whether shallow wells or deep wells had higher or lower concentrations than others (Fig. 4). However, highest TDS values were at BH8, SW4, SW5 and SW8, this indicates that inorganic salts come from onsite sanitation facilities - this is in consistent with the close distance the facilities were found to sanitation facilities.

Nitrate (NO3-) occurs in water as the product in the biological breakdown of organic nitrogen; it is produced through oxidations of ammonia. The nitrate level at Kibondemaji ranged from 0.2 to 8.6 mg/l. Nitrate concentrations in water samples at Kibondemaji suggest that 80% of the sampled wells reflected the effects of human activities (nitrate concentration greater than 3 mg/L). High levels of nitrate in shallow well are due to small scale urban agriculture activities near the wells and proximity to onsite sanitation facilities that can easily allow high nitrate levels to reach ground water. Evidence is drawn from the spatial concentrations map for Nitrate showing that wells near on-site sanitation facilities and small scale agriculture fields had high nitrate concentration (Fig. 5). The data were grouped by concentration of nitrate on the basis of the definition by Madison and Brunett (1985), who identified ground water containing nitrate in concentrations greater than 3 mg/L as being affected by human activities. Concentrations ranging from greater than 0.3 to 3.0 mg/L were assumed to indicate those wells that had not affected by human activities, whereas concentrations greater than 3.0 mg/L were affected.

Coliform bacteria are indicator microorganisms for the presence microbial contamination from faecal matter. Laboratory results indicated presence of faecal coliforms ranging from 0 to 23 CFU/100 ml. Eighty five percent (85%) of the wells sampled had higher FC counts than the allowable (0CFU/100ml) standard limit by Tanzanian Bureau of Standard (TBS) for drinking water.The distribution of FC counts indicate that of the polluted sources, 18.7% were at Majimatitu, 43.7% at Kibondemaji B, and 37.5% at Mchikichini. As such, Kibondemaji B is highly polluted, this is because the sub-ward is characterized with large number shallow wells which are easily contaminated by percolation and infiltration of contaminants from septic tanks, cesspools, pit latrines and other onsite systems that are widely used in the area. FC counts variation from sampled points can be well illustrated by using spatial distribution map (Fig. 6) in which the concentration of fecal coliform for each well is clearly illustrated. As indicated earlier, the most contaminated sources were shallow wells - this finding is consistent to the levels of TDS, EC, and pH which suggest and ascertain that contamination has been contributed by the onsite sanitation facilities in the area. Besides, the lowest FC counts were found in five boreholes (BH3, BH4, BH5, BH6, and BH10), the boreholes are sometimes called deep wells emanating from the deep aquifers. Usually, a thorough filtration through the soil strata takes place before the water enters the deep aquifers; therefore, minimum to none microbial contamination can be expected.

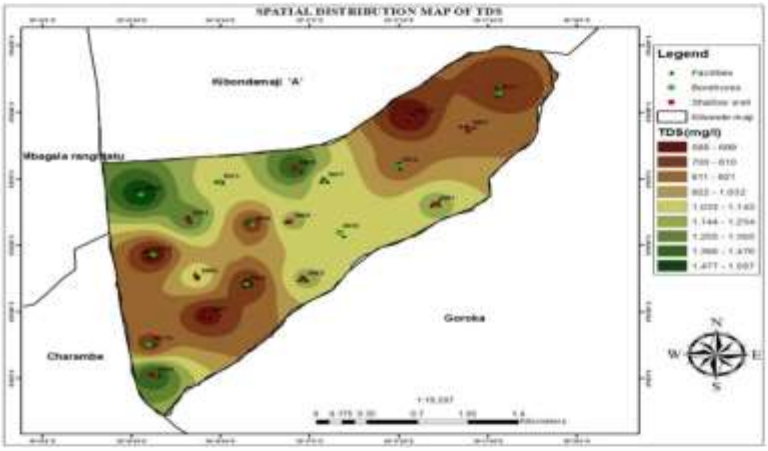

Fig. 4: Spatial distribution of TDS in wells around kibondemaji

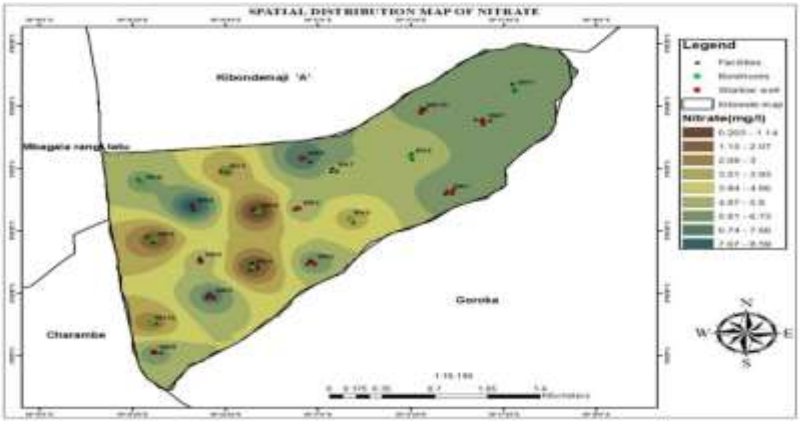

Fig. 5: Spatial distribution of Nitrate in wells around Kibondemaji

The ammonia concentrations in water samples from Kibondemaji ward ranged from 0.14 to 2.88 mg/l. The results indicate that water from shallow wells had higher concentrations than in boreholes; this finding suggest that the ammonia concentration in the water emanated from poorly managed sanitation facilities and not a result of rocks compositions in the ground. The presence of ammonia indicate further that the wells were contaminated by fresh excreta matter from onsite sanitation facilities. Moreover, from the ammonia spatial distribution map (Fig. 7) - shallow wells dominated on having higher ammonia construction which is in line with the findings for FC, pH, TDS, and EC. The phosphate concentrations at Kibondemaji ward ranged from 4 to 12mg/l. Higher concentrations were mostly found in shallow wells (SW3, SW4, SW5) (Fig. 7), suggesting that the concentrations emanated from onsite sanitation facilities principally from the use and release of washing detergents and soaps.

Excreta Contaminants Pollution Index (EPI): Weighted additive excreta contaminants pollution index was used to determine pollution index for each sample. The index values were described in terms of water quality classification and status as shown in Table 4. Most sources are susceptible to pollution; however, most boreholes had good water quality (BH 3, BH 6, BH 9, BH) to excellent water quality embraced by BH8. Only two (SW 5, and SW 9) shallow wells had good water quality whereas the majority embraced water classification C to E for poor water quality to unsuitable for consumption, respectively. The findings contribute to the previous findings and ascertains that the water in shallow wells had been affected by anthropogenic pollutants from onsite sanitation facilities

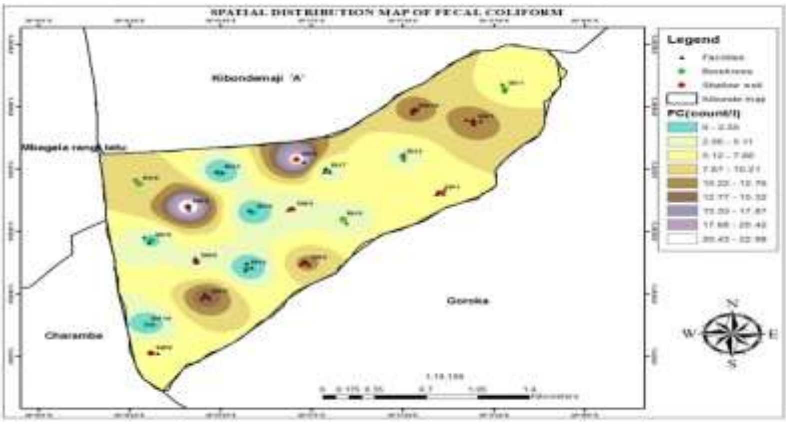

Fig. 6: Spatial distribution of Fecal coliform in wells around kibondemaji

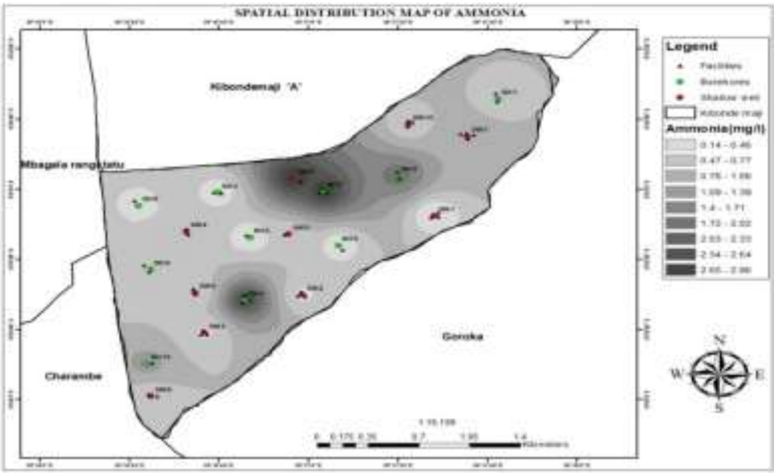

Fig. 7: Spatial distribution of Ammonia in wells around Kibondemaji

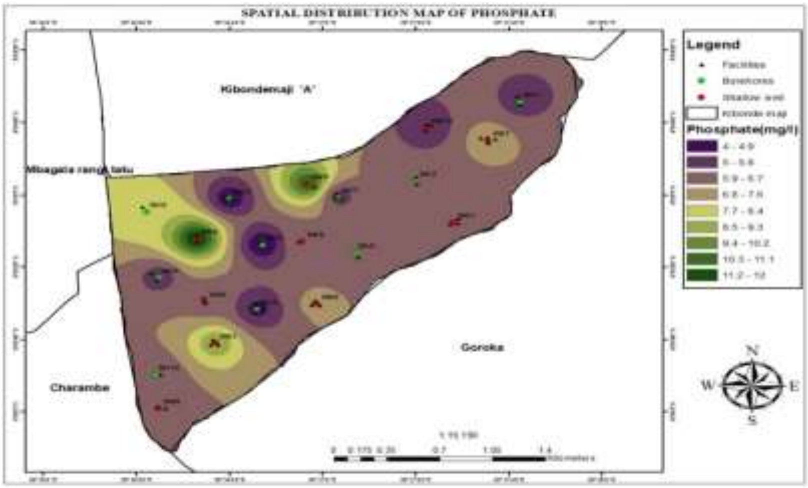

Fig. 7: Spatial distribution of Phosphate in wells around Kibondemaji

Further suggestions from the findings are that there might be other sources since some of Kibondemaji's sub-wards such as Kibondemaji B and Mchikichini undertake small scale urban agriculture, the use of fertilizers may contribute to pollution in nearby boreholes and shallow wells. An evaluation of the possible use of the waters at the case study was carried out (Table 5**)**. Most shallow wells waters did not have good quality thus, can be used for irrigation and industrial purposes and some of them need proper treatment for any kind of usage.

Implications of the results: The results obtained from this research, "the assessment of the spatial distribution of excreta contaminants in groundwater from onsite sanitation facilities at Kibondemaji" has significant not only for the ward residences but also for other areas and fields. The findings calls for efficient and effective designs of onsite sanitation facilities. The understanding of spatial distribution of contaminants informs the determination of appropriate distances, sizes, placements, and configuration of septic tanks, leach fields, and other onsite sanitation components. Besides, engineers can optimize system designs to minimize the risk of groundwater contamination though ensuring proper treatment and disposal of excreta. Also, the findings serve as a guide in selecting appropriate treatment technologies for onsite sanitation systems. Through understanding the types and concentrations of contaminants, experts can evaluate efficiencies of different treatment processes in removing specific contaminants, helping in selection and design of treatment units to ensure the desired water quality standards. Besides, the findings inspires experts on developing innovative engineering solutions through development of new technologies, materials, or approaches to enhance the performance and sustainability of onsite sanitation systems. Spatial distribution of excreta contaminants in groundwater is vital for establishing groundwater monitoring programs. Experts can use this information to design monitoring networks that capture the variability and trends in contamination levels. Monitoring wells can be strategically located based on the identified high-risk areas, allowing for regular assessment of groundwater quality and early detection of any potential issues.

Table 4: Water quality status for sampled wells

Sampled wells	Water quality index	Water quality grading	Water quality status
BH 8	0-25	A	Excellent water quality
BH 3, BH 6, BH 9, BH 10, SW 5, and SW 9	26-50	B	Good water quality
SW 8	51-75	C	Poor water quality
SW 6, SW 8, BH 1, and BH5	76-100	D	Very poor water quality
BH 2, BH 4, BH 7, SW 1, SW 2, SW 3, SW 4, and SW7	>100	E	Unsuitable for consumption

Table 5: Possible uses of sampled wells depend on pollution index at Kibondemaji

Sampled wells	Water quality status	Possible uses
BH 8	Excellent water quality	Drinking, irrigation, other domestic activities and industrial purpose
BH 3, BH 6, BH 9, BH 10, SW 5, and SW 9	Good water quality	Drinking, irrigation, other domestic activities and industrial purpose
SW 8	Poor water quality	Irrigation and industrial purpose
SW 6, SW 8, BH 1, and BH5	Very poor water quality	Irrigation purpose
BH 2, BH 4, BH 7, SW 1, SW 2, SW 3, SW 4, and SW7	Unsuitable for consumption	Proper treatment required for any kind of usage

The findings inform the need of employing numerical modeling and simulation techniques to simulate the transport of contaminants in groundwater. The spatial distribution data obtained from the research serves as input for such models to predict contaminant migration patterns, assess the travel times to different receptors (such as wells or surface water bodies), and evaluate the effectiveness of various mitigation measures. This enables experts to optimize systems design and develop strategies to minimize groundwater contamination risks. Contaminants present in human excreta can include pathogens, such as bacteria, viruses, and parasites, as well as chemical substances like nutrients, pharmaceuticals, and heavy metals. Therefore, understanding the spatial distribution of excreta contaminants in groundwater is crucial for assessing potential health risks. This was achieved through identifying areas with higher concentrations of contaminants and needing public health attention. The information informs and assists the relevant authorities to prioritize interventions and implement targeted measures to ensure safe water supplies and reduce the risk of waterborne diseases. In rapidly growing urban areas like Dar es Salaam, onsite sanitation facilities are commonly used, particularly in areas without access to centralized sewerage systems. The knowledge on spatial distribution of excreta contaminants in groundwater supports urban planners in designing appropriate locations of sanitation infrastructure and managing land use. Moreover, the findings inform development of policies and regulations related to sanitation and water quality seeking to improve community's public health. Governments and regulatory bodies can use this knowledge to establish standards and guidelines for the construction and maintenance of onsite sanitation facilities, as well as for groundwater protection. Evidence-based policies can help ensure the sustainable management of water resources and safeguard public health.

Conclusion: Most shallow wells emanated from low lands compared to deep wells/boreholes. The distance from wells to onsite sanitation facilities fell within the restricted distance (50ft) by US EPA. Besides, all onsite sanitation facilities were not lined, thus enhancing the movement of pollutants to groundwater aquifers and wells. Most wells had nitrate concentrations that are withing WHO standards (50mg/L); however, greater than 3mg/L concentrations are adequate indicators of the presence of anthropogenic pollution. Total coliforms exceeded both Tanzania and WHO standards indicating the movement of faecal contaminants from onsite sanitation facilities; the highly affected wells came from Kibondemaji B, followed by Michikichini, and Majimatitu. Presence of ammonia in most shallow wells entails an evidence of recent excreta contamination, which is likely to come from onsite sanitation facilities. Generally, most shallow wells waters did not have good quality thus, can be used for irrigation and industrial purposes and some of them need proper treatment for any kind of usage.

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