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Research Article

Groundwater Quality Assessment in Urban Areas of Malawi: A Case of Area 25 in Lilongwe

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Groundwater sources provide an important supply of alternative drinking water in most urban areas in Malawi. This study was conducted to assess the quality of groundwater in Area 25, a typical urban residential area in Malawi. Samples were collected from wells and analyzed for physicochemical and bacteriological parameters following standard methods. Results were compared to Malawi Standards (MS) and World Health Organization (WHO) drinking water quality guidelines. The overall water quality index was computed to ascertain the general quality of the water. Levels of pH, phosphate, sulfate, arsenic, lead, and potassium were below the guideline limits while, electrical conductivity, total dissolved solids, chloride, fluoride, nitrate, total hardness, calcium, and magnesium were observed above permissible limits, posing a health risk to the residents. The quality index ranged from 22 (excellent quality) to 64 (Poor quality) with an average of 41 (good quality). Fecal coliforms were present in 70% of the sampled locations with an average of 7.9 cfu/100 ml. The presence of these bacteria presents a serious risk for waterborne disease outbreaks. This study, therefore, recommends the provision of basic treatment techniques to improve the quality of water in the area before consumption, regular monitoring of groundwater resources, and proper design and setting of septic systems.

1. Introduction

Clean, safe, and adequate freshwater is of utmost importance to human existence. The United Nations recognizes access to clean, safe, and affordable drinking water as a fundamental human right [1]. The decline in the quality of water has become a global issue of concern resulting from urbanization, an increase in population, and the expansion of agricultural practices [2]. In developing countries, about 1.8 million people die each year as a result of water-borne related diseases and globally 2 million children die yearly from preventable waterborne diseases [3]. Provision and supply of safe and adequate water to the populace is an important government responsibility critical for a healthy and sustainable socio-economic development. However, as a result of rapid rates of urbanization, population growth, and poor development and maintenance of water supply infrastructure, access to this important resource is still a challenge in most developing countries including Malawi, forcing residents to seek alternative sources [4]. Only 25% of the population had access to piped water inside a dwelling unit (GoM 2010), which is also affected by intermittent supply.

Area 25 in Lilongwe is one of the most populated urban townships in Malawi. Water supply in this area is a great problem, forcing residents to seek alternative sources such as groundwater to meet their daily needs. Groundwater resources are usually perceived as safe and often consumed without any form of treatment [5]. However, greater contaminant loads have been reported in groundwater from most urban areas around the globe, especially in Africa.

A study in Uganda reported elevated levels of coliform bacteria and nitrate above permissible limits in urban groundwater and these were attributed to sewage intrusion from septic systems [6]. In Tanzania, levels of coliforms, total hardness, electrical conductivity, total dissolved solids, and manganese exceeded permissible guideline levels. These were attributed to sewage pollution, waste management, and agricultural activities [7, 8].

There is limited information on the quality status of groundwater resources in urban areas of Malawi. It is important to note that groundwater resources are being exploited in these areas and are becoming an important alternative source of drinking water. However, its exploitation in these areas presents several health concerns as a result of possible contamination associated with urbanization. Similar to other African countries, possible contamination can arise from sewage intrusion from septic systems and latrines, indiscriminate disposal of waste, agricultural runoff, and natural factors [9–11].

This study was therefore conducted to assess the quality of groundwater in Area 25, a typical developing urban area in Malawi. The results from this study will inform on the status of groundwater resources in this area and similar urban settings. This information is crucial for the safety and well-being of urban residents who rely on groundwater resources for their domestic needs. The results will also provide a monitoring standpoint for future research in this area.

2. Materials and Methods

2.1. Study Area. The study was conducted in Area 25 in Lilongwe, the capital city of Malawi (Figure 1). The area lies between latitude-13°52′44.22″ and longitude 33°46′33.384″ and is considered a high-density area, covering a land area of about 23 km^2 hectares with a population of 107,316 in 2018 rising from 64,650 in 2008 [12]. Most of the households in this area are not connected to piped water for drinking and domestic use, and for those connected, the water supply is intermittent. To cope with the supply problems, most households have dug wells within their dwelling areas. Similar to most developing urban areas in Malawi, Area 25 lacks a public sewer system for the treatment of wastewater. Households rely on septic systems that are installed at owners' discretion and without proper regulations. Indiscriminate disposal of waste is another challenge in the area, posing a threat to water resources. The topography of Lilongwe in general is characterized by low slopes rendering groundwater resources more vulnerable to contamination. Contaminated water can pool in areas for longer periods of time thereby resulting in greater infiltration and hence a greater potential for contamination migration.

2.2. Methodology. Samples were collected in September (2021) from 10 hand-dug wells selected randomly. Random points were generated in QGIS and the closest groundwater access point was selected (Figure 2). Samples were collected in triplicate from wells and transferred to clean plastic sampling bottles for laboratory analysis.

pH, conductivity, and TDS were determined electrochemically onsite immediately after drawing the sample. The remaining parameters were preserved and transferred to the laboratory for analysis following standard methods as outlined in the American Public Health Association (APHA, 2005). Metals (As and Pb) were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES, Perkin-Elmer 5300 DV).

To understand the overall quality of water, a Water Quality Index (WQI) was computed for each location. The index presents a mathematical method for calculating a single value to represent water quality from several water quality parameters [13]. The index reduces the water quality data to a common scale (Table 1) for easy and quick interpretation.

The index is calculated according to the following formula expression:

$$WQI = \frac{\sum QiWi}{\sum Wi}, \quad (1)$$

where, $Qi = (Ci/Si) \times 100$; Qi = Quality rating scale; Ci = Concentration of ith parameter; Si = standard value of ith parameter; and $Wi = 1/Si$.

3. Results and Discussion

Table 2 shows the results of pH, electrical conductivity, total dissolved solids, and turbidity. The pH values were well within the permissible limits set by WHO and MBS from all sampling locations. The variations are usually associated with the natural process and anthropogenic activities [14]. Dissolution of organic matter, carbonates, and hydroxides in bedrock and soils and other pollutants can create an imbalance in the water's natural pH of 7. Elevated pH levels below or above the neutral level indicate possible contamination and result in unpleasant smells and tastes [15].

The ionic strength of water, measured in terms of conductivity varied greatly across the sampled locations with an average of 793.8 μS/cm, well below the guideline limit. Levels higher than WHO permissible limits were observed in 3 locations (P3, P6, and P8). The inhabitants around these areas reported a slightly salty taste of the water which could be attributed to the elevated levels of dissolved ions. Water conductivity is mainly a result of dissolved inorganic ions such as Na^+, SO_4^-, K^+, Cl^-, among others. These ions have the capability to pass electrical flow and this property is directly related to the ionic strength [16].

The average TDS value was higher than the permissible limit by WHO, an indication that the water had high amounts of dissolved solids such as inorganic salts and organic matter [17]. Similar to conductivity, high TDS values indicate possible contamination and may cause health implications depending on the nature of the contaminants present.

Turbidity ranged from 0.62 to 13.6 NTU. Turbid water is aesthetically unappealing and may represent a health concern. Turbidity can provide food and shelter for pathogens and promote their growth in water leading to waterborne disease outbreaks [18]. Agitation, especially when drawing the water increases the levels of turbidity, especially at sampling point P3 where the well was located around a

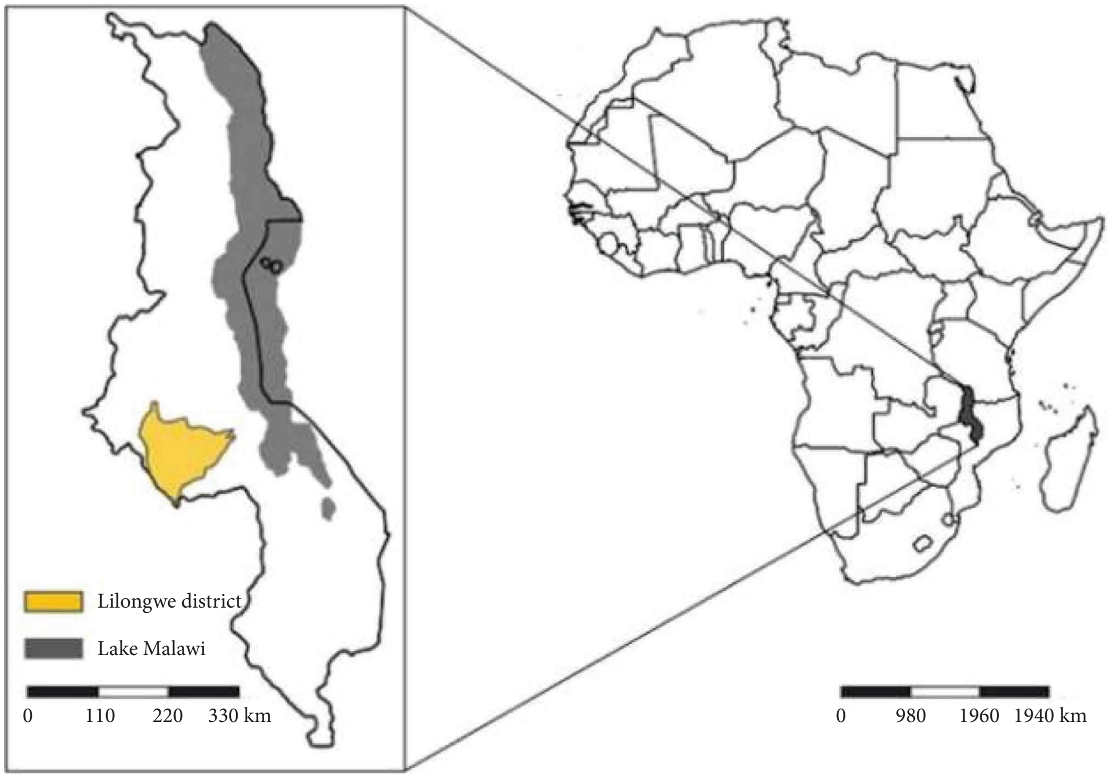

Figure 1: Map of Malawi and location of Lilongwe district.

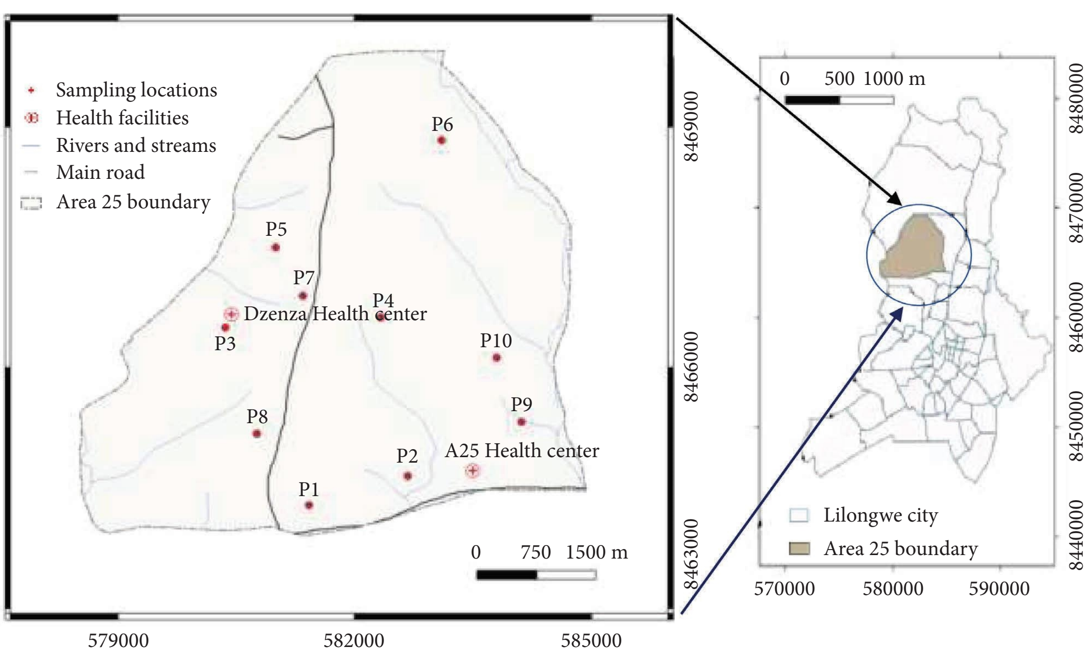

Figure 2: Location of Area 25 relative to Lilongwe city, and to the left, location of sample collection points.

compound of small houses that entirely rely on it for their daily domestic activities. Frequent drawings of the water could be attributed to the high turbidity values. Sampling point P2 is located in a fenced residential plot, and the drawing interval is far less than P3, leaving enough time for suspended solids to settle.

Anion chemistry (Table 3) showed a greater dominance of chloride varying significantly across the area. Chloride occurs in groundwater from numerous sources including minerals, sewage, and industrial effluents [19]. The levels of chloride were well within the permissible limits except for locations P4, P8, and P10. These levels could be attributed to

Table 1: Water quality index categories.

Water quality index	Description
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unfit for drinking

Table 2: pH, turbidity, conductivity, and total dissolved solids of water samples.

Sample ID	pH	Turbidity (NTU)	TDS (mg/L)	EC (μS/cm)
P1	7.3	2.85	372.45	573
P2	7.1	0.62	310.05	477
P3	6.8	10.33	1422.85	2189
P4	7.7	3.13	186.55	287
P5	8.3	0.91	202.8	312
P6	8.1	13.6	663.65	1021
P7	7.3	8.37	645.45	993
P8	6.6	7.22	859.95	1323
P9	7.3	9.25	276.9	426
P10	6.9	2.06	219.05	337
Mean	7.34 ± 0.6	5.83 ± 4.5	515.97 ± 393.6	793.8 ± 606.5
MBS	5.8–9.5	n/a	1000	3500
WHO	6.5–8.5	5 NTU	500	1000

Malawi bureau of standards (MBS); World Health Organization (WHO); total dissolved solids (TDS); electrical conductivity (EC).

natural sources and sewage intrusion from septic systems. Domestic effluent in this area is managed through septic systems and these are prone to groundwater contamination if not sited properly. This can well explain the elevated levels of conductivity and chloride in groundwater.

Fluoride had an average of 1.31 mg/L, ranging from 0.42 mg/L at P7 to 2.67 mg/L at P1, with 40% of the sample location having levels above the permissible WHO limit. Inhabitants around these areas, especially children, are at risk of skeletal fluorosis, a health condition that leads to changes in bone structure making them weak and brittle. The study, however, did not establish the occurrence of this disease in the area.

Nitrate ranged from 0.38 mg/L to 58.92 mg/L with an average value of 31.6 mg/L. The majority of sample locations (80%) showed levels below the permissible limit of 50 mg/L. Nitrate occurs naturally in groundwater at levels that do not cause health problems. Increased levels are usually associated with anthropogenic activities such as agriculture and domestic effluents [20]. Elevated levels of nitrate can affect how blood carries oxygen in the body causing methemoglobinemia (also known as blue baby syndrome), especially for individuals around points P10 and P3. Phosphate and sulfates were well below the threshold limits posing no health concerns in the study area.

Concentrations of cations are presented in Table 4. The average concentrations of Mg^{2+}, Na^{+}, Ca^{2+}, and Fe^{+} were all below the permissible limits, however, variations were observed across the sampling locations. In general, the levels observed could be attributed to the geology of the area mainly derived from minerals such as limestone, igneous rocks, and lithological calcareous constituents [21]. Levels of toxic metals (Pb and As) were all below the detection limit, posing no health risk to the inhabitants.

Groundwater can accumulate Ca^{2+} and Mg^{2+} as it percolates through the rock material. The measured content of these elements is defined as hardness. Hard water is not suitable for domestic purposes as it prevents soap from lathering by causing the development of an insoluble curdy precipitate and causing scaling in pipes and water heaters [22]. 60% of the sampled locations had levels above the permissible WHO limit of 500 mg/L as shown in Figure 3.

Results for the fecal coliform bacteria are presented in Figure 4. This group of bacteria is always present in the digestive tracts of animals, including humans. The presence of these bacteria is an indication that water was in contact with fecal material posing a risk of waterborne diseases. 70% of the samples were positive for coliforms suggesting possible contamination from sewage effluents and therefore not safe for drinking.

Septic systems could be attributed to the levels of coliforms and other contaminants in the sampled locations. Areas with high densities of septic systems and pit latrines have been attributed to high pollutant loads in groundwater [6].

The water quality index was computed to understand the overall quality of groundwater in the area. The index ranged from 22 to 64 with an average of 41 as shown in Table 5. Point P2 had excellent overall water quality. This site was located in a fenced household with almost no access to outsiders. Infrequent use of the water allowed some pollutants, especially solids to settle together with particulate pollutants. This was also evidenced by the low levels of turbidity. Points P1, P4, and P9 were all located in a

TABLE 3: Concentration of anions in sampled water.

Sample ID	Cl^- (mg/L)	F^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)
P1	152.0	2.67	46.32	0.047	4.711
P2	218.3	0.93	0.38	0.039	6.868
P3	303.1	0.67	58.92	0.042	86.686
P4	378.9	0.52	40.22	0.048	8.753
P5	140.4	2.37	38.83	0.081	5.602
P6	213.3	1.78	17.32	0.087	9.865
P7	171.9	0.42	33.09	0.039	68.563
P8	313.1	0.88	3.46	0.045	20.746
P9	119.7	1.63	22.72	0.057	63.512
P10	333.2	1.22	54.73	0.049	2.414
Mean	234.18 ± 91.2	1.31 ± 0.8	31.60 ± 20.2	0.053 ± 0.0	27.77 ± 32.1
MBS	150	2.0	50	0.5	250
WHO	250	1.5	50	0.5	250

compound, and the water from the wells was exclusively used for all household activities.

TABLE 4: Concentrations of cations and metals in the sampled water.

Sample ID	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	As (mg/L)	Pb (mg/L)
P1	27.877	39.281	3.161	bdl	0.22	bdl	bdl
P2	132.122	63.725	6.255	bdl	0.06	bdl	bdl
P3	81.104	83.704	16.885	bdl	0.15	bdl	bdl
P4	37.897	101.489	2.317	bdl	0.27	bdl	bdl
P5	4.628	76.317	0.8	bdl	0.12	bdl	bdl
P6	4.393	26.904	0.277	bdl	0.03	bdl	bdl
P7	5.602	22.137	14.476	bdl	0.08	bdl	bdl
P8	27.280	113.021	15.633	bdl	0.09	bdl	bdl
P9	154.580	34.081	12.611	bdl	0.18	bdl	bdl
P10	69.313	93.406	13.147	bdl	0.11	bdl	bdl
Mean	54.48 ± 53.8	65.41 ± 33.0	8.54 ± 6.6	—	0.131 ± 0.1	—	—
MBS	100	50	150	12	0.2	—	—
WHO	75–200	50–150	500	—	0.3	0.01	0.01

Below detection limit (bdl).

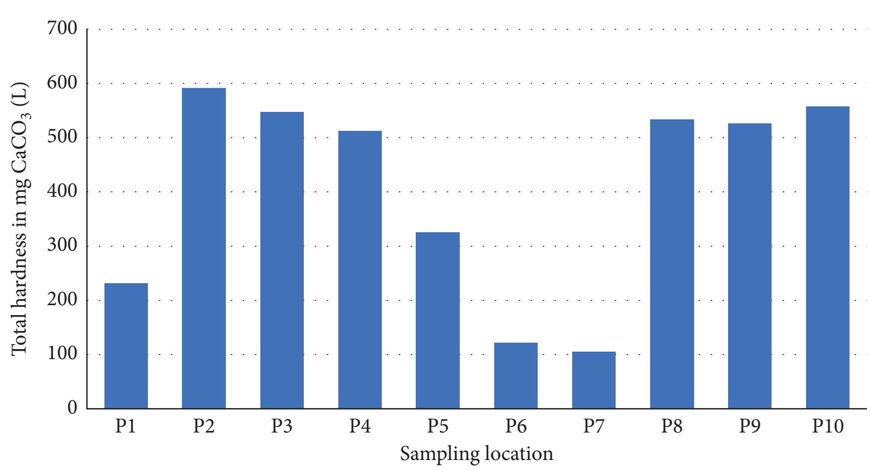

FIGURE 3: Levels of total hardness in mg $CaCO_3$/L.

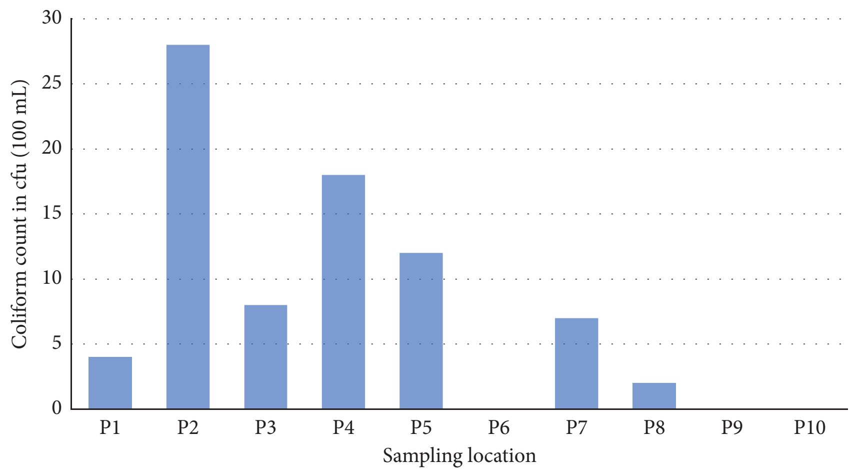

Figure 4: Fecal coliforms contamination in the sampled locations.

Table 5: WQI values for the sampled locations.

Sample ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Average
WQI	64	22	42	58	45	34	27	31	54	34	41
Description	Poor	Excellent	Good	Poor	Good	Good	Good	Good	Poor	Good	Good

4. Conclusions

Issues of water quality and safety are critical to the health and national development. The lack of access to safe water has devastating effects on the health and safety of people and has significant consequences for the realization of other human rights. Inadequate water supply is one of the most important problems in Malawi, forcing residents to seek alternative sources to meet their daily needs. Groundwater is usually perceived as clean and, in most cases, consumed without any form of treatment. Elevated levels of constituents were observed in most sampled locations presenting a health concern to the inhabitants of Area 25. The water index ranged from poor quality (30%) to excellent at one sample location with an average of good quality (70%). To ensure public health and safety, this study recommends water quality education and basic household treatment methods. The methods can include chlorination, boiling, and other suitable treatment techniques to reduce the levels of contaminants and disease-causing pathogens in the water. The study also recommends groundwater quality monitoring in urban areas to effect informed strategies for the protection of residents. The design and construction of sewer systems and latrines should be controlled and regulated to ensure the protection of groundwater resources from sewage intrusion.

Data Availability

All data used to support the findings of the study are included within this paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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