



Groundwater Quality Assessment Using Hydrochemical and GIS-Based Approaches in Heliwaa District, Mogadishu, Somalia

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Abstract

Groundwater is the primary source of domestic water supply in Somalia, particularly in urban areas such as Mogadishu. However, little is known about its quality and spatial variation. This study investigated groundwater quality in Heliwaa District, Mogadishu, Somalia, using hydrochemical testing and GIS mapping. Groundwater samples from nine borehole wells were analyzed for pH, total dissolved solids (TDS), and electrical conductivity (EC), and the results were compared with World Health Organization (WHO) drinking-water guidelines. Spatial mapping was used to identify patterns for each parameter. pH averaged 8.29 (SD 0.57; range 7.54–8.90), exceeding WHO's upper limit of 8.5 at four wells. TDS averaged 1019.7 mg/L (SD 439.1; range 601–1789 mg/L), exceeding the 1000 mg/L guideline at three wells, while EC averaged 1555.9 $\mu\text{S}/\text{cm}$ (SD 453.1; range 950–2400 $\mu\text{S}/\text{cm}$), exceeding the 1500 $\mu\text{S}/\text{cm}$ threshold at five wells. Spatial mapping revealed clear hotspots of poor groundwater quality in boreholes located in Mama Muxibo, Buulo Maxaay, SOS, and Tawakal in Heliwaa District, likely associated with mineral dissolution, groundwater over-abstraction, and inadequate waste management rather than district-wide contamination. While the investigated groundwater in Heliwaa District remains largely suitable for domestic use, the assessment is based on only nine borehole wells, which represents a relatively limited spatial coverage of the district. Therefore, the findings should be interpreted with caution and further investigation involving a larger number of boreholes and more extensive spatial and temporal sampling is recommended to provide a more comprehensive assessment of groundwater quality.

Keywords: Electrical conductivity, GIS, Groundwater quality, Heliwaa District, Hydrochemistry, Mogadishu, Somalia

1. Introduction

Freshwater available for direct human use represents only a small fraction of the planet's total water stock, and groundwater alone supports an estimated 2.5 billion people worldwide for domestic and agricultural purposes (Musie & Gonfa, 2023). Population growth, urbanization and climate variability are progressively intensifying pressure on the availability and quality of this resource, particularly in developing regions where abstraction is largely unregulated (Mishra et al., 2021; Kummu et al., 2016). Because agriculture already accounts for the majority of global freshwater withdrawals, competition between potable and productive water uses is expected to intensify further as precipitation and temperature regimes shift under climate change (Tzanakakis et al., 2020; Adeyeri, 2025).

Africa's hydrological systems are especially vulnerable to these pressures. The continent is warming faster than the global average, disrupting rainfall-runoff relationships and increasing the frequency of both physical water scarcity, arising from environmental degradation and overuse, and economic scarcity, arising from weak infrastructure and governance (Nhemachena et al., 2020; Ali et al., 2025). In the Horn of Africa, these constraints are compounded by conflict-affected institutions and limited investment in water infrastructure.

Somalia's arid-to-semi-arid climate, unpredictable bimodal rainfall (Gu and Deyr seasons), and limited perennial surface-water systems leave groundwater as the most stable and widely used water source for both rural and urban populations (FAO SWALIM, 2007). Surface water is largely restricted to the transboundary Juba and Shabelle rivers, whose flows originate predominantly outside Somalia's borders, rendering the country's water security highly dependent on upstream management decisions. In Mogadishu, decades of conflict have fragmented the centralized water infrastructure established in the 1960s, leaving the city dependent on independently operated boreholes and vendor-supplied water of variable and largely unregulated quality (Print, 2013; Ali et al., 2024). Heliwaa District, in the northern part of Mogadishu, exemplifies these pressures: rapid population growth, unregulated borehole drilling, and inadequate solid-waste management place mounting stress on the shallow aquifers on which most households depend for daily water supply.

Despite growing recognition of groundwater vulnerability in Mogadishu, integrated assessments that combine systematic hydrochemical monitoring with spatial (GIS-based) analysis remain scarce for Heliwaa District specifically. Existing evaluations tend to be descriptive, reporting water quality on a well-by-well basis without delineating the spatial extent of degradation or identifying priority zones for intervention (Elmi Abdishakur et al., 2022). This limits the ability of local authorities and utility operators to target monitoring, protection and remediation resources efficiently, and constrains evidence-based groundwater resource planning at the district level.

This study addresses that gap by combining laboratory-based hydrochemical analysis of pH, total dissolved solids (TDS) and electrical conductivity (EC) with GIS-based spatial interpolation to (i) characterize the current status of groundwater quality against World Health Organization (WHO) drinking-water guidelines, and (ii) map the spatial distribution of these parameters to identify groundwater quality hotspots across Heliwaa District. By coupling hydrochemistry with spatial analysis, the study provides an evidence base to guide groundwater protection, monitoring priorities, and urban water resource planning in Heliwaa District and in comparable post-conflict urban settings across the Horn of Africa.

1.1 Study Area

Heliwaa (Huriwa) District is located in northern Mogadishu, Somalia, between approximately 2.06°–2.10° N latitude and 45.36°–45.42° E longitude as shown in Figure 1. It forms an integral part of the Banaadir administrative region and is geographically bordered by Yaqshid District to the south, Karan District to the east, and the Middle Shabelle region to the north. Heliwaa is characterized by rapid urban expansion and high population density, which have outpaced the development of basic municipal infrastructure. Due to the absence of a reliable, centralized municipal water network, the local population depends almost exclusively on groundwater extracted from shallow boreholes and dug wells for domestic use. The district's coastal and alluvial geological setting, combined with anthropogenic pressures such as inadequate solid and liquid waste management, intensive groundwater abstraction, and poorly protected wellheads exposes the local aquifer to significant pollution risks. Hydrochemical characteristics are heavily influenced by water–rock interactions, mineral dissolution, and potential seawater intrusion. These conditions make Heliwaa suitable for assessing the spatial

distribution of pH, total dissolved solids (TDS), and electrical conductivity (EC) using hydrochemical and GIS-based methods.

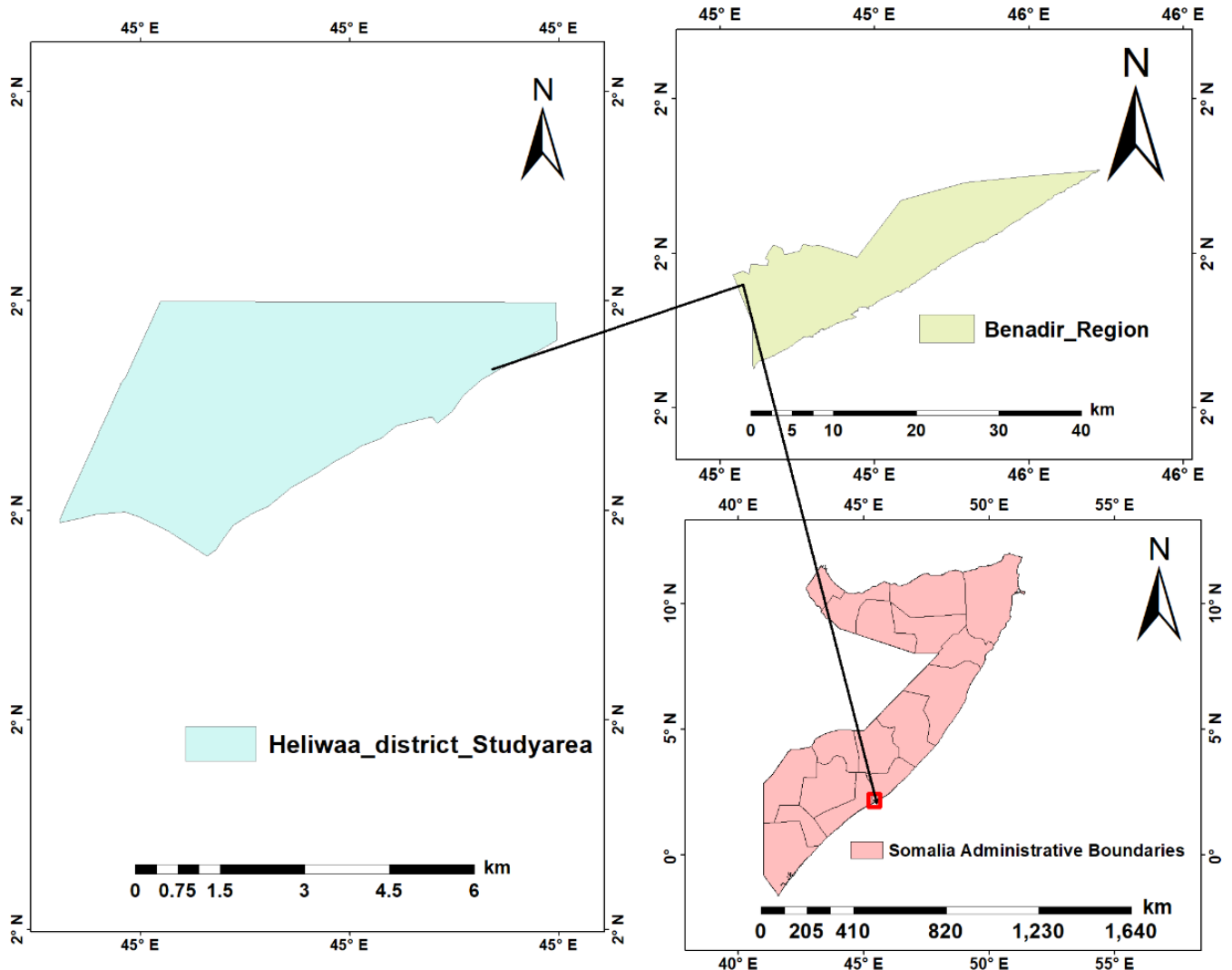


Figure 1. Location and study area map of Heliwaa District, Mogadishu, Somalia, showing the distribution of sampled wells.

2. Materials and Methods

A quantitative, descriptive cross-sectional design was used to assess groundwater quality during December 2025–June 2026. Nine wells were selected across the major sub-localities of the district: Mama Muxibo, Buulo Maxaay, SOS, Tawakal, Masjid Ibrahim Jaylaani, Abdulaahi Biirshe, Alnuur, Xareed, and MCH Waxar Cadde (Table 1). The wells were selected to provide adequate spatial coverage of the district, considering accessibility constraints. Each sampling location was georeferenced using a handheld GPS receiver.

Water samples were collected in clean, sterilized containers following standard groundwater sampling procedures and transported promptly to the laboratory for analysis. Sample identification, date, time, and location were recorded during fieldwork.

Three physicochemical parameters—pH, total dissolved solids (TDS), and electrical conductivity (EC)—were measured using calibrated meters. The measured values were

compared with WHO guideline values for drinking water: pH (6.5–8.5), TDS (1000 mg/L), and EC (1500 $\mu\text{S}/\text{cm}$). These parameters were selected to assess groundwater mineralization, salinity, and general water quality (Baraka & Ogolla, 2022; Adawe et al., 2024). Descriptive statistics, including minimum, maximum, mean, and standard deviation, were calculated for each parameter. The georeferenced data were analyzed using spatial interpolation, and the Inverse Distance Weighting (IDW) method was applied to generate spatial distribution maps for each parameter. The resulting maps were classified into low, moderate, and high categories to show the spatial variation in groundwater quality. Sampling was conducted with permission from well owners and relevant local authorities. Information obtained from well users during fieldwork was treated confidentially and used solely for academic purposes.

Table 1. Location and groundwater quality parameters of sampled wells in Heliwaa District.

Wells	Latitude	Longitude	pH	TDS (mg/L)	EC ($\mu\text{S}/\text{cm}$)
MCH Waxar Cadde	2.087083	45.386183	8.3	1250	950
Tawakal well	2.093833	45.420139	8.7	990	1200
Masjid Ibrahim Jaylaani	2.083819	45.38675	8.2	628	1523
Abdulaahi Biirshe well	2.086275	45.365189	7.54	601	1830
Alnuur well	2.080406	45.391528	7.68	602	1120
SOS	2.098217	45.384119	8.82	907	1420
Mama Muxibo well	2.096594	45.374756	8.9	1600	2400
Xareed	2.090083	45.388897	7.6	810	1620
Buulo Maxaay	2.065722	45.376334	8.9	1789	1940

3. Results

3.1 Overall Groundwater Quality Status

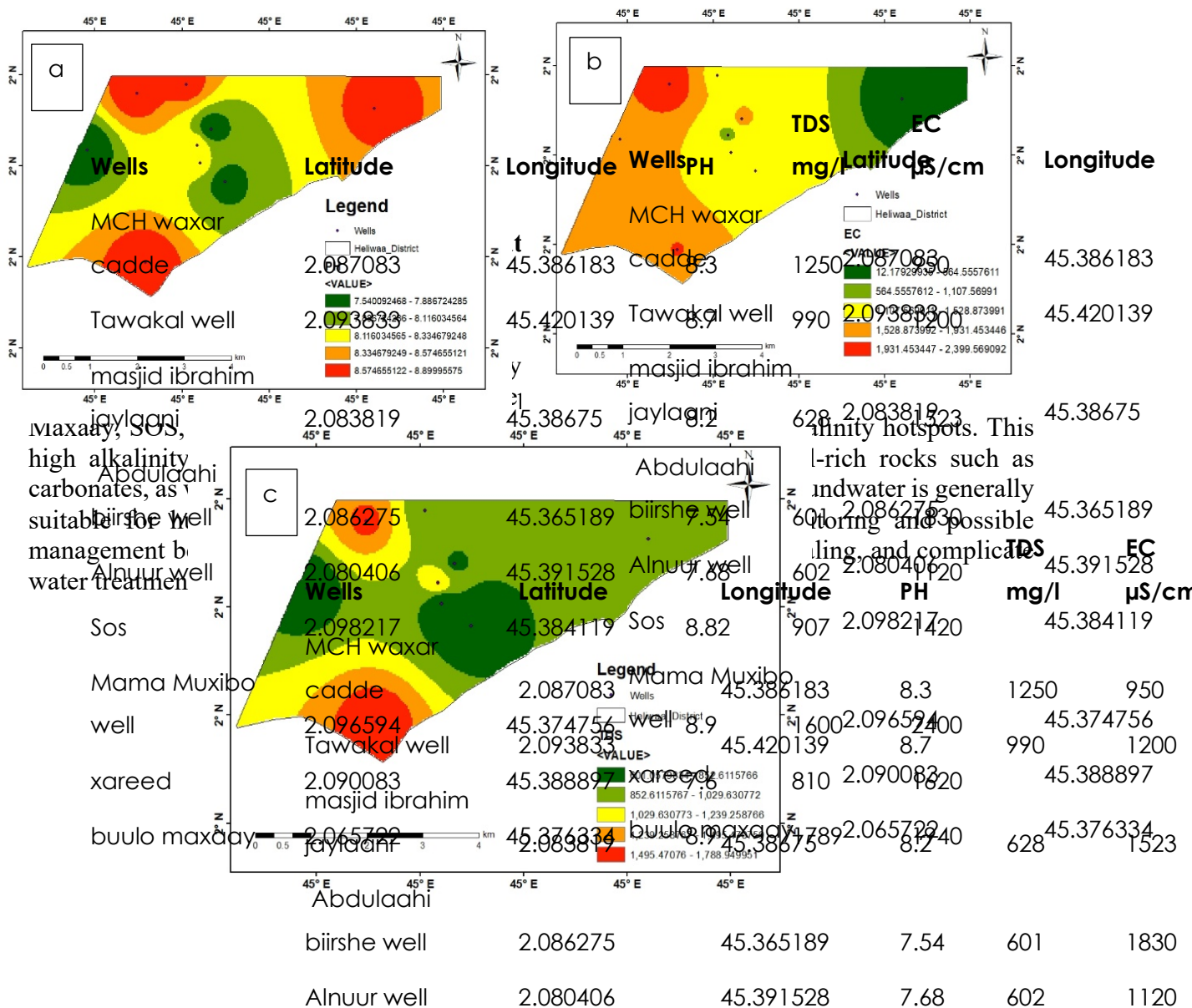
The nine sampled wells showed considerable variation in the measured groundwater-quality parameters (Table 2). pH ranged from 7.54 to 8.90, with a mean of 8.29 ± 0.57 , indicating predominantly alkaline conditions. TDS ranged from 601 to 1789 mg/L, with a mean of 1019.7 ± 439.1 mg/L, while EC ranged from 950 to 2400 $\mu\text{S}/\text{cm}$, with a mean of 1555.9 ± 453.1 $\mu\text{S}/\text{cm}$. The mean pH was within the WHO guideline range of 6.5–8.5, although the maximum value of 8.90 exceeded the upper limit. The mean TDS marginally exceeded the WHO reference value of 1000 mg/L, with three wells above this limit. Similarly, the mean EC slightly exceeded the reference value of 1500 $\mu\text{S}/\text{cm}$, with individual values ranging from 950 to 2400 $\mu\text{S}/\text{cm}$. Overall, the results demonstrate substantial well-to-well variability in groundwater quality.\

Table 2. Descriptive statistics of groundwater quality parameters (n = 9 wells) compared with WHO drinking-water guidelines.

Parameter	Minimum	Maximum	Mean	SD	WHO Guideline
pH	7.54	8.90	8.29	0.57	6.5–8.5
TDS (mg/L)	601	1789	1019.7	439.1	1000
EC (μS/cm)	950	2400	1555.9	453.1	1500

3.2 Spatial Distribution of Groundwater Quality in Heliwaa District

The IDW interpolation maps showed spatial variation in pH, TDS, and EC across Heliwaa District (Figure 2). Higher pH and TDS values were concentrated mainly in the central and southern parts of the district, particularly around Tawakal, SOS, Mama Muxibo, and Buulo Maxaay. Higher EC values were distributed across several areas, including Abdulaahi Biirshe, Xareed, Masjid Ibrahim Jaylaani, Buulo Maxaay, and Mama Muxibo. The spatial patterns differed among the three parameters. For example, Abdulaahi Biirshe exhibited relatively low pH and TDS values but comparatively high EC. Overall, the interpolated surfaces indicate spatial heterogeneity in groundwater quality, with relatively elevated values of multiple parameters occurring mainly in the central-to-southern parts of the district.



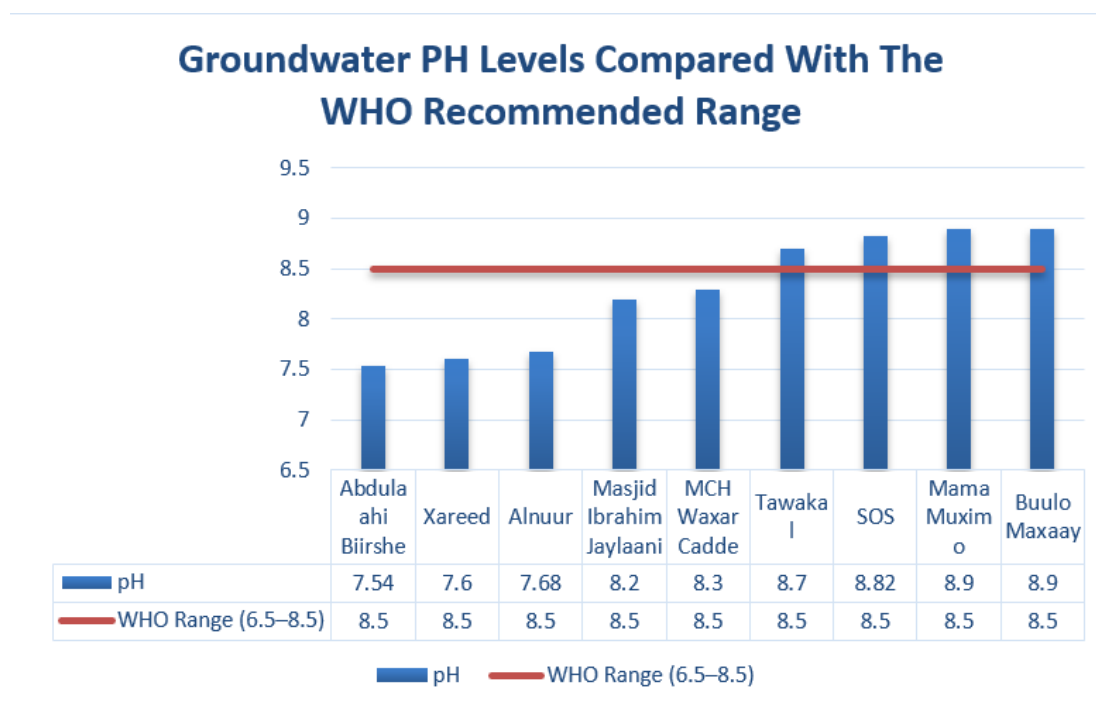


Figure 3. pH values of sampled wells relative to WHO drinking-water guidelines.

3.3.2 TDS Comparison for WHO Standard

The findings show that TDS concentrations in Heliwaa District groundwater range between 601 and 1789 mg/L. Although several boreholes recorded acceptable levels, other locations exceeded the recommended limit, indicating localized areas of high mineralization.

The high TDS content in the central and southern parts of the district suggests possible influences such as geological leaching, infiltration of contaminated surface water, and anthropogenic activities such as waste disposal. Elevated TDS can result in an unpleasant taste and may render the water unsuitable for drinking without treatment.

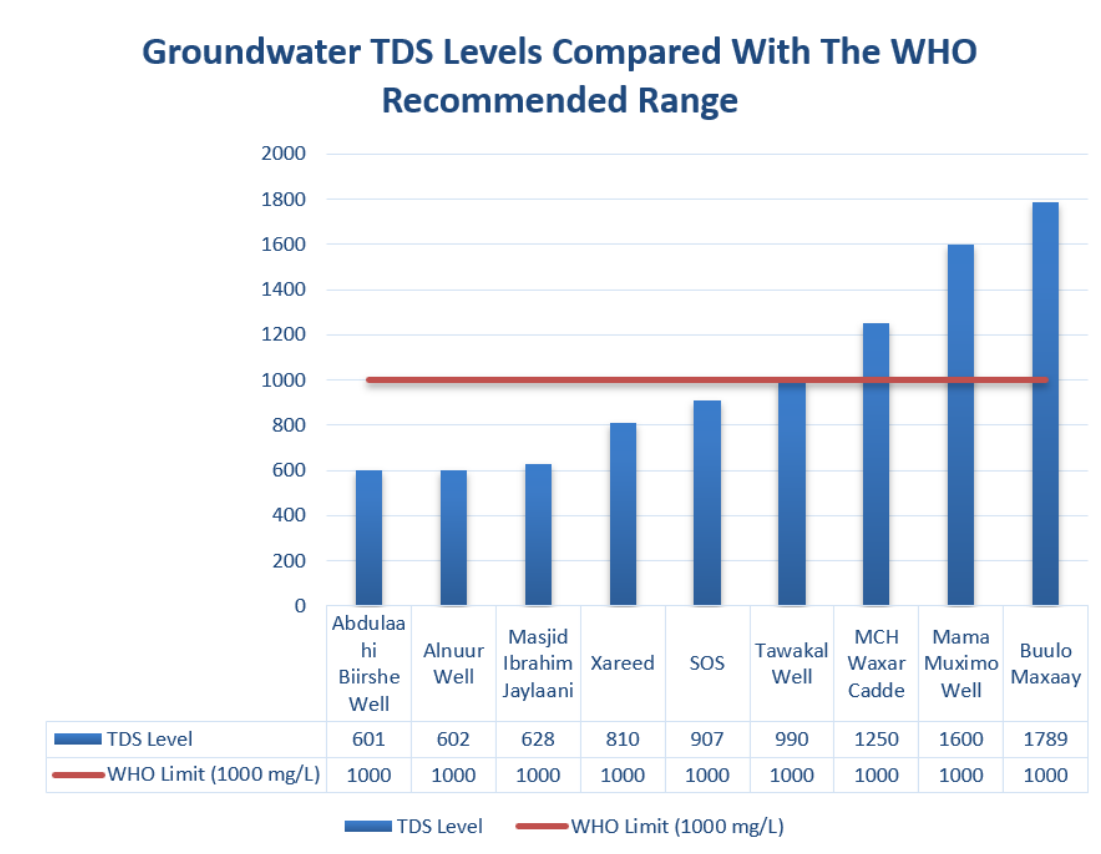


Figure 4. TDS concentrations in sampled wells relative to WHO drinking-water guidelines.

3.3.3 EC Comparison for WHO Standard

These EC values vary between 950 $\mu\text{S}/\text{cm}$ and 2400 $\mu\text{S}/\text{cm}$, indicating substantial variation in groundwater salinity. Some boreholes exceed the recommended limit, confirming the presence of high-salinity zones within the study area. The partial spatial correspondence between EC and TDS ($r \approx 0.46$) indicates that dissolved ions are important contributors to groundwater quality variation. The high EC values may be associated with seawater intrusion, geological factors, or urban pollution, particularly in densely populated areas. Overall, the joint analysis of TDS and EC highlights serious groundwater quality concerns in Heliwaa District, particularly in areas exhibiting high values for both parameters.

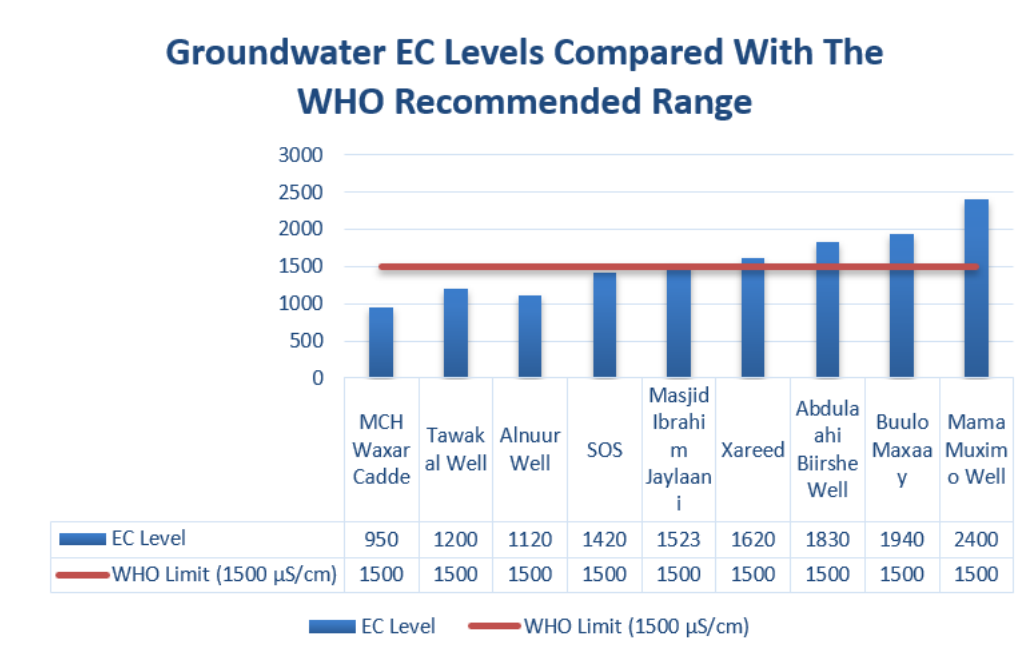


Figure 5. EC values in sampled wells relative to WHO drinking-water guidelines.

3.4 Composite Hotspot Identification

Overlaying the three interpolated surfaces identified Mama Muxibo and Buulo Maxaay as consistent multi-parameter hotspots, with pH, TDS, and EC exceeding WHO guideline values simultaneously. These elevated values may be associated with the relatively old and shallow nature of the wells, which are more susceptible to localized contamination and mineral accumulation from surface and near-surface sources. SOS and Tawakal emerged as secondary hotspots, mainly due to elevated pH rather than TDS or EC. In contrast, Alnuur showed acceptable values for all three parameters, while Abdulaahi Biirshe had acceptable pH and TDS but elevated EC, indicating localized salinity. Overall, the central and southern parts of Heliwaa District should be prioritized for groundwater quality monitoring and management.

4. Discussion

The alkaline character of groundwater across Heliwaa District, together with the locally elevated pH observed at Mama Muxibo, Buulo Maxaay, SOS, and Tawakal, is broadly consistent with the coastal and alluvial aquifer geology of Mogadishu, which is composed largely of sand, limestone, and coral formations capable of releasing carbonate ions into percolating groundwater over time (Print, 2013). Prolonged water-rock interaction in these lithologies provides a plausible geogenic explanation for the observed alkalinity. In particular, the elevated pH, TDS, and EC recorded at Mama Muxibo and Buulo Maxaay may also be partly related to the fact that these are relatively old and shallow wells. Such wells are more exposed to surface-derived contaminants, evaporation effects, and prolonged interaction with near-surface materials, which can contribute to increased dissolved solids and conductivity. However, anthropogenic inputs, including urban waste infiltration and localized groundwater degradation, cannot be excluded as contributing factors in these areas.

The magnitude and range of TDS and EC values recorded in this study are broadly comparable to those reported in wider assessments of Mogadishu's groundwater, which have documented elevated TDS, EC, and pH at some locations and linked these conditions to salinity, mineral dissolution, over-abstraction, and potential seawater intrusion in the city's coastal aquifer system (Adawe et al., 2024; Elmi Abdishakur et al., 2022). The present study

extends these earlier assessments by spatially resolving groundwater-quality conditions within a single district and demonstrating that degradation is not uniformly distributed but is concentrated around specific localities.

The partial spatial correspondence between elevated TDS and EC observed in this study ($r \approx 0.46$) reflects the established relationship between dissolved ionic concentration and electrical conductivity and suggests that similar processes may be influencing both parameters. In the identified hotspots, possible contributing factors include mineral dissolution, prolonged water-rock interaction, over-abstraction, and potential seawater intrusion in this coastal setting (FAO SWALIM, 2025). The particularly high TDS and EC observed at the old and shallow Mama Muxibo and Buulo Maxaay wells may indicate greater exposure to localized mineralization and contamination processes. In contrast, the lower spatial coincidence between EC and pH at Abdulaahi Biirshe suggests that groundwater-quality processes vary between locations and that localized salinity can occur without a corresponding increase in alkalinity.

These findings have direct implications for groundwater management in Heliwaa District. Because groundwater degradation is spatially concentrated rather than uniform, monitoring and protection efforts should prioritize identified hotspots, particularly Mama Muxibo and Buulo Maxaay. The condition of these older, shallow wells also highlights the need for routine inspection, improved well protection, and consideration of well depth and construction characteristics when assessing groundwater quality. This targeted approach is consistent with Integrated Water Resources Management (IWRM) principles, which emphasize evidence-based and spatially differentiated planning (Katusiime & Schütt, 2020; Grigg, 2024). However, technical measures alone cannot address broader governance challenges, including fragmented institutional mandates, limited enforcement capacity, and unregulated groundwater development, which have been identified as important drivers of groundwater over-exploitation and quality deterioration in Mogadishu (Mourad, 2020, 2022). Strengthening local water governance and implementing groundwater protection measures therefore remain essential, consistent with Somalia's National Water Resource Strategy (2021–2025) (Federal Ministry of Energy and Water Resources, 2021).

This study is limited by its reliance on three basic physicochemical indicators. Health-relevant parameters, including nitrate, fluoride, chloride, heavy metals, and microbiological indicators, were not assessed, while previous studies have reported microbial contamination risks in unprotected wells in Mogadishu (Elmi Abdishakur et al., 2022; Mohamed et al., 2025). Therefore, wells considered compliant based on pH, TDS, and EC should not automatically be regarded as safe for drinking. The results should instead be interpreted primarily as indicators of groundwater mineralization and salinity status. Furthermore, the study was based on nine wells sampled at a single time point, limiting the statistical robustness of the interpolation results and preventing assessment of seasonal changes in groundwater quality.

5. Conclusion

This study combined hydrochemical analysis and GIS-based spatial interpolation to assess groundwater quality across nine wells in Heliwaa District, Mogadishu, Somalia. Groundwater was generally alkaline, with the mean pH remaining within the WHO guideline range, although four of the nine wells exceeded the upper limit. TDS and EC showed greater variability and exceedances, indicating localized mineralization and salinity concerns. Spatial analysis identified Mama Muxibo and Buulo Maxaay as the main multi-parameter hotspots, with elevated pH, TDS, and EC occurring simultaneously. The elevated values at these locations may be partly associated with their relatively old and shallow wells, which are more vulnerable to surface influence and localized accumulation of dissolved materials. SOS and Tawakal represented secondary hotspots, primarily because of elevated pH, while Alnuur met the WHO guideline values for all three parameters.

Overall, the findings indicate that groundwater quality in Heliwaa District is not uniformly degraded, but specific areas require greater attention to protect long-term water security. Priority should therefore be given to regular monitoring of Mama Muxibo, Buulo Maxaay, SOS, and Tawakal; improving protection and maintenance of older and shallow wells; controlling groundwater abstraction; reducing solid-waste accumulation and infiltration; and strengthening public awareness of groundwater conservation. Groundwater from identified hotspot areas should also undergo appropriate treatment before domestic use where necessary. Future research should increase the number and geographic coverage of sampled wells and include seasonal monitoring to capture temporal variations in groundwater quality. Additional parameters such as nitrate, chloride, fluoride, heavy metals, and microbiological indicators should also be analyzed to provide a more comprehensive assessment of groundwater potability. Further investigation of aquifer recharge, well depth, well age, groundwater abstraction, and the potential influence of seawater intrusion would help clarify the causes of the elevated values observed at Mama Muxibo and Buulo Maxaay and support more effective groundwater management in Heliwaa District.

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Conflict of interest

The authors declare no conflict of interest.

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Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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