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Impact of Drought on Drinking Water Quality in Shallow Wells in the Semi-Arid Lands of Kenya

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A B S T R A C T

Shallow wells are a vital source of water for social, economic and environmental gains semi-arid areas. The sources, which tap into near-surface groundwater are realized to be sensitive to weather changes. Droughts, which characterize the semi-arid regions significantly impact shallow wells water quality by swelling the concentration of pollutants and reducing water levels. Deterioration in quality of the water makes it unsuitable, particularly for human consumption. This paper shares findings from an assessment carried out on 30 shallow wells in the semi-arid administrative wards of Kauwi and Zombe in Kitui County, Kenya, used for human, crops, and livestock. Water samples were collected in triplicates and analyzed on site using portable laboratory kits. The findings show that droughts negatively affect the water quality in shallow wells, consequently leading to the recommendation that communities and stakeholders need be empowered through training on shallow aquifer groundwater safety measures, particularly for periods of environmental stress. Emphasis need be laid on application of smart farming and sustainable waste management practices around shallow wells.

Keywords: Shallow aquifer, pollutants, deterioration, environmental stress, smart farming.

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1.0 Introduction

Atmospheric, surface and groundwater supplies are vulnerable to degradation in quality, which can have severe implications for human health, agriculture, and ecosystems (Ravindiran *et al.,* 2023). The causes are varied and largely revolve around anthropogenic and natural factors. Drought episodes, which are a common occurrence in the semi-arid areas, impact negatively on water resources, one of them being the loss of quality in the water meant for human consumption (Mosley, 2015). Unfortunately, drought frequencies are increasing, often due to climate variability and change, significantly impacting water supplies, particularly well water levels (Secci *et al.,* 2022). The period, which is characterized by below-normal precipitation does also negatively impact shallow groundwater availability due to declined aquifers recharge. With drought, the water table drops, leading to a number of impacts depending on the depth of the well. Shallow wells can dry out quickly, whereas deeper ones have some water, but of compromised effectiveness. The related severity raises significant concerns about the sustainability and safety of water from shallow wells. The lessened water supply during drought puts more demand on existing water sources (Spirnak *et al.,* 2020).

Seasonal dynamics are driven by interactions between hydrology, evaporation, geochemistry, land use, and microbial activity. Dry periods favor concentration and prolonged water–rock interaction, whereas wet periods promote dilution and mobilization of surface-derived nutrients. Reduced dilution allows pollutants from agricultural runoff and surface sources to persist at higher concentrations, increasing health risks for people relying on the wells. In some cases, wells may even dry up entirely, further restricting access to safe drinking water. Understanding these patterns is crucial for managing shallow well water quality, especially in regions prone to drought, where prolonged dry spells can exacerbate contamination, affect ecosystem health, and compromise safe drinking water supplies (Adongo *et al.,* 2022; Mosley, 2015; IPCC, 2023). During drought, it becomes crucial to more sensitively know the level of well water and quality to ensure appropriate wellbeing of people and animal health and, crop yields under the prevailing water stress. With higher water usage during dry seasons, the water level of wells depletes more rapidly due to lowered recharges and heightened water abstraction. Regular well measurement services enable getting ahead of problems by identifying trends, and allowing proactive responses.

The semi-arid Kitui County in Kenya often experiences prolonged periods of drought (Mutune *et al.,* 2017). The situation aggravates the water supply situation in a region that is disadvantaged by water scarcity. The major part of the area has to make do with groundwater and seasonal rivers. Shallow wells are mainly developed along seasonal rivers where they exploit the sand aquifers, providing water for the inhabitant population and their livelihoods. In drought periods, there is amplified concentration at the shallow well sites and intensification in water abstraction. In Kauwi and Zombe sub-locations of the county, the residents rely heavily on shallow wells as a primary source of water for domestic use, small-scale agriculture, and livestock. The water sources, which are located in and along seasonal rivers and, at homesteads variously respond to droughts with a common characteristic of altered quality and diminished yields. The majority of the sources are not protected, making them especially sensitive to drought conditions.

Kitui County experiences limited localized data on how drought specific effects on the quality of water (Hope *et al.,* 2024). Without this information, communities and county authorities are ill-equipped to mitigate water-related health risks during prolonged dry periods. Learning how drought affects well water levels is therefore extremely crucial in order to effectively manage the water resources. This study was set with the main objective being to establish the bearing of drought on the water quality of shallow wells in the semi-arid areas of Kenya, the geographical cover area being Kauwi and Zombe in Kitui County, Kenya. The specific objectives were 1) to evaluate temporal variations in water quality 2) to assess community perceptions and practices influencing shallow well water quality and, 3) to establish possible mitigation and adaptation strategies for maintaining water quality during droughts.

2.0 Materials and Methods

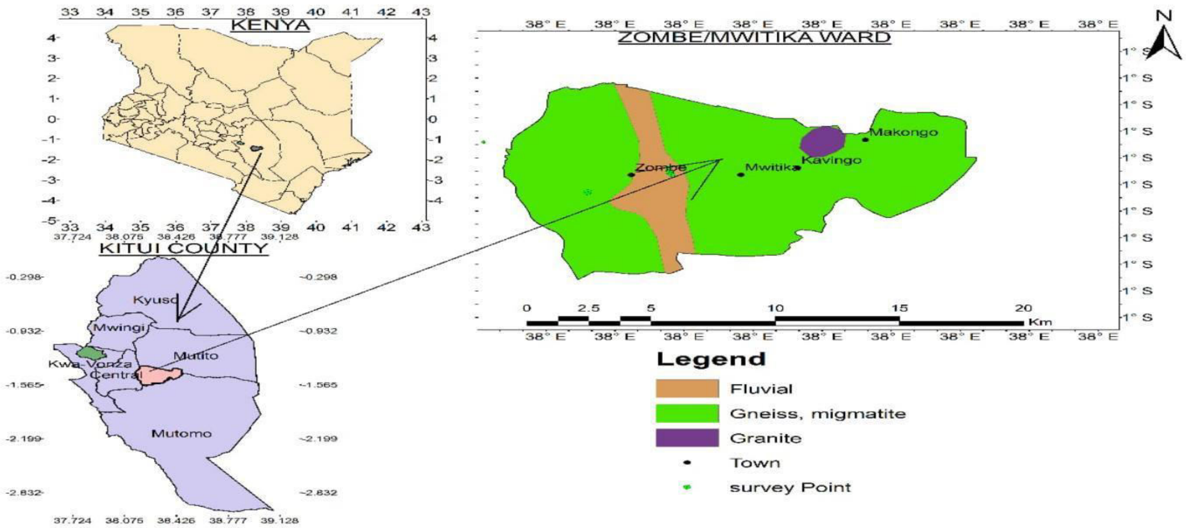
2.1 Study Area

Figures 1 and 2 show the location of the two study areas of Kauwi and Zombe Wards in Kitui County. The regions were selected due to their high dependence on shallow groundwater and being prone to recurring droughts. The hydrology of the area is comprised of seasonal rivers and limited rainwater harvesting structures, which are highly influenced by erratic rainfall patterns and high evaporation rates. The area geology is made of Precambrian basement rocks, including granites, gneisses, and schists, with pockets of weathered zones and fractures that occasionally serve as groundwater reservoirs (Gevera *et al.,* 2020). The local social and economic characteristics revolve around subsistence crop growing, livestock rearing, charcoal production and small-scale trade with water scarcity and climate variability significantly impacting livelihoods sustenance.

2.2 Water Sampling and Quality Assessment Methodology

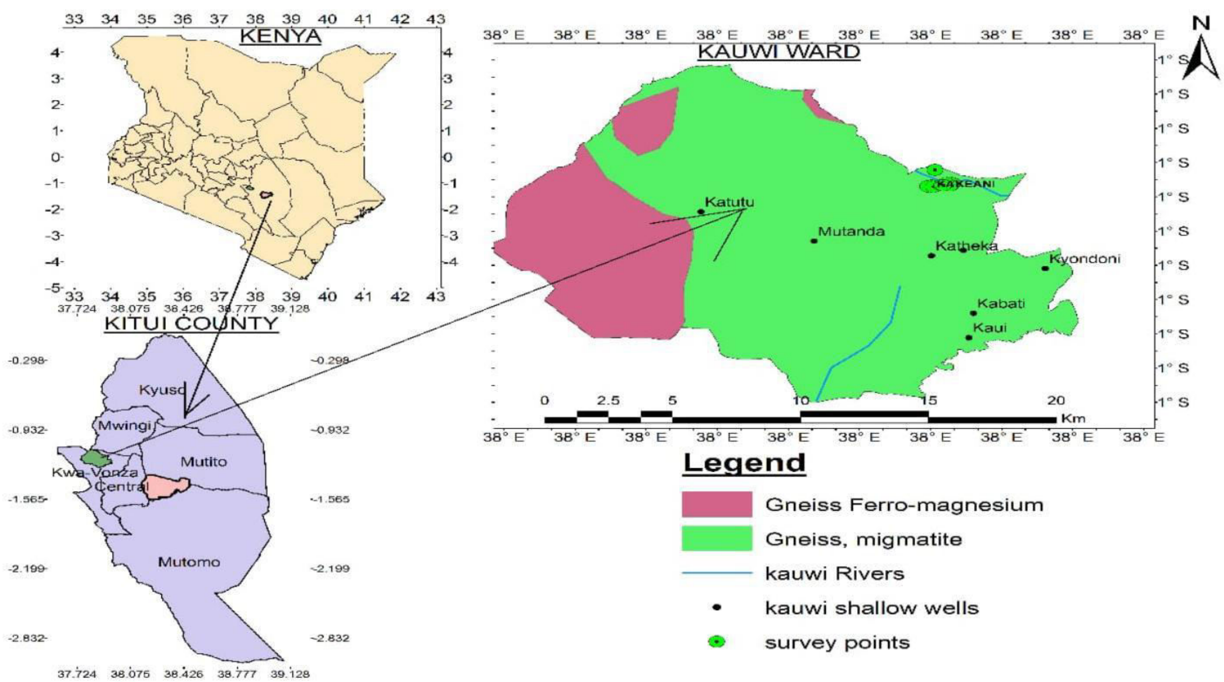
Fifteen active shallow wells in each of the two wards were purposefully selected and water samples collected in triplicates from each well during both dry and wet periods. The wells are located near farms or where anthropogenic activities that are dominated by land tilling and livestock rearing. Both physical and chemical parameters of the collected water were assessed at the shallow well sites using a portable laboratory to measure the intended parameters that included a) turbidity, b) pH, c) salinity, d) magnesium, e) calcium, f) electrical conductivity (EC), g) total dissolved solids (TDS), h) nitrates, i) sulphates, j) Potassium, k) aluminium, l) manganese, m) zinc, n) calcium carbonate, and o) fluoride.

Figure.1 Study area-Zombe



(Source: Dorcas, 2024)

Figure.2 Study area-Kauwi



(Source: Dorcas, 2024)

2.3 Stakeholder Surveys Methodology

A total of 30 local people were interviewed through a structured questionnaire to build an understanding on the community water quality perceptions and practices influencing shallow well water quality. The individuals were selected on the basis of dependence on the shallow wells for human and livelihood sustenance. Using a structured questionnaire, ten key informants from the local leadership and opinion shapers representing the government and non-governmental organizations and community based organizations working in the water, health, and climate resilience sectors, researchers and policymakers were consulted on the local shallow wells development and utilization.

2.4 Data Analysis

The collected data were entered into Microsoft Excel and exported to the Statistical Package for the Social Sciences (SPSS) for analysis to determine water quality status and temporal changes. An independent t-test was conducted to compare the mean values of physicochemical properties of the shallow wells.

3.0 Results and Discussion

3.1 Objective 1: to evaluate temporal variations in water quality

Tables 1 and 2 show comparison results of the dry and wet seasons for the study locations based on independent t-test. The average values of the physicochemical parameters for the shallow groundwater highlight significant temporal variations between the two seasons, reflecting the influence of drought conditions on physical and chemical parameters of water resources. It is evident that shallow well water quality is influenced by seasonal variations. The dry season reduces rainfall, limits groundwater recharge and lowers water levels, leading to evapo-concentration of dissolved salts and minerals. The process increases parameters such as electrical conductivity (EC), calcium, magnesium, NaCl, and chlorides, while stagnant conditions promote CO_2 accumulation, causing slight acidification (lower pH).

In contrast, the wet season brings increased rainfall and recharge, which dilutes accumulated salts and minerals, lowers EC and ion concentrations, and restores buffering capacity, leading to higher pH. However, enhanced surface runoff during this period can transport nutrients like nitrates and sulfates into shallow wells, temporarily raising their levels. Overall, water availability improves, and aquifer self-purification mechanisms, such as flushing and dilution which help to mitigate the concentration of contaminants. The elements changes due to drought can be explained as follows:

a) pH

Both locations of study exhibit a statistically significant decrease in pH during the dry season (Kauwi: 7.14 to 7.03, Zombe: 7.15 to 7.04). This slight acidification is commonly observed during drought periods due to reduced buffering capacity and increased CO_2 concentrations in stagnant or low-flow waters. Acidification can affect aquatic life and metal solubility, making it an important indicator of drought stress on water quality. This is similar to the study results of Adongo *et al.,* (2022) and Mbaka *et al.,* (2017) which documented statistically significant decreases in pH during the dry season. This was attributed to reduced recharge, leading to limited dilution of acidic inputs, accumulation of organic matter, and increased microbial respiration in stagnant conditions all of which contribute to elevated CO_2 levels and decreased buffering capacity in groundwater systems.

b) Calcium and Magnesium

Calcium trends differed between the two study sites, with Kauwi showing a significant increase during drought (118.91 to 177.77 mg/l). Zombe showed a decrease in Calcium levels (226.47 to 180.17 mg/l), suggesting contrasting hydrogeological or catchment influences. The increase in Kauwi could result from evapo-concentration as water volume decreases, whereas the decrease in Zombe might be due to lower mineral leaching or dilution by groundwater inputs. The findings of the study rhyme with ones by Gevera *et al.,* (2020) in the semi-arid Makueni County who found that Ca^{2+}, Mg^{2+}, and TDS were often higher in dry-season groundwater due to evapo-concentration and prolonged water–rock interaction. The rise in electrical conductivity (EC) and dissolved solids supports the idea that limited dilution and prolonged contact with aquifer materials elevate Ca^{2+} levels. Adongo *et al.,* (2022) reported that shallow wells exhibited higher Ca^{2+} concentrations during the wet season relative to the dry season, attributed to enhanced carbonate mineral dissolution under increased recharge. Magnesium increased in both areas but was only significant in Zombe, indicating that drought-related concentration effects or changes in water-rock interactions may vary regionally. Groundwater samples collected during the dry season in Makueni County showed elevated Ca^{2+} and Mg^{2+} (and high hardness, high TDS) sometimes exceeding drinking water standards (Gevera *et al.,* 2020). A study by Singh *et al.,* (2014) in a semi-arid reclaimed irrigation region of India observed similar seasonal behavior reporting that magnesium concentrations were notably elevated in the dry season, linked to limited recharge, longer residence times, and enhanced rock–water interaction under low-flow conditions.

Table.1 Mean Values of Water Quality Parameters of shallow wells in Kauwi Location

Parameter	Wet season mean	Dry season mean	P Value
pH	7.14(*0.07*)	7.03(*0.05*)	0.00*
Calcium(mg/l)	118.91(*77.81*)	177.77(*67.04*)	0.03*
Magnesium(mg/l)	36.57(*12.73*)	44.35(*18.04*)	0.379
Aluminium(mg/l)	0.21(*0.28*)	0.15(*0.06*)	0.372
Electrical conductivity(mg/l)	390.11(*74.64*)	514.15(*179.68*)	0.020*
TDS (mg/l)	419.57(*129.38*)	491.18(*225.91*)	0.26
Nacl(mg/l)	28.67(*14.03*)	43.61(*23.46*)	0.04*
Sulphates(mg/l)	233.25(*42.64*)	139.93(*57.59*)	0.00*
Nitrates(mg/l)	67.52(*10.70*)	54.52(*25.41*)	0.08
CaCO3(mg/l)	220.18(*125.60*)	54.43(*14.79*)	0.00*
Chlorides(mg/l)	138.87(*88.42*)	229.34(*26.89*)	0.001*
Fluoride(mg/l)	0.67(*0.64*)	0.61(*0.37*)	0.12
Zinc(mg/l)	1.41(*2.42*)	1.70(*1.87*)	0.76
Turbidity (NTU)	5.71(*6.90*)	5.80(*5.22*)	0.42

Note: Values in parentheses represent standard deviations.
* P-values are considered statistically significant at $p \leq 0.05$.

Table.2 Mean Values of Water Quality Parameters of shallow wells in Zombe Location

Parameter	Wet season mean	Dry season mean	P Value
pH	7.15(*0.07*)	7.04(*0.53*)	0.00*
Calcium(mg/l)	226.47(*62.31*)	180.17(*61.83*)	0.05*
Magnesium(mg/l)	40.56(*9.71*)	50.78(*16.02*)	0.04*
Electrical conductivity(mg/l)	452.52(*96.94*)	231.89(*97.23*)	0.00*
TDS (mg/l)	537.09(*139.0*)	544.48(*205.27*)	0.91
Nacl(mg/l)	83.09(*131.56*)	39.31(*19.72*)	0.22
Sulphates(mg/l)	298.23(*86.47*)	206.62(*69.40*	0.003*
Nitrates(mg/l)	68.52(*9.44*)	64.41(*19.06*)	0.46
$CaCO_3$(mg/l)	229.71(*89.67*)	60.02(*16.19*)	0.00*
Chlorides(mg/l)	177.03(*82.89*)	299.31(*105.46*)	0.001*
Fluoride(mg/l)	1.71(*2.48*)	0.67(*0.29*)	0.12
Zinc(mg/l)	1.27(*1.53*)	1.40(*1.79*)	0.41
Turbidity (NTU)	9.08(*14.35*)	5.43(*2.38*)	0.42

Note: Values in parentheses represent standard deviations.
* P-values are considered statistically significant at $p \leq 0.05$.

c) *Electrical Conductivity (EC) and Total Dissolved Solids (TDS)*

EC increased significantly in Kauwi during drought (from 390.11 mg/l to 514.15 mg/l), reflecting a higher concentration of dissolved ions due to evaporation and reduced inflow. Conversely, EC decreased significantly (from 452.52 mg/l to 231.89 mg/l) in Zombe, which might be explained by dilution effects from groundwater contributions or changes in runoff patterns. Similar findings were reported by Makhoha (2019) in semi-arid regions of the Kenyan Coast, where elevated EC levels during dry seasons were attributed to evapo-concentration and limited recharge. In contrast, Adongo *et al.,* (2022) documented seasonal EC variation in the Kamiti-Marengeta sub-catchment of Kiambu County, where EC values in some wells decreased from the dry to the wet season likely reflecting dilution from recharge during rains rather than evapo-concentration. Further studies (Adongo *et al.,* 2022; Wanjiku *et al.,* 2024) also reported seasonal variations in EC sometimes increasing, sometimes decreasing depending on hydrogeological context, recharge patterns, and aquifer type. Likewise, Dahan *et al.,* (2013), in a study of the arid-zone wadis in Israel, reported that subsurface lateral flow and contributions from deep-rooted vegetation zones helped mitigate salinity build-up during extended dry spells. TDS changes were not significant in either location, possibly due to offsetting processes of concentration and dilution acting simultaneously. Similar observations were made by Subramani *et al.,* (2005) in Tamil Nadu, India, where total dissolved solids showed minimal seasonal variation, attributed to the balancing effect of evaporation-driven concentration and recharge-related dilution. Likewise, Babiker *et al.,* (2007) noted stable TDS levels in groundwater across different seasons in the Kakamigahara Plateau, Japan, suggesting that mixing between shallow and deeper groundwater layers, along with variable recharge rates, can buffer against significant changes. Shrestha *et al.,* (2016) also reported negligible seasonal variation in TDS in the Kathmandu Valley aquifer, pointing to the interplay between anthropogenic sources and natural hydrogeological buffering mechanisms.

d) *Salinity-related Ions (NaCl and Chlorides)*

NaCl increased significantly in Kauwi (from 28.67 mg/l to 43.61mg/l) but decreased in Zombe (from 83.09 mg/l to 39.31 mg/l), indicating that evapo-concentration was dominant in Kauwi while Zombe may have experienced reduced surface inputs or dilution. Similar patterns were observed in a study by Marghade *et al.,* (2015), which reported elevated NaCl concentrations in semi-arid regions of central India due to intense evaporation and limited recharge during the dry season, while areas with higher recharge potential showed reduced salinity due to dilution. However, chlorides increased significantly in both locations during drought, consistent with the conservative nature of chloride ions that tend to concentrate as water evaporates. A study of shallow coastal aquifers in southwestern Nigeria found that most hydrochemical parameters including chloride were markedly higher during the dry season compared to the wet season, attributed to evaporation-driven concentration and reduced dilution in periods of low recharge (Aladejana, 2020). Further, in endemic CKDu regions of Sri Lanka researchers monitored shallow wells across seasons and observed that chloride concentrations remained high and virtually unchanged between dry and wet seasons (dry ~106 mg/L vs wet ~100 mg/L; $p > 0.05$), indicating persistent elevation in chloride levels during dry periods due to background salt inputs and limited flushing by rainfall (Jayasumana, 2021).

e) *Sulphates and Nitrates*

Sulphates declined significantly during the dry season in both locations, suggesting reduced surface runoff and agricultural leaching due to limited rainfall. In the Kamiti-Marengeta Sub-Catchment of Kiambu County in Kenya, shallow wells are reported to display a marked seasonal variation, with sulphate levels lower in the dry season (≈ 37.73 mg/L) and higher during the wet season (≈ 49.65 mg/L). This pattern indicates that shallow groundwater is more susceptible to seasonal recharge and surface processes, such as runoff and leaching, which increase sulphate input during periods of rainfall (Adongo *et al.,* 2022). Similarly, a study of shallow wells in parts of Chuka Sub-County reported elevated sulphate, nitrate and turbidity levels in some wells, with noticeable seasonal differences between dry and wet seasons pointing to combined effects of mineral weathering and human activities (Rugendo *et al.,* 2020). Furthermore, a study by Kumar *et al.,* (2016) made similar observations, highlighting the seasonal dynamics of sulfate levels influenced by both natural and anthropogenic factors. Gawle *et al.,* 2021 also concludes on the same that fluctuations in sulphate concentrations are largely driven by variations in rainfall, evaporation rates, and agricultural runoff which together affect the leaching and accumulation of sulphate in groundwater systems.

Nitrates showed a non-significant decrease, which could result from reduced fertilizer runoff or increased biological uptake in slower-flowing waters during drought. A study conducted in Kisumu City and Kano plains of Kenya which sampled 62 groundwater wells during the wet season (May–July 2017) and dry season (February 2018) found Nitrate (NO_3^-) ranged widely from < 0.04 up to 90.6 mg/L. Importantly, nitrate concentrations in shallow wells were significantly higher in the wet season than in the dry season, with up to 75 % of shallow wells exceeding the WHO drinking-water limit (Nyilitya *et al.,* 2020). Further, studies by Olonga, 2015 observed similar seasonal patterns in Ruiru Kiambu County, Kenya.

f) Calcium Carbonate ($CaCO_3$)

Both locations showed a significant decrease in $CaCO_3$ concentrations during drought, indicating a decline in water hardness. This reduction could reflect lower carbonate mineral dissolution due to decreased water movement and altered geochemical conditions during dry periods. A similar study in Ruiru, Kiambu County, Olonga *et al.,* (2015) observed clear seasonal variation in boreholes and shallow wells with many physico-chemical parameters (including total hardness as $CaCO_3$) significantly differing between the dry and wet seasons. Their findings revealed significant seasonal variability in carbonate species with dry season values noticeably lower than in the wet season. This pattern indicates that carbonate mineral dissolution such as calcite/dolomite is suppressed during drought, due to decreased water flux and recharge. Research findings by Ochieng *et al.,* (2022) and findings in Olonga (2016) indicate that shallow wells exhibit markedly higher total hardness during the wet season (mean ≈ 211 mg/L as $CaCO_3$) compared to the dry season (≈ 152 mg/L).

g) Trace Metals and Turbidity

No significant temporal changes were observed in aluminium, fluoride, zinc, or turbidity, suggesting that these parameters are less sensitive to seasonal drought fluctuations or influenced by localized factors rather than broad climatic changes. Temporal analysis of water quality parameters in Kauwi and Zombe demonstrates the multifaceted impacts of drought on aquatic systems. During droughts, processes such as evapo-concentration lead to increases in parameters like EC, chlorides, and calcium (in Kauwi), while reduced runoff and inflow contribute to declines in sulphates, nitrates, and $CaCO_3$. Differences between the two sites highlight the importance of local geology, hydrology, and land use in modulating drought effects. After drought periods, water quality may gradually return to baseline as rainfall resumes, dilution increases, and geochemical equilibria restore. However, prolonged droughts could exacerbate water quality deterioration, impacting ecosystem health and water usability (IPCC, 2023). For instance, research conducted in the Keiyo Highlands found that aluminium, fluoride, zinc, and turbidity showed minimal temporal variation, indicating that these parameters are primarily governed by local geological and geochemical conditions rather than seasonal or climatic shifts (Mbaka *et al.,* 2017). Further a study conducted in Marsabit County of Kenya found that aluminium, zinc, and fluoride concentrations in both well and borehole water remained consistently low and below acceptable limits during both dry and wet seasons, with no statistically significant seasonal differences. Similarly, turbidity showed no significant variation between seasons, indicating minimal impact from surface runoff or sediment influx in the sampled shallow water sources (Daba *et al.,* 2012).

The study findings reveal that during extended dry spells, the water level in shallow wells drop, and some dry up. This not only reduces water availability but also affects water quality through increased concentration of contaminants, intrusion of surface pollutants, microbial growth, and changes in physico-chemical characteristics. The scarcity of water during drought also compels communities to use compromised sources, increasing the risk of waterborne diseases. Additionally, droughts alter land use and water use behaviors, leading to aggravated mobilization of contaminants such as heavy metals and nutrients from soils which increase salinity, and reduces the self-purification capacity of rivers and aquifers (Mosley, 2015). The changes affect drinking water supplies, aquatic ecosystems, agriculture, and public health. With the prevailing limited water treatment options, the resulting water quality issues pose human health risks.

3.2 Objective 2: to assess community perceptions and practices influencing shallow well water quality

The study responses revealed an interplay of human practices, environmental exposure, and informal water-treatment behaviors contributing to water quality deterioration. Respondents' views were categorized according to individual wells, allowing comparison of water quality concerns across the two locations. A key finding was that 95% of the shallow wells experience the scooping to abstract water, a practice that greatly increases the risk of microbial contamination in both wet and dry seasons. Compounding the problem, the majority of the wells remain uncovered, despite the presence of freely grazing cattle in the vicinity, an indication of inadequate protection measures that heighten vulnerability to both fecal and physical contaminants. Agricultural activities surrounding the wells also emerged as a potential pathway for water contamination. Farmers commonly apply manure and chemical fertilizers, increasing the likelihood of nutrient infiltration into shallow groundwater. In terms of household drinking water management, respondents reported using multiple practices, including boiling (45%), cloth filtration (10%), and storage in clean containers (45%).

Quality perceptions were revealing. Salinity which is associated with the local geology was identified by over 80% of respondents as the most troubling characteristic, affecting taste and overall acceptability. About 60% of users expressed discomfort when drinking water from the shallow wells, suggesting both sensory and health-related concerns. When asked about solutions, respondents demonstrated a strong preference for improving existing sources. Among respondents, multiple recommendations were reported: 20% supported treatment of existing water supplies, while 60% advocated for the development of alternative water sources.

3.3 Objective 3: to establish possible mitigation and adaptation strategies for maintaining water quality during droughts.

The study shows that droughts pose threat to shallow groundwater quality. 80% of the key informants and 90% of other respondents associate the deterioration to prevailing heavier reliance on shallow wells as a result of geographical water shortages and increased pollutant concentration due to reduced recharge. Both the shallow well users and key informants subscribe to a combination of mitigation and adaptation strategies to preserve water quality and safeguard public health in addressing the challenge. Over 90% of the key informants and 65% prescribe protection of the water sources and related infrastructures through lining and covering open wells. The practice is envisioned to guard against the resultant effects of falling water tables during droughts which lead to raised turbidity and exposure to contaminants from surface runoff as an effective step towards reducing both chemical and microbiological risks. The approach is also vouched for by Howard *et al.,* (2006) who reiterates that proper wellhead protection, including sealing, fencing, and raising well linings, can significantly reduce the risk of contamination. 2013). 50% of the key informants have the view that implementation of continuous monitoring of critical physiochemical and microbial contamination is vital in detecting emerging water quality threats to help in promptly responding to seasonal contamination and developing interventions. Community-based water surveillance programs can also be effective, empowering local stakeholders to actively participate in monitoring and protecting their water sources (Taylor *et al.,* 2013; UNESCO, 2019).

The role of agricultural practices in shallow groundwater contamination becomes more pronounced during droughts. Reduced rainfall and groundwater recharge often lead to higher concentrations of pollutants, such as nitrates, chlorides, and sulphates, in shallow groundwater. To mitigate this, promoting sustainable agricultural practices such as integrated nutrient management, reduced fertilizer use, and precision irrigation can greatly minimize the leaching of agrochemicals into shallow aquifers (Burow *et al.,* 2010). Techniques like drip irrigation not only conserve water but also reduce the mobilization of nutrients. Additionally, practices like crop rotation, organic farming, and agroforestry improve soil health and reduce the dependence on chemical inputs (Sharma *et al.,* 2019). Deliberate groundwater recharge is not practiced, despite being recognized as a potential adaptation strategy by 60% of key informants and 25% of individuals in the study clusters. The practice of managed aquifer recharge systems has been effectively implemented in the arid and semi-arid areas of countries that face water stress (Parker *et al.,* 2022).

The approaches involve directing excess but safe surface water into the ground to replenish aquifers, particularly during wet seasons or storm events. Methods such as infiltration basins, check dams, and recharge wells can also increase groundwater quantity and simultaneously dilute existing contaminants, improving overall quality (Scanlon *et al.,* 2002).

4.0 Conclusion and Recommendations

Drought occurrence is not a water quantity issue only as it also threatens the quality. It makes water in shallow wells more vulnerable to pollution by increasing the concentration of naturally occurring contaminants, and raises water abstraction quantities and frequency, heightening the risk of contamination. To mitigate the challenge, it is prudent to ensure that the sources are structurally sound and regular maintenance and monitoring performed to establish changes in quality. Community-level solutions include establishing stakeholder shallow wells protection and monitoring plans, and implementing smart water abstraction and use approaches. With the climate change being projected to intensify, with the potential of bringing in more drought episodes, the actions and measures are absolutely essential for the shallow wells to serve as sustainable water sources in the semi-arid areas. At a broader level, climate-resilient water resource planning is indispensable. The government and water management agencies must integrate climate projections into their planning frameworks, conduct groundwater vulnerability assessments, and develop drought contingency plans. This includes adopting integrated water resources management to ensure coordinated use of water across domestic, agricultural, and industrial sectors. Education and awareness campaigns on water conservation, safe water storage, and pollution prevention are a necessity in building resilience against droughts.

4.1 Conflict of Interest

The authors declare no competing interests.

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