International Journal of Environment and Geoinformatics 11(2):038-051 (2024)

Research Article

Water Resources Availability and Accessibility for Water Security and Improved Livelihoods in Kenyan Drylands; Case Study of Isiolo and Samburu Counties

Mary Makokha[1, *], Clifford Obiero[2], Hosea Mwangi[2], David Mburu[2], Wycliffe Nyangau[2], Emmanuel Abban-Baidoo[3]

[1] Department of Geography, Kenyatta University, Nairobi, Kenya
[2] Department of Land Resource Planning and Management, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
[3] Department of Soil Science, School of Agriculture, University of Cape Coast, Cape Coast, Ghana

* Corresponding author: M. Makokha
E-mail: makokha.mary@ku.ac.ke

Received 23.11.2023
Accepted 09.06.2024

How to cite: Makokha, et al. (2023). Evaluating Water Resources Availability and Accessibility for Improved Livelihoods in Kenya Semi-Arid Lands; Case Study of Isiolo and Samburu Counties. *International Journal of Environment and Geoinformatics (IJEGEO)*, 11(2): 038-051. doi. 10.30897/ijegeo.1390273

Abstract

This research presents a comprehensive study on water resources in the semi-arid regions of Isiolo and Samburu counties in Kenya, with a focus on the conservancies. The aim of the study was to determine; water availability, accessibility, quality, and suitability for improved livelihoods in these regions. Data was collected through literature reviews, site visits, and laboratory experiments, with a specific focus on groundwater and surface water sources. Our study revealed that the primary source of domestic water was from boreholes. They had an average depth of approximately 70 m, with average yields of 2 to 6 m^3/hr and were strategically located along the riparian areas of Laggas, which are fairly fractured, allowing for recharge of floodwater. Some areas had poor groundwater yields of 1- 2 m^3/hr which could be attributed to the hard geological formations and limited recharge areas within the region. The areas geological composition comprises of volcanic layers of basalts, trachytes, phonolites overlain by regolith, which retain water except the basalts and trachytes have limited water storage capacity resulting into poor yields when fractured. There was a diversification of water resource use including; water pans, springs, rivers, boreholes, earth dams, rock catchment and gravity water supply to curb seasonality. The TDS, pH, dissolved oxygen (DO), and electrical conductivity (EC) were within the WHO recommended standards except for variations such as; high alkalinity, high fluoride levels, and excess algae observed especially in the water pans indicating the presence of pollution. Identified challenges included: construction and design problems, improper siting, siltation, lack of protection, absence of spillways and silt traps, and contamination by livestock and wildlife. The research highlights the significance of diversified water sources, alternative energy solutions, groundwater potential, and community-based management for addressing water scarcity and improving access to clean and safe water for arid livelihoods sustainability.

Keywords: water sources, water levels and quality, accessibility, climate variability, conservancies

Introduction

An estimated 55% of rural water supplies in Kenya, Tanzania, and Uganda are non-operational (Howard et al., 2020). Despite frequent mentions in planning manuals, achieving sustainability in this context remains a challenge. Simultaneously, climate change poses a significant threat to water supply, impacting water and food security (Erda et al., 2005). Failures in water supplies are widespread, driven by institutional issues, climate change, sustainability concerns, and maintenance challenges, among other factors (Carter et al., 1999). Kenya's arid and semi-arid regions have witnessed increasing and frequent droughts (Balint et al., 2013; Mutsotso et al., 2018), which can escalate into catastrophes when exposed to drought hazards (Mutsotso et al., 2018).

While the Ministry of Water and Irrigation collaborates with international and local organizations to address these challenges at the grassroots level, the coverage of clean water supply in many areas of Kenya remains in its infancy. It is estimated that over 60% of the Kenyan population lacks access to clean water, a situation exacerbated by unreliable stochastic rainfall. To meet the water and sanitation Millennium Development Goals (MDGs) by 2015, the ongoing efforts must be re-engineered to increase their output by 2000 (Ministry of Water and Irrigation (MWI, 2011).

Factors such as low socioeconomic status, limited water access, and constrained mobility have heightened the vulnerability of pastoralists to drought. In response, pastoralists travel long distances in search of water or settle near water points (Eriksen and Lind, 2009; Akkaya et al., 1998; Roth, 1991). However, many of these water points are located in areas designated for grazing. Insufficient management of water projects significantly impacts the sustainable delivery of water resources to rural populations (Kakumba, 2010). Earlier studies have reported operational failure rates in water projects in various African countries ranging from 30% to 60% (Harvey et al., 2004). This study seeks to explore the complex dynamics of water resources management and development, necessitating a comprehensive understanding of underlying challenges, required interventions, their outcomes, and their impact on the counties.

Samburu and Isiolo counties face challenges associated with fragile community conservancy ecosystems, aridity, climate variability, and population pressure from livestock. This leads to increased demand for water by both people and wildlife, resulting in conflicts over water resources, human-wildlife conflicts, and inter-community violence. These disruptions often stem from a lack of knowledge regarding the state of water resources, including their quantities, quality, and distribution in relation to the catchment they serve.

This study conducted a survey and mapping of both sub-surface and surface water resources, facilitating evidence-based water use planning, infrastructure development, and the promotion of sustainability. The recommended interventions play a crucial role in the sustainable management of water resources, aiming to reduce human-wildlife conflicts, improve livelihoods, facilitate knowledge transfer, and mainstream youth and gender considerations for resilience building.

Materials and Methods

Description of the study area

Isiolo County encompasses eight community conservancies, namely Biliqo Bulesa, Nakuprat-Gotu, Oldonyiro, Nasuulu, and Leparua. The Oldonyiro Conservancy is further subdivided into four units, including Oldonyiro Narupa, Oldonyiro Nanapicho, Oldonyiro Naapu, and Oldonyiro Nannapa. The county boasts a population of 268,002 residents and covers an average land area of 25,700 square kilometers. It is predominantly arid, with 65% of the land classified as very arid, 30% as arid, and the remaining 5% as semi-arid. Most of the county's terrain consists of flat, low-lying plains. Isiolo County is traversed by six perennial rivers, namely Ewaso Ngiro North, Isiolo, Kinna, Bisanadi, Likiundu, and Liliaba rivers. The Ewaso Ngiro North River has its catchment area in the Aberdare Ranges and Mount Kenya, offering significant potential for irrigation. Livestock production remains the primary economic activity, with approximately 80% of the population relying on rainfed agriculture and irrigation. It is imperative to examine climate variability, proper management, financial systems, and monitoring and evaluation systems in the study area, as these factors significantly influence sustainability.

Samburu County is situated between latitudes 0º 40' north and 2º 50' north of the equator and longitudes 36º 20' east and 38º 10' east of the prime meridian (Nanyingi et al., 2008). Covering an area of approximately 21,120.5 square kilometers, Samburu County is characterized by a semi-arid climate. The county currently hosts ten community conservancies, including Kalama, Westgate, Nkoteiya, Ltungai, Namunyak, Sera, Kalepo, Ngilai, Nalewoun, and Meibae. Kirisia Division has the highest population due to its favorable climate, fertile soils, and numerous trading centers. Maralal town serves as the principal urban center in this division (Melissa et al., 2009). The highlands of the Lorroki Divisions feature a more favorable climate and soil conditions, with thousands of hectares dedicated to wheat and barley farming (NEMA, 2009). Figure 1 provides an overview of the conservancies that are the focus of our research.

Five conservancies were selected from Isiolo and Samburu counties. The following methodology was employed:

Literature review

We conducted a comprehensive desktop literature review of water resources within five conservancies: Nakuprat-Gotu, Kalama, West Gate, Namunyak, and Ltungai. This review encompassed an extensive examination of diverse information sources, including government reports at both national and county levels, materials from non-governmental organizations, published research, and online resources that addressed water resources within these conservancies.

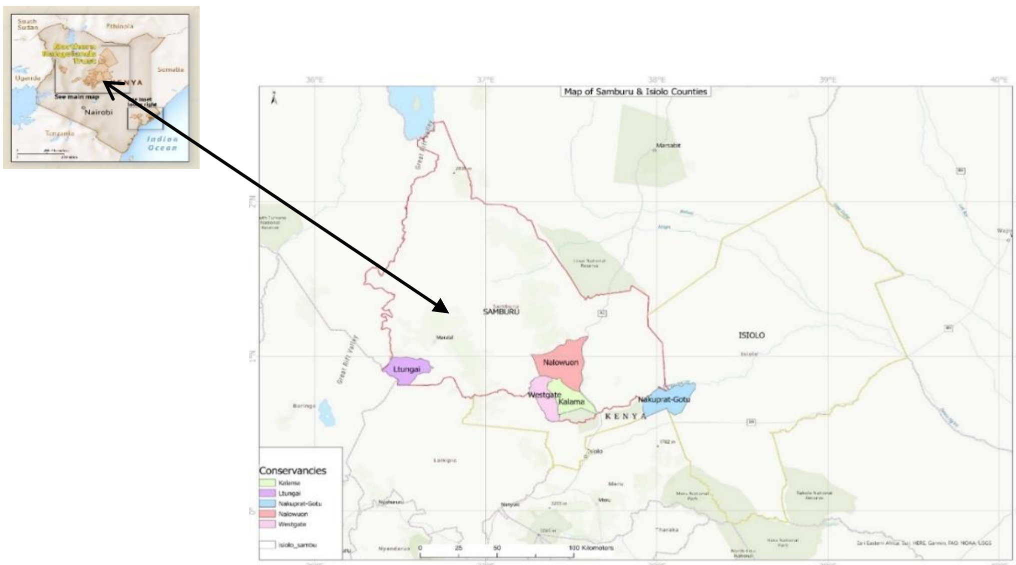


Fig. 1: Isiolo and Samburu county map with selected conservancies.

The reviewed data encompassed the following aspects: the nature and geographical distribution of available water resources, water volume and storage capacity (including measurements of volume, flow rate, and depth), water utilization (for domestic, livestock, and irrigation purposes), and water quality. Additionally, we gathered pertinent information such as population statistics and socio-economic activities that influence water demand, thereby playing a critical role in water allocation planning To enhance our understanding of the existing water resources, we analyzed satellite imagery, Google Earth images, and topographical maps. This analysis aimed to identify the location and characteristics of various water resources, including rivers, reservoirs, water pans, sand dams, and subsurface dams. Regarding groundwater data, our collection efforts involved a wide range of details on boreholes and shallow wells, including their geographic coordinates, quantity, construction year, depth, yield, abstraction methods, drilling records, utilization, water quality, and the population served. We also reviewed geological reports, topographical maps, borehole Environmental Impact Assessment (EIA) reports, borehole completion records, and drilling-related documentation as part of this comprehensive assessment.

Site visits data collection and Laboratory Experiments

Fieldwork was conducted in all five conservancies to ground truth the information obtained from the literature review (topographical, satellite images, Google Earth, reports, published literature) and collect additional data. During the fieldwork, transect walks, guided tours, maps and Global position systems (GPS) were used to locate all surface (reservoirs/dams, water pans, sand dams, streams) and underground (boreholes and shallow wells) water resources.

The coordinates of all the surface water resources were obtained by GPS for mapping in Geographical Information System (GIS). In addition to the location, other important data on the water resources such, as water quality (physical, chemical, and biological) and climatic data were determined/collected. Climatic data (rainfall, temperature, evaporation) was obtained from Kenya Meteorological Department for a period of about 30 years. The data was used for the estimation of average rainfall, trend, spatial and temporal variability of rainfall, water balance, and water requirements. Water quality (physical, chemical, and bacteriological) was determined in situ using hand-held water quality meters. Samples were collected for further analysis of water quality at the laboratories. During the fieldwork, an abstraction and pollution survey of the main streams was conducted. This shall be conducted by transect walks along the river guided by the Water Resources Users Association (WRUAs) officials. Using a checklist, the survey documented all the abstraction points and data collected including the coordinates (using a GPS), photos, method of abstraction (e.g. canal, pump, pipe (gravity)) and use of abstracted water. The amount of water abstracted was estimated depending on the method of abstraction used. Information on whether the abstraction is legal or illegal (authorized by WRA) was determined by the abstractor and confirmed from water abstraction permits at WRA offices. The volume of water abstracted was compared with the amount allowed/authorized in the WRA permits. During the transect walks any source of pollution of the water (point-source and non-point. Chemical analysis such as PH, Chemical Oxygen Demand, nitrates, phosphates and heavy metals. Total coliforms and E-coli was analyzed for bacteriological water quality. The water quality for various uses was compared against the standards (KEBS/ WHO and NEMA) for various uses (drinking, irrigation, domestic). These analyses determined the suitability of the water for various uses. On groundwater, characterizing the existing aquifers using comprehensive geophysical methods, hydro-geological and laboratory methods was done to determine potential groundwater zones and demarcate suitable areas for sustainable yields and the current groundwater quality status.

Results and Discussion

Water sources

Table 1 shows the available water resources within the Litungai, Kalama, Westgate, Nakuprat and Ngilai catchment areas. In the Litungai catchment, the main source of water for livestock during the dry season is the dam. Water pans, excavated into the ground to collect surface runoff water, serve as vital water sources for the communities in the catchment areas. However, our investigation uncovered several issues affecting their functionality. These challenges include problems with construction and design, improper siting, siltation, lack of protection, absence of spillways and silt traps, and contamination by livestock and wildlife. Similar issues in water pan construction have been documented in other semi-arid regions (Stroosnijder, 2003). These challenges underline the necessity for improved design and construction practices to enhance water pan efficiency. Furthermore, we noted that some water pans were non-operational due to maintenance issues. This highlights the importance of regular maintenance in ensuring sustainable water access (DelGrosso et al., 2019). To address this, we emphasize the need for community-based management and long-term maintenance plans, ensuring that these water pans continue to serve the community effectively. In our study, we observed the utilization of solar and wind energy to power boreholes in the region, aligning with a growing trend in arid and semi-arid areas (Scholes, 2020). The abundant sunshine and strong easterly winds make these energy sources not only economically viable but also environmentally friendly. This trend is consistent with global efforts to reduce the carbon footprint of water supply systems. The absence of structured management systems for water sources and reliance on community elders to oversee them is a common approach in this region (Quinn et al., 2007). However, our study identified potential challenges in this approach, particularly related to the imposition of tariffs and handling breakdowns. These findings underscore the need for improved community-based management systems that ensure both sustainability and equitable access to water resources.

Table 1: Water resources in the Litungai, Kalama, Westgate, Nakuprat and Ngilai conservancies.

	Number of Water Sources in each Conservancy				
Conservancies	**Litungai**	**Kalama**	**Westgate**	**Nakuprat**	**Ngilai**
Boreholes	26	19	15	27	34
Shallow wells	10	0	3	104	15
Water pans	12	4	8	18	13
River/spring	6	1	0	12	17
Wetlands	5	0	0	0	1
Dam	1	0	0	0	0
Rock catchment	0	1	0	0	0
Sand dam	0	0	0	0	2
Rainwater storage	0	0	0	0	9
Gravity water supply	0	0	0	0	2

The study revealed the presence of perennial rivers (Ewaso Ngiro, Ngare-Narok and Amaya), seasonal springs, and wetlands in the study area, providing significant alternative sources of water for domestic use (Figure 2). This emphasizes the importance of diverse water sources in arid and semi-arid regions to ensure resilience against water scarcity (Garg and Wani, 2012). Identifying these sources is crucial for local communities and water resource planners as they offer potential solutions to address water shortages.

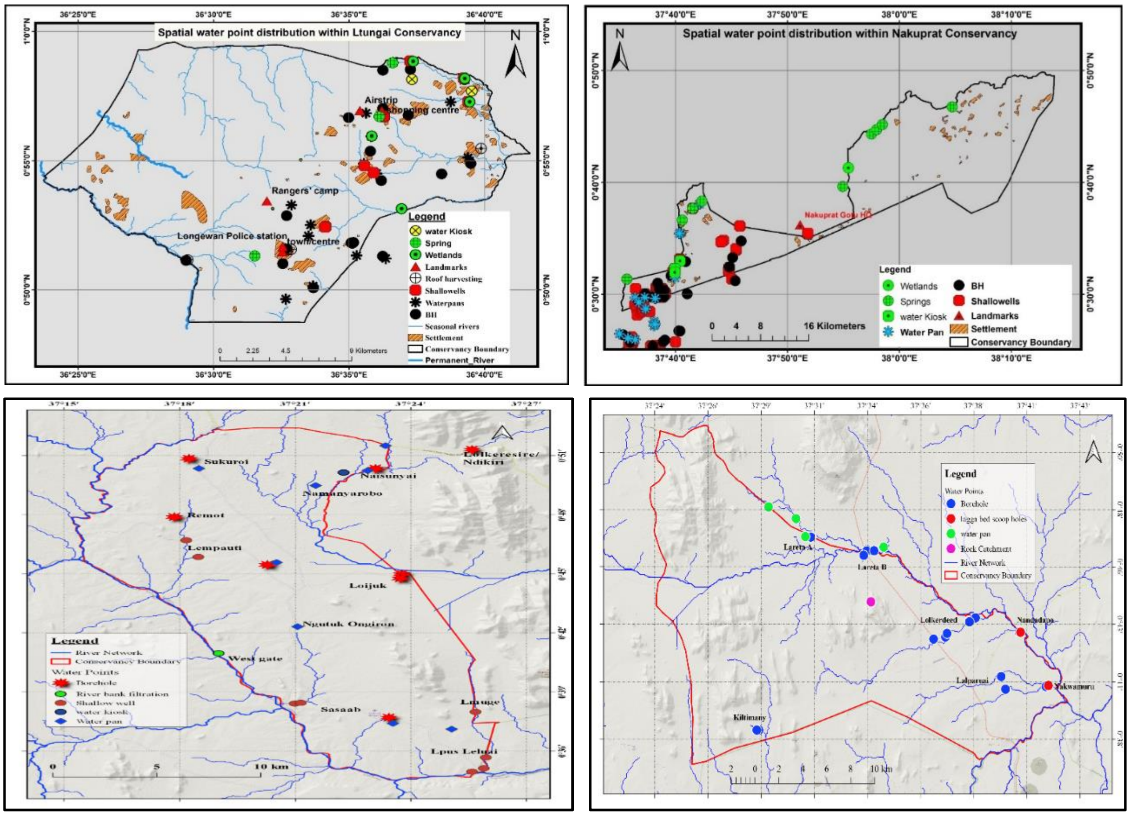


Fig. 2: Geospatial distribution of the water resources

The findings of this study reflect the challenges and opportunities that are commonly encountered in water resource management in arid and semi-arid regions. By addressing the challenges, such as those in water pan construction, and leveraging the available resources, such as alternative energy sources and diverse water sources, it is possible to improve water resource availability and accessibility. This, in turn, can contribute to enhanced livelihoods and community development in catchment areas.

Water Accessibility

Water accessibility, defined as the proportion of the population with a reliable improved water supply, aligns with internationally recognized standards. Improved sources, such as piped water, boreholes, protected springs, and rainwater collection, are essential for ensuring safe and dependable water access. Conversely, unimproved sources, including surface water from rivers, dams, and tanker truck deliveries, can raise concerns related to health and water quality (WHO and UNICEF, 2021). Our study revealed that the primary source of domestic water in the counties was groundwater (Figures 3 and 4) from boreholes, which had been drilled by a range of stakeholders, including the National and county governments and non-state actors such as the Northern Rangeland Trust (NRT), Samburu Project, and the Catholic mission. This finding is consistent with previous research, which has frequently identified boreholes as a reliable water source in arid and semi-arid regions (Zamani et al., 2022). The involvement of non-state actors in borehole construction highlights collaborative efforts to address water accessibility challenges. The boreholes examined in our study had an average depth of approximately 70 meters, with water yields ranging from 2 to 6 cubic meters per hour. These details offer valuable insights into the technical considerations of water supply. The depth of boreholes aligns with the common practice of deep drilling in semi-arid areas to access sufficient groundwater reserves, and the variability in yield can be attributed to hydrogeological conditions (Marigi, 2019).

In the West Gate Conservancy, we identified several factors affecting domestic water accessibility. Distance to water sources, socio-economic factors, political factors, and water source management emerged as key influencers. Most boreholes were conveniently located within the recommended 3-5 km radius for basic water accessibility, in accordance with Ministry of Water, Irrigation, and Sanitation guidelines. However, there were exceptions, such as the boreholes at Ngutuk Ongiron, Loijuk, and Lchoro South, which were located outside this radius, as shown in Figure 3.

The breakdown of the borehole in the Sukoroi zone is another noteworthy observation. This situation resulted in the community resorting to drawing water from Sukuroi pan for domestic purposes, illustrating the resilience of local communities when faced with water source challenges. This practice aligns with findings from similar regions, where communities adapt by turning to alternative water sources when their primary sources fail (Yifru et al., 2021).

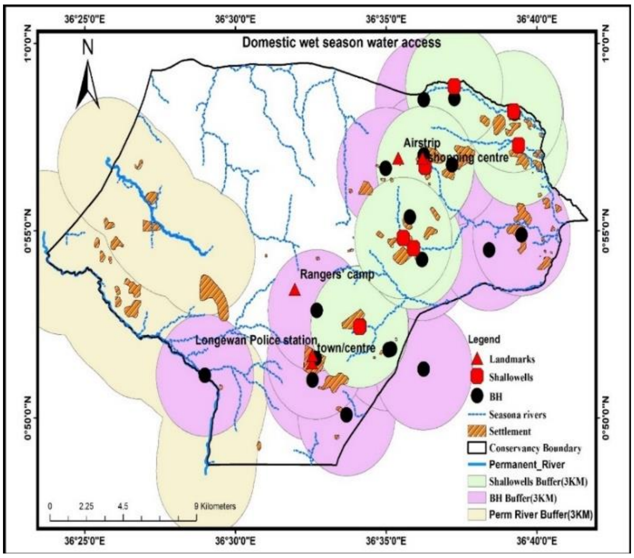
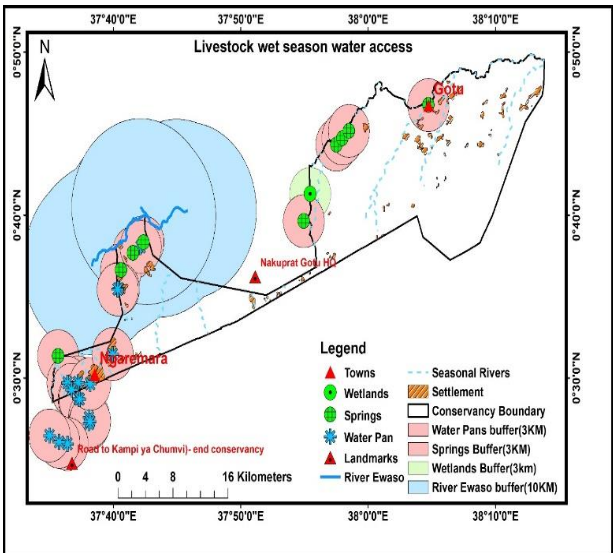


Fig. 3: Wet season domestic water access



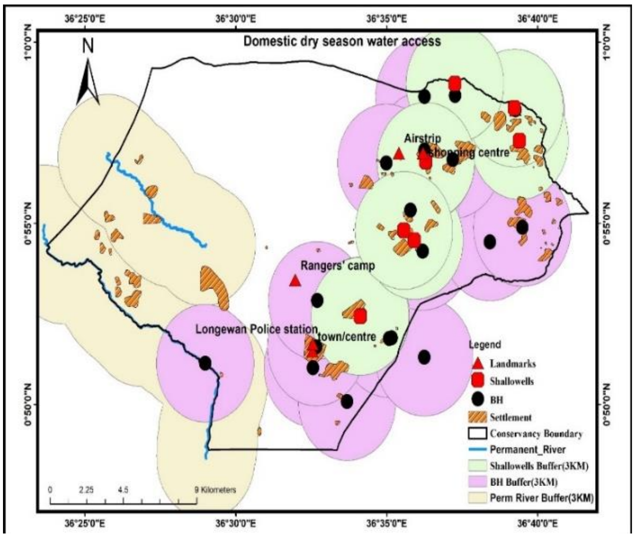
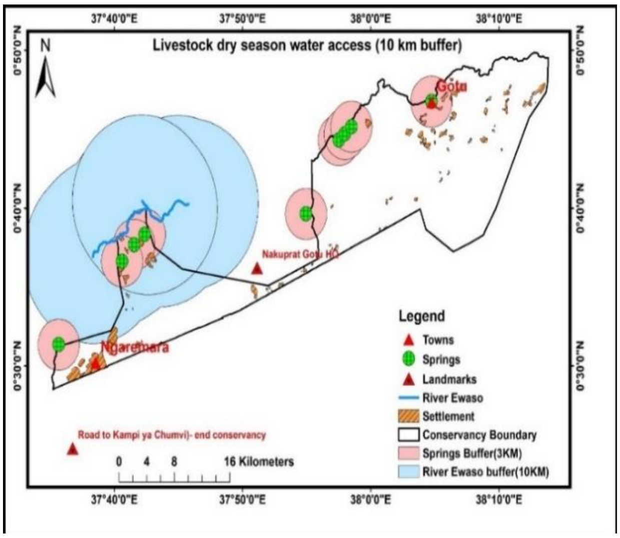


Fig. 4: Dry season domestic water access



Wet season livestock water accessibility

The Nakuprat Gotu community relies primarily on livestock and charcoal burning for their livelihood. As a result, access to water for their livestock is of paramount importance within the conservancy. During the wet season, the community utilizes a combination of water sources to cater to their livestock's needs, which includes 15 water pans, 3 main rivers, and numerous springs (Figure 5). Availability and accessibility of water by livestock is a key consideration for their well-being. Our findings reveal that the Nakuprat Gotu community strategically employs multiple water sources, including water pans, rivers, and springs. This diversification of water sources aligns with established practices in arid and semi-arid regions, where communities adopt a portfolio approach to water resource management (Hargrove et al., 2023). This approach helps them hedge against water scarcity during different seasons, ensuring a consistent water supply for their livestock.

Figure 5 illustrates that during the wet season, livestock within the conservancy enjoy relatively good water accessibility. Animals are able to access water within a 3-kilometer radius. Notably, this radius falls well below the Ministry of Water and Irrigation's recommended guideline of 10 kilometers for water accessibility. The primary reliance on livestock as a source of income and sustenance is consistent with the socio-economic landscape of many semi-arid regions. Livestock often serve as a critical lifeline for communities in such areas, emphasizing the necessity of ensuring that their water needs are met (Seré et al., 2008). The observation that livestock enjoys access to water within a 3-kilometer radius during the wet season is significant. It suggests that, at least during this period, water accessibility for livestock exceeds the Ministry's recommended radius of 10 kilometers. This finding may indicate the community's success in optimizing their use of existing water sources and management practices. It underscores the community's resilience and resourcefulness in ensuring their livestock's well-being, even in a semi-arid environment.

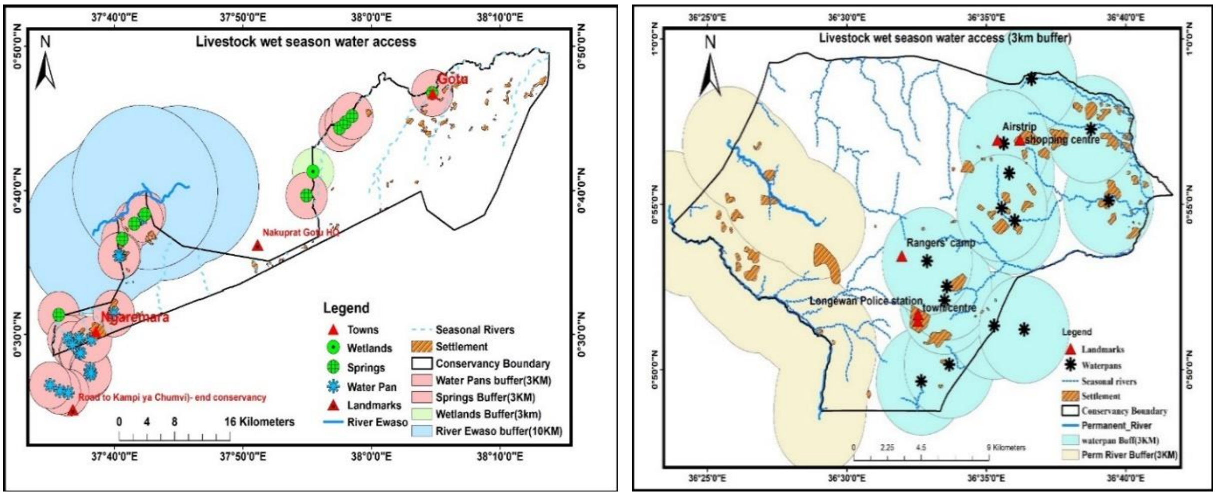


Fig. 5: Wet Season livestock water accessibility in Nakuprat Gotu conservancy.

Dry season livestock water accessibility

Nakuprat Gotu Conservancy experiences an annual dry spell from June to September, a period marked by limited water resources. Climate variability and global climatic phenomena, such as El Nino and the Indian Ocean Dipole, significantly affect the short rainy season from October to December. Climate variability and climate change can disrupt local weather patterns, including rainfall (Thornton and Herrero, 2015). These external factors compound the challenges of dry season water accessibility in the region. In addition to climate-related effects, local factors such as land degradation and overgrazing/stocking further exacerbate the issue of water accessibility during the dry season. These local factors contribute to landscape degradation, reducing its ability to retain water and impacting the availability of water for both humans and livestock (Hanjra and Qureshi, 2010).

The dry season domestic accessibility map (Figure 6) illustrates the significant variability in water accessibility within the conservancy. While some settlement zones, such as Ngare Mara, Attan, and Manyatta Zebra, have water accessible within 3 kilometers, the Gotu settlement zones face more severe challenges, with many settlements located outside the 3-kilometer buffer zone. This variation underscores the uneven distribution of water resources within the conservancy. During the dry season, when seasonal springs dry up, rivers like Amaya and Ngare-Nyiro become crucial sources of water for both communities and livestock. The year-round availability of water pans in the conservancy ensures that many livestock are well served, even during the dry season (Singh and Chudasama, 2021).

The observed water accessibility challenges in the Amaya settlement zone highlight the need for additional water infrastructure. Specifically, the recommendation to construct more water pans in this zone aims to reduce competition for water from the Amaya river, ultimately improving water access during the dry season. In light of these findings, it is evident that both external and local factors influence dry-season livestock water accessibility in semi-arid regions.

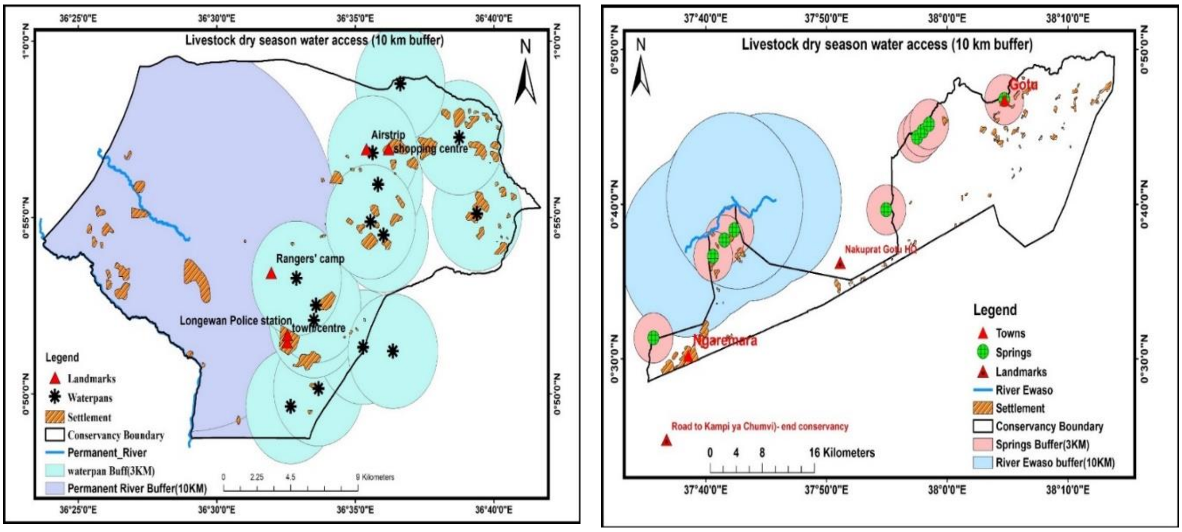


Fig. 6: Dry Season livestock water accessibility in Nakuprat Gotu conservancy.

Livestock Movement during dry season

Livestock in various conservancies and regions exhibit specific patterns of migration during the severe dry season, driven by the pressing need for pastures and water. These movements occur as the availability of these essential resources becomes increasingly scarce within their home conservancies. As shown in Figure 7, livestock migration during the dry season exerts significant pressure on the limited grazing areas and water resources in the destination regions. This migration can lead to overgrazing, resource competition, and potential degradation, underlining the importance of sustainable resource management and conflict prevention (De Haan et al., 2016).

The mention of "strategic dry season boreholes" in specific areas, such as Gotu and Merti sub-county of Isiolo county, suggests the existence of planned interventions to provide water sources for migrating livestock. This aligns with findings in similar regions where communities and authorities establish supplementary water points to support livestock during the dry season (Ngugi and Nyariki, 2005). These interventions are essential for enhancing the resilience of pastoralist communities during periods of resource scarcity. Livestock movement across county and conservancy boundaries is a common phenomenon during the dry season. These interactions between different regions can have significant implications for land use, resource management, and potential conflicts. It emphasizes the need for cross-boundary resource management and collaborative efforts between various administrative regions to address common challenges (Turner and Schlecht, 2019).

The inclusion of maps (Figure 7), showing livestock movements during the dry season, enhances our understanding of these dynamic patterns. Visual representations of these migrations are instrumental in planning and decision-making for local authorities and conservation organizations. Livestock movements during the dry season are a well-documented adaptation strategy in semi-arid regions. These movements enable communities to access distant resources to sustain their herds and livelihoods. However, it emphasizes the importance of sustainable resource management to avoid over-exploitation and ensure the long-term well-being of both people and livestock (Niamir-Fuller, 1998).

Groundwater Potential

The conservancy is predominantly covered by the Precambrian quartzite formation, an exceptionally hard metamorphic rock that originated from sandstone. Alternating areas are characterized by fractured colluvial weathered rocks and loose red soils. These geological formations pose significant challenges due to their hardness, compactness, and lack of primary porosity. These conditions create unfavourable hydrogeological circumstances for the exploitation of groundwater. Such challenges in semi-arid regions have been well-documented (Priyan, 2021). The study reveals that most of the conservancy lacks recharge zones, making the replenishment of aquifers through rainfall nearly impossible. However, specific areas within the conservancy, such as Medol, Akadol, Chumvi, Gotu, and Chofu, exhibit some potential for recharge, with rates reaching up to 220 mm per year. This localized recharge can be attributed to unique geological and hydrogeological conditions. It emphasizes the importance of understanding local variations and potential opportunities (Konikow and Kendy, 2005).

Boreholes within the conservancy are strategically located along the riparian areas of laggas, which are fairly fractured, allowing for the indirect recharge of floodwater. This strategic positioning results in higher yields, typically ranging from 10 to 18 cubic meters per hour, particularly in the South West of the conservancy (Figure 8). A variety of water pumping methods are employed, including hand and Photovoltaic systems, as well as scoop holes or singing wells. This diversity of extraction methods reflects the adaptability of the community in accessing water resources. The geological composition in the area includes volcanic layers of basalts, trachytes, phonolites overlain by regolith. While these geological formations can retain water, basalts and trachytes have limited water storage capacity and yield water primarily when fractured. The geological diversity affects the capacity of aquifers to store and transmit groundwater, underscoring the importance of understanding the local hydrogeology (Olaka et al., 2022). The conservancy experiences generally poor groundwater yield, ranging between 1 and 2.0 cubic meters per hour. This is in line with the challenges presented by hard geological formations and limited recharge areas. Water sources predominantly rely on hand pumps, submersible pumps powered by solar and diesel engines, and manual water fetching. The presence of non-functional boreholes at the time of field visits highlights the importance of effective management and maintenance to ensure the long-term reliability of water sources. Prior research has also emphasized the need for regular maintenance to sustain water access (Sahrawat et al., 2010).

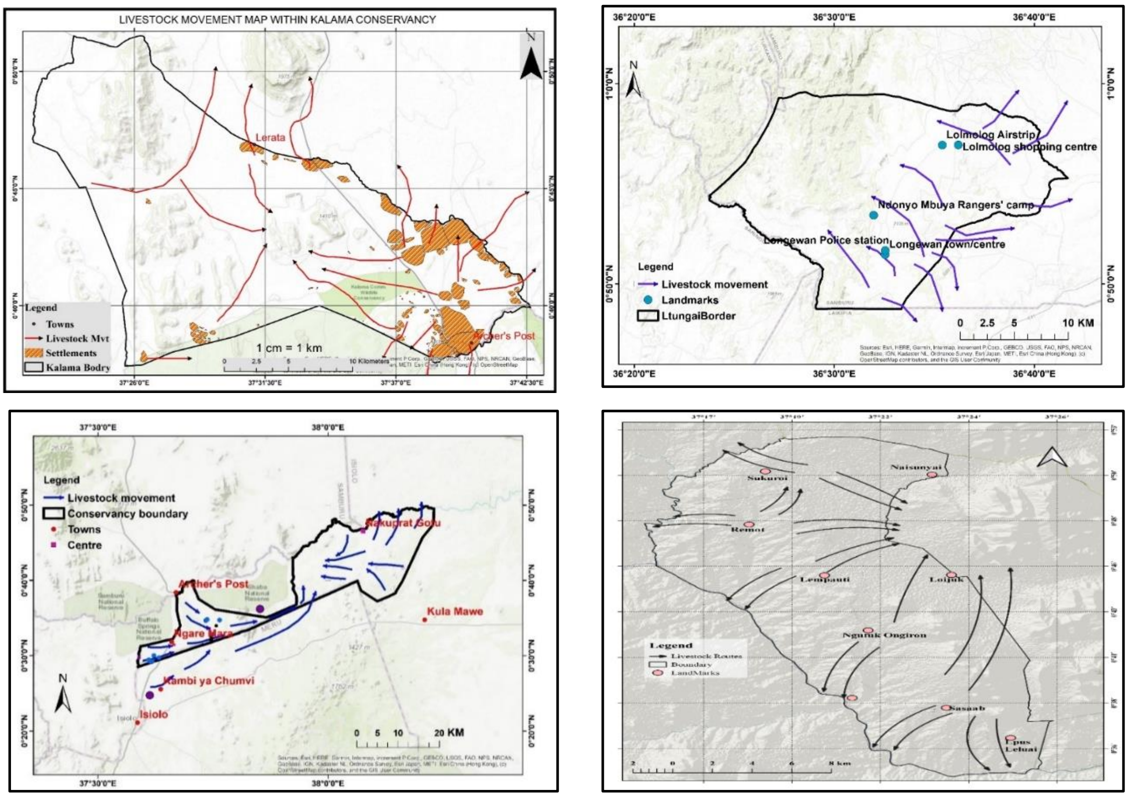


Fig. 7: Livestock movement within Kalama Conservancy.

Water quality

Water quality samples were systematically collected from all water points in Kalama conservancy using appropriate sampling techniques. Multiple parameters, including pH, dissolved oxygen (DO), and electrical conductivity, were measured to assess the quality of the water. This rigorous analysis is in line with established practices for evaluating water quality (Baird et al., 2017). The results for pH, as presented in Figure 5, revealed some variations among different water sources. Sasaab and Lempaute water pans were found to have high alkaline water, suggesting potential contamination or issues related to the method of water abstraction. In contrast, most other sources fell within the normal pH range recommended by the Kenya Bureau of Standards (KEBS). The observation of mottled teeth in both adults and children in the area raised concerns about high fluoride levels in the water. Dental fluorosis is a well-documented issue associated with excessive fluoride consumption through drinking water (WHO and UNICEF, 2021). The presence of excess algae in a water pan indicated potential water pollution. Algal blooms can be detrimental to water quality and may have adverse health effects, including the production of toxins (Anderson, 2009). In general, the water quality test indicated that the alkalinity of most water sources was within the recommended range by KEBS, except for samples from Gideon Ekadal Shallow well in Attan Settlement zone and Elati shallow well in Manyatta Zebra settlement zone. Alkaline water is not necessarily harmful, but it can affect the taste and suitability of water for different purposes.

The pH was also within the EU, (2020/2184) standards the pH value ranges between 6.5 – 8.5, indicating no need for further treatment. The findings emphasize the significance of water contamination and pollution as major health hazards and threats to groundwater aquifer water resources. Contaminants can pose serious risks to public health and the sustainability of water sources (Li and Wu, 2019). Variations in water quality, such as high alkalinity, suspected fluoride levels, and excess algae, are not uncommon in many semi-arid regions. These localized issues often result from geological and environmental factors unique to specific areas (Singhal et al., 2020). High alkalinity and suspected high fluoride levels pose potential health risks to the local population. Addressing these issues is essential to ensure the safety of the water supply, particularly for drinking and cooking (Brindha and Elango, 2011). The rigorous monitoring of water quality, as conducted in our study, is a crucial component of ensuring safe and reliable water sources. Regular testing and surveillance are necessary to detect and mitigate contamination and pollution (Rouse, 2013).

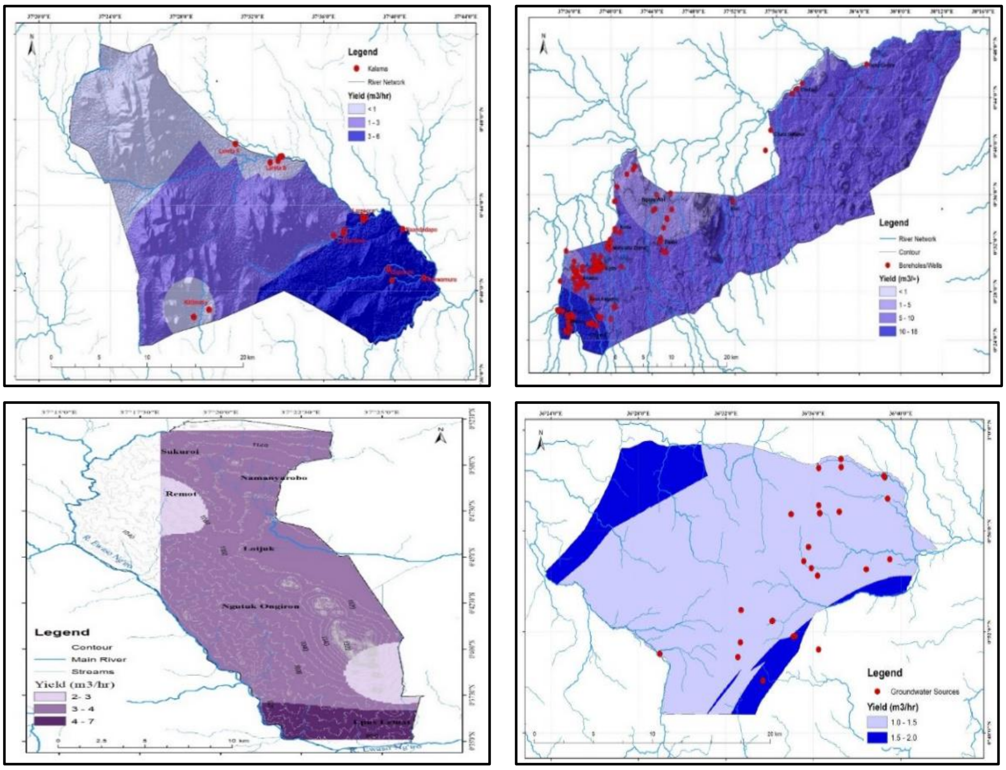


Fig. 8: Nakuprat Gotu Groundwater Potential

Total Dissolved Solids

Contamination and water pollution pose significant threats to groundwater aquifer water resources, making water quality a critical concern for the conservancy. To assess water quality, we used the electrical conductivity (EC) measurements and converted them into Total Dissolved Solids (TDS) using Equation 1.

TDS (mg/L) = EC (μS/m) x 0.640……………. (1)

The water quality test results for TDS in all the water source points tested in the conservancy were found to be within the normal range recommended by both the Kenya Bureau of Standards (KEBS) and the World Health Organization (WHO). These guidelines set the maximum allowable TDS levels in drinking water at 1500 mg/L and 1200 mg/L, respectively. TDS is a crucial parameter that offers valuable insights into water quality as it represents the total concentration of inorganic and organic substances dissolved in water. Our findings indicate that TDS levels in all tested water sources met the recommended standards (Figure 10). This conversion of EC to TDS is a standard practice in water quality analysis, allowing for a direct comparison of TDS levels with established guidelines (Escalante et al., 2020). The compliance of TDS levels with established standards is reassuring for the health and well-being of the local population. High TDS levels can adversely affect water taste and palatability. However, more importantly, excessive TDS levels can have adverse health effects when consumed in excess (WHO, 2008). These findings align with previous research in semi-arid regions, which often reports relatively low TDS levels in groundwater sources. The geology and hydrogeological conditions in such areas can contribute to the natural purification of water and the removal of dissolved solids (Wang et al., 2014).

Dissolved Oxygen

Dissolved Oxygen (DO) is a vital parameter in water quality assessment, influencing both water taste and its suitability for human consumption. Our findings reveal that most boreholes in the conservancy exhibited low DO levels (Figure 11), a characteristic typically associated with borehole water. Low DO levels can indeed affect the taste of water, particularly when consumed directly. However, it is crucial to emphasize that despite the low DO levels, all water sources within the conservancy are considered fresh and safe for human consumption. This assertion is reassuring and signifies the overall quality and safety of the water available in the conservancy. The observation of low DO levels in boreholes aligns with established knowledge about groundwater characteristics. Boreholes often tap into deeper underground aquifers, where DO levels are naturally lower compared to surface water sources. The reduced DO content in deep aquifers is primarily due to limited aeration and minimal contact with the atmosphere (Boyd, 2015). Low DO levels in water can indeed affect its taste and odor. When DO is insufficient, water may acquire a flat or stale taste, which can be noticeable to consumers. This is a common concern for individuals who rely on groundwater sources, such as boreholes, for their daily water supply (Kannel et al., 2007).

Fig. 9: pH of water in the Kalama conservancy.

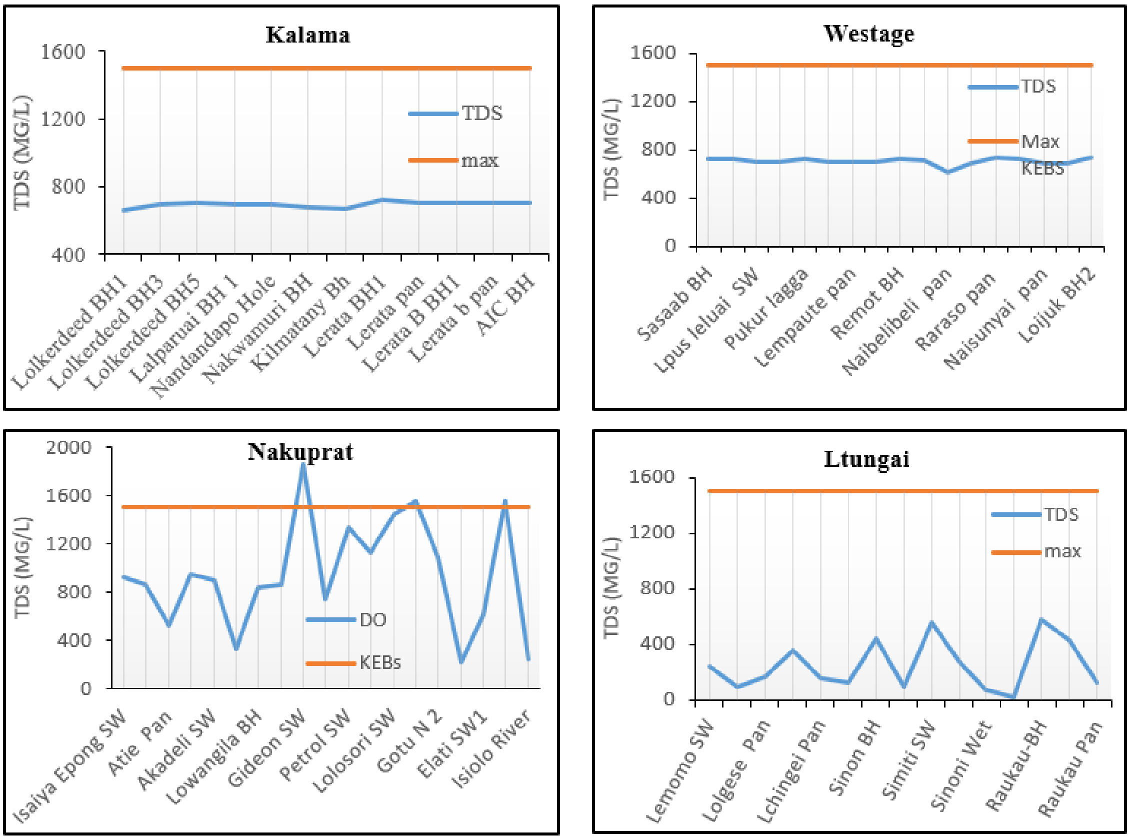


Fig.10: Total Dissolved Solids (TDS) of water source points in the conservancy.

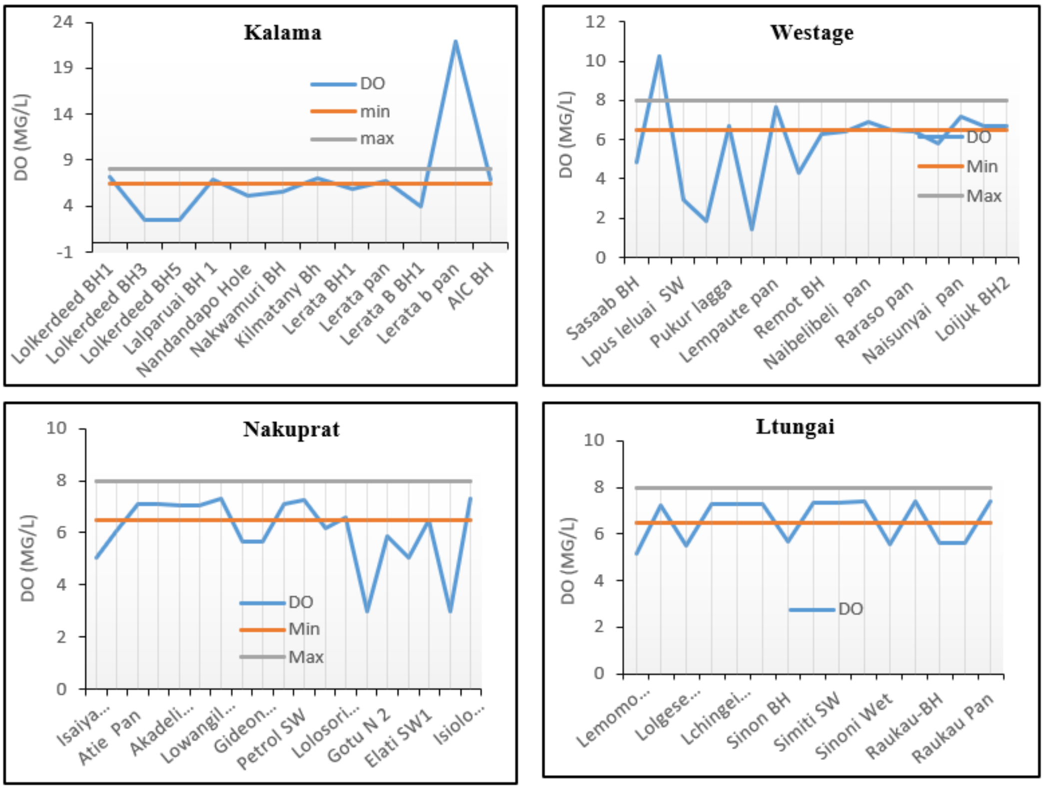


Fig. 11: Dissolved oxygen of water source points in the conservancy

The assertion that all water sources within the conservancy are considered fresh and suitable for human consumption is of paramount importance. Freshwater is generally preferred for drinking and domestic use due to its palatability and reduced risks of contamination (WHO and UNICEF, 2021).

Conclusion

This study offers a comprehensive evaluation of water resources in Isiolo and Samburu counties, focusing on the sustainability, availability, and accessibility of water in semi-arid regions. Despite the challenges, the research uncovers unique water sources in these counties that, with proper management and strategic interventions, can significantly improve local livelihoods. The study underscores the importance of community-based management, long-term maintenance plans, and the use of alternative energy sources like solar and wind power to ensure reliable access to clean water. Diversification of water sources, particularly during the wet season, emerges as a crucial strategy to combat water scarcity. Collaboration among various stakeholders is vital for sustainable water resource management. The research also identifies areas within the conservancies with potential for groundwater recharge, while others face constraints due to geological factors. Sustainable water access during the dry season is affected by climate variability, landscape degradation, and the distribution of water sources. Responsible resource management is crucial to avoid over-exploitation. Continuous monitoring of water quality is highlighted as essential, considering the risks of contamination and pollution. Overall, this research enhances our understanding of water resources in semi-arid regions, providing a basis for sustainable strategies to enhance water availability and access. Addressing challenges and leveraging opportunities can improve local livelihoods and resilience against water scarcity. The knowledge and insights gained from this study can inform future water resource management efforts in similar semi-arid areas, benefiting the well-being of the local populations relying on these vital water sources.

Acknowledgements

We appreciate the Jomo Kenyatta University of Agriculture for provision of equipment to make the research possible.

References

Akkaya, M.A, Gazioğlu, C., Yücel, Z.Y., Burak, S. (1998). Kıyı Alanlarının Rasyonel Kullanımı ve Yönetiminde Kamu Yararı İlkesi. (The Public Benefit Principle in the Rational Use and Management of Coastal Areas) *Turkey's Coastal and Marine Areas II. National Conference, Turkish Coasts 98 Conference Proceedings:*39-47.

Anderson, D. M. (2009). Approaches to monitoring, control and management of harmful algal blooms (HABs). *Ocean and Coastal Management*, *52*(7), 342–347. https://doi.org/10.1016/j.ocecoaman.2009.04.006

Baird, R., Eaton, A. D., Rice, E. W., Bridgewater, L., American Public Health Association, American Water Works Association, and Water Environment Federation. (2017). *Standard Methods for the Examination of Water and Wastewater* (E. W. Rice and R. B. A. D. E. A. D. Baird, Eds.; 23rd ed.). American Public Health Association, American Water Works Association, Water Environment Federation.

Balint, Z., Mutua, F., Muchiri, P., and Omuto, C. T. (2013). Monitoring Drought with the Combined Drought Index in Kenya. In *Developments in Earth Surface Processes* (Vol. 16, pp. 341–356). Elsevier B.V. https://doi.org/10.1016/B978-0-444-59559-1.00023-2

Boyd, C. E. (2015). *Water Quality*. Springer International Publishing. https://doi.org/10.1007/978-3-319-17446-4

Brindha, K., and Elango, L. (2011). *Fluoride in Groundwater: Causes, Implications and Mitigation Measures*. https://www.novapublishers.com/catalog/product_info.php?products_id=15895

Carter, R. C., Tyrrel, S. F., and Howsam, P. (1999). The Impact and Sustainability of Community Water Supply and Sanitation Programmes i n Developing Countries. *J. CIWEM*, 1–5.

De Haan, C., Robinson, T., Conchedda, G., Ericksen, P., Said, M., Robinson, L., Flintan, F., Shaw, A., Kifugo, S., Wane, A., Touré, I., Ickowicz, A., Corniaux, C., Barr, J., Martignac, C., Mude, A., Cervigni, R., Morris, M., Mottet, A., … Alfani, F. (2016). Livestock Production Systems: Seizing the Opportunities for Pastoralists and Agro-pastoralists. In *Confronting Drought in Africa's Drylands* (pp. 47–70).

DelGrosso, Z. L., Hodges, C. C., and Dymond, R. L. (2019). Identifying Key Factors for Implementation and Maintenance of Green Stormwater Infrastructure. *Journal of Sustainable Water in the Built Environment*, *5*(3). https://doi.org/10.1061/jswbay.0000878

Erda, L., Wei, X., Hui, J., Yinlong, X., Yue, L., Liping, B., and Liyong, X. (2005). Climate change impacts on crop yield and quality with CO2 fertilization in China. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1463), 2149–2154. https://doi.org/10.1098/rstb.2005.1743

Eriksen, S., and Lind, J. (2009). Adaptation as a political process: Adjusting to drought and conflict in kenya's Drylands. *Environmental Management*, *43*(5), 817–835. https://doi.org/10.1007/s00267-008-9189-0

Escalante, E. F., Casas, J. D. H., Medeiros, A. M. V., and Sauto, J. S. S. (2020). Regulations and guidelines on water quality requirements for Managed Aquifer Recharge. International comparison. *Acque Sotterranee - Italian Journal of Groundwater*, *9*(2), 7–22. https://doi.org/10.7343/as-2020-462

European Union. (2020). Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption. Journal of the European Union, L 435/1. https://eur-lex.europa.eu/eli/dir/2020/2184/oj

Garg, K. K., and Wani, S. P. (2012). Opportunities to Build Groundwater Resilience in the Semi-Arid Tropics. *Groundwater*, no-no. https://doi.org/10.1111/j.1745-6584.2012.01007.x

Hanjra, M. A., and Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy*, *35*(5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006

Hargrove, W. L., Heyman, J. M., Mayer, A., Mirchi, A., Granados-Olivas, A., Ganjegunte, G., Gutzler, D., Pennington, D. D., Ward, F. A., Chavira, L. G., Sheng, Z., Kumar, S., Villanueva-Rosales, N., and Walker, W. S. (2023). The future of water in a desert river basin facing climate change and competing demands: A holistic approach to water sustainability in arid and semi-arid regions. *Journal of Hydrology: Regional Studies*, *46*. https://doi.org/10.1016/j.ejrh.2023.101336

Harvey, P., Reed, B., and Water, E. (2004). *Rural water supply in Africa: building blocks for handpump sustainability*. Water, Engineering and Development Centre.

Howard, G., Bartram, J., Williams, A., Overbo, A., Fuente, D., and Geere, J.-A. (2020). *Domestic water quantity, service level and health, Second edition.* (Second edition). World Health Organization.

Kakumba, U. (2010). International Review of Administrative Sciences Local government citizen participation and rural development: reflections on Uganda's decentralization system. *International Review of Administrative Sciences*, *76*(1), 171–186.

Kannel, P. R., Lee, S., Lee, Y. S., Kanel, S. R., and Khan, S. P. (2007). Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. *Environmental Monitoring and Assessment*, *132*(1–3), 93–110. https://doi.org/10.1007/s10661-006-9505-1

Konikow, L. F., and Kendy, E. (2005). Groundwater depletion: A global problem. *Hydrogeology Journal*, *13*(1), 317–320. https://doi.org/10.1007/s10040-004-0411-8

Li, P., and Wu, J. (2019). Drinking Water Quality and Public Health. *Exposure and Health*, *11*(2), 73–79. https://doi.org/10.1007/s12403-019-00299-8

Marigi, S. N. (2019). *Hydrology and Best Practices for Managing Water Resources in Arid and Semi-Arid Lands in Kenya* (pp. 229–250). https://doi.org/10.4018/978-1-7998-0163-4.ch011

Melissa, A., Lesamana, J., and Havnevik, K. (2009). *Transition from Subsistence to Monetary Economy-A Counter Discourse to Mainstream Development Strategies. Case study from Samburu District, Kenya*.

Ministry of Water and Irrigation (MWI). (2011). *Water sector status report.*

Mutsotso, R. B., Sichangi, A. W., and Makokha, G. O. (2018). Spatio-Temporal Drought Characterization in Kenya from 1987 to 2016. *Advances in Remote Sensing*, *07*(02), 125–143. https://doi.org/10.4236/ars.2018.72009

Nanyingi, M. O., Mbaria, J. M., Lanyasunya, A. L., Wagate, C. G., Koros, K. B., Kaburia, H. F., Munenge, R. W., and Ogara, W. O. (2008). Ethnopharmacological survey of Samburu district, Kenya. *Journal of Ethnobiology and Ethnomedicine*, *4*. 10.1186/1746-4269-4-14.

NEMA. (2009). *Samburu District environment action plan 2009-2013.* Retrieved from Www.Nema.Go.Ke.

Ngugi, R. K., and Nyariki, D. M. (2005). Rural livelihoods in the arid and semi-arid environments of Kenya: Sustainable alternatives and challenges. *Agriculture and Human Values*, *22*(1), 65–71. https://doi.org/10.1007/s10460-004-7231-2

Niamir-Fuller, M. (1998). The Resilience of Pastoral Herding in Sahelian Africa. In E. Fratkin, K. A. Galvin, and E. A. Roth (Eds.), *African Pastoralist Systems: An Integrated Approach* (2nd ed., pp. 127–149). Lynne Rienner Publishers.

Olaka, L. A., Kasemann, S. A., Sültenfuß, J., Wilke, F. D. H., Olago, D. O., Mulch, A., and Musolff, A. (2022). Tectonic Control of Groundwater Recharge and Flow in Faulted Volcanic Aquifers. *Water Resources Research*, *58*(7). https://doi.org/10.1029/2022WR032016

Priyan, K. (2021). Issues and challenges of groundwater and surface water management in semi-arid regions. In C. B. Pande and K. N. Moharir (Eds.), *Groundwater Resources Development and Planning in the Semi-Arid Region* (pp. 1–18). Springer Nature. https://doi.org/https://doi.org/10.1007/978-3-030-68124-1

Quinn, C. H., Huby, M., Kiwasila, H., and Lovett, J. C. (2007). Design principles and common pool resource management: An institutional approach to evaluating community management in semi-arid Tanzania. *Journal of Environmental Management*, *84*(1), 100–113. https://doi.org/10.1016/j.jenvman.2006.05.008

Roth, E. A. (1991). Education, Tradition, and Household Labor among Rendille Pastoralists Northern Kenya. In *Human Organization* (Vol. 50, Issue 2).

Rouse, M. (2013). *Institutional governance and regulation of water services.* (2nd ed.). IWA publishing.

Sahrawat, K. L., Wani, S. P., Pathak, P., and Rego, T. J. (2010). Managing natural resources of watersheds in the semi-arid tropics for improved soil and water quality: A review. In *Agricultural Water Management* (Vol. 97, Issue 3, pp. 375–381). https://doi.org/10.1016/j.agwat.2009.10.012

Scholes, R. J. (2020). The future of semi-arid regions: A weak fabric unravels. *Climate*, *8*(3). https://doi.org/10.3390/cli8030043

Seré, A., Ayantunde, A., Duncan, A., Freeman, M., Herrero, S., Tarawali, I., and Wright. (2008, June 29). Livestock production and poverty alleviation - challenges and opportunities in arid and semi-arid tropical rangeland based systems. *The XXI International Grassland Congress / VIII International Rangeland Congress*.

Singh, P. K., and Chudasama, H. (2021). Pathways for climate change adaptations in arid and semi-arid regions. *Journal of Cleaner Production*, *284*. https://doi.org/10.1016/j.jclepro.2020.124744

Singhal, A., Gupta, R., Singh, A. N., and Shrinivas, A. (2020). Assessment and monitoring of groundwater quality in semi –arid region. *Groundwater for Sustainable Development*, *11*. https://doi.org/10.1016/j.gsd.2020.100381

Stroosnijder, L. (2003). Water Conservation Technologies for Sustainable Dryland Agriculture in Technologies for Improving Green Water Use Efficiency in West Africa. *Africa Symposium and Workshop*.

Thornton, P. K., and Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. In *Nature Climate Change* (Vol. 5, Issue 9, pp. 830–836). Nature Publishing Group. https://doi.org/10.1038/nclimate2754

Turner, M. D., and Schlecht, E. (2019). Livestock mobility in sub-Saharan Africa: A critical review. In *Pastoralism* (Vol. 9, Issue 1). SpringerOpen. https://doi.org/10.1186/s13570-019-0150-z

Wang, H., Wang, T., Zhang, B., Li, F., Toure, B., Omosa, I. B., Chiramba, T., Abdel-Monem, M., and Pradhan, M. (2014). Water and Wastewater Treatment in Africa - Current Practices and Challenges. In *Clean - Soil, Air, Water* (Vol. 42, Issue 8, pp. 1029–1035). Wiley-VCH Verlag. https://doi.org/10.1002/clen.201300208

WHO, and UNICEF. (2021). *Progress on household drinking water, sanitation and* *hygiene 2000-2020: five years into the SDGs.* http://apps.who.int/bookorders.

WHO. (2008). *Guidelines for Drinking-water Quality* (3rd ed., Vol. 1). WHO press.

Yifru, B. A., Kim, M. G., Lee, J. W., Kim, I. H., Chang, S. W., and Chung, I. M. (2021). Water storage in dry riverbeds of arid and semi-arid regions: Overview, challenges, and prospects of sand dam technology. In *Sustainability (Switzerland)* (Vol. 13, Issue 11). MDPI. https://doi.org/10.3390/su13115905

Zamani, M. G., Moridi, A., and Yazdi, J. (2022). Groundwater management in arid and semi-arid regions. *Arabian Journal of Geosciences*, *15*(4), 362. https://doi.org/10.1007/s12517-022-09546-w.