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Water Accessibility and Quality, for Sustainable Water Resource Management in Kenyan Arid Lands; A Case Study of Kalepo and Ngilai Conservancies

Mary Makokha[a&*]

[a]Assistant Professor, Geography Department, Kenyatta University, Nairobi, Kenya.

[*]Corresponding Author, E-mail address: makokha.mary@ku.ac.ke

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Abstract

Kenya's arid lands, including Ngilai and Kalepo conservancies, face multiple challenges such as poverty, poor infrastructure, weak governance, and climate change—leading to prolonged droughts, flash floods, and declining water sources. This study investigates water accessibility, depth, and quality of 125 water sources using focus group discussions (FGDs) and water quality experiments. Rainfall analysis showed 1997 as the wettest year (RAI +4.6, El Niño) and 2017 as the driest (RAI –4.2). A Mann-Kendall trend test revealed a non-significant positive trend ($p = 0.368$). Most water pans deplete within two months of dry season onset, and face issues like siltation, poor infrastructure, and contamination. Capacities ranged from 150–12,000 m^3 with depths of 0.5–2 m. Boreholes are the main water source, while Kalepo also features springs and seasonal rivers due to its undulating terrain. The geology comprises metamorphic and sedimentary rocks. In wet seasons, seasonal springs within 3 km buffers offer accessible domestic water. During dry seasons, water conflicts occur within 10 km zones due to human-wildlife competition. Livestock migrates to the Mathews Ranges in search of vegetation, the perennial Ewaso Ngiro River, and permanent boreholes. Groundwater recharge occurs in sandy seasonal laggas, with yields of 5 m^3/hr and borehole depths of 103–122 m, aided by fault lines. Water pH ranged from 6.5- 8.64, indicating acidic to slightly alkaline conditions, while EC values ranged from 250 to 4000 µS/cm. Findings highlight the need to improve water storage and manage siltation to build climate-resilient communities.

Keywords: Seasonal variation, Water accessibility, Water management, Water quality, Water source

1. Introduction

Dryland resilience entails the capacity to navigate through various stressors and unexpected challenges, adapting or even transforming in the midst of uncertainty. This resilience is crucial for fostering development, enhancing human well-being, and ensuring the sustainability of water, ecosystems, and livelihoods that directly depend on them (Barrett and Constas, 2014; Mortimore et al., 2009; Reed and Stringer, 2015). Enhancing dryland resilience involves bolstering human capabilities to manage both social and climate-related stressors, enabling adaptation or transformation amidst uncertainty. This fortification empowers communities to persist within the system, ensuring their sustained presence and well-being. (Engle, 2011; Folke, 2016).

Given the importance of water resources for both human well-being and ecosystem health, understanding the dynamics of water availability and quality in arid regions is paramount. Effective water resource management strategies must consider the climatic, ecological, social, and economic dimensions of water use, taking into account the needs of both present and future generations (Smith and Jones, 2020). Water resource management in arid regions is a complex endeavor shaped by climatic variability, population growth, and competing demands from agriculture, industry, and domestic use (Paz, et al., 2018). The escalating water challenges faced by arid regions have been extensively documented in numerous research publications (Smith et al., 2020).

Arid regions in Kenya, are characterized by low precipitation levels and high evaporation rates, resulting in limited freshwater availability (UNEP, 2019). According to the Kenya Water Act of 2016, water resources in Kenya are governed by regulations aimed at ensuring equitable access and efficient management (Kenya Water Act, 2016). However, the implementation of these regulations in arid regions faces unique obstacles due to the sporadic nature of water availability and the vulnerability of ecosystems to water stress (UNDP, 2020). Regulating water supply is the overarching dryland ecosystem service which has a negative effect on all dryland livelihoods (Safriel et al., 2005). Water governance plays a major role in dryland development pathways and needs to address climatic uncertainty and changing social-ecological system conditions, that affect the water quality and quantity endangering its livelihoods in the drylands (Davies et al., 2016; DeCaro et al., 2017b; Smidt et al., 2016).

In the Arid and Semi-Arid Lands (ASAL) in northern Kenya, water availability and accessibility face a wide range of challenges stemming from poverty, inadequate infrastructure, and inadequate governance. Samburu county is remote and geographically isolated occupied mainly by pastoralist communities who grapple daily with the escalating impacts of climate change (Makokha, et al., 2024) Lengthening dry spells, intensifying droughts, and diminishing surface water reserves exacerbate their plight, making access to water for household and productive purposes increasingly precarious. Achieving Sustainable Development Goal (SDG), a universal access to clean water and sanitation, seems like a distant aspiration, especially considering that only 59% of Kenyans enjoy basic access to drinking water. Water supply and distribution remains one of the most glaringly inequitable facets of pastoral life. Governance structures are hampered by deficient policies, compounded by challenges in water legislation and management, exacerbated by the devolution of water management responsibilities to county governments.

In Samburu County where Kalepo and Ngilai conservancy lies, water security is a major community concern whose absence sparks conflicts, loss of livelihoods, poverty and misery (Mutsotso et al., 2018) During the dry season over 91% of the rural households in the county suffer a serious threat of water security. This situation is exacerbated by climate variability, conflicts, shared water resources, land degradation and vandalism (DelGrosso et al., 2019)

While previous studies have examined water scarcity in Kenya's drylands, there remains a critical knowledge gap in localized assessments of water availability, quality, and governance in conservancy-managed landscapes. This study uniquely integrates long-term satellite rainfall data with community-based field assessments to evaluate water source accessibility, depth, quality, and management practices in Ngilai and Kalepo conservancies. By combining geospatial analysis, water quality testing, and focus group discussions, this research provides a holistic understanding of how local communities address water scarcity amid climatic and socio-political challenges.

2. Materials and Methods

2.1. Study area

Kalepo and Ngilai are form part of the conservation units of the expansive Namunyak Conservancy which constitutes 39 conservancies under the Northern Rangeland Trust (NRT) in Samburu County. These conservancies lie approximately between latitude 1.42° to 1.66° N and longitude 37.14° to 37.25° E. The Kalepo conservancy unit is divided into West and East by the Mathews range of mountains Figure 1.

2.2. Temperature and rainfall of study area

Their climate is majorly influenced by the embossing Mathews range of mountains which is about 2689 meters above mean sea level that traverses it. The rainfall distribution in the unit is bimodal with peaks of long rains in March/April and short rains in October/November (Figure 2). The region experiences a long dry spell from June to October and a short dry spell in January to March. Rainfall is relatively low and highly variable with mean annual minimum of 250 mm and mean annual maximum of about 800 mm (Figure 3). The minimum and maximum daily temperatures within the Matthews Range Forest and surrounding lowlands recorded for the last decade are estimated at 12.3^{0}C – 15.5^{0}C minimum and 31.8^{0}C to 32.8^{0}C maximum. The extreme variation of recorded monthly range of temperatures shows a large disparity range of at least 16.0^{0}C while the mean monthly range varies between 5.5^{0}C and 7.5^{0}C. The main economic activity of Kalepo community is nomadic pastoralism with over 90% earning their living from income obtained from rearing of livestock. Other livelihoods include sale of livestock and forestry products.

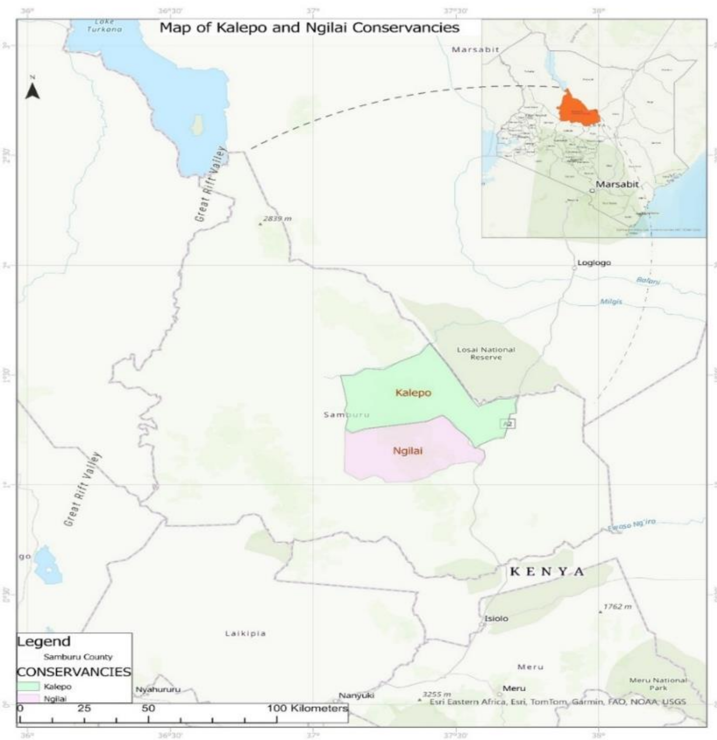

Fig. 1. Map of the study area

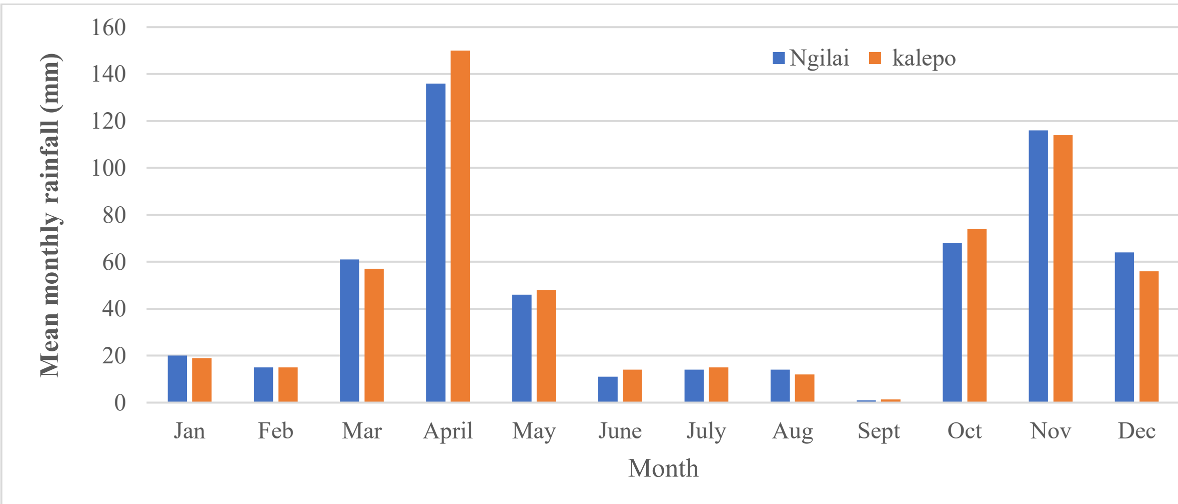

Fig. 2. Mean monthly rainfall of Kalepo and Ngilai Conservancies

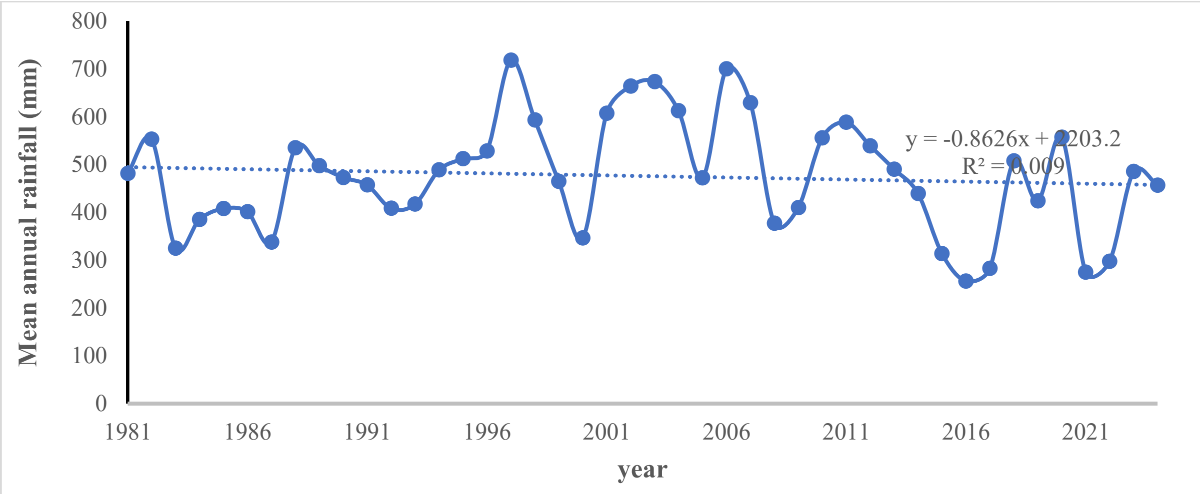

Fig. 3. Mean annual rainfall of Samburu County (1981-2024). Data source: NASA POWER (Prediction of Worldwide Energy Resource), accessed July 2025.

2.3. Methodology

This study employed a mixed-methods approach that combined spatial mapping, water quality analysis, climate data review, and community-based participatory assessments. Fieldwork was conducted to both ground truth secondary data obtained from literature and remote sources and to collect primary data on the location, type, and quality of water sources, as well as community perceptions regarding water availability.

The study methodology involved the following:

A: Secondary data collection

The study conducted a comprehensive desktop literature review of water resources within the two conservancies: Kalepo and Ngilai. Extensive review was done from diverse information sources, including government reports at both national and county levels, materials from non-governmental organizations, published research, and online resources to capture information on water resources within these conservancies. The reviewed data included: the nature and geographical distribution of available water resources, detailed measurements of water volume, storage capacity, flow rates, and depths. Furthermore, information on; water utilization for domestic, livestock, and irrigation purposes, alongside with considerations of water quality was studied.

The study also looked at; satellite imagery, Google Earth images, geological reports, borehole Environmental Impact Assessment (EIA) reports, borehole completion records, and drilling-related documentation and topographical maps to help understand the water resources more. This analysis was aimed at identifying the location and characteristics of various water resources, including rivers, reservoirs, water pans, sand dams, and subsurface dams. Regarding groundwater data, information collected included: boreholes and shallow wells geographical coordinates, quantity, construction year, depth, yield, abstraction methods, drilling records, utilization, water quality, and the population served. The geology was also determined from the country's geological map. The stepwise flow chart is as seen in Figure 4.

B: Site visits and laboratory experiments

B-1: Ground truthing and spatial mapping

To verify the location of water points, Global Positioning System (GPS) devices were used to map both surface and subsurface water sources. These included sand dams, water pans, reservoirs, shallow wells, boreholes, and seasonal streams. The coordinates were recorded in decimal degrees and later used to develop geospatial maps using GIS software for spatial distribution analysis of water infrastructure across the two conservancies.

B-2: Water quality assessment

To assess the quality of available water resources, physical and chemical parameters were measured—specifically pH and Electrical Conductivity (EC)—as standard indicators of water suitability for human and livestock use.

B-2-1: Sampling Procedure

Water samples were collected from each water point visited during the field survey. A 250 ml plastic sampling bottle was used, and standard protocol was followed: each bottle was rinsed three times with the target sample before the actual sample was collected to minimize cross-contamination. For open water sources (e.g., water pans), samples were taken from a representative point away from stagnation or edge contamination.

B-2-2: Field Measurement

On-site measurements of pH and Electrical Conductivity (µS/cm) were taken using a Hanna HI 9142 multiparameter portable meter. The instrument was calibrated before field use, and readings were taken at each site after stabilization. The values were recorded for later interpretation in line with WHO and national water quality standards.

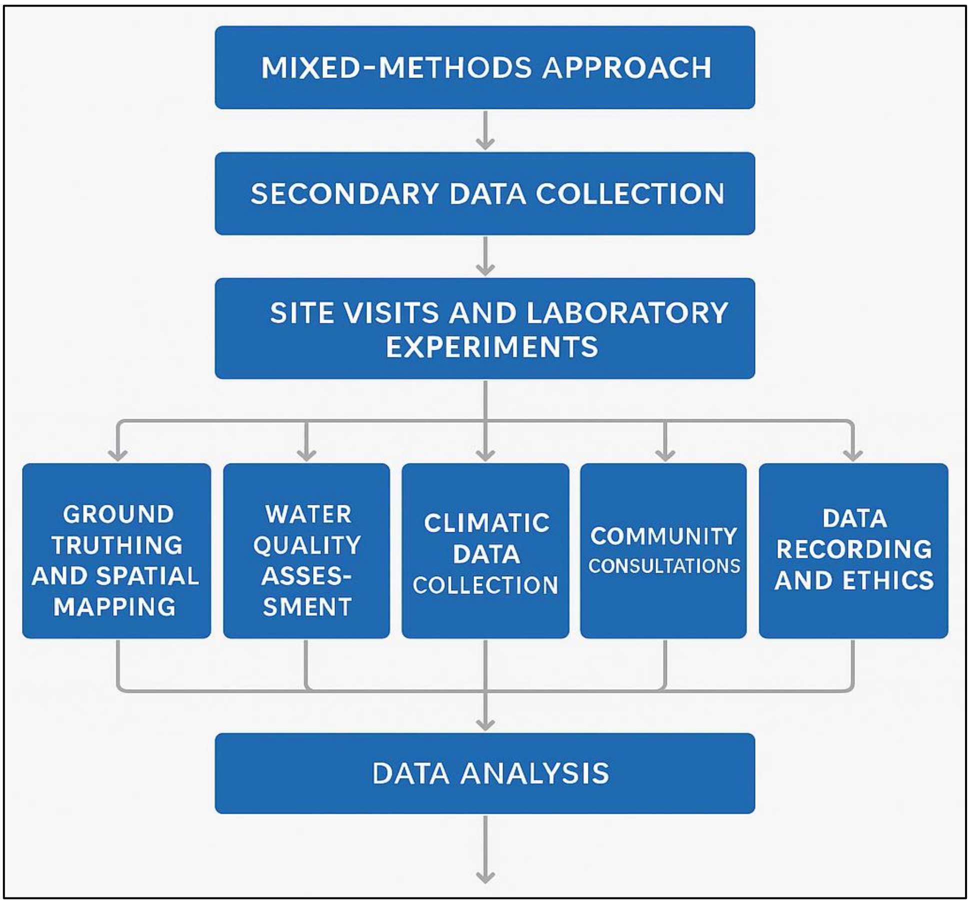

Fig. 4. Stepwise flowchart of Methodology

B-3: Climatic Data Collection

Historical climatic data—including rainfall, temperature, and evaporation—were obtained from the Kenya Meteorological Department (KMD) for a period of approximately 40 years (1981–2024). This dataset provided a basis for assessing long-term climatic trends influencing water availability in the region. The data were sourced from nearby KMD weather stations and validated using available metadata for consistency.

B-4: Community Consultations

To complement physical measurements, focus group discussions (FGDs) were conducted with community elders, water user committee members, and relevant government officials at the local level. The purpose was to understand historical trends in water availability, the perceived impact of sand dams, and adaptive strategies used during dry seasons.

B-4-1: Sampling and tools

Participants for FGDs were selected purposively to ensure a balance of gender, age, and local knowledge. Each group consisted of 6–10 participants and discussions were guided by a semi-structured checklist. Key topics included seasonal water availability, changes before and after sand dam construction, water conflict dynamics, and indigenous water management practices.

B-4-2: Data recording and ethics

Discussions were held in local languages with the help of interpreters where necessary. Notes were taken by trained enumerators, and participants gave verbal informed consent prior to participation. Ethical considerations were upheld, including confidentiality and cultural sensitivity.

B-5: Data analysis

Water quality data were analyzed descriptively using mean values, and results compared to threshold values for domestic and livestock use. Climatic data were analyzed using the Mann-Kendall trend test and Sen's slope estimator to detect significant trends in annual rainfall. Spatial data (GPS coordinates) were mapped using QGIS to visualize the distribution of water points.

Qualitative data from FGDs were thematically analyzed to identify recurring perceptions and experiences related to water availability and use.

3. Results and Discussion

3.1. Rainfall Trend Analysis of Seasonal Rainfall in Samburu County, Kenya (1981–2024)

To assess changes in annual rainfall from 1981 to 2024, both the Augmented Dickey-Fuller (ADF) and Mann-Kendall (MK) tests were applied. The ADF test returned a statistic of –3.97 (p = 0.0016), indicating stationarity in the time series. This confirms that the mean and variance remained stable over time, justifying further trend analysis. The MK test yielded an S value of –22 and a Z-score of –0.21 (p = 0.83), suggesting no statistically significant trend. Although the results hint at a slight decrease in rainfall, the trend is weak and not significant. These findings highlight that annual rainfall in the study area fluctuates from year to year but does not exhibit a clear long-term trend, emphasizing the need to prioritize variability and extremes in water resource planning.

For the March-April-May (MAM) long rains, a near-significant increasing trend was observed (Z = 1.92, p = 0.055), with Sen's slope indicating a rise of +1.12 mm/year, aligning with observed regional precipitation shifts in East Africa (Ongoma et al., 2018).The October-November-December (OND) short rains showed no significant trend (Z = -0.25, p = 0.80), consistent with pastoralists' reports of stable short rains despite increasing droughts (Samburu County Government, 2020). Annual trends were non-significant (p = 0.51), though a slight increase (+0.63 mm/year) mirrors global arid-region variability (IPCC, 2021). The rainfall anomaly index (RAI) was also calculated to determine the wet and dry years and results are as seen in Figure 5.

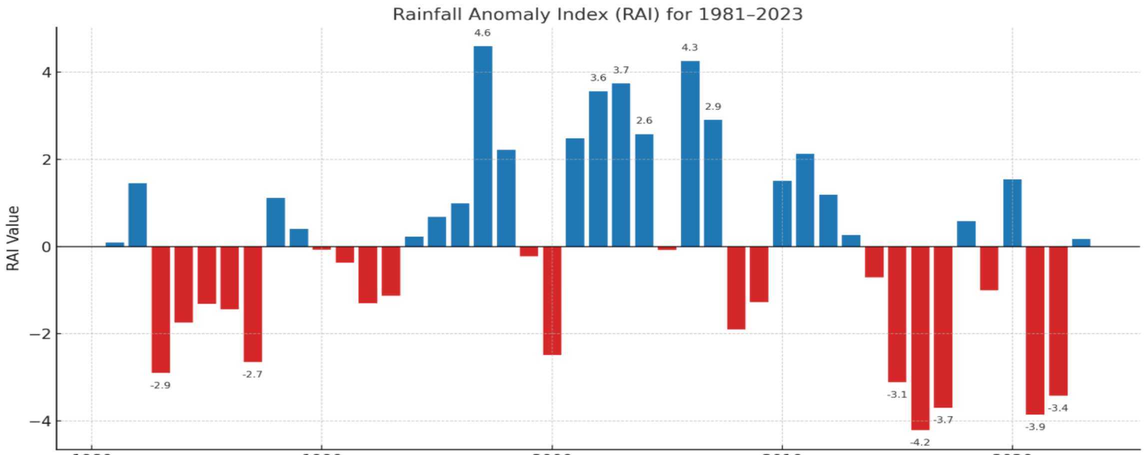

Fig. 5. Rainfall anomaly index (RAI) for Kalepo and Ngilai Conservancies in Samburu County

The analysis revealed that the wettest year within the 1981–2024 period was 1997, with a Rainfall Anomaly Index (RAI) of approximately +4.6, coinciding with the strong El Niño event that year. In contrast, the driest year was 2017, with an RAI of –4.2, followed closely by 2021 (–3.9) and 2022 (–3.4), all of which reflect the recent severe droughts experienced across Kenya. These findings highlight distinct periods of anomalously high and low rainfall, demonstrating clear inter-annual variability and prolonged phases of both dryness and wetness, which have significant implications for water availability, agriculture, and pastoral livelihoods in the region

3.2. Water sources

The study examined approximately 125 water sources, encompassing boreholes, water pans, shallow wells, perennial rivers, seasonal rivers, and rainwater harvesting systems, among others. Findings revealed that the majority of water pans experienced depletion within two months following the onset of dry weather, particularly evident in August. Notably, the water pans established by the national government in Ndonyo Wasin proved to be the sole perennial water sources, sustaining through the dry period and primarily serving small ruminant livestock, aligning with prior research conducted by Nyaligu (2013).

Boreholes emerged as the predominant water source (Figure 6), particularly prominent within Ngilai conservancy, while springs and seasonal rivers were prevalent in Kalepo, attributed to the topography and the presence of the Mathews ranges within the conservancy. Previous research by, Kiringe et al. (2016) also underscored the influence of topography on water source distribution.

Key challenges observed in water pans encompassed high siltation due to the absence of silt traps, inadequate watering points, and contamination by livestock and wildlife (Sternfert et al., 2020). Additional factors included poor design and construction, poor site selection, lack of protection and fencing, and absence of spillways. Water pans capacities ranged from 150-12,000 m^3 with depths of 0.5-2 m. Shallow wells, also known as singing wells, served as another vital water source for livestock, particularly situated along dry Laggas, drawing from unconfined alluvial aquifers beneath significant sand deposits (Churu et al., 2023). These wells served as alternative sources during dry seasons and represented promising sites for constructing sub-surface dams to enhance water storage and groundwater recharge. Boreholes within the conservancy lacked documented records of repair and maintenance, and a structured management system was absent, typically overseen by community elders or their designees (Kiringe et al., 2016). Other water sources included sand dams, rock catchments, wetlands (adjacent to Milgis river), and gravity water systems. Figure 7 illustrates the drainage system within the conservancies.

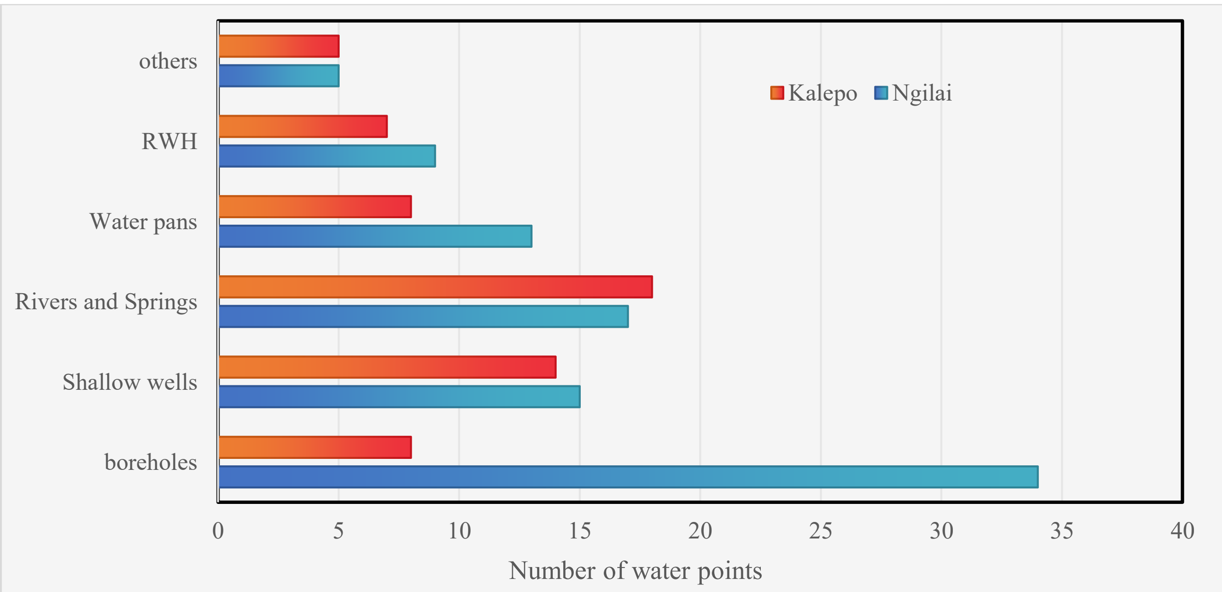

Fig. 6. The water sources in Ngilai and Kalepo Conservancies

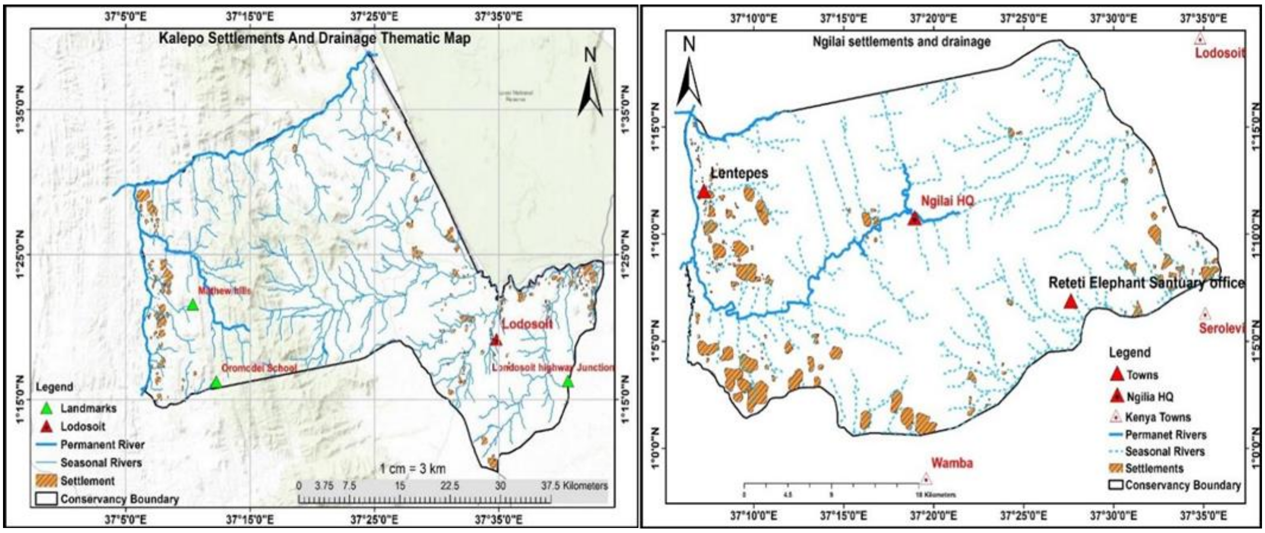

Fig. 7. Kalepo and Ngilai Community Conservancy settlement and drainage map

3.3. Geology and Soils

Studies on geology of Kenya from (bgs.ac.uk) revealed that the ecosystem formation is from erosion of the Precambrian basement rock system that consists of metamorphic and sedimentary rocks (Figure 8) The rock system has gneiss, granites and fluvial accumulation of sediments and soils deriving from volcanic activities. The soil characteristics are strongly influenced by topography which dictated the drainage system Matchavariani, (2019). Soils of the lowlands were generally waterlogged, very deep, dark greyish brown, saline calcareous clay. These is important as it influences the water quality and aquifer formation and groundwater recharge within the ecosystem.

3.4. Water accessibility

Water accessibility is defined as the proportion of the population with access to a reliable improved water supply, which can be categorized as either improved or unimproved (World Bank, 2006). Improved sources encompass piped water into dwellings or yards, public taps or standpipes, boreholes, protected springs or dug wells, and rainwater collection facilities that ensure affordability and continuity. Conversely, unimproved sources include unprotected springs and dug wells, water vendors using small tanks or tanker trucks, surface sources such as rivers, dams, streams, and irrigation canals, as well as bottled water sourced from unimproved sources (UNICEF/WHO, 2012). In the context of domestic, livestock, and wildlife water accessibility within conservancies, an assessment was conducted during the wet seasons, as depicted in Figure 9. The community's access to domestic water was facilitated by numerous springs and rivers within the conservancy, ensuring coverage within a 3 km buffer zone or a return journey of 30 minutes, as per the recommendations outlined in the Ministry of Water, Irrigation, and Sanitation guidelines for basic water accessibility (MWI, 2015). In Ngilai, it was observed that many springs originating from the Mathews range supported thriving ecosystems, while the groundwater yield remained high due to significant recharge during the rainy seasons (Seddon et al., 2021).

3.5. Seasonal water accessibility

During the dry season, numerous settlements experienced a shift in water accessibility dynamics, particularly within a 3 km buffer zone and the seasonal springs dried up (Figure 10). Notably, the southeastern region of Samburu, encompassing Ndikir Nanyekie and Ndonyo, Nasipa, encountered significant challenges as boreholes broke down ceased functioning due to the high-water demand. The period of dry season, typically spanning from January to February and June to September, witnessed a scarcity of water resources, resulting in the depletion of surface water sources. Consequently, both human and livestock populations faced constraints in accessing water, a situation well-documented in previous studies (Omondi et al., 2014). To cope, communities heavily relied on stored water from boreholes, wells, or other water storage facilities, as evidenced by existing literature (Indeje et al., 2006).

Seasonal variability plays a critical role in shaping water accessibility in arid and semi-arid regions; therefore, it was necessary to examine both wet and dry seasons to capture the full spectrum of hydrological and social dynamics influencing water availability. During the wet season, a substantial proportion of livestock had access to water within a 10 km buffer zone, as illustrated in Figure 11. This spatial accessibility aligns with findings by Komina et al. (2019), who observed improved livestock–water proximity during periods of increased rainfall. However, this situation markedly deteriorated in the dry season, particularly in settlement areas such as Lksin and Lorain, where households faced significant challenges in accessing water within the same distance threshold. As water sources within the buffer zone diminished, pastoralist communities were compelled to undertake seasonal migrations in search of alternative water points and viable grazing lands for their herds.

As depicted in Figure 12, the dry season was also characterized by intensified competition over the limited water resources, often leading to localized conflicts, consistent with observations reported by Diaz and Markgraf (2000) and Ngaina and Mutai (2013). These conditions disproportionately affected vulnerable groups, notably women and children, who were frequently required to travel longer distances to access water. The resulting increase in physical and time burdens had direct implications for household welfare, food security, and community resilience.

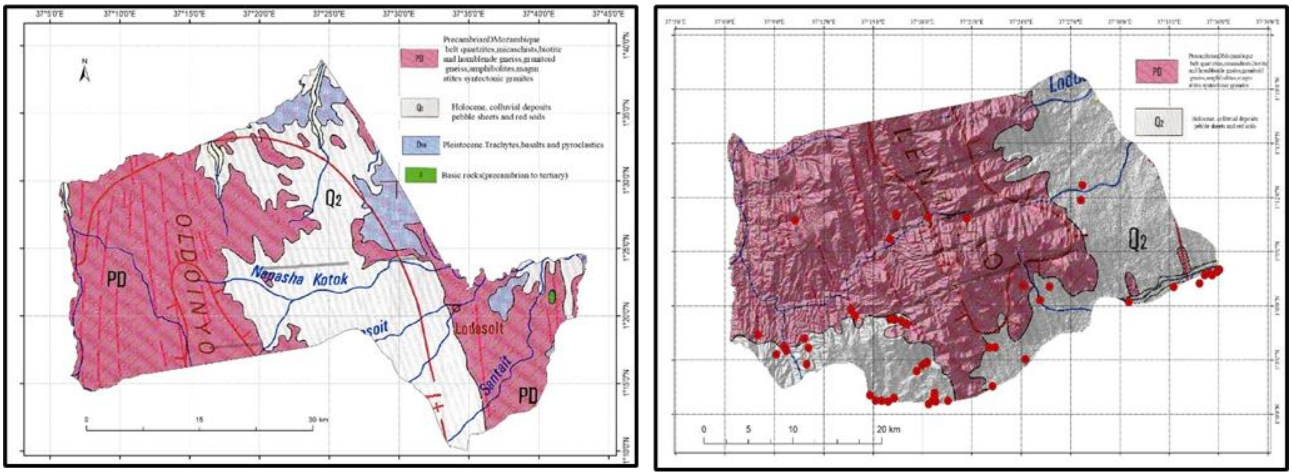

Fig. 8. Geology of Kalepo and Ngilai Conservancy

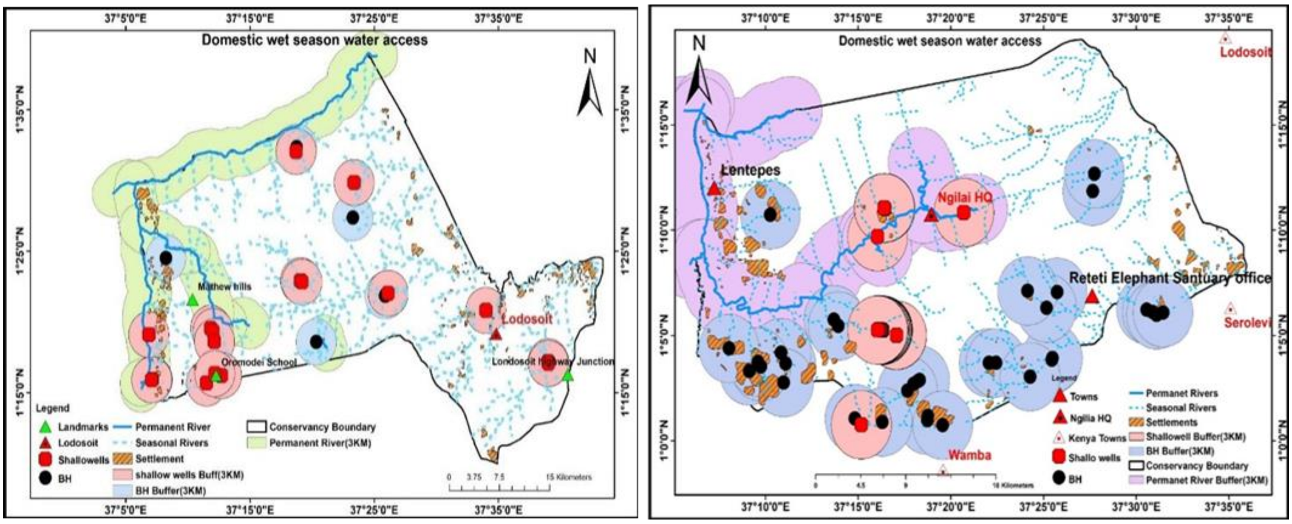

Fig. 9. Domestic water sources accessibility during wet season in Kalepo and Ngilai Conservancies

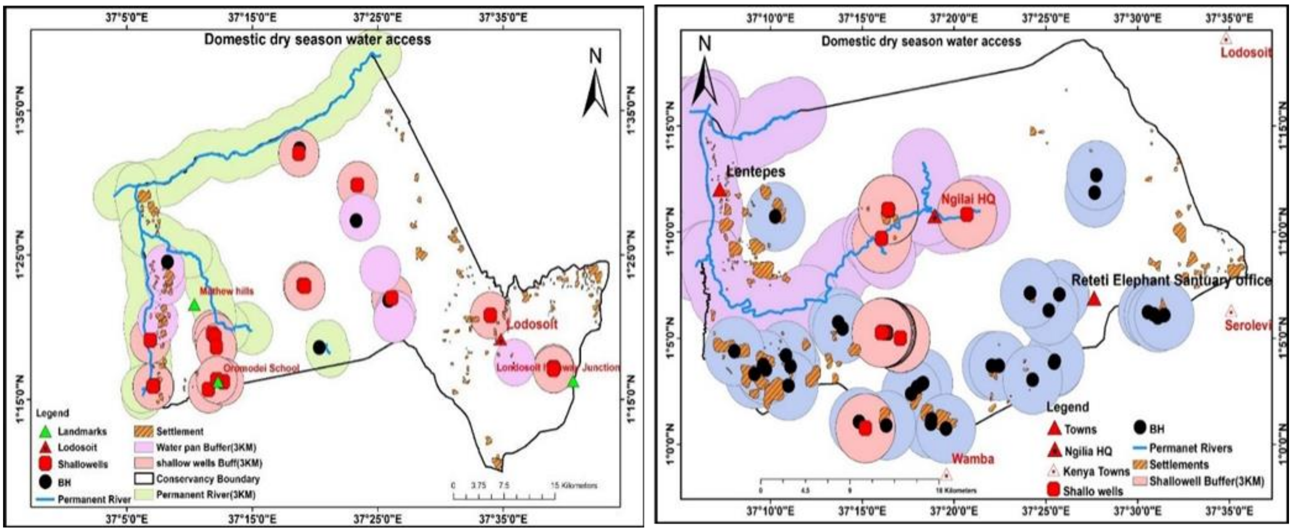

Fig.10. Domestic water sources accessibility during dry season in Kalepo and Ngilai Conservancies

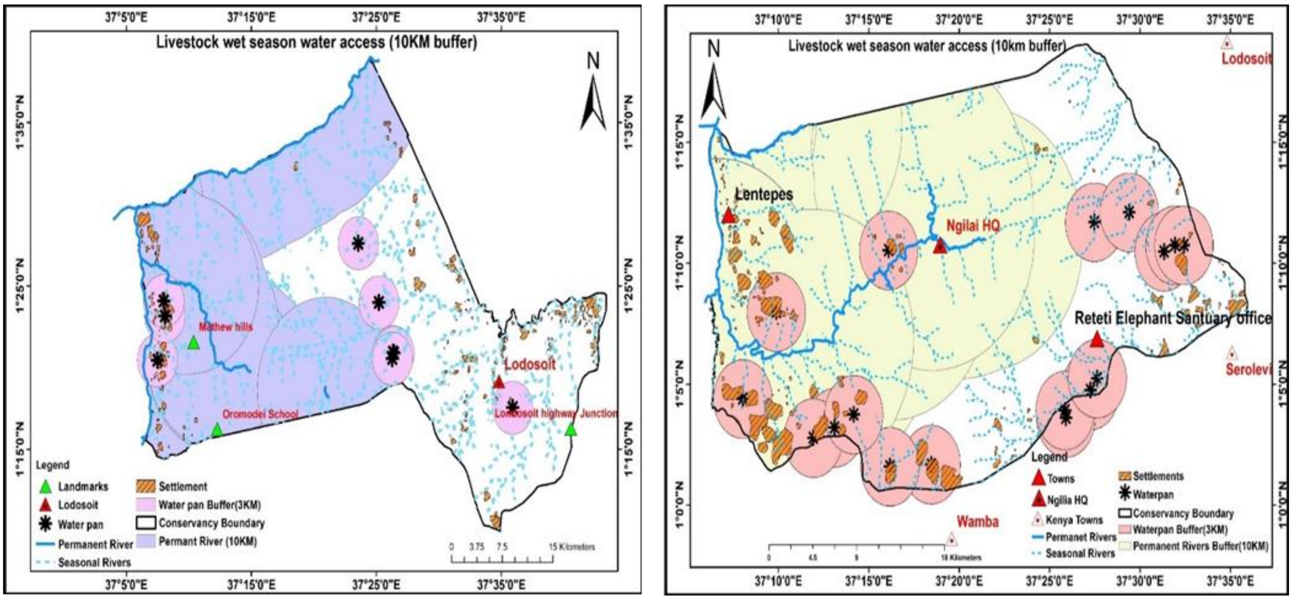

Fig. 11. Livestock water sources accessibility in Kalepo and Ngilai Conservancies- wet season

The classification of wet and dry seasons in the study was based on historical monthly rainfall patterns and seasonal climatology specific to northern Kenya, particularly Samburu County. Data from the Kenya Meteorological Department (KMD) and existing climate literature (e.g., Nicholson, 2017; FEWS NET, 2021) indicate a bimodal rainfall pattern, with: the wet season defined as months with mean rainfall exceeding 50 mm/month, typically: March to May (long rains) and October to December (short rains). The dry season includes months with mean rainfall below 30 mm/month, typically: January to February and June to September. These thresholds were guided by regional climatological norms and validated using the 30-year mean monthly rainfall data (1981–2023) sourced from the Kenya Meteorological

3.6. Livestock migration patterns

Pastoralism has historically constituted the primary livelihood for many communities in northern Kenya, enabling them to adapt to and endure the region's arid and semi-arid climatic conditions for centuries (Birch & Grahn, 2007; Schilling et al., 2014). In response to livestock losses—often caused by drought, disease, or conflict—pastoralists frequently rely on informal social networks to recover, including borrowing livestock or money from relatives and friends (Chantarat et al., 2013). Mobility remains a central adaptation strategy, enabling pastoralists to respond to the spatial and temporal variability of water and pasture resources. This adaptive behavior was evident during the dry season in Kalepo Conservancy, where livestock migration exhibited complex spatial patterns (Figure 13). Herds originating from Kalepo East moved towards the Mathew Ranges, Sera Conservancy, and Melako in Marsabit County, drawn by access to permanent boreholes and the perennial Ewaso Ng'iro River. Meanwhile, herders from Kalepo West migrated toward Oromodei in the Mathew Ranges, with some traversing the Milgis River toward Baragoi in northern Samburu County. In Ngilai Conservancy, livestock movements predominantly converged on the Mathew Ranges, underscoring their ecological significance as a critical dry-season refuge. These patterns illustrate the strategic mobility of pastoralist communities in optimizing access to water and forage across a fragmented and variable landscape.

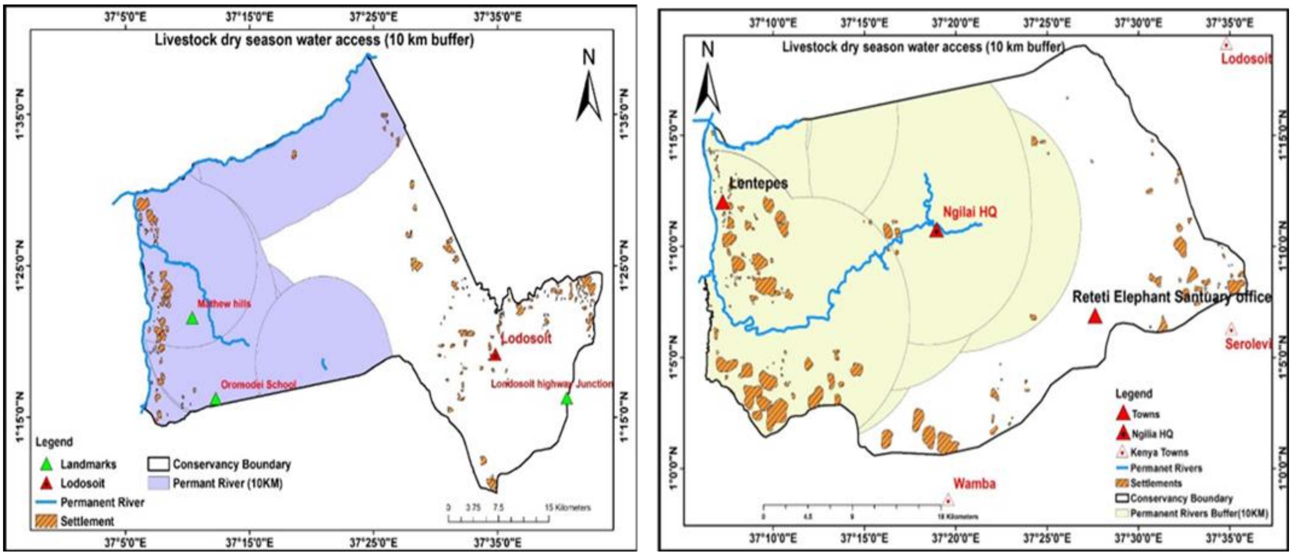

Fig. 12. Livestock water sources accessibility in Kalepo and Ngilai Conservancies- dry season

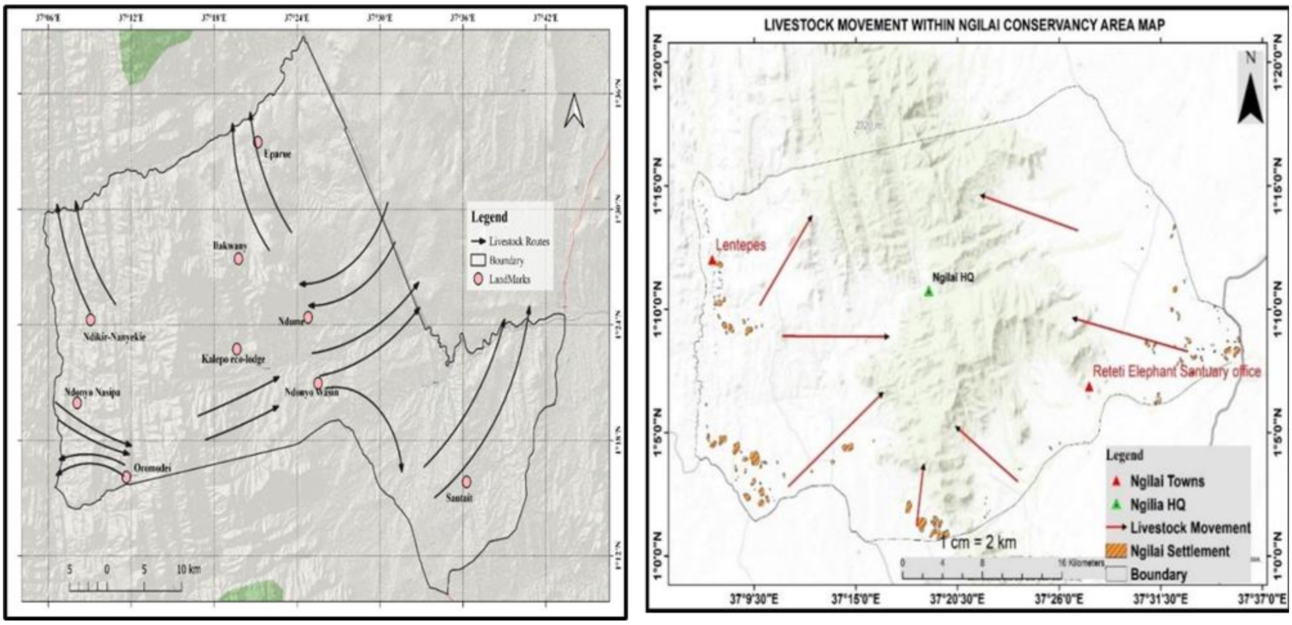

Fig. 13. Kalepo and Ngilai conservancy dry season livestock movement

3.7. Groundwater yield

Given that groundwater constituted the primary water source, the study examined its yield, recharge rates, and extraction methods using existing drilling records. Analysis of the groundwater potential yield revealed generally modest outcomes, ranging from 1 -5 m^3/hr (Figure 14). Notably, the highest yield recorded, 5 m^3/hr in Kalepo, was situated in the mountainous region near the Mathews Ranges, benefiting from significant rainfall capture (Seddon et al., 2021). Groundwater extraction predominantly occurred beneath sandy seasonal lagga's, which served as natural reservoirs, safeguarding wildlife, livestock, and local communities against water scarcity during drought periods. Communities residing adjacent to mountains as well as domestic and wildlife populations, benefited from this groundwater resource (Kiringe et al., 2016). Moreover, numerous seasonal rivers and boreholes were strategically located along the lagga's, which exhibited notable fracturing, facilitating enhanced recharge in these areas (Villeneuve et al., 2015).

3.8. Groundwater recharge

Observations revealed that recharge primarily occurred through rainfall and the presence of seasonal rivers in Kalepo Conservancy proved advantageous, with recharge levels reaching up to 220/year mm of the total precipitation received in the area (Figure 15). The geological composition of the region likely played a role in facilitating high recharge rates, as trachyte allow for better infiltration and percolation through fault lines, enabling groundwater recharge underground (Espejel-García, 2007). The recharge potential is notably higher near the eastern escarpment of the Mathews Ranges, where higher rainfall and orographic effects promote enhanced runoff and infiltration. Several boreholes with relatively high yields (up to 5 m^3/hr) are located near these zones, indicating the hydrological significance of the mountainous terrain. Additionally, prominent fracturing and the presence of wide, sandy riverbeds in the lower elevation areas facilitate the storage and transmission of groundwater, particularly during the wet season

Conversely, in drier areas, where temperatures are higher, total evaporation surpassed groundwater flow, resulting in minimal to no recharge (Kuria, 2013). In Ngilai, recharge levels reached up to 160 mm/year, with certain areas in the East exhibiting pockets of Holocene colluvial formation, which facilitate greater recharge despite experiencing low rainfall (Kuria, 2013). These *lagga*-based systems serve as critical conduits for groundwater replenishment during episodic rainfall events, allowing temporary surface water to percolate into underlying aquifers. The recharge zones in Ngilai are further influenced by the proximity of moderately elevated terrain that channels surface runoff toward natural infiltration points.

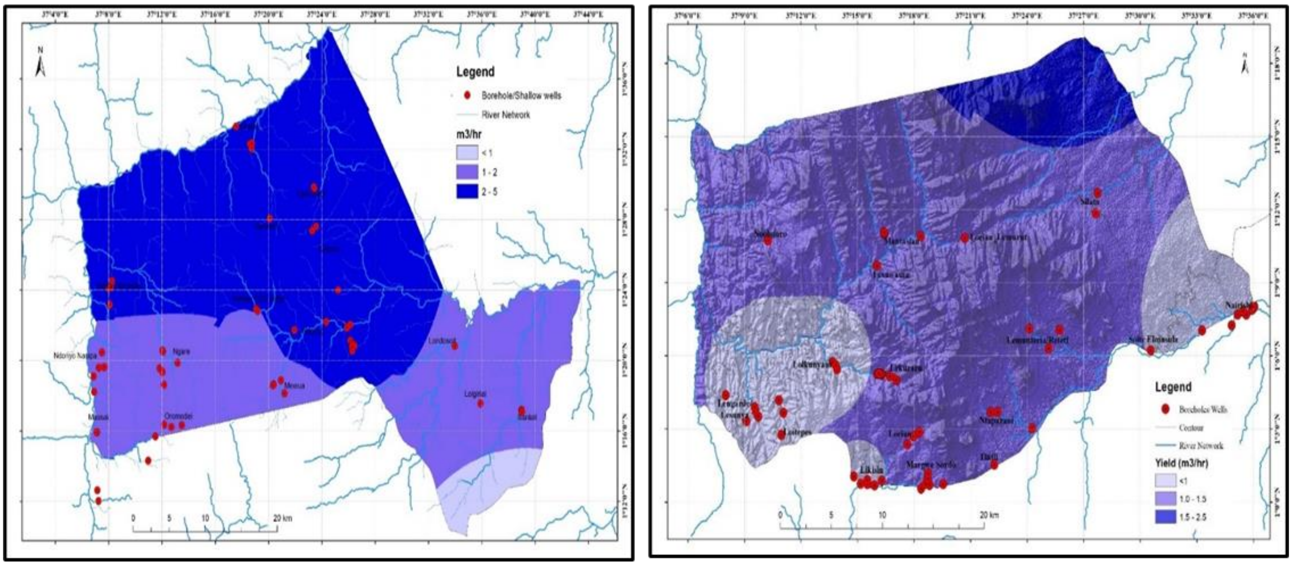

Fig. 14. Groundwater yield in Kalepo and Ngilai Conservancies

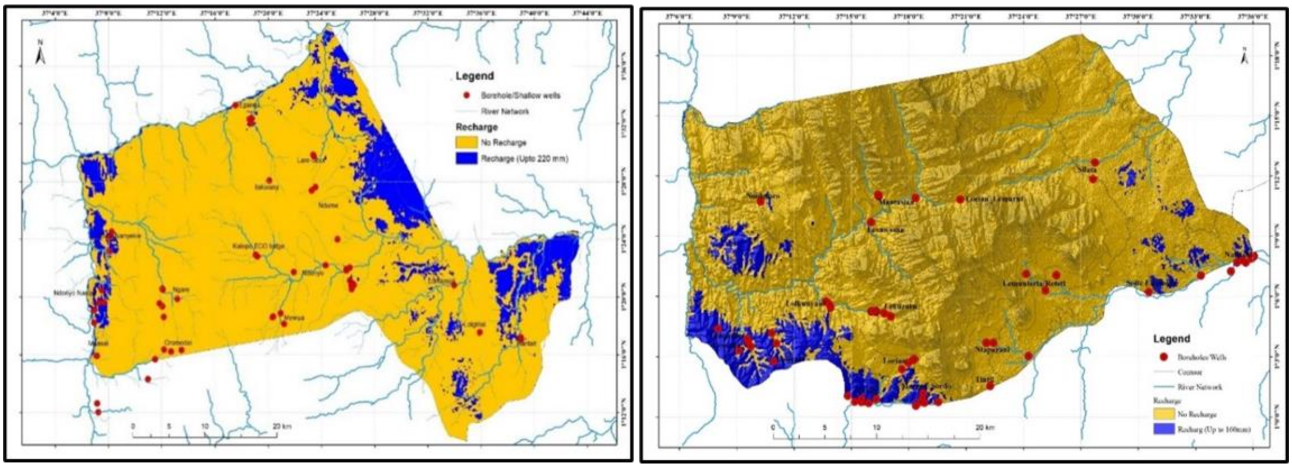

Fig. 15. Groundwater recharge maps of Kalepo and Ngilai Conservancy

3.9. Abstraction methods

The predominant sources of water are typically equipped with hand-pumps (Figure 16), although in certain areas, submersible pumps powered by solar energy are utilized, while manual fetching is carried out in others as also highlighted by Adelana and Macdonald (2008). Solar energy has emerged as a promising technology, particularly in the context of powering irrigated agriculture, garnering significant attention in recent years (Hartung and Pluschke, 2018). Groundwater depth exhibits variation, with deeper wells reaching depths of 122 meters located in the southwest region at Lengarde and Lesunyai, contrasted by relatively shallower wells at 103 meters found in the eastern part of the conservancy at Nairishi. The predominance of hand-pump installations aligns with findings in research conducted by Foster et al. (2019). However, access to water from sandy riverbeds is typically performed manually through sand-scooping.

3.10. The pH values of water

The study examined about 125 water sources which provided a comprehensive overview of water quality parameters across various water sources in the study area, including pH, and electrical conductivity (EC), which are fundamental indicators of water quality WHO, 2017). pH values ranged from 6.5 -8.64 (Figure 17), that is from slightly acidic to slightly alkaline, with significant variability observed. The recommended WHO limits for pH are 6.5 - 8.5. The slight pH elevation above 8.5 was mostly observed in shallow wells and the seasonal rivers. This variability likely reflects high siltation due to the absence of silt traps in the water sources, inadequate watering points, and contamination by livestock and wildlife. Also, the spatial heterogeneity influenced by geological factors such as rock types and formations, impacting water chemistry and suitability for different uses could influence the pH (Espejel-García et al., 2007).

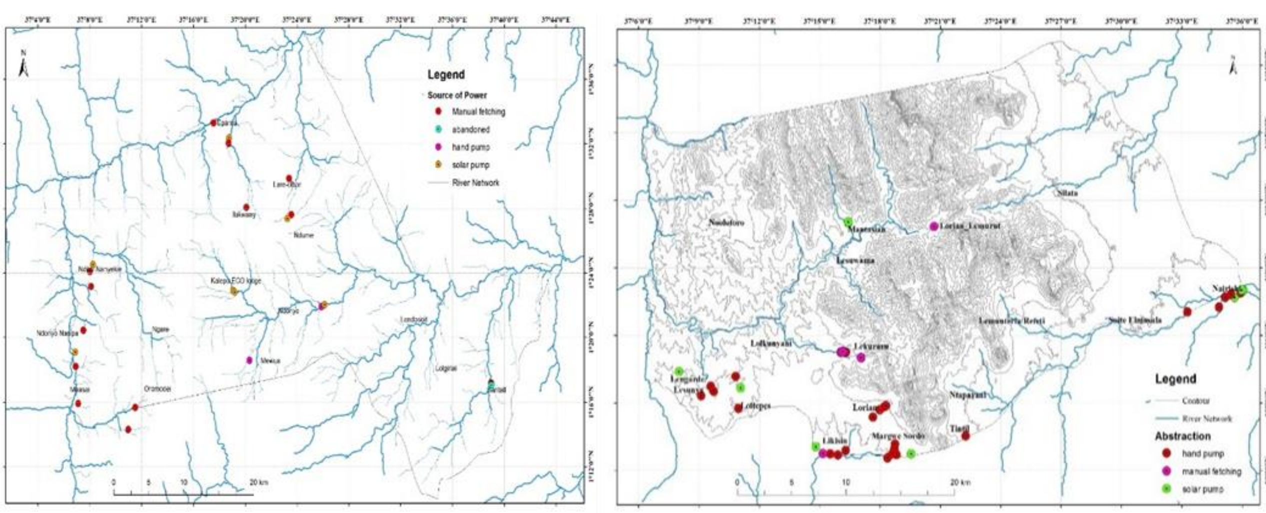

Fig. 16. Water abstraction methods in Kalepo and Ngilai Conservancies

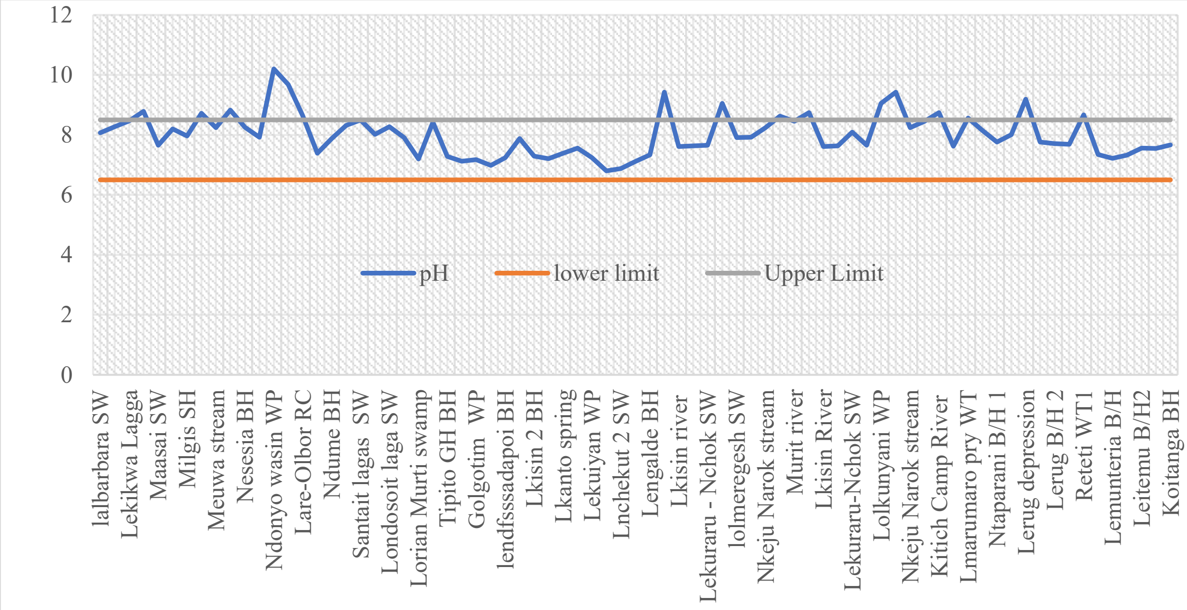

Fig. 17. pH values of the Ngilai and Kalepo Conservancies

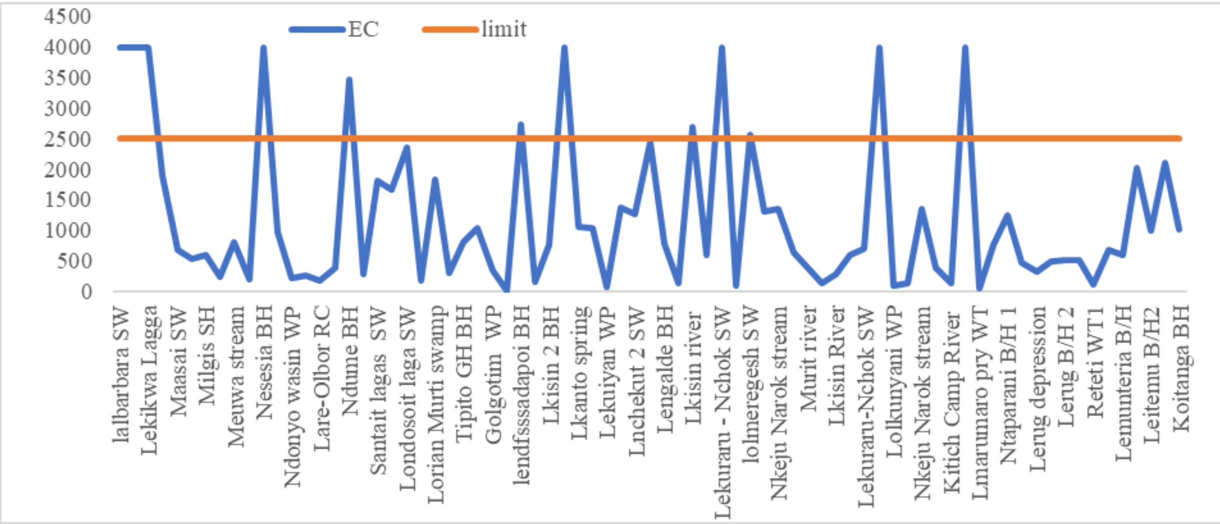

Fig. 18. EC values of the Ngilai and Kalepo Conservancies

3.11. Electric Conductivity (EC) values

Additionally, EC measurements (Figure 18) indicate variations in dissolved ion concentrations and the total dissolved solids (TDS). WHO recommends an EC of Max 2500 µS/cm. The high EC values of about 4000 µS/cm in the water pans, shallow wells and seasonal rivers could be attributed to the human activities within the drylands. Pastoralist activities, such as livestock grazing and overgrazing, significantly contribute to soil erosion. Intensive grazing leads to soil erosion and compaction, exacerbating sedimentation in nearby water bodies and elevating alkalinity levels (Nyariki et al., 2008). Overgrazing reduces vegetation cover, disrupting nutrient cycles and increasing the influx of nutrients into water sources, further contributing to alkalinity (Oba et al., 2000; Reid et al., 2004). Additionally, watering livestock directly in streams or shallow wells introduces organic matter and nutrients, fostering processes like decomposition and nutrient cycling that raise alkalinity in the water (Mekuria et al., 2011). Furthermore, improper disposal of livestock waste introduces nutrients into water bodies, impacting water quality parameters including alkalinity (Gitau et al., 2016; Koech et al., 2018). of normal range of pH.

Although this study uses mean annual rainfall for trend analysis, the considerable year-to-year variability, such as the extreme wet year of 1997 and the severe drought of 2016 highlights the variability nature of rainfall in Kenya arid lands. Relying solely on long-term means can cover critical extremes that significantly affect water availability, infrastructure performance, and community coping strategies. As dry and wet conditions are inherently non-static and often influenced by large-scale climate drivers (Gebrechorkos, Hülsmann, & Bernhofer, 2020), water management strategies should incorporate metrics of variability and extremes, such as rainfall anomalies, frequency of dry spells, and standard deviation. This approach enables more resilient and adaptive planning under conditions of climatic uncertainty.

4. Conclusion

Findings revealed that the majority of water pans experienced depletion within two months following the onset of dry weather, particularly evident in August. The rainfall analysis revealed that the wettest year within the 1981–2024 period was 1997, with a Rainfall Anomaly Index (RAI) of approximately +4.6, coinciding with the strong El Niño event that year. In contrast, the driest year was 2017, with an RAI of –4.2, followed closely by 2021 (–3.9) and 2022 (–3.4), all of which reflect the recent severe droughts experienced across Kenya. The Mann-Kendall test showed a positive trend in annual rainfall from 1981 to 2024, but the result was not statistically significant ($p = 0.368$. Boreholes emerged as the predominant water source, while springs and seasonal rivers were prevalent in Kalepo, underscored the influence of topography on water source distribution. Key challenges observed in water pans encompassed high siltation due to the absence of silt traps, inadequate watering points, and contamination by livestock and wildlife. Additional factors included poor design and construction, poor site selection, lack of protection and fencing, and absence of spillways. Water pan capacities within the study area ranged from 150 m^3 to 12,000 m^3, with depths varying between 0.5 and 2 meters. Despite these considerable storage volumes, field observations revealed that most pans dried up within approximately two months following the end of the rainfall season. This relatively short water retention period can be attributed primarily to the high evapotranspiration rates typical of arid and semi-arid environments. Elevated temperatures accelerate surface water loss through evaporation, while sparse vegetation cover and shallow pan depths further reduce the effectiveness of water retention. In addition, the coarse-textured soils and possible seepage losses through the base of unlined pans may contribute to rapid depletionBoreholes within the conservancy lacked documented records of repair and maintenance, and a structured management system was absent, typically overseen by community elders or other stakeholders. The predominant geological formation is from erosion of the Precambrian basement rock system that consists of metamorphic and sedimentary rocks. The community's access to domestic water was facilitated by numerous springs and rivers within the conservancy, ensuring coverage within a 3 km buffer zone or a return journey of 30 minutes, allowing for water accessibility. The dry season witnessed heightened competition for water resources, escalating conflicts over access to water points within the 10 km buffer zone. livestock migrations within the two conservancies were mainly towards the Mathews ranges where there was the lush vegetation; The source of water during dry season was both from the perennial Ewaso Ngiro river and the permanent boreholes. The groundwater yield was between 1-5 m^3/hr, the high yields were towards the Mathews Ranges. Groundwater extraction predominantly occurred beneath sandy seasonal Laggas, which served as natural reservoirs, safeguarding wildlife, livestock, and local communities. Recharge primarily occurred through rainfall along the river Laggas where fault lines were present and ranged between 160mm/yr to 220mm/year. The groundwater depth was within 103 m – 122 m. The pH values of the water resources were ranging from 6.5 – 8.64. The EC values were ranging from 250 – 4000 µS/cm in some water sources indicating the high siltation emerging from the sandy formation. The findings reveal that communities heavily rely on stored water from boreholes, wells, or other storage facilities during dry periods to cope with water scarcity. This highlights the importance of maintaining and managing water storage infrastructure to ensure resilience during prolonged droughts.

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6. Conflict of Interest

No potential conflict of interest was reported by the authors.

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