

Seasonal Microbial and Physicochemical Variations in Shared Water Resources Within the Arid and Semi-Arid Southwestern Kenya Landscape

Environmental Health Insights
Volume 20: 1-12
© The Author(s) 2026
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1786302261443019
journals.sagepub.com/home/ehi



Brian Marvis Waswala-Olewe^{1,2,3} , George Paul Omondi⁴ ,
Romulus Abila¹  and Paul Webala⁵ 

Abstract

Water scarcity and poor access to potable water are growing concerns in sub-Saharan Africa. This study investigated seasonal variations in microbial contamination and physicochemical properties of surface waterpoints, the primary sources of water in southwestern Kenya, using a cross-sectional environmental surveillance design (May 2024–April 2025). Total coliforms and *Escherichia coli* isolates were quantified, to assess water safety and ecosystem health using membrane filtration and differential chromogenic agar. Results revealed high microbial contamination in all samples (100% for total coliforms; 62.5% for *E. coli*), with significantly higher bacterial loads during the wet season. Total coliforms and *E. coli* averaged 1.13×10^6 CFUs/mL and $1.34 \pm 1.26 \times 10^5$; and 2.84×10^5 CFUs/mL and $9.82 \pm 9.78 \times 10^4$, respectively, for wet and dry seasons respectively. Prevalence of *E. coli* in sampled sites was statistically significant between seasons ($\chi^2(1, N=28)=20.57, P<.05$). Physicochemical parameters varied seasonally, with the dry season having higher pH, temperature, total dissolved solids and dissolved oxygen, while the wet season had higher conductivity. During the dry season, *E. coli* and total coliforms were not correlated while in the wet season, a weak but significant correlation existed ($r=0.465, P=.003$). Microbial parameters showed no significant correlation with physicochemical variables in either season, emphasising distinct seasonal interaction patterns. MANOVA conducted to assess the influence of water bodies, seasons and their interactions on microbial and physicochemical parameters revealed that water quality was significantly influenced by both water body type and season ($P<.001$). Total coliforms were significantly influenced by season but not water sources. The presence of unsafe microbial loads and poor water quality highlights public health risks and potentially impact on livestock and livelihoods. These microscale findings, advocate for continuous ecological surveillance and public health monitoring on water quality status and community awareness. We recommend promotion of nature-based indigenous solutions for water and ecosystem management amid climate change.

Keywords

environmental pollution, Narok, seasonal variation, water quality, water sources

Received: 27 September 2025; accepted: 1 April 2026

Introduction

Water as an enabler to development contributes to human wellbeing and survival and resilient ecosystems.¹ Access to clean water is a universal human right² and promotes human health and productivity. Despite its significance, this vital finite and irreplaceable³ resource, continues to face a lot of threats that compromises its availability and quality both temporally and spatially.

Water, Sanitation and Hygiene (WASH) is compromised by poor or lack of water accessibility and infrastructure.⁴ It is estimated that close to 2 billion people are devoid of potable water services.⁵ This lack of access to adequate

¹Department of Environmental Studies, Geography and Planning; Maasai Mara University, Narok, Kenya

²Kenya National Commission for UNESCO, Nairobi, Kenya

³Baruk Yadiym Ecosphere, Nairobi, Kenya

⁴Centre for Epidemiological Modelling and Analysis, University of Nairobi, Kenya

⁵Department of Forestry and Wildlife Management, Maasai Mara University, Narok, Kenya

Corresponding Author:

Brian Marvis Waswala-Olewe, Department of Environmental Studies, Geography and Planning; Maasai Mara University, Narok 20500, Kenya.
Email: brianmarv@gmail.com



potable water, which leads to consumption of contaminated water, is estimated to cause over 1.8 million human deaths and approximately 4 billion cases of illness annually.^{6,7} Many rapidly developing urban and rural centres in Africa are faced with unsustainable sources of potable water.⁸⁻¹¹

Waterborne microorganisms in drinking water are a major public health concern,¹²⁻¹⁴ especially from human and animal faecal sources.^{15,16} The pathogens are primarily transmitted through ingestion of contaminated water; contact with urine, body fluids or faecal-oral route transmission of infected animals or indirectly through water or soil contaminated with infected animal exudates and excreta. Increased use of shared water points by humans, livestock and wildlife, predisposes fragile wetlands to ubiquitous zoonotic waterborne and water-related diseases.^{11,17-19} Waterborne and water-related pathogens of public health importance when ingested can result into severe stomach cramps, bloody diarrhoea, vomiting, kidney failure and death.¹⁹⁻²¹ Studies reveal that waterborne diseases cause high morbidity and mortality in low- and middle-income countries (LMICs), killing an estimated 4.9 of every 1,000 children who are below 5 years.²²

In Narok County, Kenya and sub-Saharan Africa, available surface water resources are currently decreasing in quality and quantity.²³⁻²⁵ This is attributed to weather variation, global warming and land-use change, water pollution (surface-runoff, industrial waste, agro-based chemicals and human waste), population increase, urbanisation, and poor water resource management.²⁶⁻²⁸ Article 43(1)(d) of the Constitution of Kenya,²⁹ provides that '*every person has the right to clean and safe water in adequate quantities*'. The county lags in provision of potable water as water, sanitation and hygiene (WASH) infrastructure in most rural areas is either poorly developed or non-existent, as less than 10% of Narok County households have access to piped water.^{10,11} Moreover, environmental hygiene is compromised in Narok as over 50% of Narok residents practice open defecation due to lack of improved sanitary infrastructure in form of pit latrines and toilets,^{28,30} a scenario that exposes the community to increased incidents of morbidity and compromised health in a shared human–livestock–wildlife landscape. Furthermore, cultural sanitary norms, livestock husbandry in form of pastoralism and wildlife conservation exacerbate environmental pollution, which predisposes the shared multi-use fragile surface water sources to pathogenic faecal pollution and contamination, especially in downstream communities.^{11,31}

Additionally, in Narok West subcounty, the most arid of the 6 Narok sub-counties, close to 70% of the residents' source water from unimproved surface water points, such as open water pans, rivers and unprotected springs.¹¹ These surface sources are prone to pollution and contamination by faecal matter.¹⁷ We define open water pans as natural or excavated depressions filled by water and are used by herders to water livestock, farmers for irrigation, water wildlife and other community members for domestic use. Open water pans store surface runoff water and usually lose water through seepage and evaporation.

World Health Organization (WHO) and World Organisation for Animal Health has approved various physicochemical levels of water for human and animal consumption, with deviations likely to result in illness, reduced productivity and jeopardise livelihoods. Conversely, Kenya's National Research Agenda for 2008-2030,³² advocates for environmental research in a myriad of areas including water resources and pollution, environmental health and public health. It postulated that the human disease burden (morbidity and mortality) attributed to zoonosis is projected to increase, including those attributed to gastro-intestinal ailments.³³ Sadly, most of these have not been quantified in the global south, including Kenya and its arid and semi-arid lands.³⁴ Moreover, there is a growing dearth of knowledge in relation to the spatial temporal variation of surface water resources in Kenya's arid and semi-arid lands (ASALs) including Narok, vis-à-vis the waterborne and water-related pathogen loads, One Health implications (human, animal, and ecosystem), and remedial medical policy reforms which the study seeks to attempt to fill. In view of these, the main premise of this study was to establish systematic seasonal prevalence of water quality on surface water sources in the shared human-animal landscape of Narok. This quantitative hydro-ecological baseline risk assessment in the ASAL human-livestock-wildlife landscape of Narok West subcounty, Narok County, Kenya (May 2024 to April 2025) is critical for environmental monitoring and microbial pollution, for public health importance. Specifically, our study sought to: (i) establish prevalence of *E. coli* isolates in surface waters; (ii) assess influence bacterial loads by season and water sources; and (iii) determine seasonal microbial and physicochemical relationships across sampling periods and surface water bodies. The study was guided by the hypotheses: (i) there was significant variation of *E. coli* isolates in shared surface waters; (ii) bacterial loads are significantly influenced by seasons and water sources; and (iii) significant microbial and physicochemical variations occur across sampling seasons and within shared surface water sources.

Materials and Methods

Study Area

Narok West subcounty, classified as semi-arid^{23,25} spans 17,944 km² and is located south-west of Kenya in Narok County (Figure 1). It is characterised by a bimodal annual rainfall ranging between 300 and 1,000 mm,³⁵ influenced by the Intertropical Convergence Zone and topographic relief from Lake Victoria.^{36,37} Ambient temperature range between 18°C in the highlands and 28°C in the lowlands, with a mean of 25°C.³⁸ Annual potential evaporation is about 1,820 mm, with a daily evaporation at 165 mm per day during the hot dry season.³⁹ The dominant plant is *leleshwa* (*Tarchonanthus camphoratus*), thorn scrub, sansevieria grass and scattered patches of forest.⁴⁰ The region is currently witnessing a decrease in annual rainfall and an increase in ambient temperatures.^{40,41} The subcounty lies

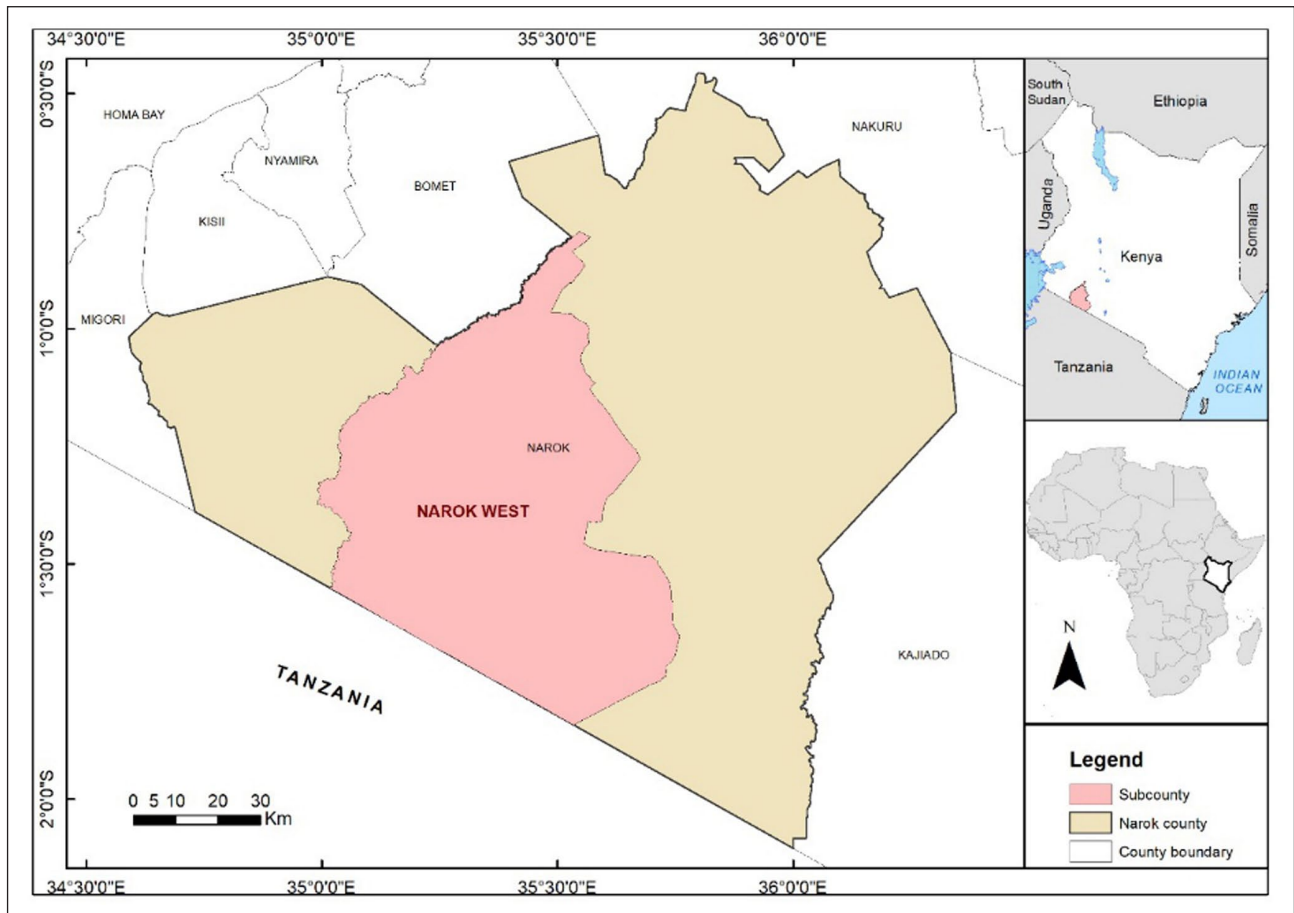


Figure 1. Map of Africa, Kenya and Narok West subcounty.
Source: Author.

within the Greater Maasai Mara Serengeti Ecosystem, a critical migratory corridor for wildlife.^{42,43} In relation to geology, the area is characterised by vertisol, cambisol, ferralsol and lithosol/rock outcrops.⁴⁴ The study area is dominated by the Maasai ethnic community,⁴⁵ who predominantly engage in pastoralism, wildlife tourism/conservation and crop farming as socio-economic activities.⁴⁶ The subcounty is a fragile ASAL currently witnessing increased land degradation, fragmentation and natural resource use conflicts attributed to changing land tenure.⁴⁷⁻⁴⁹

Selection of Sampling Sites

The study was conducted from May 2024 to April 2025. The sampling sites were selected through stratified random convenience sampling to represent the diverse landscape, based on surface water type (river or OWP), access and major water use/surrounding anthropogenic activity in the landscape (Figure 1). The sampling sites were geo-located using a handheld Global Positioning System (GPS) receiver (Garmin e-Trex 10, Olathe, USA; Figure 2). The geological coordinates and description of the sites are given in Table 1. Twenty-eight (28) surface open water points comprising 20 OWPs and 8 rivers, each with a single sampling point were sampled. The sampling sites were either in private or communal lands.⁵⁰ All sampling sites were open access,

multi-use, accessible and used by humans, livestock and wildlife.

Water Sampling for Physicochemical and Bacteriological Parameters

Physicochemical parameters were collected *in-situ* from 28 surface water points using a calibrated handheld HI-98194 Multiparameter Waterproof Meter field sonde (USA). The sonde probes were submerged in the water sampling point at a depth of 10 cm from the surface and the readings were taken directly by reading from the screen. Before sampling at each point, the probes were cleaned with deionised water. The *in situ* variables noted were dissolved oxygen (DO; %/mg/L), temperature (Temp.; °C), electrical conductivity (EC; μ S/cm), pH, and total dissolved solids (TDS; mg/L).

Aseptic polyethylene bottles were used for microbial water sampling and collection from multi-use surface waters, 10 to 15 cm below the water surface.⁵¹ Caution was taken to reduce rising sediments when filling the bottles since sediments harbour settled microbes.⁵² Water sampling was conducted in triplicate 4 times per site (twice during wet season and twice during dry season). All water samples collected were stored in a cool box with ice and transported to Biological Sciences Laboratory at the Maasai Mara

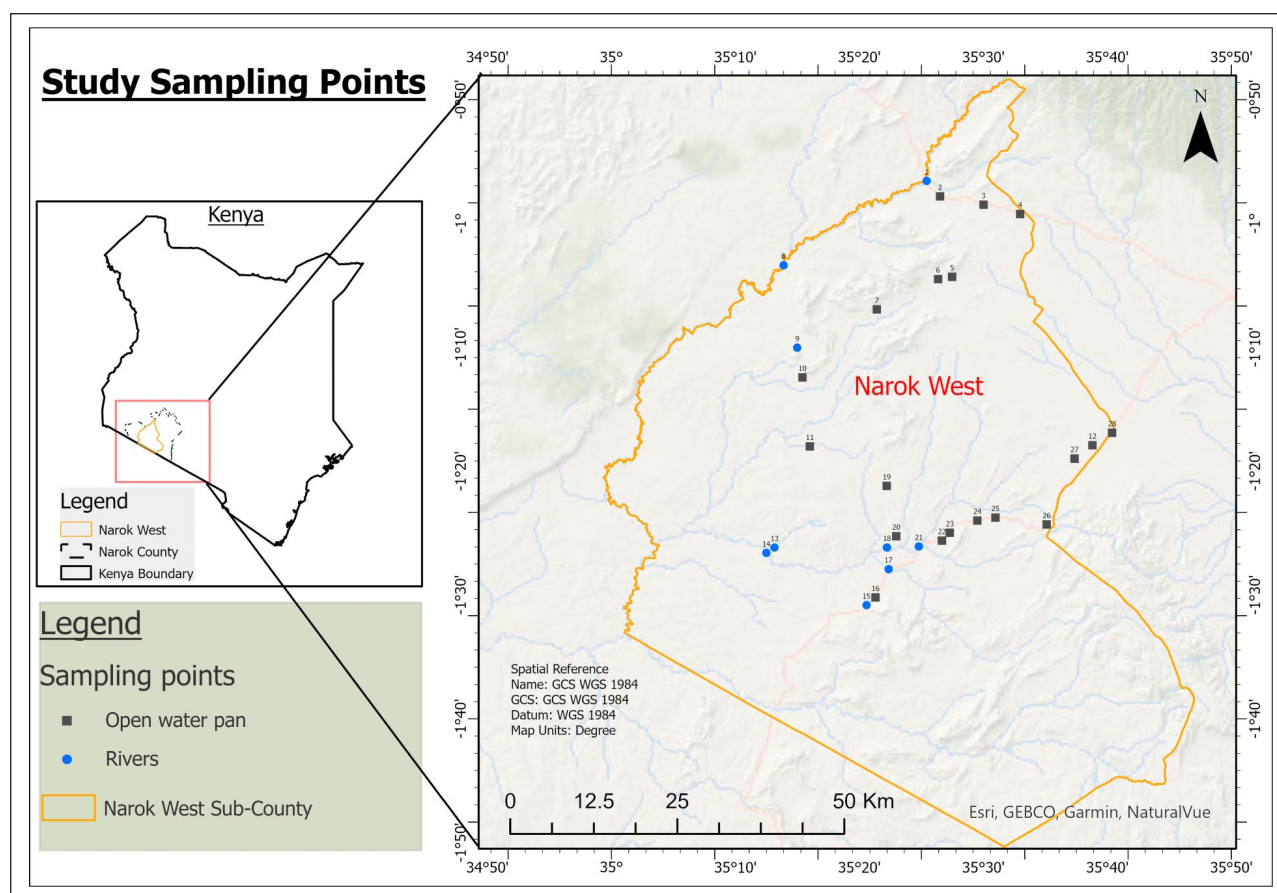


Figure 2. Map Narok West subcounty and sampling points.
Source. Author.

University for quantitative microbial assessment within 24 hours.

Culture and Enumeration of Coliforms

Using Eppendorf pipettes (Germany) and serial dilution technique, 50 μ L aliquots water were filtered through sterile cellulose acetate membrane filters (47 mm diameter and 0.45 μ m porosity; Millipore, County Cork, Ireland) by a sterile BioVAc 330B laboratory 3-branches stainless steel vacuum filter (China). Thereafter, the filter papers were placed in selective agar-filled Petri dishes in duplicate and incubated. Differential culture media (HiCrome™ Chromogenic Coliform Agar, India) incubated for 24 hours at 37°C was used to morphologically distinguish visible *E. coli* coliforms (dark-blue pigmentation) from other non-faecal indicator bacteria (bright pink/red colonies; Figure 3). ATCC 29522 *E. coli* was used as a positive control. Visible colonies (both purple/blue and pink/red) were enumerated using a colony counter and reported as colony forming units (CFUs) per 100 mL surface water following incubation.

Data Analysis

The data was collected, cleaned and entered in SPSS version 27 which was used in carrying out the analysis. Values of physicochemical and bacteriological variables were

summarised using means and standard deviations. Pearson correlation analysis was used to assess the existence of relationships between microbial and physicochemical parameters. Multivariate analysis of variance (MANOVA) and Tests of Between-Subjects Effects were used to assess the effect of water body (OWP and river), season (dry and wet), and their interaction on microbial and physicochemical parameters, with $P < .05$ significance level.

Results

Microbial and Physicochemical Water Quality

Cumulatively, there was a 100% ($n=112$) and 62.5% ($n=70$) rate of encountering CFUs and *E. coli* isolates in the surface water points within Narok West. Prevalence of *E. coli* in the sampled sites was statistically significant, ($\chi^2(1)=20.57$, $P < .05$). Seasonally, there were nuanced findings based on the bacterial loads and physicochemical parameters (Table 2). The dry season had higher pH, temperatures and TDS than wet season which exhibited higher mean total CFUs and *E. coli* loads together with conductivity and dissolved oxygen. Seasonal analysis of microbial quantities against water bodies revealed that rivers had higher total CFUs and *E. coli* loads during the wet season as opposed to dry season (Table 3). This was also evident for *E. coli* loads, though higher *E. coli* loads were

Table 1. Description of Sampled Water Bodies (Coordinates – Geographic WGS84).

Sampling site	GPS location (d.dddd°)		Water body	Activity and water use around sampling area
	Latitude	Longitude		
001	-0.9427	35.4238	River	Urban centre, water collection, car wash, crops farming and livestock husbandry
002	-0.9636	35.4416	Open water pan	Domestic water collection, crop farming and livestock husbandry
003	-0.9748	35.5002	Open water pan	Crops farming, irrigation and livestock husbandry
004	-0.9873	35.5493	Open water pan	Crop farming and livestock watering
005	-1.0718	35.4578	Open water pan	Domestic water collection and livestock watering
006	-1.0749	35.4390	Open water pan	Livestock watering
007	-1.1156	35.3566	Open water pan	Domestic water collection and livestock watering
008	-1.0563	35.2313	River	Livestock watering
009	-1.1673	35.2499	Open water pan	Livestock watering
010	-1.2072	35.2568	Open water pan	Livestock watering and wildlife conservation
011	-1.3001	35.2667	Open water pan	Livestock watering and wildlife conservation
012	-1.2985	35.6465	Open water pan	Livestock watering and wildlife conservation
013	-1.4361	35.2193	River	Urban centre, laundry, livestock watering and wildlife conservation
014	-1.4433	35.2082	River	Urban centre, laundry, water collection, bathing and livestock watering
015	-1.5136	35.3427	River	Urban centre, laundry, water collection, swimming, bathing and livestock watering
016	-1.5032	35.3548	Open water pan	Livestock watering
017	-1.4650	35.3723	River	Sand harvesting, laundry, water collection, bathing and livestock watering
018	-1.4358	35.3702	River	Livestock watering and wildlife conservation
019	-1.3531	35.3699	Open water pan	Wildlife conservation
020	-1.4208	35.3827	Open water pan	Wildlife conservation
021	-1.4346	35.4131	River	Livestock watering and wildlife conservation
022	-1.4267	35.4442	Open water pan	Wildlife conservation
023	-1.4162	35.4548	Open water pan	Livestock watering. wildlife conservation and irrigation
024	-1.3997	35.4917	Open water pan	Livestock watering. wildlife conservation and irrigation
025	-1.3957	35.5161	Open water pan	Livestock watering and wildlife conservation
026	-1.4050	35.5849	Open water pan	Livestock watering. wildlife conservation and irrigation
027	-1.3164	35.6225	Open water pan	Livestock watering and wildlife conservation
028	-1.2817	35.6729	Open water pan	Livestock watering and wildlife conservation

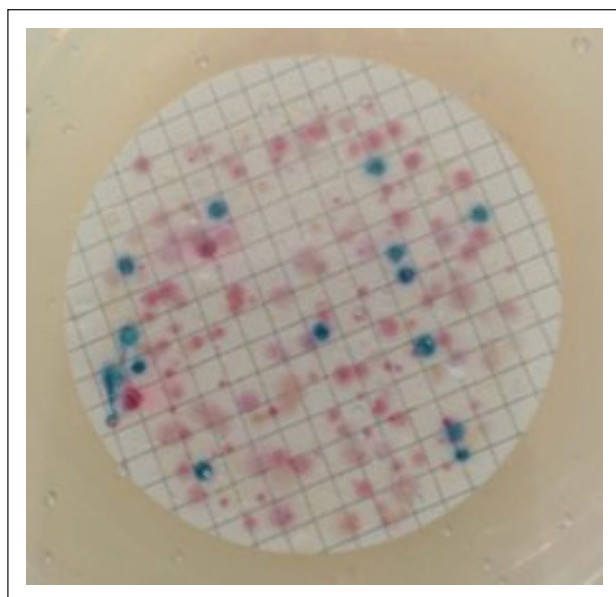


Figure 3. Phenotypical identification and enumeration of *E. coli* and CFUs using differential culture media (HiCrome™ CCA) upon incubation at 24 hours at 37°C. *E. coli* coliforms (dark-blue pigmentation) from other non-faecal indicator bacteria (bright pink/red).

established during dry season (Table 2) were found. Moreover, during the dry season, both open water pans and rivers had higher pH, temperature, DO and TDS than during the wet season. Only conductivity was higher during the wet season as opposed to dry season, for both rivers and open water pans. The study established that seasonally, both rivers and OWPs in the landscape had lower CFUs and *E. coli* loads, with lower pH, temperature, conductivity, DO and TDS during the dry season as opposed to wet season. Conversely, concerning surface water sources, rivers had more total coliform and *E. coli* loads, conductivity, DO and TDS in the wet season. The landscape witnessed higher CFUs, pH, temperature, conductivity, DO and TDS in rivers as opposed to open water pans during dry season, unlike *E. coli*. However, seasonality, all measured variables were higher in rivers during the wet season.

Seasonal Correlation Analysis of Water Quality Parameters

Seasonal Pearson correlation analysis was conducted to examine the relationships among microbial and physico-chemical parameters, with significant correlations determined at $P < .05$. During the dry season (Table 3), total

Table 2. Seasonal Descriptive Statistics Across Sampled Water Points.

Parameter vs Season \pm SD	Mean CFUs/100 mL	Mean <i>E. coli</i> isolates	pH	Temp ($^{\circ}$ C)	Cond. (μ s/cm)	DO (mg/L)	TDS (mg/L)
Dry Season Mean of surface water points	$2.84 \pm 3.20 \times 10^5$	$9.82 \pm 9.78 \times 10^4$	8.6 ± 0.5	24.2 ± 3.1	384.5 ± 672.5	4.2 ± 0.9	236.2 ± 365.3
Dry Season OWP Mean	$1.07 \pm 0.79 \times 10^6$	$0.95 \pm 1.29 \times 10^5$	8.31 ± 0.39	24.0 ± 3.07	232.65 ± 409.33	4.66 ± 2.62	115.15 ± 203.76
Dry Season River Mean	$1.17 \pm 0.65 \times 10^6$	$1.24 \pm 1.16 \times 10^5$	8.72 ± 0.2	24.52 ± 3.16	663.38 ± 874.85	5.42 ± 0.71	331.88 ± 442.17
Wet Season Mean of surface water points	$1.13 \pm 1.10 \times 10^6$	$1.34 \pm 1.26 \times 10^5$	8.4 ± 0.4	22.8 ± 3.7	$509.02 \pm 1,046.3$	5.1 ± 1.9	192.38 ± 335.1
Wet Season OWP Mean	$0.91 \pm 1.25 \times 10^6$	$0.58 \pm 0.57 \times 10^5$	8.15 ± 0.36	20.9 ± 3.93	256.9 ± 506.92	4.87 ± 1.44	128.7 ± 271.45
Wet Season River Mean	$1.79 \pm 1.56 \times 10^6$	$1.49 \pm 2.02 \times 10^5$	8.6 ± 0.34	23.16 ± 3.41	1675.88 ± 2168.24	5.66 ± 1.2	405.12 ± 521.04

coliforms and *E. coli* exhibited a weak positive correlation, which was not statistically significant. Neither microbial parameter demonstrated significant associations with physicochemical variables. Among physicochemical parameters, several significant correlations were observed. Conductivity correlated positively with temperature ($r = .324, P = .015$), though weak. pH showed a significant positive correlation with DO ($r = .302, P = .024$). Conductivity was positively correlated with DO ($r = .308, P = .021$). Similarly, TDS was significantly positively correlated with DO ($r = .350, P = .008$), Temperature ($r = .335, P = .012$) and conductivity ($r = .984, P < .01$).

In the wet season (Table 4), a weak but statistically significant positive correlation was observed between CFUs and *E. coli* ($r = .465, P = .003$). No significant associations were found between microbial parameters and physicochemical variables. Physicochemical parameters displayed several significant relationships. pH correlated positively with temperature ($r = .394, P = .003$), while DO revealed a positive correlation with temperature ($r = .317, P = .017$). TDS demonstrated a moderate positive correlation with conductivity ($r = .648, P < .01$).

A multivariate analysis of variance (MANOVA) was conducted to assess the influence of water body (OWP and river), season (dry and wet), and their interaction on microbial and physicochemical parameters. The multivariate test statistics indicated significant main effects for both water body (*Wilks' λ* = .669, $F(7,62) = 4.387, P = .001$) and season (*Wilks' λ* = .643, $F(7,62) = 4.920, P < .001$). However, the interaction effect of water body \times season was not statistically significant (*Wilks' λ* = .811, $F(7,62) = 2.062, P = .061$).

Having found significant main effects from the MANOVA, a post hoc analysis was conducted for each of the main effects to assess the levels that had a significant difference. The results of these analyses were as shown in Table 5. The results showed that CFUs was significantly influenced by season ($P < .001$), but not by water body ($P = .136$). *E. coli* counts were not significantly affected by water body ($P = .727$) or season ($P = .138$). Regarding physicochemical parameters, pH showed a significant effect of water body ($P = .001$) and season ($P = .050$). Water temperature was significantly affected by season ($P = .025$), but not by water body ($P = .096$).

Conductivity was significantly influenced by water body ($P = .007$), but not by season ($P = .170$). Dissolved oxygen was significantly affected by water body ($P = .003$) but not season ($P = .098$). Total dissolved solids were significantly influenced by water body ($P = .011$) and not season ($P = .801$).

Discussion

The overall objective of this study was to establish seasonal variation in microbial and physicochemical water quality on surface water sources in the shared human-animal ASAL of Narok. The study revealed several notable findings. First, it established high encounter rates of CFUs and *E. coli* isolates in the surface water points within Narok West. Secondly, it revealed bacterial loads are

Table 3. Dry Season Correlation Analysis of Water Quality Parameters.

Season			Mean CFUs 100mL	Mean <i>E. coli</i> 100 mL	pH	Temp (°C)	Cond. (µs/cm)	DO (mg/L)	TDS (mg/L)
Dry	Mean CFUs 100 mL	Pearson correlation	–						
		N	56						
	Mean <i>E. coli</i> 100 mL	Pearson correlation	0.253	–					
		N	33	33					
	pH	Pearson correlation	0.008	0.266	–				
		N	56	33	56				
	Temp (°C)	Pearson correlation	0.158	–0.096	–0.179	–			
		N	56	33	56	56			
	Cond. (µs/cm)	Pearson correlation	0.102	0.014	0.154	0.324*	–		
		N	56	33	56	56	56		
	DO (mg/L)	Pearson correlation	0.194	–0.089	0.302*	0.186	0.308*	–	
		N	56	33	56	56	56	56	
	TDS (mg/L)	Pearson correlation	0.132	0.035	0.146	0.335*	0.984**	0.350**	–
		N	56	33	56	56	56	56	56

*P < .05. **P < .01.

Table 4. Wet Season Correlation Analysis of Water Quality Parameters.

Season			Mean CFUs 100mL	Mean <i>E. coli</i> 100 mL	pH	Temp (°C)	Cond. (µs/cm)	DO (mg/L)	TDS (mg/L)
Dry	Mean CFUs 100 mL	Pearson correlation	–						
		N	56						
	Mean <i>E. coli</i> 100 mL	Pearson correlation	0.465**	–					
		N	39	39					
	pH	Pearson correlation	0.030	0.155	–				
		N	56	39	56				
	Temp (°C)	Pearson correlation	0.070	0.176	0.394**	–			
		N	56	39	56	56			
	Cond. (µs/cm)	Pearson correlation	0.002	–0.189	0.201	0.090	–		
		N	56	39	56	56	56		
	DO (mg/L)	Pearson correlation	0.140	0.108	0.122	0.317*	0.031	–	
		N	56	39	56	56	56	56	
	TDS (mg/L)	Pearson correlation	0.049	–0.200	0.164	0.110	0.648**	–0.028	–
		N	56	39	56	56	56	56	56

*P < .005. **P < .001.

Table 5. Tests of Between-Subjects Effects of Water Quality Parameters.

Variable	Parameter	Mean square	F	Df	Sig.
Water	Mean CFUs/100 mL	1.97 × 10 ¹²	2.276	1	.136
	Mean <i>E. coli</i> /100 mL	1.62 × 10 ⁹	0.122	1	.727
	pH	1.812	11.194	1	.001
	Temp (°C)	31.048	2.854	1	.096
	Cond. (µs/cm)	6934833.313	7.865	1	.007
	DO (mg/L)	22.453	9.450	1	.003
	TDS (mg/L)	915 189.090	6.858	1	.011
Season	Mean CFUs/100 mL	1.60 × 10 ¹³	18.443	1	.000
	Mean <i>E. coli</i> /100 mL	2.98 × 10 ¹⁰	2.258	1	.138
	pH	0.647	3.997	1	.050
	Temp (°C)	57.076	5.247	1	.025
	Cond. (µs/cm)	1 693 129.713	1.920	1	.170
	DO (mg/L)	6.674	2.809	1	.098
	TDS (mg/L)	8507.907	0.064	1	.801

significantly influenced by seasons and water sources. Finally, it revealed nuanced statistically significant seasonal microbial and physicochemical fluctuations within surface water bodies. These findings on the prevalence of coliform forming units and *E. coli* colonies and physicochemical profile of surface waters of Narok are in correspondence to previous studies³¹ which established 5.1-9.7 pH ranges and high faecal and non-faecal bacteria in water pans of Narok South subcounty. Additionally, higher faecal indicator bacteria (*E. coli*) encounters were significant during the wet season compared to with dry-season levels in congruence previous studies.^{53,54} These high coliform numbers can plausibly be attributed to human excreta, livestock pastoralism and seasonal migration of wildlife, though requires further studies. Moreover, the *E. coli* loads were higher than those established from Nairobi River,⁵⁵ thus could be attributed to surface runoff from open defecation, overflowing and flooding of sanitation

amenities, animal waste and wastewater treatment plants. These sources can be established via faecal-source and non-faecal pollution tracking.⁵⁶⁻⁵⁹

High TDS levels in the water points may be attributed to high levels of hydrogen ions found in clay soils, which increase acidity in water pans,³¹ though warrants confirmatory tests. Higher bacterial loads during wet season can be attributed to increased introduction of CFUs and *E. coli* isolates from surface runoff, human excreta and animals waste into the water bodies,⁵⁴ while lower mean water temperatures during wet season compared to dry season can be attributed to lower ambient temperatures. Conversely, higher DO during wet season can be because of increased churning of waters during inflows. Our findings negate⁶⁰ findings which established that water pans in Baringo had higher pH and conductivity during wet season in comparison to dry season.

Our findings reveal that surface water sources, the primary sources of water including for domestic use in Narok County, are not suitable for direct human consumption based on bacterial and physicochemical properties. Additionally, recreational activities in these waters such as swimming should be limited as ingestion of water (swallowing) predisposes the residents to faecal-oral transmission of waterborne pathogens and other gastrointestinal parasites.^{11,61-63} Furthermore, since these sources are prone to pollution,^{11,17,64,65} Narok County should invest in providing potable water for its residents to avert waterborne diseases in the face of changing weather and environment.^{66,67} In areas where access to potable water is unavailable, active awareness of water treatment modes should be encouraged. Furthermore, community members should be made aware of the negative impacts of direct consumption of water from surface water sources.⁶⁸ This can aid in reducing regional, national and global waterborne disease burden.⁶⁹ Additionally, further studies on *E. coli* anti-microbial resistance (AMR) levels within the shared multi-use water points are required.⁷⁰⁻⁷²

In relation to established water parameters and livestock productivity, we noted that seasonal levels of pH in surface waters were within marginable permissible levels for cattle and other livestock, though not ideal. In as much as TDS levels below 500 mg/L is considered safe for livestock, higher variations witnessed during dry season might lead to diarrhoea, temporary digestive issues and mineral related deficiencies including stunted growth among calves, lambs and kids. However, in relation to CFU and *E. coli* levels, the surface waters of Narok West subcounty were above recommended levels. These high microbial levels could potentially reduce livestock productivity and subsequently affect livestock keepers' livelihoods. Furthermore, since mature livestock might possess some resistance to common waterborne pathogens, the high *E. coli* loads in the water can affect young animals due to immature immune systems and manifest in form of severe diarrhoea, dehydration, and fatalities. This would result in economic losses due to veterinary costs and reduced productivity. It is worth noting that studies have revealed that calves drinking microbial contaminated water put on less weight than those drinking

clean water.⁷³ With Narok being a beef and dairy production hub, it is prudent that clean water be made available for livestock, in the pursuit of maximising productivity. During our study, it was noted with concern that waters from some rivers and open water pans are being used for horticulture irrigation. This practice could potentially affect food safety and quality, especially for those vegetables and fruits eaten raw, poorly washed and/or undercooked.⁷⁴⁻⁷⁶

With recommended pH range of livestock water being 6.5 to 8.5, levels exceeding 8.5 might cause alkalosis in ruminants. This can result in reduced feed digestibility and nutrient absorption leading to reduced milk yield and / or weight gain, thus not suitable for prolonged consumption. While water temperature between 10 and 25°C is generally acceptable for livestock, as it encourages intake, warmer water temperatures exhibited during dry season can result in microbial contamination and proliferation (>25°C) including cyanobacteria. In relation to conductivity, levels below 1,000 µs/cm are considered generally safe for livestock with ranges approaching or exceeding 1000 µs/cm could pose risks to livestock in form of diarrhoea, reduced water intake and mineral imbalances especially wet season.

Our findings established that DO levels were lower during the dry season as compared to the wet season. Low DO levels can support anaerobic bacteria and increase waterborne pathogenic risks, reduce consumption and impact productivity through reduced hydration. The observed low DO levels can be attributed to decomposition of organic matter, dead algal blooms or introduction of nutrient rich runoff.⁷⁷ Low DO levels (<2-3 mg/L) render water hypoxic and thus unsuitable for aquaculture, especially during dry season.

Study Limitations

Seasonal precipitation, river flows, water source dimensions and sources of microbial pollution were beyond the scope of the study. Previous studies have noted changes in rainfall precipitation attributed to weather variation²⁸ in the study area, which subsequently would affect river flows and water source dimensions. In relation to microbial varieties, we were limited to total coliform forming units and *E. coli* colony counts as opposed to faecal coliforms and enterococci counts. Finally, since the ecosystem is quite extensive coupled by paucity of data of number of OWPs and limited resources (finances, time and equipment), this study sought to establish baseline data on surface water sources and recommends further studies.

Conclusion

The study showed seasonal microbial and physicochemical parameters in surface water bodies in an ASAL region in sub-Saharan Africa, in the face of weather variability.²⁸ It revealed high bacteria loads and physicochemical levels above approved WHO levels. These high levels are likely to predispose humans and animals to waterborne diseases of public health importance, thus resulting in increased human morbidity and mortality vis-à-vis reduced livestock

productivity and livelihood losses. Cumulatively, these could dent the attainment of national, regional, and global agenda ranging from the Kenyan Vision 2030⁷⁸; The African Union Agenda 2063⁷⁹; International Decade for Action 2018-2028: Water for Sustainable Development; International Decade of Sciences for Sustainable Development: 2024-2033; and a myriad of UN SDGs² including UN SDG 3: Good health and well-being; SDG 6: Clean water and sanitation; SDG 14: Life below water; SDG 15: Life on land; SDG 16: Peace, Justice and Strong Institutions; and SDG 17: Partnerships for the Goals. We advocate for adoption, management and improvement of water conservation strategies^{8,80} such as rainwater harvesting, fencing of multiple use open water pans and provision of alternative water points to avoid soiling by animals and reduce disturbing sediments⁶⁵ as these harbour pathogens and could possibly result into increased waterborne disease infections. We also call for incorporation of local indigenous knowledge systems and nature-based solution practices into water resource management, and periodic spatiotemporal physicochemical and microbial assessments of surface wetlands. Lastly, in a bid to ensure consumption of potable water, we emphasise the need for effective water, sanitation and hygiene campaigns with support from all water and sanitation sector stakeholders.

Recommendation

We propose increased access to potable water and awareness creation on the demerits of direct consumption of water from surface water sources. We also propose further studies on ecosystem health in relation to pathogenic waterborne diseases including *E. coli* anti-microbial resistance analysis of ubiquitous waterborne pathogens within the waterbodies. This should include seasonal prevalence of waterborne diseases in the face of changing weather and climate, horticultural food safety attributed to irrigated surface waters use vis-à-vis community knowledge, attitude and practices on water, sanitation and hygienic practices in the landscape. Using the Information, Education, and Communication strategy, community members should be made aware of water quality within surface water points and empowered on how to improve public health, making informed decisions and adopting healthy behaviours. We recommend concerted efforts to protect water points from point and non-point contamination, with the communities taking a lead. Through interagency collaboration, Kenya's Ministry of Health in collaboration with Ministry of Water, Sanitation and Irrigation, Ministry of Environment, Climate Change and Forestry, county governments and public-private health sector players should develop, fund, build capacity and implement national microbial water quality monitoring framework which will conduct ecological health assessments including faecal-source and non-faecal pollution tracking.

Acknowledgements

We extend gratitude to the community of Narok where the sampling was done; Francis Koya and Sammy Yegon (community

laymen and translators); together with Fanuel Onyango (Water Quality and Pollution Control Officer at Water Resource Authority, Lake Victoria Basin Area) who assisted with *in situ* water sampling. We acknowledge Brian O. Otiego for developing the sampling point map. Lastly, we thank George Njoroge, Jamlick Lepaa Mpakany and Faith Jepkemei Waswala for assisting in the preparation and analysis of the microbial samples.


AI Acknowledgement

No generative AI was used in the preparation of this manuscript.

ORCID iDs

Brian Marvis Waswala-Olewe  <https://orcid.org/0000-0001-9604-9746>

George Paul Omondi  <https://orcid.org/0000-0003-2041-4457>

Romulus Abila  <https://orcid.org/0000-0001-8762-7153>

Paul Webala  <https://orcid.org/0000-0003-0576-8935>

Ethical Considerations

The study protocols and procedures were approved by Egerton University Institutional Scientific and Ethics Review Committee (EUISERC/APP/327/2024); and National Commission for Science, Technology and Innovation (NACOSTI/P/24/35318).

Author Contributions

BMW conceptualized the idea, conducted the study, did data curation together with formal analysis, administered the project, validated results, developed the draft document together with review & editing. GPO helped in methodology, supervision, and reviewing & editing developed document. RO was instrumental in funding acquisition, supervision, and reviewing & editing developed document. PW contributed to the study's methodology, supervision, and reviewing & editing developed document. All authors provided intellectual input to the drafts, read and approved the final version of the manuscript.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was partially supported by a National Geographic Society Grant NGS-98595R-23 to RA for water collection and bacteriology.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Changwony C, Sichangi AW, Murimi Ngigi M. Using GIS and remote sensing in assessment of water scarcity in Nakuru County, Kenya. *Adv Remote Sens.* 2017;06(01):88-102.
2. United Nations. Sustainable development goals. 2020. Accessed June 6, 2025. <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>
3. Valhondo C, Carrera J. Water as a finite resource: from historical accomplishments to emerging challenges and artificial recharge. In: Galanakis CM, Agrafioti E eds. *Sustainable Water and Wastewater Processing.* Elsevier; 2019;1-17.
4. World Health Organization and the United Nations Children's Fund. *Progress on Household Drinking Water, Sanitation and Hygiene 2000-2020: Five Years into the SDGs.* World Health

- Organization (WHO) and the United Nations Children's Fund (UNICEF); 2021. Accessed February 22, 2023. <https://www.who.int/publications/i/item/9789240030848>
5. Hope R. Four billion people lack safe water. *Science*. 2024;385(6710):708-709.
 6. Shayo GM, Elimbinzi E, Shao GN, Fabian C. Severity of waterborne diseases in developing countries and the effectiveness of ceramic filters for improving water quality. *Bull Natl Res Cent*. 2023;47(1):113.
 7. Ashbolt NJ. Microbial contamination of drinking water and disease outcomes in developing regions. *Toxicology*. 2004;198(1-3):229-238.
 8. Nyika J, Dinka MO, eds. Management of water challenges in Sub-Saharan Africa. In: *Water Challenges in Rural and Urban Sub-Saharan Africa and Their Management*. Springer International Publishing; 2023:57-75.
 9. Nyika J, Dinka MO, eds. Water challenges in rural Sub-Saharan Africa. In: *Water Challenges in Rural and Urban Sub-Saharan Africa and Their Management*. Springer; 2023;39-55.
 10. County Government of Narok. *Narok County Integrated Development Plan 2018-2022*. County Government of Narok; 2018. Accessed March 20, 2025. <https://narok.go.ke/wp-content/uploads/2022/06/NAROK-CIDP-2018-2022.pdf>
 11. Waswala-Olewe BM, Olewe MA, Oloitipitip F, Omondi GP, Webala P, Abila R. Assessment of water, sanitation and hygiene (WASH) knowledge, attitudes and practices in water stressed Kenyan semi-arid landscape. *PLOS Water*. 2026;5(2):e0000503.
 12. Ashbolt NJ. Microbial contamination of drinking water and human health from community water systems. *Curr Environ Health Rep*. 2015;2(1):95-106.
 13. Forstinus N, Ikechukwu N, Emenike M, Christiana A. Water and waterborne diseases: a review. *Int J Trop Dis Health*. 2016;12(4):1-14.
 14. Moreira NA, Bondelind M. Safe drinking water and waterborne outbreaks. *J Water Health*. 2017;15(1):83-96.
 15. Jenkins MW, Tiwari S, Lorente M, Gichaba CM, Wuertz S. Identifying human and livestock sources of fecal contamination in Kenya with host-specific Bacteroidales assays. *Water Res*. 2009;43(19):4956-4966.
 16. Schriewer A, Odagiri M, Wuertz S, et al. Human and animal fecal contamination of community water sources, stored drinking water and hands in rural India measured with validated microbial source tracking assays. *Am Soc Trop Med Hyg*. 2015;93(3):509-516.
 17. Chigor VN, Sibanda T, Okoh AI. Studies on the bacteriological qualities of the Buffalo River and three source water dams along its course in the Eastern Cape Province of South Africa. *Environ Sci Pollut Res*. 2013;20(6):4125-4136.
 18. El-Liethy MA, Abia ALK, eds. Some bacterial pathogens of public health concern in water and wastewater: an African perspective. In: *Current Microbiological Research in Africa*. Springer International Publishing; 2020;1-27.
 19. Magana-Arachchi DN, Wanigatunge RP. Ubiquitous waterborne pathogens. In: Prasad MNV, Grobelak A eds. *Waterborne Pathogens*. Elsevier; 2020;15-42.
 20. Okeke IN. Diarrheagenic Escherichia coli in sub-Saharan Africa: status, uncertainties and necessities. *J Infect Dev Ctries*. 2009;3(11):817-842.
 21. Xavier RJ, Thomas HJ. Gastrointestinal diseases. In: Ryan ET, Hill DR, Solomon T, Dondorp AM eds. *Hunter's Tropical Medicine and Emerging Infectious Disease*. Elsevier; 2013;18-27.
 22. Khan AI, Amin MA. Understanding deaths from diarrhoea in children younger than 5 years. *Lancet Glob Health*. 2024;12(6):e891-e892.
 23. Korir CJ. Climate change stress on pastoral livelihoods in Narok County, Kenya. *Eur J Soc Sci Stud*. 2019;4(4). Accessed February 2, 2023. <https://oapub.org/soc/index.php/EJSSS/article/view/598>
 24. McNally A, Verdin K, Harrison L, et al. Acute water-scarcity monitoring for Africa. *Water*. 2019;11(10):1968.
 25. Opiyo F, Wasonga O, Nyangito M, Schilling J, Munang R. Drought adaptation and coping strategies among the Turkana pastoralists of Northern Kenya. *Int J Disaster Risk Sci*. 2015;6(3):295-309.
 26. Martin SMW, Philip OO, Fredrick OK, Ayub VOO, Said-Ally M. Influence of land use practices on water physicochemical parameters and nutrients loading along the Mara River of East Africa. *Afr J Environ Sci Technol*. 2018;12(7):235-243.
 27. Ofori SA, Cobbina SJ, Obiri S. Climate change, land, water, and food security: Perspectives from Sub-Saharan Africa. *Front Sustain Food Syst*. 2021;5. doi:10.3389/fsufs.2021.680924
 28. Waswala-Olewe BM, Webala PW, Omondi GP, Troon JB, Abila R. Assessing temporal drought severity in Kenya's arid and semi-arid landscape using Google Earth engine and the normalised difference Drought Index. *Meteorol Appl*. 2026;33(1). doi:10.1002/met.70147
 29. Kenya LO. *The Constitution of Kenya: 2010*. 2013.
 30. Njuguna J, Muruka C. Open defecation in newly created Kenyan counties: a situational analysis. *J Health Care Poor Underserved*. 2017;28(1):71-78.
 31. Ndubi D, Oyaro N, Githae E, Afullo A. Determination of physico-chemical properties of sources of water in Narok North Sub-County, Kenya. *Int Res J Environ Sci*. 2015;4(1): 47-51.
 32. National Environment Management Authority. *National Environment Research Agenda for 2008-2030*. National Environment Management Authority; 2009.
 33. di Bari C, Venkateswaran N, Pigott D, Flastl C, Devleesschauwer B. The global burden of neglected zoonotic diseases: current state of evidence. *Eur J Public Health*. 2022;32(Suppl 3). doi:10.1093/eurpub/ckac129.757
 34. Osunla CA, Okoh AI. Vibrio pathogens: a public health concern in rural water resources in Sub-Saharan Africa. *Int J Environ Res Public Health*. 2017;14(10):1188.
 35. Mwanja J, Van der Velde R, Vekerdy Z, Mtamba J. Runoff modeling of the Mara River using satellite observed soil moisture and rainfall. *Rwanda J*. 2017;1(1S). doi:10.4314/rj.v1i1S.9D
 36. Campbell K, Hofer H. People and wildlife: spatial dynamics and zones of interaction. In: Sinclair ARE, Arcese P, eds. *Serengeti II: Dynamics, Management and Conservation of an Ecosystem*. The University of Chicago Press; 1995;534-570.
 37. Norton-Griffiths M, Herlocker D, Pennycook L. The patterns of rainfall in the Serengeti Ecosystem, Tanzania. *Afr J Ecol*. 1975;13(3-4):347-374.
 38. Mutie SM, Mati BM, Home P, Gadain H, Gathenya J. *Evaluating land use change effects on river flow using USGS geospatial stream flow model in Mara River basin, Kenya*. Center for Remote Sensing of Land Surfaces. Published online 2006:141-148. Accessed November 29, 2025. https://www.researchgate.net/profile/Bancy-Mati/publication/297784677_Evaluating_land_use_change_effects_on_river_flow_using_USGS_geospatial_stream_flow_model_in_Mara_River_basin_Kenya/links/59b50a71458515a5b49375c4/

- Evaluating-land-use-change-effects-on-river-flow-using-USGS-geospatial-stream-flow-model-in-Mara-River-basin-Kenya.pdf
39. Brown JAH, Ribeny FMJ, Wolanski EJ, Codner GP. A mathematical model of the hydrologic regime of the Upper Nile Basin. *J Hydrol.* 1981;51(1-4):97-107.
 40. Ogutu JO, Piepho HP, Dublin HT, Bholá N, Reid RS. Rainfall influences on ungulate population abundance in the Mara-Serengeti ecosystem. *J Anim Ecol.* 2008;77(4):814-829.
 41. Bartzke GS, Ogutu JO, Mukhopadhyay S, Mtui D, Dublin HT, Piepho HP. Rainfall trends and variation in the Maasai Mara ecosystem and their implications for animal population and biodiversity dynamics. *PLoS One.* 2018;13(9):e0202814.
 42. Msoffe FU, Ogutu JO, Said MY, et al. Wildebeest migration in East Africa: Status, threats and conservation measures. *Preprint posted online* February 11, 2019. doi:10.1101/546747
 43. Serneels S, Lambin EF. Impact of land-use changes on the wildebeest migration in the northern part of the Serengeti-Mara ecosystem. *J Biogeogr.* 2001;28(3):391-407.
 44. Birundu AM. *Analyzing Catchment Behavior through Rainfall-Run-Off Modeling: A Case Study of Mara Basin in Kenya.* Master's thesis. University of Tlemcen; 2016. Accessed November 29, 2025. <https://repository.pauwescop.net/handle/1/98>
 45. Kereto J, Oywaya Nkurumwa A, Obara J, Mango N. Livestock management and protection using indigenous technical knowledge among the Maasai of Narok county, Kenya. *Cogent Soc Sci.* 2022;8(1). doi:10.1080/23311886.2022.2040793
 46. Mukeka JM, Ogutu JO, Kanga E, Røskaft E. Human-wildlife conflicts and their correlates in Narok County, Kenya. *Glob Ecol Conserv.* 2019;18:e00620.
 47. Gicheru P, Makokha SN, Chen L, Gachimbi L, Wamuongo JW. Land subdivision and degradation in Narok, Kenya. In: McNeill D, Nesheim I, Brouwer F eds. *Land Use Policies for Sustainable Development.* Edward Elgar Publishing; 2012.
 48. Kotikot SM, Smithwick EAH, Gergel S, Nankaya J, Abila R, Mabwoga S. Historical land policies influence contemporary landscape patterns in agropastoral landscapes. *Landsc Ecol.* 2025;40(8):163.
 49. Li W, Buitenwerf R, Munk M, Amoke I, Bøcher PK, Svenning JC. Accelerating savanna degradation threatens the Maasai Mara socio-ecological system. *Glob Environ Change.* 2020;60:102030.
 50. Løvschal M, Juul Nørmark M, Svenning JC, Wall J. New land tenure fences are still cropping up in the Greater Mara. *Sci Rep.* 2022;12(1):11064.
 51. American Public Health Association. *Standard Methods for the Examination of Water and Wastewater.* 23rd ed. American Public Health Association; 2017.
 52. Alegbeleye O, Alisoltani A, Abia ALK, et al. Investigation into the bacterial diversity of sediment samples obtained from Berg River, Western Cape, South Africa. *Folia Microbiol.* 2021;66(6):931-947.
 53. Gershom NA, Stella K, John M, Anthony K. Variation of total coliforms and bacteria during dry and wet seasons in rivers of Sigor Division, West Pokot County, Kenya. *J Adv Microbiol.* 2020;20:41-51.
 54. Strauch AM. Seasonal variability in faecal bacteria of semi-arid rivers in the Serengeti National Park, Tanzania. *Mar Freshw Res.* 2011;62(10):1191-1200.
 55. Musyoki AM, Abednego M, Suleiman MA, Mbithi JN, Maingi JM. Water-borne bacterial pathogens in surface waters of Nairobi river and health implication to communities downstream Athi river. *World Appl Sci J.* Published online 2013.
 56. Field KG, Samadpour M. Fecal source tracking, the indicator paradigm, and managing water quality. *Water Res.* 2007;41(16):3517-3538.
 57. Griffith JF, Weisberg SB, McGee CD. Evaluation of microbial source tracking methods using mixed fecal sources in aqueous test samples. *J Water Health.* 2003;1(4):141-151.
 58. Luyt CD, Tandlich R, Muller WJ, Wilhelm BS. Microbial monitoring of surface water in South Africa: an overview. *Int J Environ Res Public Health.* 2012;9(8):2669-2693.
 59. Nguyen KH, Senay C, Young S, et al. Determination of wild animal sources of fecal indicator bacteria by microbial source tracking (MST) influences regulatory decisions. *Water Res.* 2018;144:424-434.
 60. Kurui EJ, Ogendi GM, Moturi WN. Microbiological contamination of water pans in Baringo County. *J Water Sanit Hyg Dev.* 2017;7(3):485-494.
 61. Delamare H, Septfons A, Alfandari S, Mailles A. Freshwater sports and infectious diseases: a narrative review. *Infect Dis.* 2024; 54(4):104883. doi:10.1016/j.idnow.2024.104883
 62. Rodrigues C, Cunha MÂ. Assessment of the microbiological quality of recreational waters: indicators and methods. *Euro-Med J Environ Integr.* 2017;2(1):25.
 63. Sinclair RG, Jones EL, Gerba CP. Viruses in recreational water-borne disease outbreaks: a review. *J Appl Microbiol.* 2009;107(6):1769-1780.
 64. Moseti MB, Mabwoga S, Jared B, Abila R. Water quality, phytoplankton composition, and microcystins concentrations in water pans in Narok Semi-Arid Landscape, Kenya. *East Afr J Environ Nat Resourc.* 2025;8(2):397-412.
 65. Bragina L, Sherlock O, van Rossum AJ, Jennings E. Cattle exclusion using fencing reduces *Escherichia coli* (E. coli) level in stream sediment reservoirs in northeast Ireland. *Agric Ecosyst Environ.* 2017;239:349-358.
 66. Gerard J, Kibaara T, Blom IM, et al. Climate-sensitive health outcomes in Kenya: a scoping review of environmental exposures and health outcomes research, 2000–2024. *Climate.* 2025;13(7):133.
 67. Hunter PR. Climate change and waterborne and vector-borne disease. *J Appl Microbiol.* 2003;94:37S-46S.
 68. Li P, Wu J. Drinking water quality and public health. *Expo Health.* 2019;11(2):73-79.
 69. Prüss-Ustün A, Wolf J, Bartram J, et al. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low- and middle-income countries. *Int J Hyg Environ Health.* 2019;222(5):765-777.
 70. Abia ALK. Antimicrobial resistance and environmental health. *Antibiotics.* 2025;14(2):113.
 71. Hart A, Warren J, Wilkinson H, Schmidt W. Environmental surveillance of antimicrobial resistance (AMR), perspectives from a national environmental regulator in 2023. *Eurosurveillance.* 2023;28(11). doi:10.2807/1560-7917.ES.2023.28.11.2200367
 72. Zhang XX, Zhang T, Fang HH. Antibiotic resistance genes in water environment. *Appl Microbiol Biotechnol.* 2009;82(3):397-414.

73. Willms Walter D, Kenzie Orin R, McAllister Tim A, et al. Effects of water quality on cattle performance. *Rangeland Ecol Manage/J Range Manage Arch*. 2002;55(5):452-460.
74. Akinde SB, Sunday AA, Adeyemi FM, et al. Microbes in irrigation water and fresh vegetables. *Appl Biosaf*. 2016; 21(2):89-97.
75. Ijabadeniyi OA, Debusho LK, Vanderlinde M, Buys EM. Irrigation water as a potential preharvest source of bacterial contamination of vegetables. *J Food Saf*. 2011;31(4):452-461.
76. Steele M, Odumeru J. Irrigation water as source of food-borne pathogens on fruit and vegetables. *J Food Prot*. 2004; 67(12):2839-2849.
77. Dutton CL, Subalusky AL, Hamilton SK, Rosi EJ, Post DM. Organic matter loading by hippopotami causes subsidy overload resulting in downstream hypoxia and fish kills. *Nat Commun*. 2018;9(1):1951.
78. Government of the Republic of Kenya. *Kenya Vision 2030 (Popular Version)*. 2007. Accessed March 20, 2025. <https://vision2030.go.ke/wp-content/uploads/2018/05/Vision-2030-Popular-Version.pdf>
79. Africa Union. *Agenda 2063 Report of the Commission on the African Union Agenda 2063: The Africa We Want in 2063*. Africa Union; 2015.
80. Nyika J, Dinka MO. Recommendations to improve management of water challenges in Sub-Saharan Africa. In: Leal Filho W, Azul AM, Brandli L, Blaikie P eds. *Water Challenges in Rural and Urban Sub-Saharan Africa and Their Management*. Springer International Publishing;2023:103-112.