Baseline Assessment of Water Quality, Quantity, and Sediment Transport in the Kabutie Watershed, Upper Yala River Catchment, Nandi County, Kenya: Implications for Watershed Health and Drinking Water Security

Stella Wanjala[1,2,*], Rose Wamalwa[2], David Ruto[3], Vivian Okoth[2], Paul Wanjala Mutevi[4]

[1]Department of Biological Sciences, School of Natural and Applied Sciences, Masinde Muliro University of Science and Technology (MMUST), P.O. Box 190-50100, Kakamega

[2]Women in Water and Natural Resources Conservation (WWANC), P.O. Box 2802-50100, Kakamega

[3]Water Resources Authority (WRA), Kipkaren Upper Yala Sub Basin, P.O. Box 3040-30100, Eldoret

[4]Department of Biological Sciences, School of Pure and Applied Sciences, Maasai Mara University, P.O. Box 861-20500, Narok

***Corresponding Author**

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ABSTRACT

Watershed degradation resulting from soil erosion and organic pollution threatens water security and ecosystem health in many rural catchments of Kenya. The Kabutie watershed, a key sub-catchment of the Upper Yala River in Nandi County, supplies drinking water to Kapsabet Town and surrounding communities, yet baseline information on its hydrology and water quality has been lacking. This study established baseline conditions of water quality, stream discharge, and sediment transport across the Kabutie watershed to support future monitoring and management interventions. A cross-sectional survey was conducted in July 2025 at fourteen monitoring sites. Stream discharge was measured using an Acoustic Doppler Velocimeter. Physicochemical parameters including temperature, pH, electrical conductivity, total dissolved solids, turbidity, and Dissolved oxygen were measured in situ using calibrated field probes. Total suspended solids were determined using APHA standard methods, and sediment loads were estimated from discharge and suspended sediment concentrations. Stream discharge ranged from 0.004 to 1.306 m^3/s. Turbidity exceeded the Kenyan drinking water standard of 25 NTU at 85.7% of sampling sites, with Kapyagan Stream recording the highest value (301 NTU). TSS exceeded the recommended limit of 30 mg/L at 42.9% of sites, reaching 282 mg/L at Kapyagan. Dissolved oxygen levels were below the recommended 80% saturation threshold for aquatic life at all sites, with critically low values observed at Kaptilalon Stream (45.5%). Sediment loads ranged from 0.004 to 15.008 tons/day, with the Kabutie River exporting an estimated 5,478 tons of sediment annually. In contrast, pH, conductivity, and TDS remained within acceptable limits across all sites. The Kabutie watershed is experiencing significant degradation driven by soil erosion and organic pollution. Kapyagan Stream, a major drinking water source, was identified as the most vulnerable site. Immediate riparian restoration, livestock exclusion, pollution-source investigations, and long-term watershed monitoring are recommended to safeguard water quality and drinking water security.

Keywords: Watershed health, Sediment transport, Physicochemical parameters, Upper Yala River, Nandi County

INTRODUCTION

Background

Freshwater resources worldwide are increasingly threatened by land-use change, agricultural intensification, urbanization, and climate variability, all of which contribute to declining water quality and watershed degradation [1,2]. In sub-Saharan Africa, catchment degradation has emerged as a major environmental challenge, reducing ecosystem resilience, increasing sediment yields, and compromising drinking water security for rapidly growing populations [3,4].

Kenya's river catchments have experienced substantial anthropogenic pressure over the past three decades due to expansion of agriculture into riparian zones, deforestation, overgrazing, and increasing human settlement densities [5,6]. These pressures accelerate soil erosion and sediment transport into rivers, resulting in elevated turbidity, increased treatment costs for potable water, reduced aquatic biodiversity, and diminished reservoir storage capacity [7,8].

The Upper Yala River catchment is among the most important hydrological systems in western Kenya. It supports agricultural production, domestic water supply, and ecosystem services for hundreds of thousands of residents within Nandi and Kakamega counties [9]. The Kabutie watershed, a tributary system within the Upper Yala catchment, supplies raw water to Kapsabet Town and surrounding communities. Despite its strategic importance, there has been no comprehensive assessment of hydrological conditions, sediment transport dynamics, and water quality status within this watershed.

Sediment pollution has become one of the leading causes of freshwater ecosystem degradation globally. According to the Food and Agriculture Organization (FAO), excessive sediment loads arising from watershed disturbance can reduce aquatic productivity, impair water treatment infrastructure, and alter stream habitat quality [10]. In tropical highland watersheds such as those found in western Kenya, sediment generation is often intensified by cultivation on steep slopes and inadequate riparian protection [11].

Dissolved oxygen (DO) remains one of the most important indicators of aquatic ecosystem health. Reduced DO concentrations are frequently associated with organic pollution, nutrient enrichment, and microbial decomposition processes that threaten aquatic biodiversity [12]. Recent studies in East African watersheds have shown that streams subjected to livestock access, domestic wastewater discharge, and market runoff often experience significant oxygen depletion despite appearing visually clean [13,14].

Establishing baseline information on discharge, sediment transport, and physicochemical water quality is therefore essential for evidence-based watershed management and sustainable water resource planning [15]. The present study provides the first comprehensive baseline assessment of water quality, water quantity, and sediment dynamics in the Kabutie watershed, generating critical information for watershed restoration, drinking water protection, and long-term environmental monitoring.

Objectives

The primary objectives of this baseline survey were to:

1. Quantify discharge and sediment load at 14 representative monitoring sites across the Kabutie watershed;
2. Assess in-situ water quality parameters (temperature, pH, electrical conductivity, TDS, turbidity, dissolved oxygen) against Kenyan standards;
3. Identify priority sites requiring immediate intervention;
4. Establish a reproducible baseline for long-term watershed monitoring

Significance of Study

This study provides the first empirical baseline for the Kabutie watershed, enabling:

1. Evidence-based prioritization of conservation investments;

2. Tracking of future trends in water quality and quantity;
3. Compliance monitoring with Kenyan water quality regulations;
4. Community awareness of watershed health status

METHODOLOGY

Study Area

The Kabutie watershed is in Nandi County, Kenya, within the Upper Yala River catchment (Figure 1). The watershed spans approximately 85 km² and ranges in altitude from 1,907 m to 2,157 m above sea level. The climate is humid tropical with bimodal rainfall (March-May long rains; October-December short rains), averaging 1,200-1,600 mm annually. The main land uses include smallholder agriculture (maize, tea, dairy), settled areas (including Kapsabet town), and remnant natural vegetation along riparian corridors.

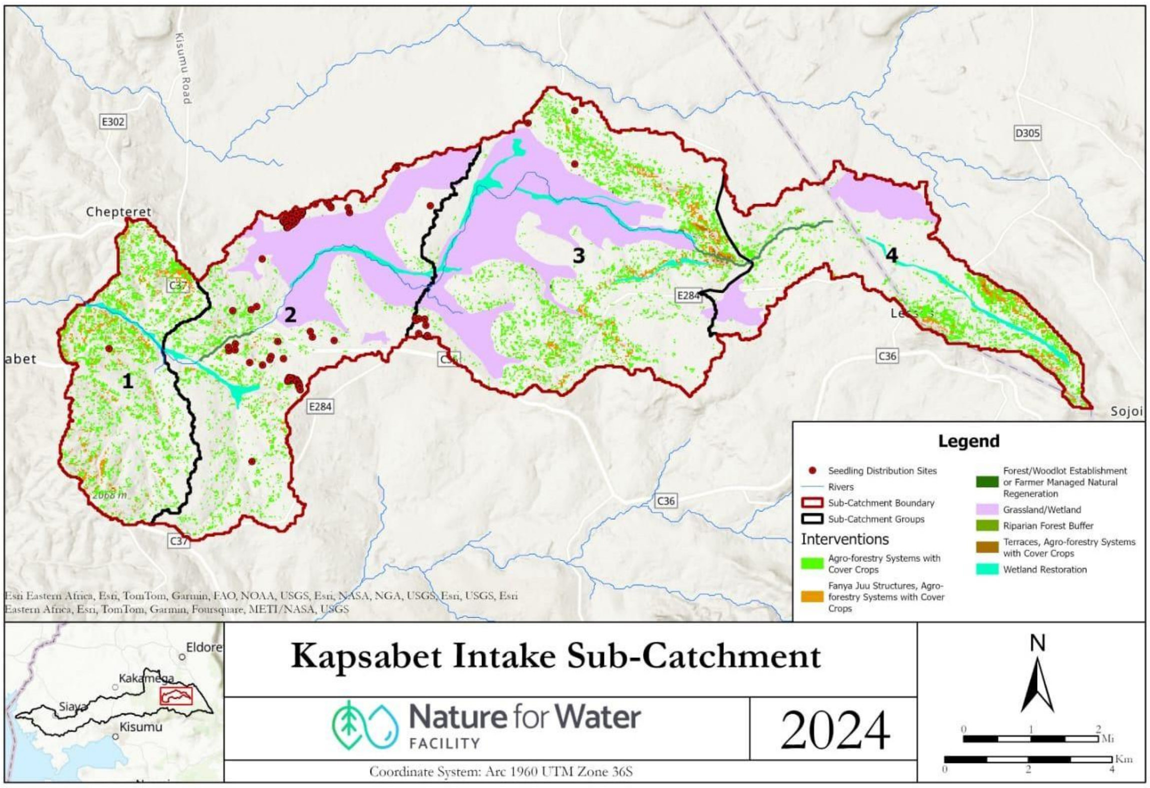

Figure 1. Map of the study area showing all 14 sampling sites

Sampling Site Selection

Fourteen monitoring sites were selected to represent:

1. The main stem of Kabutie River (downstream of all tributaries)
2. Tributaries supplying Kapsabet town drinking water (Kapyagan, Kaptilalon)
3. Streams receiving runoff from market centers (Nganiat, downstream of Kilibwoni market)
4. Streams draining agricultural areas (all remaining sites)
5. Reference condition (Kaptilalon, based on low turbidity)

Site coordinates were recorded using handheld GPS (Garmin GPSMAP 64s). Site locations and characteristics are summarized in Table 1.

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Table 1: Monitoring Site Locations and Characteristics

Site ID	Site Name	Latitude	Longitude	Altitude (m.a.s.l)	Stream Order	Dominant Land Use
KBT-01	Kabutie River	0.21613	35.11970	1907	3	Mixed agriculture
KBT-02	Kunurter Stream	0.21319	35.13719	1937	1	Agriculture
KBT-03	Kapyagan Stream	0.21784	35.12377	1926	1	Water supply intake
KBT-04	Nga stream	0.20213	35.13571	1952	1	Residential/Agriculture
KBT-05	Chebarbar Stream	0.20328	35.14056	1931	1	Agriculture
KBT-06	Olengata Stream	0.19086	35.14070	1952	1	Agriculture
KBT-07	Mukuri River	0.21133	35.16300	1951	2	Agriculture/market
KBT-08	Nganiat Stream	0.20130	35.22419	2001	1	Market/agriculture
KBT-09	Katanin Stream	0.22460	35.21839	1981	1	Agriculture
KBT-10	Kapchumba Stream	0.24145	35.21316	1974	1	Swamp drainage/maize
KBT-11	Kirobi river (u/s bridge)	0.22467	35.26710	2084	2	Agriculture/cattle
KBT-12	Kaptilalon Stream	0.21485	35.24484	2072	1	Water supply intake
KBT-13	Kirobi river (Terige)	0.23079	35.27356	2101	2	Agriculture
KBT-14	Koisagat Stream	0.21791	35.31175	2157	1	Agriculture/roads

Field Data Collection

All measurements were conducted during the dry season (July 2025) to establish baseline conditions comparable to low-flow periods. Measurements were performed between 09:00 and 16:00 under stable weather conditions.

Discharge Measurement

Discharge was measured using an Acoustic Doppler Velocimeter (ADV, SonTek RiverSurveyor M9) following WRA standard operating procedures (WRA, 2022). At each site, a representative cross-section was identified, and velocity measurements were taken at 0.6 depth at 20-30 vertical increments across the channel. Cross-sectional area was calculated from depth measurements, and discharge (Q) was computed as:

$$Q = \int v(x,z)\, dA$$

Where v = velocity, A = cross-sectional area.

In-Situ Water Quality Parameters

In-situ parameters were measured using a calibrated multi-parameter probe (YSI ProDSS):

1. Temperature (°C) – APHA 2550 B
2. pH – APHA 4500 H^+ B

3. Electrical Conductivity (µS/cm) – APHA 2510 B
4. Total Dissolved Solids (mg/L) – APHA 2510 A
5. Turbidity (NTU) – APHA 2130 B
6. Dissolved Oxygen (% saturation) – APHA 4500 O-H

The probe was calibrated prior to fieldwork using standard solutions. At each site, the probe was submerged at mid-depth in flowing water until readings stabilized (approximately 3-5 minutes), then triplicate readings were recorded.

Water Sampling for Laboratory Analysis

Grab samples were collected at each site using 1-liter acid-washed polyethylene bottles. Samples were stored on ice (4°C) and transported to the WRA laboratory within 12 hours. Total Suspended Solids (TSS) were analyzed using APHA 2540 D: filtration through GF/C glass fiber filters (1.2 µm pore size), drying at 103-105°C, and gravimetric determination.

Sediment Load Calculation

Sediment load (L, tons/day) was calculated as: $L = Q \times SSC \times 0.0864$

Where:

- Q = discharge (m^3/s)
- SSC = suspended sediment concentration derived from TSS (mg/l)
- 0.0864 = conversion factor (seconds per day × kg to tons)

Quality Assurance/Quality Control (QA/QC)

QA/QC procedures included:

1. Daily calibration of the multi-parameter probe
2. Field blanks (deionized water) for each sampling day (n=5, all below detection)
3. Duplicate samples at 20% of sites (n=3) showing relative percent difference <10%
4. Chain-of-custody documentation for laboratory samples

Data Analysis

Statistical analyses were performed using R version 4.2.2 (R Core Team, 2023). Descriptive statistics (mean, median, standard deviation, range) were calculated for each parameter. Correlation analysis (Pearson's r) was used to examine relationships between parameters. Comparisons with regulatory standards were performed using one-sample t-tests.

Comparison Standards

Results were compared to:

1. Kenya Water Quality Regulations (Legal Notice No. 120 of 2020) – Drinking water source standards
2. WHO Guidelines for Drinking-Water Quality (4th edition, 2022) – Where Kenyan standards are absent

RESULTS

Discharge and Stream Morphology

Discharge varied by four orders of magnitude across the 14 sites, reflecting the hierarchical structure of the watershed (Table 2). The main stem Kabutie River (KBT-01) had the highest discharge (1.306 m^3/s), which was

3.7 times greater than the next largest tributary (Mukuri, 0.472 m³/s). The smallest streams (Katanin, Kaptilalon) had discharges below 0.01 m³/s.

Table 2: Discharge and Channel Characteristics

Site ID	**Width (m)**	**Mean Depth (m)**	**Cross-sectional Area (m²)**	**Mean Velocity (m/s)**	**Discharge (m³/s)**
KBT-01	8.20	0.80	4.084	0.320	1.306
KBT-02	1.40	0.28	0.264	0.282	0.075
KBT-03	1.20	0.22	0.211	0.200	0.042
KBT-04	1.60	0.10	0.088	0.264	0.023
KBT-05	2.40	0.27	0.495	0.493	0.244
KBT-06	1.30	0.52	0.458	0.473	0.217
KBT-07	3.60	0.72	1.820	0.259	0.472
KBT-08	1.40	0.18	0.202	0.315	0.064
KBT-09	0.70	0.18	0.084	0.092	0.008
KBT-10	2.20	0.26	0.430	0.331	0.142
KBT-11	2.10	0.46	0.768	0.119	0.092
KBT-12	0.50	0.11	0.041	0.272	0.011
KBT-13	1.50	0.20	0.233	0.250	0.058
KBT-14	1.00	0.18	0.094	0.248	0.023

Physical Water Quality Parameters

Temperature

Water temperature ranged from 15.94°C (KBT-13, Terige) to 21.92°C (KBT-03, Kapyagan), with a mean of 18.9 ± 1.5°C (Table 3). All sites were well below the Kenyan standard of 30°C for drinking water sources. A significant inverse correlation was observed between temperature and altitude ($r = -0.72$, $p < 0.01$), with higher elevation sites having cooler water.

Turbidity

Turbidity values ranged from 8.2 NTU (KBT-12, Kaptilalon) to 301 NTU (KBT-03, Kapyagan), with a mean of 75.1 ± 72.3 NTU. Twelve of 14 sites (85.7%) exceeded the Kenyan drinking water standard of 25 NTU. The exceedance was significant (one-sample t-test, $p < 0.001$).

Table 3: Physical Water Quality Parameters

Site ID	Temp (°C)	pH	Turbidity (NTU)	Conductivity (µS/cm)	TDS (mg/l)	DO (%)
KBT-01	19.74	7.77	155.0	39	20	73.2

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KBT-02	19.16	7.29	64.0	66	33	70.5
KBT-03	21.92	6.47	301.0	57	29	73.1
KBT-04	20.38	6.47	63.2	57	29	62.0
KBT-05	18.04	6.97	50.0	48	24	72.0
KBT-06	19.28	7.12	47.0	45	25	72.6
KBT-07	19.48	7.47	68.0	59	30	72.3
KBT-08	20.20	6.75	30.0	32	16	65.5
KBT-09	19.22	7.26	42.2	37	19	67.8
KBT-10	18.83	7.80	62.4	126	62	73.6
KBT-11	17.69	7.98	39.5	174	86	72.9
KBT-12	17.88	6.86	8.2	30	15	45.5
KBT-13	15.94	7.69	37.5	196	98	68.9
KBT-14	17.60	7.55	70.2	283	142	57.2

Total Suspended Solids (TSS)

TSS ranged from 4 mg/L (KBT-12, Kaptilalon) to 282 mg/l (KBT-03, Kapyagan), with a mean of 54.6 ± 68.9 mg/l. Six sites (42.9%) exceeded the Kenyan standard of 30 mg/l. Strong positive correlation was observed between TSS and turbidity ($r = 0.96$, $p < 0.001$), confirming turbidity as an effective proxy for suspended solids.

Chemical Water Quality Parameters

pH

pH ranged from 6.47 (KBT-03, Kapyagan; KBT-04, Nga) to 7.98 (KBT-01, Kabutie; KBT-11, Kirobi), with a mean of 7.23 ± 0.50. All sites fell within the Kenyan standard range of 6.5-8.5, indicating no acidity/alkalinity concerns.

Electrical Conductivity and Total Dissolved Solids

Conductivity ranged from 30 µS/cm (KBT-12, Kaptilalon) to 283 µS/cm (KBT-14, Koisagat), well below the Kenyan standard of 1500 µS/cm. TDS followed a similar pattern, ranging from 15 mg/l to 142 mg/l (standard: 1200 mg/l). These low values indicate minimal dissolved mineral pollution from industrial or sewage sources.

Dissolved Oxygen

Dissolved oxygen ranged from 45.5% (KBT-12, Kaptilalon) to 73.6% (KBT-10, Kapchumba), with a mean of 67.6 ± 7.7%. All 14 sites (100%) were below the 80% saturation standard for healthy aquatic life. This finding was statistically significant (one-sample t-test, $p < 0.00001$). The most severely affected site, Kaptilalon, had DO levels below 50%, indicating severe organic pollution stress.

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Sediment Load

Sediment load varied dramatically across sites (Table 4), ranging from 0.004 tons/day (KBT-12, Kaptilalon) to 15.008 tons/day (KBT-01, Kabutie). Based on dry-season measurements and assuming constant flow conditions, the Kabutie River transported the equivalent of approximately 5,478 tons of suspended sediment annually. This value should be interpreted as a baseline estimate rather than a true annual sediment yield because seasonal flow variability was not captured.

Table 4: Sediment Load by Site

Site ID	Site Name	Sediment Load (tons/day)	Rank
KBT-01	Kabutie River	15.008	1 (highest)
KBT-07	Mukuri River	1.917	2
KBT-03	Kapyagan Stream	1.031	3
KBT-05	Chebarbar Stream	0.949	4
KBT-06	Olengata Stream	0.824	5
KBT-10	Kapchumba Stream	0.541	6
KBT-02	Kunurter Stream	0.315	7
KBT-11	Kirobi River	0.198	8
KBT-08	Nganiat Stream	0.132	9
KBT-13	Kirobi River (Terige)	0.131	10
KBT-14	Koisagat Stream	0.101	11
KBT-04	Nga Stream	0.097	12
KBT-09	Katanin Stream	0.017	13
KBT-12	Kiptilalon Stream	0.004	14 (lowest)

Correlation Analysis

Significant correlations ($p < 0.05$) among parameters are summarized in Table 5:

Table 5: Pearson Correlation Matrix (Selected Parameters)

Parameter Pair	**Correlation (r)**	**p-value**	**Interpretation**
Turbidity vs. TSS	+0.96	<0.001	Very strong positive; turbidity is excellent proxy for solids
TSS vs. Sediment Load	+0.89	<0.001	Strong positive; sediment load driven by solids
Discharge vs. Sediment Load	+0.92	<0.001	Strong positive; higher flows transport more sediment

Altitude vs. Temperature	-0.72	<0.01	Moderate negative; expected elevation effect
DO vs. Altitude	+0.45	0.10	Weak positive, not significant
pH vs. Any parameter	<0.30	>0.10	No significant correlations

Notably, DO was not significantly correlated with any other measured parameter, suggesting that oxygen depletion represents an independent stressor (likely organic pollution) unrelated to erosion or sediment load.

Priority Site Classification

Based on the combined severity of parameter exceedances, sites were classified into four priority tiers (Table 6):

Table 6: Site Classification by Intervention Priority

Priority	**Sites**	**Criteria**	**Number of Sites**
Critical	Kapyagan, Kabutie	Turbidity >100 NTU OR TSS >100 mg/L OR Sediment >10 tons/day	2
High	Mukuri, Kaptilalon, Nganiat, Koisagat	DO <65% OR Turbidity >50 NTU OR TSS >40 mg/L	4
Medium	Kunurter, Nga, Kapchumba, Chebarbar, Olengata	Moderate exceedances (25-50 NTU)	5
Low	Katanin, Kirobi, Terige	Within or near standards for most parameters	3

DISCUSSION

Turbidity, Suspended Solids and Sediment Transport

The widespread exceedance of turbidity and suspended sediment standards observed in the Kabutie watershed indicates substantial catchment disturbance and ongoing soil erosion. Elevated turbidity is widely recognized as one of the most sensitive indicators of watershed degradation because it responds rapidly to land-use changes, vegetation removal, and soil disturbance within drainage basins [16]. The extremely high turbidity values recorded at Kapyagan Stream (301 NTU) and Kabutie River (155 NTU) greatly exceed both Kenyan and international guidelines for source-water quality and indicate active sediment mobilization from upstream agricultural landscapes.

The strong correlation between turbidity and TSS ($r = 0.96$) is consistent with findings from tropical watershed studies where suspended sediment concentrations are the primary determinant of turbidity levels [17,18]. Similar relationships have been reported in agricultural catchments across Kenya, Ethiopia, and Uganda where cultivation on steep slopes, livestock grazing near waterways, and degradation of riparian vegetation have significantly increased sediment transport rates [19–21].

The estimated annual sediment export of approximately 5,478 tons from the Kabutie River highlights the magnitude of ongoing soil loss within the watershed. Excessive delivery of sediment to aquatic ecosystems can alter channel morphology, reduce habitat quality, impair aquatic biodiversity, accelerate reservoir siltation, and increase operational costs for drinking-water treatment facilities [22]. The observed sediment loads therefore suggest that erosion-control measures are urgently needed to prevent further deterioration of watershed conditions.

Importantly, the present study was conducted during the dry season when stream flows were relatively low and rainfall-induced runoff was minimal. Consequently, the measured sediment loads should be interpreted as baseline low-flow conditions rather than estimates of annual watershed behaviour. Numerous studies have demonstrated that sediment transport in tropical catchments is highly episodic, with a large proportion of annual sediment export occurring during a relatively small number of high-intensity rainfall events [19,22]. During the long-rain and short-rain seasons, increased runoff is expected to mobilize substantially greater quantities of sediment from cultivated slopes, unprotected streambanks, road networks, and livestock-access points. Therefore, actual annual sediment exports from the Kabutie watershed are likely to be considerably higher than estimates derived from the dry-season survey.

The dry-season findings nevertheless provide an important baseline because elevated turbidity and suspended solids were detected even under relatively stable hydrological conditions. This suggests that sediment-generating processes are already active throughout the watershed and may become substantially more severe during wet-season storm events.

Implications for Drinking Water Security

The poor water quality recorded at Kapyagan Stream is particularly concerning because the stream serves as a drinking-water source for Kapsabet Town. Elevated turbidity has direct implications for water-treatment efficiency because suspended particles can shield pathogens from disinfection processes and increase chemical coagulant demand [23].

Studies have shown that source-water turbidity exceeding 100 NTU substantially increases treatment costs and may compromise drinking-water safety during high-flow events [24]. The turbidity levels recorded in this study therefore represent both environmental and public health concerns.

Because the survey was undertaken during a dry-season period, the observed conditions likely represent a conservative estimate of risks to drinking-water treatment operations. In tropical highland watersheds, turbidity frequently increases several-fold during rainfall events due to rapid overland flow and channel-bank erosion [19,21]. Consequently, water-treatment facilities drawing from Kapyagan Stream may experience substantially greater treatment challenges during the rainy seasons than those documented during this baseline survey.

The degradation observed at Kapyagan likely results from a combination of livestock access, riparian vegetation removal, and cultivation close to stream channels. Riparian buffers are known to reduce sediment delivery by 50–90% depending on vegetation structure and slope characteristics [25,26]. Restoration of these buffer zones should therefore be considered a high-priority intervention.

Dissolved Oxygen and Organic Pollution

A notable finding of this study was the universal failure of all sites to attain the recommended dissolved oxygen saturation threshold for healthy aquatic ecosystems. Dissolved oxygen is widely regarded as a key ecological indicator because it integrates multiple biological and chemical processes occurring within aquatic systems [27].

The critically low dissolved oxygen recorded at Kaptilalon Stream (45.5%) suggests significant organic pollution stress. Similar reductions in dissolved oxygen have been linked to livestock waste inputs, untreated domestic wastewater, and decomposition of organic matter in streams [28,29].

The absence of a significant relationship between dissolved oxygen and sediment-related variables indicates that oxygen depletion is likely driven by a different set of pollution sources. This finding supports previous observations in East African watersheds where biological oxygen demand and microbial activity were found to operate independently of sediment transport processes [30].

Seasonal variability should also be considered when interpreting these results. Dissolved oxygen concentrations often fluctuate throughout the year in response to changes in streamflow, water temperature, organic matter loading, and biological activity [27]. During rainy periods, increased turbulence and aeration may improve oxygenation in some streams, while elevated organic matter runoff from farms and settlements may increase oxygen demand in others. Consequently, the low dissolved oxygen levels reported here represent a snapshot of dry-season ecological conditions and should not be assumed to characterize all seasons equally. Nevertheless, the widespread occurrence of oxygen depletion across all sites indicates that organic pollution is a watershed-wide concern requiring further investigation.

The results further emphasize that visually clear water does not necessarily indicate good ecological condition. Streams such as Kaptilalon exhibited low turbidity yet severe oxygen depletion, highlighting the importance of incorporating multiple water-quality indicators into watershed monitoring programmes.

Conductivity and Dissolved Solids

Electrical conductivity and total dissolved solids remained well below Kenyan and WHO guideline values at all monitoring sites. Low conductivity values generally indicate limited industrial contamination and low concentrations of dissolved salts [31].

The results suggest that watershed degradation in Kabutie is driven primarily by non-point source pollution associated with sediment and organic matter rather than industrial or chemical contamination. Similar patterns have been reported in rural agricultural catchments throughout western Kenya where diffuse erosion and livestock-related pollution dominate water-quality concerns [32].

Unlike turbidity and suspended sediment, conductivity and TDS often exhibit less dramatic seasonal fluctuations in rural catchments unless influenced by major pollution events or prolonged drought conditions [31]. The relatively low values observed throughout the watershed therefore suggest that dissolved mineral contamination is currently not a major concern. Continued monitoring is nevertheless necessary because future land-use intensification and expanding settlement development may alter these conditions over time.

Seasonal Variability and Interpretation of Baseline Conditions

A key consideration in interpreting the findings of this study is that all measurements were collected during July 2025 under dry-season, low-flow conditions. Consequently, the results should be viewed as establishing baseline watershed conditions rather than providing a complete representation of annual hydrological and water-quality dynamics.

Seasonality is a dominant driver of watershed processes in the Upper Yala catchment, where rainfall occurs in bimodal patterns characterized by long rains (March–May) and short rains (October–December). Previous studies in East African highland watersheds have shown that stream discharge, sediment transport, turbidity, nutrient concentrations, and microbial contamination frequently increase during rainfall periods due to enhanced runoff and erosion processes [19–21,30]. In many tropical catchments, a substantial proportion of annual sediment and pollutant transport occurs during relatively short storm-flow periods.

The dry-season assessment conducted in this study therefore provides a critical reference condition against which future wet-season and long-term monitoring data can be compared. The fact that significant turbidity, sediment loading, and dissolved oxygen impairment were observed even during low-flow conditions suggests that watershed degradation is already well established. It is reasonable to expect that several parameters, particularly turbidity, TSS, sediment load, and discharge, will increase substantially during rainy seasons. Consequently, future monitoring programmes should incorporate seasonal sampling campaigns to quantify hydrological variability, improve annual sediment-load estimates, and identify periods of greatest ecological risk.

Rather than representing the full magnitude of watershed degradation, the present findings should therefore be interpreted as the baseline dry-season condition from which future assessments of restoration success, climate impacts, and land-use change can be measured.

Watershed Management Implications

The study identifies two distinct but interacting forms of watershed degradation: sediment-related pollution and organic pollution. Effective management therefore requires a dual strategy. Soil-conservation practices such as

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contour farming, terracing, riparian restoration, and controlled grazing can reduce sediment export, while improved livestock management, sanitation infrastructure, and wastewater-control measures can address dissolved oxygen depletion [33,34].

The baseline established by this study provides a foundational dataset against which future restoration efforts can be evaluated. Because the present assessment captures dry-season conditions, future monitoring should prioritize wet-season surveys to quantify seasonal extremes and improve understanding of annual watershed dynamics. Such a monitoring framework will strengthen evidence-based decision-making and enable evaluation of restoration effectiveness under varying hydrological conditions.

CONCLUSIONS

The Kabutie watershed exhibits severe physical degradation dominated by soil erosion. Turbidity exceeds drinking water standards at 12 of 14 sites (85.7%), TSS exceeds standards at 6 sites (42.9%), and the Kabutie River alone loses approximately 15 tons of soil daily – equivalent to an estimated 5,478 tons annually. Kapyagan Stream, the drinking water source for Kapsabet town, is the most critically degraded site. With turbidity 12 times above standard and TSS 9 times above standard, it requires immediate intervention. All sites fail the dissolved oxygen standard for aquatic life (0/14 sites achieve >80% saturation). Kaptilalon Stream (45.5% DO) shows severe organic pollution, indicating that clean-appearing water can be biologically degraded. All measured chemical parameters were within the applicable standards. Conductivity (30-283 µS/cm) and TDS (15-142 mg/L) are well below thresholds, indicating no industrial or sewage point-source pollution. Two independent stressors affect the watershed: physical degradation (erosion, turbidity) and organic pollution (low DO). Both require different management interventions.

It is important to note that the present assessment was conducted during the dry season and therefore represents baseline low-flow watershed conditions. Seasonal rainfall events are expected to increase stream discharge, turbidity, suspended sediment concentrations, and sediment transport throughout the watershed. Consequently, the magnitude of degradation reported in this study may underestimate annual watershed impacts. Continued wet-season and multi-year monitoring will be necessary to fully characterize temporal variability and establish comprehensive watershed health trends.

RECOMMENDATIONS

Immediate (0 - 6 months)

Priority	Site	Action	Responsible
1	Kapyagan	Establish 10 m riparian buffer (trees/grass), exclude livestock, install cut-off drains on adjacent farms	WRA + Kapsabet water utility + Community
2	Kaptilalon	Investigate potential upstream sources of organic pollution, including livestock operations, cattle dips, and domestic wastewater inputs.	WRA + County veterinary + Community
3	Nganiat	Assess market runoff impacts, improve drainage from Kilibwoni market	County government + WRA

Short-term (6 - 18 months)

Action	Target Sites	Expected Outcome
Install staff gauges and data loggers	Kabutie, Kapyagan, Chebarbar, Mukuri, Nganiat, Kirobi	Continuous flow monitoring

Conduct wet-season sampling	All 14 sites	Capture peak erosion/flood dynamics
Begin macroinvertebrate bioassessment	Priority sites	Biological confirmation of organic pollution
Community education on riparian protection	All villages	Reduced cattle access, increased vegetation

Long-term (18 - 36 months)

Action	Target	Success Indicator
Riparian restoration along all priority streams	10 km total	80% survival of planted trees
Soil and water conservation on adjacent farmlands	500 hectares	Reduced turbidity by 30%
Permanent monitoring network	6 stations	Continuous data availability
Watershed management plan with community input	Entire watershed	Approved and funded plan

RESEARCH RECOMMENDATIONS

Future research should adopt a more comprehensive and long-term monitoring framework to improve understanding of hydrological processes, water quality dynamics, and ecological health within the Kabutie watershed. Given that the present study represents baseline dry-season conditions, future investigations should incorporate both wet- and dry-season sampling to capture seasonal variability in stream discharge, sediment transport, and water quality parameters. Continuous hydrological monitoring through the installation of automated water-level recorders, discharge gauging stations, and data loggers at strategically selected sites would enhance the accuracy of flow measurements and facilitate the development of flow-duration curves and sediment-rating relationships.

To improve estimates of sediment export, future studies should deploy automated sediment samplers at critical locations such as Kapyagan Stream and the main Kabutie River. Such systems would enable the capture of stormflow events and peak sediment transport periods, which are often missed by conventional grab-sampling approaches and typically account for a substantial proportion of annual sediment loads. In addition, greater emphasis should be placed on identifying the primary sources of sediment and organic pollution within the watershed. Detailed source-tracking investigations focusing on livestock access points, cultivated riparian zones, road drainage systems, market-centre runoff, and potential domestic wastewater discharges would provide critical information for designing targeted management interventions.

Future watershed assessments should also integrate biological indicators of ecosystem health, including benthic macroinvertebrate communities, aquatic habitat assessments, and other bioassessment tools. Such indicators would provide an independent measure of ecological integrity and strengthen interpretations derived from physicochemical and hydrological data. Furthermore, studies examining livestock densities, grazing intensity, and riparian land-use practices would help clarify the drivers of sediment generation and dissolved oxygen depletion observed in the present study.

At a broader scale, the development of watershed-wide sediment budgets and erosion-risk models using geospatial analysis, remote sensing, and field-based measurements would help identify critical source areas and prioritize conservation investments. Long-term evaluations of restoration interventions, including riparian buffer establishment, livestock exclusion measures, and soil and water conservation practices, should also be undertaken to assess their effectiveness in reducing sediment loads, improving water quality, and enhancing overall watershed health. Together, these research efforts would provide a stronger scientific foundation for sustainable watershed management and the protection of drinking water resources within the Upper Yala River catchment.

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Disclaimer

The findings, interpretations, conclusions, and recommendations presented in this publication are those of the authors and do not necessarily reflect the views, policies, or official positions of Women in Water and Natural Resources Conservation (WWANC), the Water Resources Authority (WRA), the Nature for Water Facility (N4W), The Nature Conservancy (TNC), or any affiliated institutions. The mention of specific organizations, products, or services does not imply endorsement by the authors or supporting organizations. Any errors or omissions remain the sole responsibility of the authors.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The dataset includes field measurements of stream discharge, physicochemical water quality parameters, total suspended solids concentrations, sediment load calculations, and associated geographic coordinates collected from the fourteen monitoring sites within the Kabutie watershed, Upper Yala River catchment, Kenya. Access to specific geospatial data may be subject to approval by relevant regulatory authorities to protect sensitive water resource infrastructure and environmental monitoring sites.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors further declare that there are no conflicts of interest regarding the publication of this manuscript.

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