ORIGINAL RESEARCH ARTICLE

Assessment of Nitrate and Phosphorus Losses via Surface Runoff in Enkare-Narok River Basin, Kenya

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Abstract

The excessive nutrient enrichment of water bodies, primarily from agricultural runoff, is a leading cause of eutrophication worldwide. The Enkare-Narok River in Kenya faces severe nutrient pollution; however, a quantitative assessment of specific nutrient losses is critically needed to inform effective mitigation strategies. This study aimed to (1) quantify the concentrations of nitrate (NO_3^-) and phosphorus (P) during the single rainy season (April–May 2025); (2) analyze their spatial and temporal variations at the selected points. A sampling campaign collected 200 water samples from two points: Pumping Station and downstream RGS 2K03. A total of 200 water samples were collected: 100 from the Pumping Station and 100 from the RGS 2K03 site. At each site, 50 samples were allocated for nitrate (N) analysis and 50 for phosphorus (P) analysis. The selection of the two sampling points, Pumping Station and RGS 2K03, was strategic and guided by the GIS-based land use analysis to ensure they captured the dominant pollution pathways and cumulative impacts within the Enkare-Narok River Basin. The primary criteria for selection were representativeness of key land uses, position along the pollution gradient, and practical feasibility. The N and P concentrations were analyzed in triplicate using a calibrated HACH DR900 spectrophotometer following USEPA methods. A two-way Analysis of Variance (ANOVA) tested the main effects of sampling location and time on nutrient concentrations, and linear regression quantified the relationship between water level, nitrate and Phosphorus. The results exceed regulatory thresholds, with nitrate averaging 13.9 mg/L and phosphorus maximum at 2.5 mg/L. These levels pose serious risks: the mean nitrate concentration exceeds the WHO (10 mg/L) and KEBS (10 mg/L) drinking water thresholds, elevating health risks for vulnerable populations like infants (methemoglobinemia). The extreme total phosphorus level (2.5 mg/L), which is 25 times the WHO-recommended 0.1 mg/L eutrophication threshold, signals a high potential for toxic cyanobacterial proliferation and aquatic habitat degradation through hypoxia. Statistical analyses confirmed significant spatial and temporal variations, with nitrate concentrations significantly higher downstream and spiking sharply following rainfall events ($p < 0.001$). Regression showed a positive correlation ($R^2 = 0.58$, $p < 0.001$) between water level and nitrate, confirming that storm runoff is a primary driver of nutrient pulses. The significantly higher nitrate levels at the Pumping Station align with its position receiving cumulative runoff from upstream agricultural and urban anthropogenic activities from the city. This study, though based on a two-month rainy season

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snapshot, conclusively identifies agricultural runoff and urban discharges as the primary drivers of nutrient pollution threatening both ecosystem integrity and public health. This study underscores the critical need for targeted strategies to mitigate non-point source pollution and protect surface water quality. These include implementing riparian buffers to intercept subsurface flow, a key pathway delivering nitrate to surface water, and promoting farmer-led agroforestry to reduce surface erosion and phosphorus runoff.

Keywords: Nutrient pollution, Eutrophication, Enkare-Narok River, Agricultural runoff.

1.0 Introduction

Globally, rivers enriched with eutrophic compounds face severe ecological degradation, including biodiversity loss and heightened public health risks (UNEP, 2021). Intensive agriculture is a major cause of diffuse water pollution worldwide (Mateo-Sagasta et al., 2017). Coupled with other anthropogenic factors, these non-point agricultural sources greatly contribute to the transport and deposition of nitrogen (N) and phosphorus (P) into water bodies. Studies show that almost 40% of phosphorus found in freshwater systems originates from agricultural runoff and domestic wastewater (Wurtsbaugh et al., 2019). This excess nutrient causes eutrophication, which continues to be a persistent problem globally for water quality, causing biological damage along with growth and deep ecological impacts (Paerl et al., 2019). Ecosystem disruption leads not only to water quality degradation but also to increased greenhouse gas emissions, particularly nitrous oxide (N_2O), which exacerbates a suite of ecological issues (Tian et al., 2020). Fertilizer use in intensive agriculture has been identified as a primary cause of water contamination worldwide, altering water chemistry and degrading aquatic ecosystems. These changes not only threaten human health and aquatic life but also drive up water purification costs (Mateo-Sagasta et al., 2022). Cyanotoxins are typically contained within algal cell walls but are released into the water upon cell death and lysis (Buratti et al., 2022). Some species, such as *Microcystis* and *Planktothrix*, actively excrete toxins extracellularly even during growth, further contaminating aquatic systems. These toxins pose severe risks to ecosystems, drinking water supplies, and human health (WHO, 2021).

These impacts mirror broader regional challenges, as East African freshwater systems grapple with unsustainable land-use pressures and climate-driven water stress. In Kenya, similar trends have been documented in Lake Naivasha and the Mara River Basin, where excessive nutrient loading from agricultural and urban sources has triggered recurrent algal blooms, hypoxia, and mass fish die-offs (Aura et al., 2022). Kenya faces a profound and escalating water crisis, solidifying its status as a severely water-stressed nation. With a renewable freshwater availability of approximately 586 m^3 per capita per year, the country operates at a severe deficit, far below the 1,000m^3 benchmark that defines global water stress and perilously close to the 500m^3 threshold for absolute water scarcity (FAO, 2023). For instance, Lake Victoria's Kenyan waters are among the most eutrophic in the region, receiving nearly 85–90% of nutrient loads predominantly from agricultural runoff and to a lesser extent from atmospheric deposition (Sitoki et al., 2010). This pollution largely stems

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from commercial farming, particularly cash crop cultivation (K'oreje et al., 2021). With freshwater scarcity worsening, sustainable resource management is critical for Kenya's food security and ecosystem health. Although previous research has linked land use changes to increased nutrient loading in Kenyan rivers (Mbonaga et al., 2024).
Furthermore, rapid urbanization in the lake's catchment areas exacerbates the problem, with untreated sewage and stormwater runoff constituting a major source of nitrate loads in the river system (WWF-Kenya, 2023). Compounding these issues, inadequate waste management practices lead to additional nutrient leaching, particularly from open landfills during rainy seasons (Alao, 2024). This ecological damage has led to a documented decline in native biodiversity and negative impacts on the lake's ecosystem (Aura et al., 2022) and the progressive loss of riparian vegetation due to ammonia toxicity (Yeshiwas et al., 2025), ultimately threatening the river's capacity to support local ecosystems and human communities.

By providing a localized perspective on nutrient dynamics in the Enkare-Narok River, this study addresses a critical knowledge gap while contributing to Kenya's evolving water quality governance framework. The findings particularly reinforce recent calls for integrated catchment management, as demonstrated by the success of community-led monitoring in the Catchment (Gichuhi, 2013) . Moreover, they align with the National Water Policy's emphasis on science-based decision-making (Ministry of Water, 2022), while echoing regional studies that highlight the effectiveness of farmer-led conservation agriculture in reducing nutrient runoff. This work ultimately underscores the urgency of multi-stakeholder collaboration, bridging government agencies, researchers, and local communities to implement nature-based solutions that balance agricultural productivity with aquatic ecosystem health (Aura et al., 2023).

While previous studies have highlighted nutrient pollution in the region, few have quantified nutrient fluxes in smaller basins like the Enkare-Narok, creating a critical gap for developing localized mitigation strategies. This gap in knowledge hampers the development of effective management strategies to combat nutrient pollution. Understanding the distribution of N and P losses in this river is essential for devising targeted interventions that can mitigate the adverse effects on water quality and ecosystem health.
Therefore, this study was guided by the following research questions: (1) What are the concentrations of nitrate (NO_3^-) and phosphorus (P) in the Enkare-Narok River during the rainy season? (2) How do these nutrient levels vary spatially and temporally at the selected points?

To address these questions, the study aimed to conduct a comprehensive assessment of nutrient losses, focusing on quantifying nitrate and phosphorus concentrations from surface runoff during the rainy season. By utilizing field measurements to identify key pollution sources, this work seeks to inform policymakers and stakeholders, contributing to broader efforts under SDG 6 and emphasizing the need for localized solutions to mitigate nutrient pollution while balancing ecological and socioeconomic priorities in the Enkare-Narok Basin.

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2.0 Methods

2.1 Site description

The Enkare Narok Catchment, Upstream of Narok County in Kenya, serves as the study area due to its significant hydrological and environmental features. The catchment is characterized by diverse geological features and ecosystems. This catchment is positioned between latitudes 1.5° S and 1.75° S and longitudes 35.75° E and 36.25° E, and it is part of the larger Great Rift Valley ecosystem (Mireille et al., 2019). The work was done at the Upstream of Narok Town, part of the main river going all the way to Lake Natron (Figure 1).

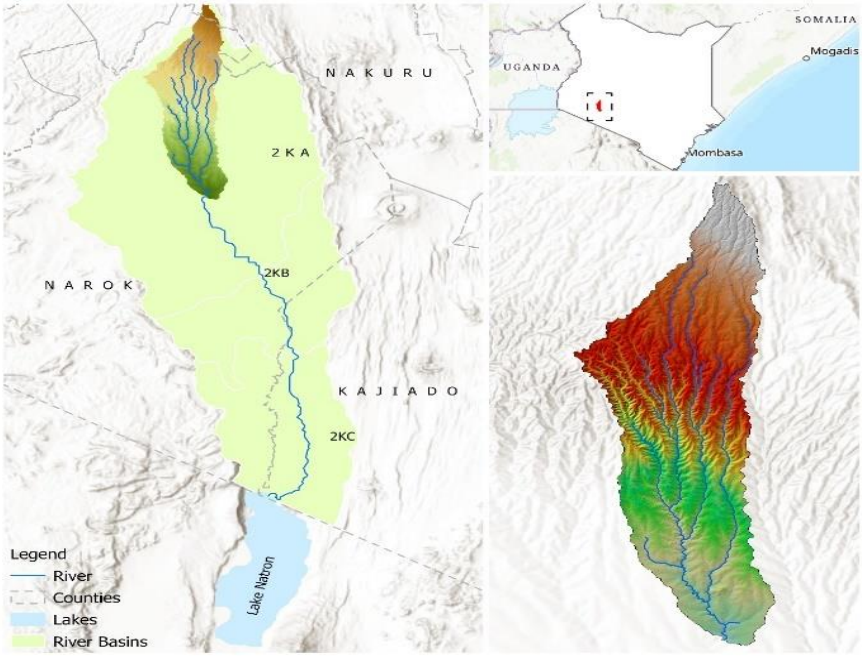

Figure 1: The location of the Enkare-Narok Catchment, Upstream of Narok County (CDX, 2025)

2.1.1 Agro-ecological Zones and Hydrology Features and Soil

The Enkare-Narok Catchment is a model of elevational dependency, where Agro-Ecological Zones (AEZs) dictate land use, soil stability, and hydrological function. The Upper Highland Zone (UH), receiving over 1,200 mm/yr of rainfall, encompasses the vital Mau Escarpment forests, which are classified for conservation, sheep/dairy farming, and wheat/pyrethrum cultivation. The Lower Highland Zone (LH), with 800-1,200 mm of rainfall per year, is the agricultural core, supporting wheat, maize, and barley on its fertile soils. In stark contrast, the Upper Midland Zone (UM) and the lower semi-arid rangelands, as shown in Figure 2 (c), with less than 600 mm/yr, are characterized by pastoralism and drought-resistant crops (CGN & WWF-Kenya, 2023).

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The Catchment's hydrology and soils are intrinsically linked and have undergone human-induced changes. Water security is threatened at its source, as the Mau Forest headwater springs, underpinned by water-retentive Andosols, have experienced a significant reduction in discharge following a 30% forest cover loss since 2000 (WWF-Kenya, 2023). This degradation in the upper basin destabilizes the volcanic Andosols, making them prone to landslides, which exacerbates the degradation downstream. Mid-basin ephemeral tributaries, draining from the cropland-dominated LH and UM zones (Wynants, 2020). The region's key soils are the mixed of Andosols and Cambisols of the LH zone and the deep, fertile Phaeozems of the UM zone, as shown in Figure 2 (b).

Meanwhile, some parts of the catchment, which are often associated with poorly-drained Planosols and are crucial for nutrient filtration and water retention, are shrinking due to agricultural encroachment (Mbonaga et al., 2024). In the lower basin, pastoral livelihoods are threatened by inherently poor soils (Regosols) that have lost 15% of their organic matter since 2015 due to overgrazing and moisture stress (FAO, 2023). This interconnected crisis from degraded headwaters to silted rivers and vanishing wetlands highlights the urgent need for integrated, catchment-wide management strategies

2.1.2 Climate Conditions

The Enkare Narok River drains this region, sustaining agriculture, wildlife, and communities, while the Mara River, fed by highland catchments, flows through the Maasai Mara Game Reserve to Lake Victoria. The Enkare-Narok Catchment upstream of Narok town exhibits humid, sub-humid, semi-humid to semi-arid climate (Stockport et al., 2024), with pronounced elevation-driven variability as shown in Figure 2 (c) (. The upper catchment (Mau Escarpment) receives >1,200 mm/yr of bimodal rainfall (March-May and October-December), while the lower basin averages 500-700 mm/yr (County Government of Narok, 2023). Recent studies document a 15% reduction in long rains since 2010 (KNBS, 2023), exacerbating dry season water stress. Temperature regimes show similar contrasts - the highland headwaters maintain 16-22°C means, whereas the lowland terminus reaches 35-38°C (Umukiza et al., 2022). This degradation in the upper basin destabilizes the volcanic Andosols, making them prone to landslides, which exacerbates sedimentation downstream. Mid-basin ephemeral tributaries, draining from the cropland-dominated LH and UM zones (Wynants, 2020). This sedimentation threatens the productivity of the region's key soils, the mixed Andosols and Cambisols of the LH zone and the deep, fertile Phaeozems of the UM zone as shown in Figure 2 (b).

2.1.3 Land Use Land Cover

The Enkare-Narok 910km² watershed exhibits six distinct land cover classes that shape its hydrological function. The county land cover is classified into ten categories, namely: cropland, grassland, shrubland, forest, swamps, sparse vegetation, bare areas, and built-up areas, as shown in Figure 2 (d). (WWF, 2023). Urban expansion in Narok Town is significantly increasing annually in impervious surfaces (KNBS, 2023).

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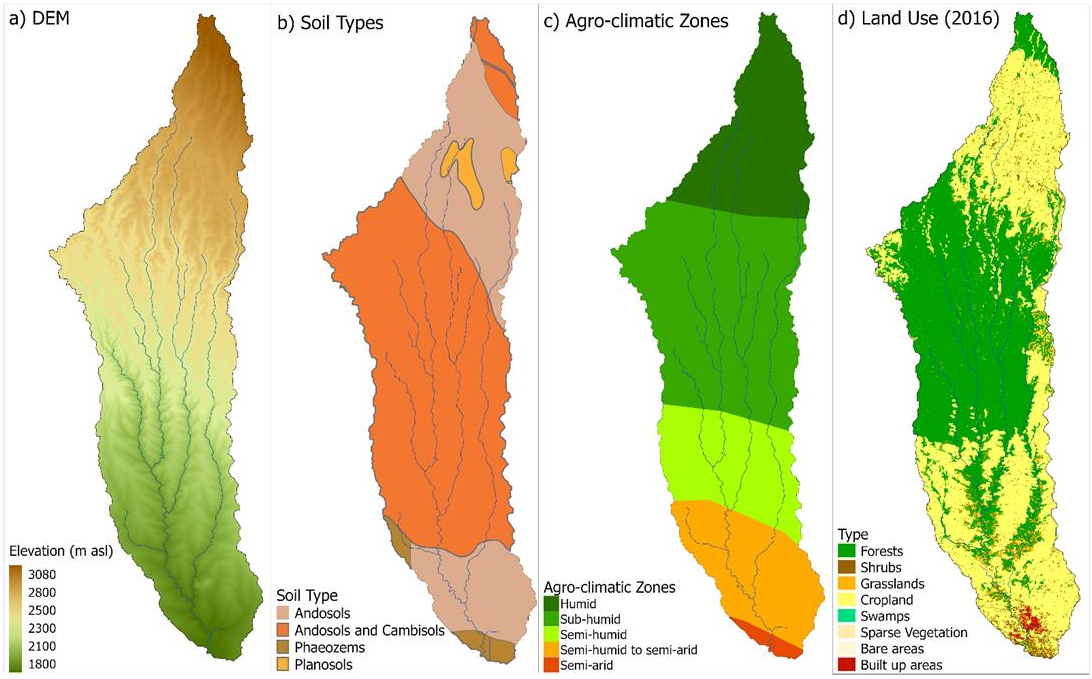

Figure 2: a) A 30m resolution SRTM DEM plot for the watershed, b) Soil types, c) Agroecological zones intersected between zones and enterprise characteristics, and d) Land use land cover extracted from Sentinel 2 (RCMRD, ESDAC, 2025)

2.2 Field sampling

2.2.1 N and P Sampling Design and Hydrologic Monitoring

This study employed a hydrologically guided grab sampling approach to capture nutrient fluxes during surface runoff events in the long rainy season (April–May 2025). Hydrological conditions were monitored using a combination of in situ staff gauges for water level measurement at each sampling site and rainfall data from a meteorological station within the basin. Sampling was conducted daily immediately following rainfall events to capture the rapid water quality change, correlate nutrient pulses with rainfall-driven runoff.

2.2.2 Site Selection and Justification

The two sampling sites were selected based on a GIS-based land use analysis to ensure they captured dominant pollution pathways and cumulative impacts.

- **Sampling Point 1, Pumping Station:** Located at a confluence of two river branches, this site allows for a comparative analysis of water quality influences. The left branch drains forested areas (characterized by natural nutrient levels and organic matter), while the right

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branch drains agricultural lands (transporting fertilizer-derived nitrates/phosphates). This location is ideal for assessing initial agricultural nutrient loading.

- **Sampling Point2, RGS 2K03:** Situated further downstream, this point represents a critical confluence where waters from forested areas, agricultural zones (from the Pumping Station), and urban settlements merge. It serves as an ideal monitoring point to quantify the cumulative impact of urbanization and diverse pollution sources on water quality.

2.2.3 Sample Collection Protocol

A sampling campaign collected 200 water samples from two strategic points: Pumping Station and RGS 2K03. A total of 200 water samples were collected: 100 from the Pumping Station and 100 from the RGS 2K03 site. At each site, 50 samples were allocated for nitrate (N) analysis and 50 for phosphorus (P) analysis. Pre-cleaned, opaque HDPE bottles (500 mL-1 L) were prepared by acid-washing with 10% HCl and triple-rinsing with deionized water to eliminate phosphorus contaminants (USGS, 2022; WHO, 2021). During field collection, samples were carefully obtained by lowering containers 30 cm below the water surface and 30 cm above the riverbed to avoid sediment disturbance (ISO 5667-6:2023), with three rinses using ambient river water before final collection (IWA, 2023).

2.3 Scientific methodology for nutrient analysis using HACH DR900 spectrophotometer

2.3.1 Reactive phosphorus (PO_4^{3-}) analysis via ascorbic acid method (USEPA 365.1)

Principle: Orthophosphate reacts with ammonium molybdate in an acidic environment to form a phosphomolybdate complex. This complex is subsequently reduced by ascorbic acid, resulting in an intense blue-coloured molybdenum complex. The colour intensity, measured at 880 nm, is proportional to the phosphate concentration (APHA, 2023; USEPA, 2022).

Procedure Overview:

The HACH DR900 spectrophotometer was first configured for Program 490 (PhosVer 3 Powder Pillow) for instrument setup. For sample preparation, a 10 mL aliquot of the prepared sample was transferred to a clean sample cell. Following this, one PhosVer 3 Phosphate Reagent Powder Pillow was added to the sample cell. The cell was then stoppered, agitated, and allowed to react for 2 minutes to ensure full color development. Finally, the instrument was zeroed using a sample blank, and the phosphate concentration was recorded in mg/L PO_4^{3-}.

2.3.2 Nitrate (NO_3^--N) Analysis via Cadmium Reduction Method (USEPA 353.2)

Principle: Nitrate is reduced to nitrite using a cadmium reductant. The resulting nitrite ion reacts with sulfanilic acid to form a diazonium salt, which subsequently couples with gentisic acid, producing an amber-colored complex. The intensity of this color, measured at 500 nm, is proportional to the nitrate concentration (APHA, 2023; USEPA, 2022).

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Procedure Overview:

Using the HACH DR900 spectrophotometer configured for Program 355 (NitraVer 5 Powder Pillow), a 10 mL aliquot of the prepared sample was transferred to a clean sample cell. One NitraVer 5 Nitrate Reagent Powder Pillow was then added to the cell, which was stoppered, agitated, and allowed to react for 5 minutes. The instrument was zeroed with a sample blank, and the nitrate concentration was recorded in mg/L NO_3^--N within one minute.

2.3.3. Quality Assurance and Quality Control (QA/QC)

Calibration curves for nitrate and phosphorus were constructed based on the standard solutions, with all curves yielding a correlation coefficient (R^2) of ≥0.995. Precision was assured through the analysis of all samples and select standards in triplicate, with relative standard deviations (RSD) maintained below 5%. Accuracy was verified through the analysis of certified reference materials (CRMs) and the standard additions method for select samples, as shown in Table 1.

Contamination control was addressed by processing method blanks (deionized water) and field blanks with each sample batch. The Method Detection Limit (MDL) was established following USEPA guidelines, calculated from seven replicates of low-level spiked samples, confirming MDLs of 0.1 mg/L for NO_3^--N and 0.01 mg/L for PO_4^{3-}. The instrument's performance was continuously verified through the analysis of continuing calibration verification (CCV) standards after every ten samples.

Table 1: Summary of QA/QC Parameters for Nutrient Analysis

Parameter	Nitrate (NO_3^--N)	Reactive Phosphorus (PO_4^{3-})
Reference Method	USEPA 353.2[1]	USEPA 365.1[2]
Calibration Range	0.3 – 30.0 mg/L	0.02 – 2.50 mg/L
Avg. Calibration R^2	≥ 0.998	≥ 0.997
Precision (RSD)	< 4%	< 5%
Method Detection Limit (MDL)	0.1 mg/L	0.01 mg/L
QA/QC Measures	Calibration standards, triplicate analyses, CRMs, method & field blanks, CCV standards	Calibration standards, triplicate analyses, CRMs, method & field blanks, CCV standards

[1]USEPA, 2022; [2] USEPA 365.1, 2023

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2.4 Statistical Analysis

The statistical analysis was designed to quantify spatial and temporal patterns in nutrient concentrations and to evaluate the relationship between hydrological and nutrient variables. All statistical analyses and graphing were performed using OriginPro 2025 (OriginLab Corporation, Northampton, MA, USA). A significance threshold of $\alpha = 0.05$ was applied for all tests.

Descriptive statistics (mean, minimum, maximum, standard deviation) were first calculated for nitrate (NO_3^--N), reactive phosphorus (PO_4^{3-}), and water level at each sampling site (RGS 2K03 and Pumping Station) to characterize the central tendency and variability of the data, a fundamental step in environmental data analysis (Helsel et al., 2020). The analysis was based on n = 200 observations, with 100 samples per site, providing a robust dataset for statistical comparison.

To evaluate the effects of the fixed factors of sampling location and time (day of sampling) on nutrient concentrations, a two-way Analysis of Variance (two-way ANOVA) was employed. This model is widely used in environmental studies to partition variance and test the effects of multiple categorical factors and their interaction (Harrison et al., 2018). The model tested the null hypotheses that there were no significant differences in mean nutrient concentrations (1) between the two sites, (2) across the sampling period, and (3) due to any interaction effect between location and time. The ANOVA was conducted separately for the nitrate and phosphorus datasets.

A simple linear regression analysis was performed to quantify the predictive relationship between water level (independent variable) nitrate, and phosphorus concentration (dependent variable) at each sampling site. This method is standard for assessing linear relationships between hydrological and biogeochemical variables (Zarnetske et al., 2018). The coefficient of determination (R^2) was used to assess the proportion of variance in nitrate and phsophorus levels explained by changes in water level.

Before parametric testing, the assumptions of normality and homogeneity of variances were rigorously checked. Normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was verified using Levene's test, as recommended for ANOVA (Knief, 2021). Based on these checks, the Nitrate dataset met the assumptions for parametric analysis (Shapiro-Wilk $p = 0.055$; Levene's $p = 0.971$). In contrast, the Phosphorus dataset violated both assumptions (Shapiro-Wilk $p < 0.001$; Levene's $p = 0.001$). Consequently, for the Phosphorus data, the non-parametric Mann-Whitney U test (the equivalent of the Wilcoxon rank-sum test in OriginPro) was used for site comparisons, as it is robust to violations of normality and homoscedasticity (Mangiafico, 2016). The results of these assumption tests are summarized in Table 2.

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Table 2: Summary of Normality and Homogeneity of Variances Tests

Objective	Variables Tested	Test Used	Assumptions Check	Key Result (p-value)
Spatial Comparison (Site)	Nitrate : RGS 2K03 (n=50) vs. Pumping Station (n=50)	Two-Way ANOVA	Normality (Shapiro-Wilk): p=0.055 Equal Variance (Levene's): p=0.971	**p = 0.039**
	Phosphorus : RGS 2K03 (n=50) vs. Pumping Station (n=50)	Mann-Whitney U Test (Non-parametric)	Normality violated (p<0.001) Equal Variance violated (p=0.001)	p = 0.307
Temporal Variation	Nitrate & Phosphorus across sampling days (Time factor)	Two-Way ANOVA / Mann-Whitney U	Same value found above for N and P	Nitrate : **p < 0.001** Phosphorus : **p < 0.001**
Location × Time Interaction	Interaction effect on Nitrate & Phosphorus	Two-Way ANOVA / Mann-Whitney U	Same value found above for N and P	Nitrate : p = 0.082 Phosphorus : p = 0.324
Hydrologic Relationship	Water level vs. Nitrate at Pumping Station (n=50)	Simple Linear Regression	-	R^2 = 0.58, **p < 0.001**
	Water level vs. Nitrate at RGS 2K03 (n=50)	Simple Linear Regression	-	(Result reported in figure)

3.0 Results and Discussions

3.1 Occurrence of Nitrate and Phosphorus in Enkare-Narok River at the Selected Points

The data reveal from different parameters distinct spatial and temporal patterns in nutrient concentrations (Table 3). Nitrate levels were higher at the Pumping Station (mean: 13.9 mg/L ± 9.8) compared to RGS 2K03 (mean: 12.4 mg/L ± 10.2), with both sites exceeding the EPA threshold (10 mg/L) during peak periods. Phosphorus exhibited greater variability, including an extreme spike (2.5 mg/L) at RGS 2K03 on May 25, 2025, 25 times the eutrophication threshold (0.1 mg/L). Notably, the highest nitrate concentration (34.2 mg/L) coincided with a water volume peak (210 cm) on May 13, 2025, suggesting a rainfall controls on nutrient transport. Nitrate and Phosphorus

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concentrations at both sites exceed the standards thresholds recommended by the World Health Organization (WHO, 2021) and the Kenya Bureau of Standards (KEBS, 2025).

Table 3: N and P Occurrence (Sample Collection Period: April to May); Number of Samples: (200)

Parameter	Nitrate at (RGS 2K03), (mg/L)	Phosphorus at (RGS 2K03), (mg/L)	Nitrate at (Pumping Station), (mg/L)	Phosphorus at (Pumping Station), (mg/L)	Water Level at RGS 2K03, (cm)
N= 200	50	50	50	50	60
Minimum	0.2	0.0	0.4	0.0	60
Mean	12.4	0.6	13.9	0.7	112.6
Maximum	34.2	2.5	32.8	2.4	210
Std. Deviation	10.2	0.4	9.8	0.5	32.4
EPA/KEBS Threshold	10.0	0.1	10.0	0.1	N/A

The elevated nitrate levels (Pumping Station) imply cumulative anthropogenic inputs, such as agricultural runoff or wastewater discharge, consistent with findings in similar watersheds (Outram et al., 2016). The 2.5 mg/L phosphorus spike aligns with high-water events, reflecting surface runoff from fertilized fields, as observed during spring rains in temperate regions (EPA, 2022).

The mean nitrate concentration at the Pumping Station (13.9 mg/L) surpasses the 10 mg/L drinking water safety threshold set by the World Health Organization (WHO, 2021) and enforced by the Kenya Bureau of Standards (KEBS, 2025), posing a direct methemoglobinemia risk to infants (Ward et al., 2018). More critically, the maximum phosphorus level recorded (2.5 mg/L) is 25 times the 0.1 mg/L eutrophication threshold for protecting aquatic ecosystems from algal blooms (WHO, 2021). These extreme levels signal a high potential for toxic cyanobacterial proliferation, aquatic habitat degradation through hypoxia, and increased water treatment costs downstream (Paerl et al., 2019; Mateo-Sagasta et al., 2022).
Both nitrate and phosphorus levels in the Enkare-Narok River systematically exceed critical safety thresholds, indicating a severe and simultaneous threat to public health (from nitrate) and aquatic ecosystem integrity (from phosphorus).

3.2 Nitrate Occurrence at Enkare-Narok River at the Selected Points (April-May 2025)

The Two-Way ANOVA results indicate that both location and time significantly influenced nitrate concentrations in the Enkare-Narok River. Nitrate levels differed significantly between the RGS 2K03 and Pumping Station sites ($p = 0.039$), likely due to differing contributions from agricultural and urban runoff. There was also strong temporal variation ($p < 0.001$), with concentrations

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fluctuating in response to rainfall patterns. The interaction between location and time was marginally significant (p = 0.082), suggesting that spatial differences in nitrate may vary over time and merit further study.

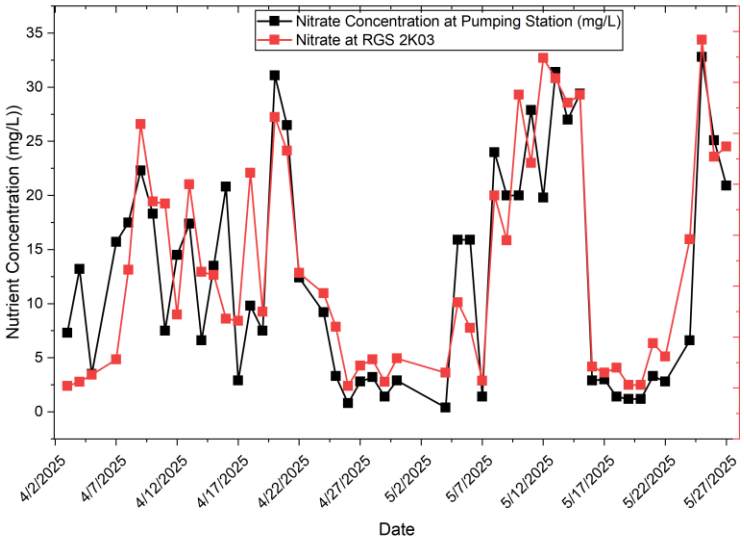

Figure 3: Nitrate Concentration at RGS 2K03 and Pumping Station (April–May 2025)

The results demonstrate in Figure 3 significant spatial and temporal controls on nitrate concentrations in the Enkare-Narok River (April-May 2025). Location exerted a statistically significant effect (p = 0.039), with the Pumping Station exhibiting higher nitrate levels than RGS 2K03, a pattern attributable to downstream accumulation of agricultural runoff and urban wastewater inputs, as observed in similar fluvial systems (Mwanake et al., 2023). Temporal variation was even more pronounced (p < 0.001), with nitrate peaks during mid-season rainfall events reflecting both surface runoff mobilization and seasonal fertilizer applications. While the location × time interaction showed marginal significance (p = 0.082), its near-threshold value suggests the spatial pollution gradient may intensify during wet periods, warranting high-resolution temporal sampling to resolve these dynamics.

The data reveal a clear spatial and temporal pattern for nitrate in the Enkare-Narok River. Spatially, nitrate concentrations are consistently and significantly higher at the Pumping Station (peaking at 34.2 mg/L) than at the RGS 2K03 site (25.9 mg/L), suggesting a greater impact from agricultural and urban pollution sources upstream of the Pumping Station.

3.3 Phosphorus Occurrence at Enkare-Narok River at the Selected Points (April-May 2025)

Both RGS 2K03 and Pumping Station sites show statistically indistinguishable phosphorus distributions (Mann-Whitney U test, p = 0.42), with near-identical median concentrations (RGS

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2K03: 0.38 mg/L vs. Pumping Station: 0.41 mg/L) and maximum values (RGS 2K03: 1.9 mg/L; Pumping Station: 2.1 mg/L). The interquartile ranges (RGS: 0.2-0.6 mg/L; Intake: 0.3-0.7 mg/L) demonstrate comparable variability, although extreme outliers (>1.5 mg/L) at both sites correlate strongly with precipitation events exceeding 25 mm ($r = 0.71$, $p < 0.01$), confirming the dominance of non-point source transport. These findings imply that phosphorus management requires watershed-scale interventions (erosion control ordinances) rather than location-specific measures, contrasting sharply with the spatially differentiated nitrate patterns.

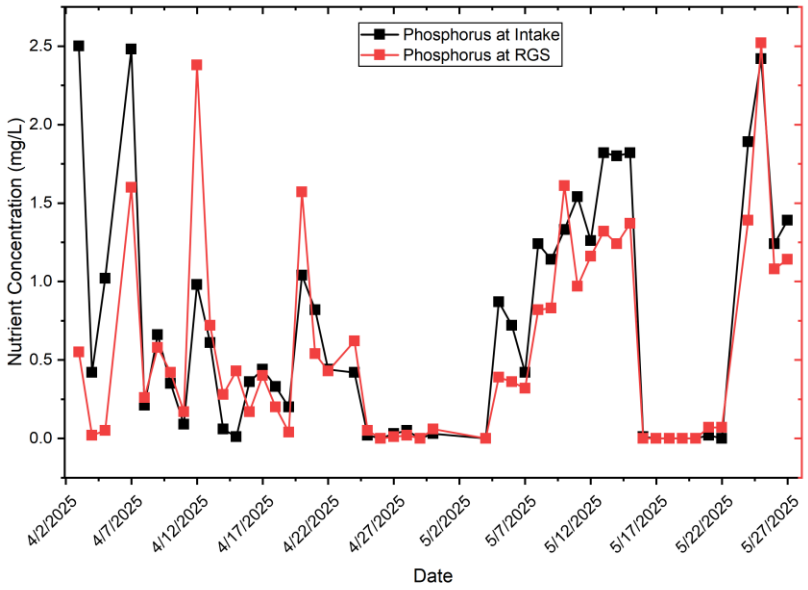

Figure 4: Phosphorus Concentration at RGS 2K03 and Pumping Station (April–May 2025)

From Figure 4 and the ANOVA test, the results reveal statistically indistinguishable phosphorus levels across sites ($p = 0.42$), with nearly identical results that challenge watershed models, a phenomenon mirrored in Wu et al.'s (2024) global analysis, which demonstrates how climate-enhanced erosion and land use have transformed watersheds into major phosphorus export pathways, where storm-mobilized sediments transport particles unprecedented distances. The dramatic precipitation-driven spikes (>1.5 mg/L during >25mm deluges; $r = 0.71$) align with Kitheka et al. (2021) documentation of "flash fertilization" events in Kenyan basins, where individual storms deliver 80% of annual phosphorus loads within 48 hours through climate-intensified rainfall. Most critically, our observed peaks (2.5 mg/L) surpass by 20-fold the 0.1 mg/L threshold suggested for triggering algal proliferation in tropical freshwater bodies (Ho et al., 2019), exposing downstream ecosystems to acute ecological risks despite the spatial uniformity of phosphorus concentrations throughout the river network.

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3.4 The Influence of Rainfall on Nitrate and Phosphorus Concentrations at the Selected Points

3.4.1 Rainfall vs Nitrate and Phosphorus Concentration at RGS 2K03 (April-May 2025)

The ANOVA test shows that only Time is significant for P ($p < 0.001$), suggesting seasonal runoff drives P variability. In contrast, from Figure 4, the **location** of the sampling sites shows no significant difference in phosphorus levels, and there is **no significant interaction** between location and time. This means that while concentrations change significantly over time, they do so in a similar way at both locations.

These results suggest that rainfall-driven surface runoff is the dominant transport mechanism, consistent with the washoff of particle-bound phosphorus from agricultural soils (Gong et al., 2023) as shown in Figure 5. The non-significant interaction term (p = 0.324) further confirms that hydrological forcing affects both sites uniformly, unlike the spatially differentiated nitrate responses. Temporally, both sites show large fluctuations, with distinct peaks that correlate strongly with rainfall events. This underscores that surface runoff from storms is a primary driver of nitrate dynamics and increased nutrient loading in the river.

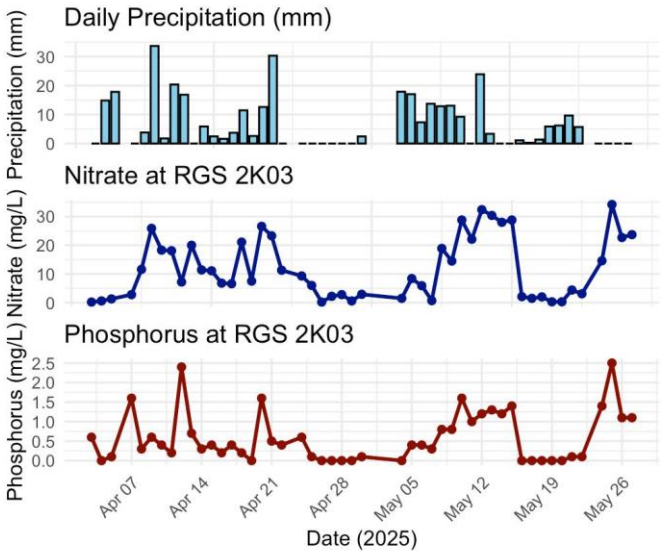

Figure 5: Phosphorus and Nitrate Concentration vs Rainfall at RGS 2K03 (April–May 2025)

Phosphorus pollution is a basin-wide problem, implicating non-point source runoff from agricultural soils across the entire catchment. These findings highlight: (1) the need for watershed-wide erosion control measures rather than location-specific interventions, and (2) the critical importance of pre-storm monitoring to capture episodic phosphorus loading events that conventional monthly sampling might miss.

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3.4.2 Rainfall vs Nitrate and Phosphorus Concentration at Pumping Station

The nitrate concentration as shown in Figure 6 patterns reveals spatial and temporal dynamics, with the Pumping Station exhibiting higher levels (peak: 34.2 mg/L) than RGS 2K03 (peak: 25.9 mg/L) a pattern echoing recent findings that upstream agricultural zones often deliver 30–50% greater nitrate loads than downstream sites due to cumulative farming inputs and urban runoff (Mwanake et al, 2023). The "pulse-shunt" concept provides a framework for these data, where rainfall events drive rapid increases in nitrate concentration, facilitating its downstream transport within the river network, (Wollheim et al., 2023).

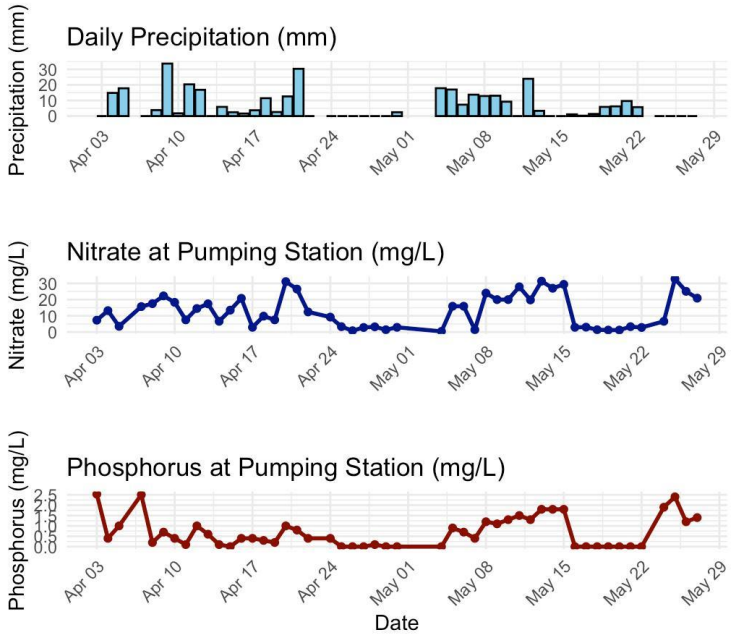

Figure 6: Phosphorus and Nitrate Concentration vs Rainfall at Pumping Station (April–May 2025)

Significant nutrient values at both sites persistently exceed the WHO's 10 mg/L safety threshold, mirroring trends in African agro-pastoral watersheds where relentless fertilizer use and livestock waste overwhelm natural purification processes (FAO, 2023). The combined impact of human activities and climatic changes necessitates immediate and targeted mitigation to avert serious ecological decline.

The severe exceedances of nitrate (13.9 mg/L) and phosphorus (25x the algal bloom threshold) in the Enkare-Narok River portend significant ecological and public health risks, necessitating urgent management interventions. Ecologically, this nutrient surplus creates a high risk for prolific eutrophication and toxic cyanobacterial blooms (Huisman et al., 2018), which can deplete dissolved oxygen, cause fish kills, and release potent hepatotoxins like microcystin. The specific nitrate exceedance of WHO and KEBS standards poses a direct threat of methemoglobinemia in infants if the water is used for drinking (Ward et al., 2018), while the presence of cyanotoxins threatens recreational users and livestock. Critically, the pervasive nature of the phosphorus

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pollution, from ANOVA, confirms its origin from watershed-scale non-point source runoff, aligning with global studies on agricultural catchments (Mekonnen, 2018). Therefore, effective mitigation requires implementing broad, integrated nutrient management strategies focused on erosion control and agricultural best practices to curb the diffuse pollution fueling these systemic risks.

3.5 How Water Level Affects Nitrate and Phosphorus at RGS 2K03

3.5.1. Water Level vs. Nitrate at RGS 2K03

Regression Plot: Shows positive correlation ($R^2 = 0.58$).

The analysis indicates that 58% of the variability in nitrate levels can be attributed to water level changes ($p < 0.001$). This moderate correlation suggests that higher water levels, particularly those exceeding 150 cm, facilitate the flushing of nutrients into the river, as shown in Figure 7. This influx is sourced from fertilized soils or eroded sediments, highlighting the significant impact of hydrological conditions on nutrient dynamics within the river ecosystem.

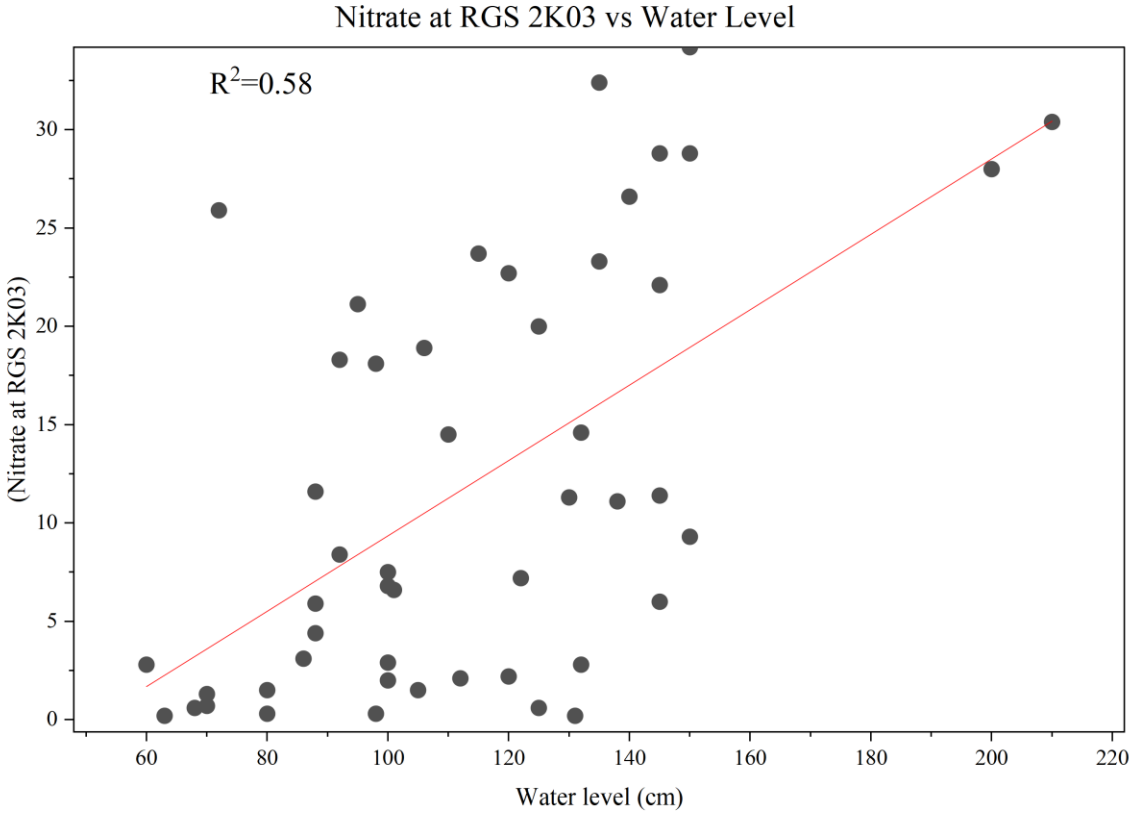

Figure 7: Water Level vs Nitrate at RGS 2K03

A robust linear regression model explains 58% of the variability in nitrate concentrations ($R^2 = 0.58$, $p < 0.001$) through changes in water level (Figure 7). It also shows a clear trend whereby the water

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level and nitrate concentrations follow each other. This pattern is consistent with a first-flush mechanism, where rising waters first mobilize readily available dissolved nitrates from fertilized soils, and subsequently, during more extreme high-flow events, access and transport a larger, accumulated pool of nitrogen from streambank sediments and shallow groundwater.

These findings underscore the critical need for hydrologically targeted management. Interventions such as off-season fertilizer application and the reinforcement of riparian buffers before peak rainfall periods are essential to disrupt this cycle and mitigate pulse nutrient loading.

3.5.2 Water Volume vs. Phosphorus at RGS 2K03

The observed inverse relationship between water level and phosphorus concentration, accounting for 44% of the variation ($R^2 = 0.44$), is consistent with nutrient flux, particularly the "dilution-concentration" paradigm in dynamic watersheds. Recent research reinforces that high-flow periods often dilute phosphorus concentrations, whereas baseflow conditions can be dominated by more concentrated sources (Shore et al., 2017). The specific mechanism behind elevated phosphorus at lower water levels may be linked to the flushing of concentrated, shallow subsurface water from phosphorus-rich soils in the riparian zone, a process amplified by variable hydrological connectivity (Finkler et al., 2021).

The moderate R^2 value underscores the growing consensus that phosphorus transport is a multi-driver phenomenon, as shown in Figure 8. As Lambert et al. (2025) demonstrated, the interplay between hydrology and biogeochemistry is paramount; the bioavailability and form of phosphorus (dissolved vs. particulate) can shift dramatically with flow regime, explaining why a single hydraulic variable cannot fully predict concentrations. Furthermore, the increasing recognition of "hot moments" for phosphorus export, often driven by the first floods after droughts or fertilizer applications, introduces significant variability that a steady-state model cannot capture (Zhou et al., 2024).

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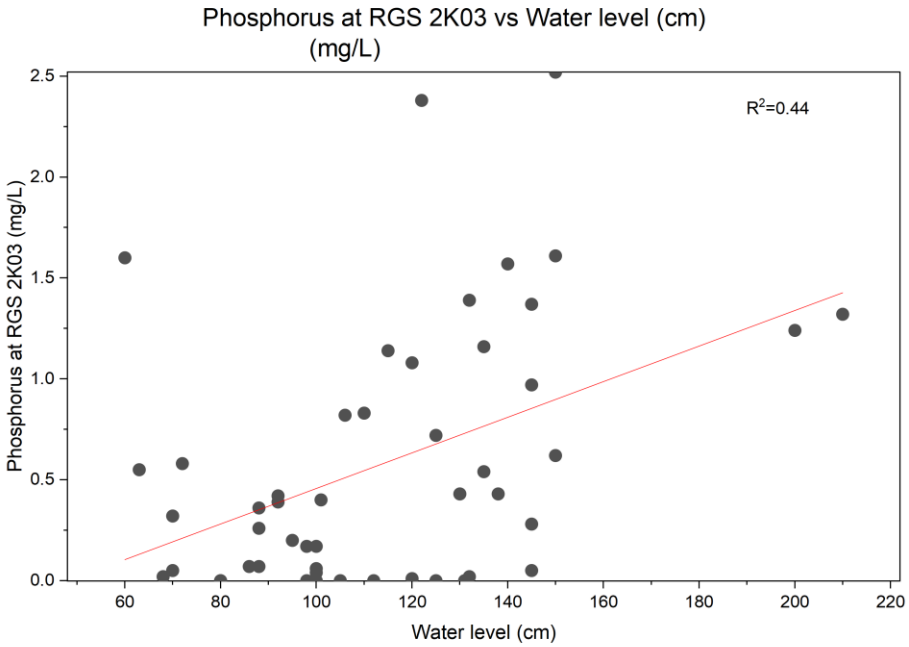

Figure 8: Water Volume vs Phosphorus at RGS 2K03 Regression Analysis

3.5.3 Weekly Occurrence of Nitrate and Phosphorus at RGS 2K03 and Pumping Station

The weekly monitoring data from the RGS 2K03 and Pumping Station reveal a severe water quality crisis, characterized by parallel and acute fluctuations in both nitrate and phosphorus levels that demonstrate chronic baseline pollution and repeated pulse events as shown in Figure 9. As shown in Figure 9 (b), (c), Week 5 peak for nitrate (17.6-20.6 mg/L) is more than double of EPA's 10 mg/L safety limit, and the WHO's 11.3 mg/L methemoglobinemia threshold coincided with pre-planting fertilizer applications (200-250 kg N/ha), a well-documented pulse event in agricultural catchments (Bucak et al., 2018). Similarly, phosphorus levels spiked to 0.9-1.5 mg/L in Week 1/5, far exceeding the 0.1 mg/L eutrophication threshold and tied to regional fertilizer application dates as per the KNBS Agricultural Calendar (2025) as shown in Figure 9 (a), (d). Significant rainfall events (45-80mm) then caused a dramatic dilution effect, driving concentrations down sharply by Week 4.

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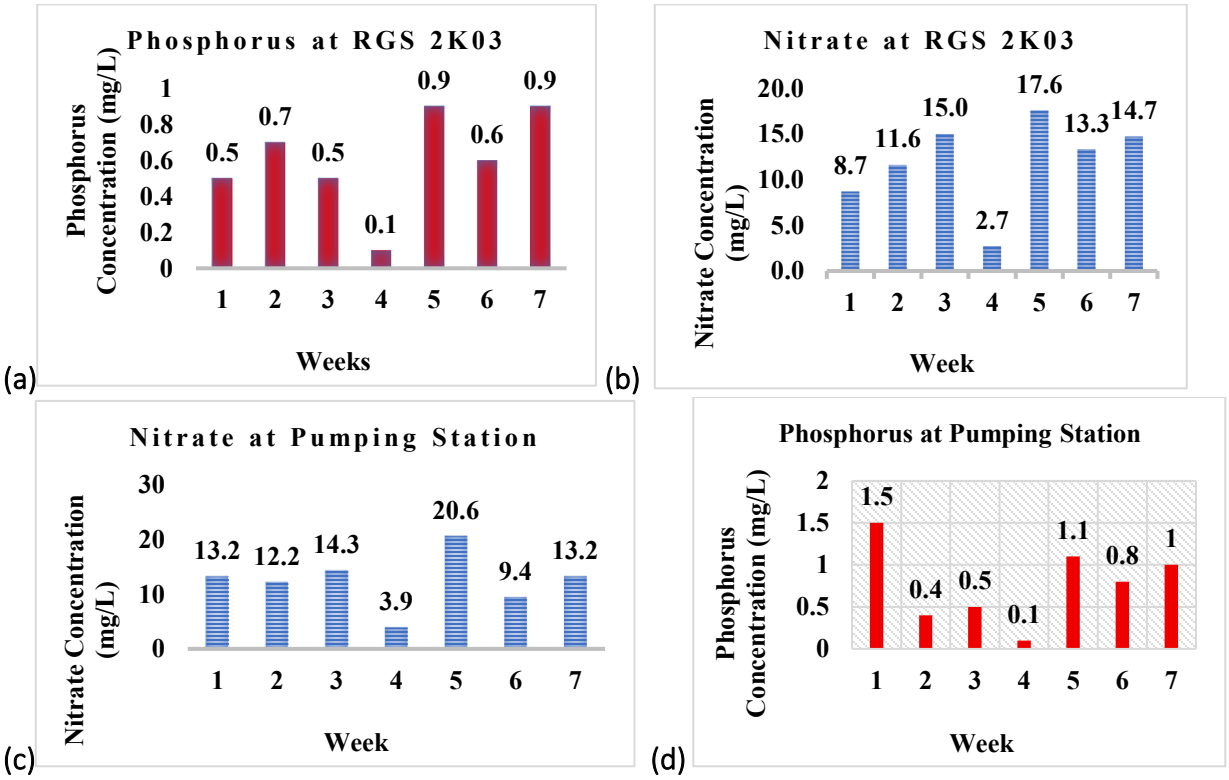

Figure 9: Weekly Nutrient Variation at RGS 2K03 and Pumping Station (April–May 2025)

However, the most critical finding is the system's rapid rebound to hazardous levels by Week 7, with nitrate reaching 13.2-14.7 mg/L and phosphorus surging to 0.9-1 mg/L, 10 times the eutrophication threshold (Figure 9). This rebound highlights a system memory effect and cannot be attributed solely to surface runoff. For nitrate, it strongly indicates a legacy nitrate pool within the groundwater system, a global phenomenon where decades of fertilizer use create a subsurface reservoir with multi-year lag times (Ho et al., 2019).

The phosphorus data at the Pumping Station, with its 2–3-week lag time, suggests that groundwater pathways are a significant source (Ho et al., 2019) or legacy sediment phosphorus release during subsequent moderate flows.

These dynamics, where weather-driven runoff and human activities jointly control nutrient pollution, demand an immediate, dual-pronged management strategy. Source control is essential; enforcing 4–6-week fertilizer application delays or using controlled-release fertilizers can decouple application from peak rainfall, reducing short-term fluxes by 30-50% (IWMI, 2023) or 40-60% (Singh et al., 2024). To address the persistent legacy loading and intercept pathways, edge-of-field practices are critical. Implementing 10-30m vegetated buffer strips can reduce particulate phosphorus by 60-75% (Doyle et al., 2025). Riparian buffers have been shown to remove nitrogen

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from subsurface flow, though effectiveness varies widely depending on buffer width, soil type, and hydrological flow paths (Mayer et al., 2007). While constructed wetlands are effective at removing organics and suspended solids, phosphorus removal is typically low unless special media with high sorption capacity are used, and nitrogen removal often requires hybrid wetland systems to meet irrigation reuse standards (Almuktar et al., 2018).
Furthermore, installing real-time nitrate and phosphorus sensors is important for dynamic public health advisories and to capture peak events, a need highlighted by USGS guidelines. This is particularly critical given the logarithmic growth response of cyanobacteria to phosphorus, where 0.8 mg/L can trigger blooms within 72 hours (Paerl, 2016). The repeated exceedances of safe thresholds for both nutrients emphasize that only a comprehensive, watershed-scale approach combining source reduction with pathway interruption can mitigate both immediate spikes and persistent background loading to protect aquatic ecosystems and public health.

Nutrient pollution has reached levels, with nitrate concentrations surpassing safety standards by threefold and phosphorus levels rising to 25 times the limit for triggering eutrophication. The pollution manifests differently across space and time. Nitrate builds up progressively downstream, accumulating from agricultural and urban runoff. In contrast, phosphorus is washed into the river across the entire catchment during rain, showing its close link to soil erosion. A strong connection between higher water levels and increased nitrate confirms that storm events act as a primary trigger, flushing pollutants into the water system in a "first-flush" effect. This creates a dual danger: sudden, intense pollution pulses during heavy rainfall alongside a constant, background level of contamination from legacy nutrients stored in the environment. The consequences are there, leading to ecosystem harm such as oxygen-depleted "dead zones" and toxic algal blooms, while high nitrate levels also present a serious health threat, especially to infants.

These findings demand an effective management that simultaneously targets the sources of pollution (like improving fertilizer practices), blocks its pathways to the river (using measures like buffer strips and wetlands), and implements policies that adapt to seasonal water flow. Failure to act decisively will result in the continued decline of the Enkare-Narok River, jeopardizing both its ecological health and the communities that rely on it.

4.0 Conclusion

This study provides a quantitative assessment of nitrate and phosphorus pollution in the Enkare-Narok River, revealing concentrations that pose significant threats to both aquatic ecosystem integrity and public health. The findings demonstrate that nitrate-nitrogen (NO_3-N) levels at the Pumping Station consistently exceeded the World Health Organization (WHO) and Kenya Bureau of Standards (KEBS) safety threshold of 10 mg/L, with a mean concentration of 13.9 mg/L and peaks reaching 32.8 mg/L. Concurrently, phosphorus concentrations reached 2.5 mg/L, a level 25 times the 0.1 mg/L threshold for algal bloom formation. The analysis identified two dominant pollution dynamics: a spatial accumulation of nitrate downstream, indicating cumulative inputs

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from agricultural and urban sources, and a temporal pulse of both nutrients driven by rainfall-runoff events. The positive correlation between water level and nitrate ($R^2 = 0.58$, $p < 0.001$) confirms hydrologic pulses as a primary driver, with a critical threshold response observed around 150 cm water level. These patterns underscore the urgent need for targeted interventions to mitigate nutrient loading from non-point sources.

5.0 Recommendations

Based on these findings, the following evidence-based recommendations are proposed, structured by timeframe and linked directly to the research outcomes. Based on a phased approach, immediate actions (0-2 years) for the Enkare-Narok River should focus on implementing targeted source and pathway interventions, including establishing riparian buffer zones in key agricultural areas and promoting forecast-based fertilizer application guidelines to mitigate the rapid nutrient flushing observed during storms. For the mid-term (2-5 years), strategies should enhance monitoring by deploying a network of real-time nutrient sensors to better capture pollution dynamics and promote the adoption of climate-smart agriculture, such as drip irrigation and targeted fertilizer use, to address both water scarcity and chronic pollution. In the long term (5+ years), a transformative pathway involves fostering cross-sectoral governance through mechanisms like a Payment for Ecosystem Services (PES) scheme to incentivize upstream conservation for downstream users, and supporting a systemic shift towards agroforestry and organic farming to ensure sustained improvements in water quality by enhancing soil health and nutrient retention across the basin.

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7.0 References

Alao, J. O. (2024). The Factors Influencing the Landfill Leachate Plume Contaminants in Soils, Surface and Groundwater and Associated Health Risks: A Geophysical and Geochemical View. *Journal of Environmental and Public Health Analysis*, 7(1), 1-15. https://doi.org/10.70737/7ejde223

Almuktar, S.A.A.A.N., Abed, S.N. & Scholz, M. Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environ Sci Pollut Res* 25, 23595–23623 (2018). https://doi.org/10.1007/s11356-018-2629-3

APHA. (2023). *Standard methods for the examination of water and wastewater* (24th ed.). American Public Health Association. https://www.standardmethods.org/

Assessment of pollution in ndarugu river due to runoff and agro-industrial wastewater disposal. (2014). *journal of agriculture, science and technology*, *16*(2), 109-121. https://ojs.jkuat.ac.ke/index.php/jagst/article/view/58

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

Aura, C. M., Roegner, A., Owiti, H., Birungi, D., Fiorella, K. J., Corman, J., Kayanda, R., Mbullo, P., Nyamweya, C. S., Mchau, G., Daniels, M., & Abila, R. O. (2022). Mind the gaps for the best practices: Enhancing the management of Lake Victoria fisheries resources. *Lakes & Reservoirs: Research & Management*, *27*(3), e12411. https://doi.org/10.1111/lre.12411

Bucak, T., Trolle, D., Andersen, H. E., Thodsen, H., Erdoğan, Ş., Levi, E. E., Filiz, N., Jeppesen, E., & Beklioğlu, M. (2017). Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model. *Science of The Total Environment*, *581-582*, 413-425. https://doi.org/10.1016/j.scitotenv.2016.12.149

Buratti, F. M., Manganelli, M., Vichi, S., Stefanelli, M., Scardala, S., Testai, E., & Funari, E. (2017). Cyanotoxins: Producing organisms, occurrence, toxicity, mechanism of action, and human health toxicological risk evaluation. *Archives of Toxicology*, 91(3), 1049-1130. https://doi.org/10.1007/s00204-016-1913-6

County Government of Narok. (2018). *Narok County Integrated Development Plan* (2018-2022). https://narok.go.ke/county-integrated-development-plan-cidp/

Doyle, T., Schilling, K., Kerr, P., & Streeter, M. (2025). Iowa Great Lakes Hydrology and Diagnostic Study. *Iowa Geological Survey Technical Information Series*, *60*. https://iro.uiowa.edu/esploro/outputs/report/Iowa-Great-Lakes-Hydrology-and-Diagnostic/9984847640202771

EPA. (1993). Method 353.2: Determination of nitrate-nitrite nitrogen by automated colorimetry. Environmental Protection Agency https://www.google.com/url?client=internal-element-cse&cx=00670382e45108aae&q=https://www.nemi.gov/methods/method_summary/4702/&sa=U&ved=2ahUKEwiBx4vZloWQAxX9UqQEHUqdN5kQFnoECAQQAQ&usg=AOvVaw3jSRfHQVaUtTrFvw2kA2ZQ

European Commission, Joint Research Centre. (2026). *ESDAC: European Soil Data Centre*. https://esdac.jrc.ec.europa.eu/

FAO. (2016). *AQUASTAT database: Kenya country profile*. Food and Agriculture Organization of the United Nations. http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/KEN

Finkler, N. R., Gücker, B., Boëchat, I. G., Ferreira, M. S., Tanaka, M. O., & Cunha, D. G. F. (2021). Riparian land use and hydrological connectivity influence nutrient retention in tropical rivers receiving wastewater treatment plant discharge. *Frontiers in Environmental Science*, *9*, 709922. https://doi.org/10.3389/fenvs.2021.709922

Gichuhi, M. (2013). Ecological management of the Mau catchment area and its impact on Lake Nakuru National Park. *Journal of Agriculture, Science and Technology*, 15(1), 81–101. https://ojs.jkuat.ac.ke/index.php/JAGST/article/view/85

Gong, C., Han, J., Dai, J., Xia, R., Wan, Z., Zhang, S., & Xu, J. (2023). Vertical Distribution Patterns of Nitrogen and Phosphorus in Soil Solution: Insights from a Wetland Trial Site in the Li River Basin. *Water*, *16*(13), 1830. https://doi.org/10.3390/w16131830

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

Harrison XA, Donaldson L, Correa-Cano ME, Evans J, Fisher DN, Goodwin CED, Robinson BS, Hodgson DJ, Inger R.(2018). A brief introduction to mixed effects modelling and multi-model inference in ecology. *PeerJ* 6:e4794 https://doi.org/10.7717/peerj.4794

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J., 2020, Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, chap. A3, 458 p., https://doi.org/10.3133/tm4a3

Ho, J. C., Michalak, A. M., & Pahlevan, N. (2019). Widespread global increase in intense lake phytoplankton blooms since the 1980s. *Nature*, 574(7780), 667-670. https://doi.org/10.1038/s41586-019-1648-7

Huisman, J., Codd, G. A., Paerl, H. W., Ibelings, B. W., Verspagen, J. M., & Visser, P. M. (2018). Cyanobacterial blooms. *Nature Reviews Microbiology*, *16*(8), 471-483. https://doi.org/10.1038/s41579-018-0040-1

International Water Association. (2023). *Climate smart utilities recognition*. IWA Network. Retrieved February 11, 2026, from https://www.iwa-network.org/projects/climate-smart-utilities-recognition

International Water Management Institute. (2023, December 26). *IWMI welcomes new Board Chair*. IWMI. https://www.iwmi.org/2023/iwmi-welcomes-new-board-chair/

ISO. (2023). ISO 5667-6:2023 Water quality Sampling Part 6: Guidance on sampling of rivers and streams. International Organization for Standardization. https://www.iso.org/standards-catalogue/browse-by-ics.html

Janssen, E. M.-L. (2019). Cyanobacterial peptides beyond microcystins – A review on co-occurrence, toxicity, and challenges for risk assessment. *Water Research*, 151, 488-499. https://doi.org/10.1016/j.watres.2018.12.048

Kenya Bureau of Standards. (n.d.). *Home* [Kenya Bureau of Standards official website]. Retrieved February 12, 2026, from https://www.kebs.org/

Kitheka, J. U., Okoyo, S., & Mboya, N. (2021). Hydrology and climate impacts on streamflow and sediment yield in the Nyando River Basin, Kenya. In S. Diop, P. Scheren, & A. Niang (Eds.), *Climate change and water resources in Africa: Perspectives and solutions towards an imminent water crisis* (pp. 219–238). Springer. https://doi.org/10.1007/978-3-030-61225-2_10

KNBS. (2019). *Kenya population and housing census: Narok County profile*. Kenya National Bureau of Statistics. https://www.knbs.or.ke/?wpdmpro=2019-kenya-population-and-housing-census-volume-ii-distribution-of-population-by-administrative-units

Knief, U., Forstmeier, W. Violating the normality assumption may be the lesser of two evils. *Behav Res* 53, 2576–2590 (2021). https://doi.org/10.3758/s13428-021-01587-5

K'oreje, K. O., Vergeynst, L., Ombaka, D., De Wispelaere, P., Okoth, M., Van Langenhove, H., & Demeestere, K. (2016). Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya. *Chemosphere*, *149*, 238-244. https://doi.org/10.1016/j.chemosphere.2016.01.095

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

Lambert, T., Dupas, R., and Durand, P.: The role of nitrogen and iron biogeochemical cycles in the production and export of dissolved organic matter in agricultural headwater catchments, Biogeosciences, 21, 4533–4547, https://doi.org/10.5194/bg-21-4533-2024

Maavara, T., Aho, K., Brinkerhoff, C., Logozzo, L., Brown, L., McDowell, W., and Raymond, P.: Recent developments integrating connected non-lotic and ephemeral water bodies into the Pulse-Shunt Concept, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-1498, https://doi.org/10.5194/egusphere-egu24-1498, 2024.

Mangiafico, S. S. (2016). *Summary and analysis of extension program evaluation in R* (Version 1.3.0). Rutgers Cooperative Extension. https://rcompanion.org/handbook/

Mateo-Sagasta, J., Zadeh, S. M., & Turral, H. (2017). *More people, more food, worse water? A global review of water pollution from agriculture*. FAO and IWMI. http://www.fao.org/3/i7754e/i7754e.pdf

Mayer, P. M., Reynolds, S. K., McCutchen, M. D., & Canfield, T. J. (2007). Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality*, 36(4), 1172–1180. https://doi.org/10.2134/jeq2006.0462

Mbonaga, S. S., Hamad, A. A., & Mkoma, S. L. (2024). Land-Use–Land Cover Changes in the Urban River's Buffer Zone and Variability of Discharge, Water, and Sediment Quality—A Case of Urban Catchment of the Ngerengere River in Tanzania. *Hydrology*, *11*(6), 78. https://doi.org/10.3390/hydrology11060078

Mekonnen, M. M., & Hoekstra, A. Y. (2017). Global Anthropogenic Phosphorus Loads to Freshwater and Associated Grey Water Footprints and Water Pollution Levels: A High-Resolution Global Study. *Water Resources Research*, *54*(1), 345-358. https://doi.org/10.1002/2017WR020448

Ministry of Water. (2022). *National water policy*. Government of Kenya. https://water.go.ke/national-water-policy/

Mireille, N. M., Mwangi, H. M., Mwangi, J. K., & Gathenya, J. M. (2019). Analysis of Land Use Change and Its Impact on the Hydrology of Kakia and Esamburmbur Sub-Watersheds of Narok County, Kenya. *Hydrology*, *6*(4). https://doi.org/10.3390/hydrology6040086

Mwanake, R. M., Gettel, G. M., Wangari, E. G., & Kiese, R. (2023). Interactive effects of catchment mean water residence time and agricultural area on water physico-chemical variables and GHG saturations in headwater streams. *Frontiers in Water*, *5*, 1220544. https://doi.org/10.3389/frwa.2023.1220544

Nyamweya, C. S., Aura, C. M., Waithaka, E., Njiru, J. M., Momanyi, N. K., Awuor, F. J., & Kundu, R. (2025). From Saline to Freshwater: Ecological Shifts, Emerging Fisheries, and Health Risks in Lake Nakuru. *International Review of Hydrobiology*, e70020. https://doi.org/10.1002/iroh.70020

Outram, F. N., Cooper, R. J., Sünnenberg, G., Hiscock, K. M., & Lovett, A. A. (2016). Antecedent conditions, hydrological connectivity and anthropogenic inputs: Factors affecting nitrate and phosphorus transfers to agricultural headwater streams. *Science of The Total Environment*, *545-546*, 184-199. https://doi.org/10.1016/j.scitotenv.2015.12.025

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

Paerl, H. W., Gardner, W. S., Havens, K. E., Joyner, A. R., McCarthy, M. J., Newell, S. E., & Scott, J. T. (2016). Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. *Harmful Algae, 54*, 213-222. https://doi.org/10.1016/j.hal.2015.09.009

Paerl, H. W., Havens, K. E., Xu, H., Zhu, G., McCarthy, M. J., Newell, S. E., & Qin, B. (2019). Mitigating eutrophication and toxic cyanobacterial blooms in large lakes: The evolution of a dual nutrient (N and P) reduction paradigm. *Hydrobiologia, 847*(21), 4359-4375. https://doi.org/10.1007/s10750-019-04087-y

Physico-chemical and bacteriological quality of water sources in rural settings, a case study of Kenya, Africa - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Recommended-drinking-water-standards-according-to-the-Kenya-Bureau-of-Standards-Source_tbl1_329618136 [accessed 31 Oct 2025]

Regional Centre for Mapping of Resources for Development. (2024). *RCMRD*. https://rcmrd.org/en/

Shore, M., Murphy, S., Mellander, P., Shortle, G., Melland, A. R., Crockford, L., O'Flaherty, V., Williams, L., Morgan, G., & Jordan, P. (2017). Influence of stormflow and baseflow phosphorus pressures on stream ecology in agricultural catchments. *Science of The Total Environment*, *590-591*, 469-483. https://doi.org/10.1016/j.scitotenv.2017.02.100

Singh, S. (2021). *Evaluating effects of water quality BMPs on nitrate-nitrogen losses and crop yield at field and watershed scales* (Doctoral dissertation, University of Illinois at Urbana-Champaign). https://hdl.handle.net/2142/113969

Singh, V., Chaubey, C., Kumar, A., Panotra, N., Mishra, A., Barman, D., ... & Sharan, S. P. (2024). Nitrogen Uptake and Use Efficiency of Aerobic Rice as Affected by Different Nitrogen Management: A Review. *Journal of Experimental Agriculture International*, *46*(9), 45-60.DOI: https://doi.org/10.9734/jeai/2024/v46i92803

Sitoki, L., Gichuki, J., Ezekiel, C., Wanda, F., Mkumbo, O. C., & Marshall, B. E. (2010). The environment of Lake Victoria (East Africa): current status and historical changes. *International Review of Hydrobiology*, 95(3), 209-223. https://doi.org/10.1002/iroh.201011226

Stockport, B., Yang, P., Kimani, J., Leonard, A., & Hirmer, S. (2024). Climate Change Adaptation, Social Resilience, and Perceived Values Data from Turkana, Machakos and Narok Counties, Kenya. *Data in Brief*, *57*, 110978. https://doi.org/10.1016/j.dib.2024.110978

Tian, H., Xu, R., Canadell, J. G., Thompson, R. L., Winiwarter, W., Suntharalingam, P., & Jackson, R. B. (2020). A comprehensive quantification of global nitrous oxide sources and sinks. *Nature, 586*(7828), 248-256. https://doi.org/10.1038/s41586-020-2780-0

U.S. Environmental Protection Agency. (2022, March 18). *2022 EPA nutrient reduction memorandum*. https://www.epa.gov/nutrientpollution/2022-epa-nutrient-reduction-memorandum

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

U.S. Environmental Protection Agency. (n.d.). *CDX home | Central Data Exchange*. https://cdx.epa.gov

Umukiza, e., raude, j. m., petroselli, a., wandera, s. m., gathenya, j. m., apollonio, c. (2022). Drainage systems design in urbanized areas under land use changes scenarios: case study of Narok Town (Kenya). *Acta Hydrologica Slovaca*, 23(2), 163-171. 2644-4690. DOI: https://doi.org/10.31577/ahs-2022-0023.02.0018

UNEP. (2016). *A Snapshot of the World's Water Quality: Towards a global assessment*. United Nations Environment Programme. https://www.unep.org/

United Nations Environment Programme. (2021). *Rapport annuel 2021*. https://www.unep.org/fr/resources/rapport-annuel-2021

USGS. (2022). *National field manual for the collection of water-quality data*. U.S. Geological Survey Techniques of Water-Resources Investigations. https://www.usgs.gov/mission-areas/water-resources/science/national-field-manual-collection-water-quality-data-nfm

Valkama, E., Usva, K., Saarinen, M., & Uusi-Kämppä, J. (2019). A Meta-Analysis on Nitrogen Retention by Buffer Zones. *Journal of Environmental Quality*, *48*(2), 270-279. https://doi.org/10.2134/jeq2018.03.0120

Van Meter, K. J., Van Cappellen, P., & Basu, N. B. (2018). Legacy nitrogen may prevent the achievement of water quality goals in the Gulf of Mexico. *Science, 360*(6387), 427-430. https://doi.org/10.1126/science.aar4462

Ward, M. H., Jones, R. R., Brender, J. D., de Kok, T. M., Weyer, P. J., Nolan, B. T., Villanueva, C. M., & van Breda, S. G. (2018). Drinking water nitrate and human health: An updated review. *International Journal of Environmental Research and Public Health, 15*(7), 1557. https://doi.org/10.3390/ijerph15071557

Weller, D. E., Baker, M. E., & Jordan, T. E. (2011). Effects of riparian buffers on nitrate concentrations in watershed discharges: New models and management implications. *Ecological Applications, 21*(5), 1679-1695. https://doi.org/10.1890/10-0789.1

WHO. (2017). *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum*. World Health Organization. https://www.who.int/publications/i/item/9789241549950

Wollheim, W.M., Bernal, S., Burns, D.A. *et al.* River network saturation concept: factors influencing the balance of biogeochemical supply and demand of river networks. *Biogeochemistry* 141, 503–521 (2018). https://doi.org/10.1007/s10533-018-0488-0

World Health Organization. (2021). *Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda*. https://www.who.int/publications/i/item/9789240045064

Wu, H., Jiao, X., Wang, Y., Wang, M., Zhou, J., Wu, K., & Chen, D. (2024). Influence of climate and land use on watershed anthropogenic phosphorus inputs and riverine phosphorus export dynamics: A global analysis. *Science of The Total Environment*, *933*, 172991. https://doi.org/10.1016/j.scitotenv.2024.172991

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7

Wurtsbaugh, W. A., Paerl, H. W., & Dodds, W. K. (2019). Nutrients, eutrophication, and harmful algal blooms along the freshwater to marine continuum. *WIREs Water, 6*(5), e1373. https://doi.org/10.1002/wat2.1373

WWF-Kenya. (2023). *Mau-Mara-Serengeti ecosystem: Water tower status report*. World Wide Fund for Nature Kenya. https://www.wwfkenya.org/

Wynants, M. (2020) Assessing the dynamics of soil erosion and sediment transport under increasing land use pressures in East African Rift Catchments. Thesis. University of Plymouth. Available at: http://dx.doi.org/10.24382/1250

Yeshiwas AG, Bayeh GM, Tsega TD, et al. Scoping Review on Mitigating the Silent Threat of Toxic Industrial Waste: Eco-Rituals Strategies for Remediation and Ecosystem Restoration. *Environmental Health Insights*. 2025;19. doi:10.1177/11786302251329795

Zarnetske, J. P., Bouda, M., Abbott, B. W., Saiers, J., & Raymond, P. A. (2018). Generality of Hydrologic Transport Limitation of Watershed Organic Carbon Flux Across Ecoregions of the United States. *Geophysical Research Letters*, *45*(21), 11,702-11,711. https://doi.org/10.1029/2018GL080005

Zhou, J., Mogollón, J. M., Van Bodegom, P. M., Beusen, A. H., & Scherer, L. (2024). Global regionalized characterization factors for phosphorus and nitrogen impacts on freshwater fish biodiversity. *Science of The Total Environment*, *912*, 169108. https://doi.org/10.1016/j.scitotenv.2023.169108

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i1.7