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Water Quality Parameters Effect on Zooplankton Distribution, Diversity, and Abundance in Water Pans in Semi-Arid Narok Socio-Ecological Landscape, Kenya

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Abstract

Water pans in the semi-arid Narok County are essential resources supporting domestic use, livestock production, small-scale irrigation, and aquatic biodiversity. However, these systems face increasing threats from climate variability, population growth, and land-use pressures that alter water quality and ecosystem functioning. Limited empirical data linking specific water-quality stressors such as elevated nitrogen and phosphorus, turbidity, and conductivity to zooplankton populations and ecosystem services hinders effective management in this landscape. This study examined the distribution, diversity, and abundance of zooplankton in relation to water-quality variations and contrasting land-use practices across 20 water pans in the Narok socio-ecological system. Monthly sampling was conducted in February, June, and July 2023, representing the late dry season, early wet season, and post-rainy period. Physico-chemical parameters were measured *in situ*, while nutrients and chlorophyll-*a* were analyzed using APHA 2017 standard protocols. Chlorophyll-*a* ranged from 19.08 ± 1.05 μg/L (M118) to 176.61 ± 140.19 μg/L (M396). TN varied from 393.00 ± 30.25 μg/L (M100) to 2,609.43 ± 52.47 μg/L (M392), and TP ranged from 295.43 to 1331.14 μg/L. Zooplankton communities were dominated by Rotifera (48.9%), followed by Copepoda (25.8%), Cladocera (19.9%), and Ostracoda (5%). Taxa richness increased from the dry season (14.21 ± 0.79) to the wet season (16.43 ± 0.67;

p = 0.043), while Shannon-Wiener Index rose from 1.76 to 1.96 and Simpson's Index reached 10.72. Diversity and richness showed a negative correlation with TN, indicating nutrient enrichment as a major stressor. The dominance of stress-tolerant Rotifers in nutrient-rich pans reflected catchment land-use influences. Conserving these semi-arid water pans through riparian buffer restoration, controlled livestock access, and improved water abstraction is important for sustaining zooplankton biodiversity and ecological integrity.

Keywords: Zooplankton, Narok County, Water Pans, Diversity, Land Use, Water Quality, Semi-Arid Ecosystems

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Introduction

Semi-arid water pans in Narok County are critical socio-ecological resources, supporting rural livelihoods through water provision for domestic use, livestock, small-scale irrigation, and local biodiversity. They also enhance ecosystem resilience by sustaining wildlife and serving as freshwater reservoirs in landscapes characterized by variable rainfall and prolonged dry seasons. For the predominantly pastoral and agro-pastoral Maasai communities, access to reliable water sources supporting cultural, economic, and environmental stability. These water pans face increasing ecological pressures from hydrological seasonality, prolonged droughts, overgrazing, sedimentation, agricultural expansion, and nutrient enrichment, which alter water quality and aquatic community structure (Mondal et al., 2023). Narok's landscape comprises contrasting land-use systems, including pastoral grazing zones and humid agricultural areas, which influences water pans quality through livestock trampling, fertilizer use, soil erosion, and catchment degradation. These activities often elevate nutrient loads, increase turbidity, and contribute to organic pollution. Key water quality parameters including temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), turbidity, total nitrogen (TN), total phosphorus (TP), soluble reactive phosphorus (SRP), and chlorophyll-*a* play important roles in determining the ecological status of semi-arid freshwater bodies, affecting productivity, energy flow, and community structure (Rayori et al., 2023).

Zooplankton is central to aquatic ecosystems due to their roles in nutrient cycling, energy transfer, and trophic interactions. As primary consumers, they mediate energy flow from phytoplankton to higher trophic levels, particularly fish, thereby influencing productivity and food web stability (Calbet, 2025; Declerck et al., 2023). Their rapid reproduction, short generation times, and sensitivity to environmental fluctuations make them effective bioindicators of water quality. Zooplankton distribution, diversity, and abundance have been widely used to assess ecological responses to nutrient enrichment, chlorophyll-*a*, turbidity, conductivity shifts, and other physico-chemical stressors, particularly in temporary or semi-arid freshwater systems where water levels and nutrient variations vary seasonally (Oduor et al., 2024; Ogamba et al., 2023).

Despite their ecological importance, empirical data on how water quality and land-use jointly influence zooplankton communities in Narok's semi-arid water pans remain limited. This knowledge gap constrains effective water resource management, biodiversity conservation, and planning for ecosystem resilience under increasing climate variability. Exploring these relationships is essential in regions where freshwater scarcity, high livestock densities, and agricultural intensification interact to shape ecosystem functioning.

This study examined how spatial variations in physico- chemical parameters (TN, TP, SRP, Chl-*a*, pH, DO, EC, temperature, turbidity) and contrasting land-use types (humid agricultural vs. pastoral) influence zooplankton distribution, diversity, and abundance in Narok water pans. We hypothesized that water pans influenced by agricultural activities would show increased nutrient and chlorophyll-*a* concentrations, reduced zooplankton taxa richness, and a community dominated by stress-tolerant Rotifera compared with pastoral pans. Seasonal changes particularly the transition from the late dry to the wet period is expected to increase taxa richness as a result of enhanced hydrological connectivity and greater phytoplankton availability. By examining these patterns, the study aimed to provide evidence-based information for the sustainable management of water pans, supporting freshwater conservation and aquaculture productivity in alignment with SDG 6.

Materials and Methods

Study Area

This study was conducted in Narok County, located in southern Kenya along the Great Rift Valley, Fig. 1 and Table 1. The county covers approximately 17,944 km² at an average elevation of 1,827 m above sea level and exhibits diverse ecological zones ranging from semi-arid lowlands to humid highlands.

According to the 2019 national census, the county has a population of 1,157,873 people (Government of Kenya, 2019). The region is socio-economically characterized by predominant pastoral and agro-pastoral livelihoods, with water pans serving as critical freshwater sources for domestic use, livestock, wildlife, and small-scale irrigation.

Sampling was conducted between February and July 2023 to capture hydrological variability during both dry and wet periods that influence water quality and zooplankton population. Twenty perennial water pans were purposively selected based on Google Earth imagery and field verification to confirm accessibility, stability across seasons, geographic distribution, and relevance to local water use. Only pans that retained water throughout prolonged dry periods were included to ensure consistent ecological assessment.

The study sites were distributed across two distinct environmental zones representing contrasting land-use and hydrological conditions. Eleven water pans (M110, M112, M116, M100, M114, M117, M115, M118, M119, M120, M121) occurred in relatively humid areas along the Narok Town–Mulot transect, where small-scale farming, washing activities, and water abstraction were common. The remaining nine pans (M225, M221, M222, M348, M391, M364, M392, M396, M398) were situated in drier rangelands along the Narok Town–Sekenani transect, predominantly used for livestock watering and wildlife access. These spatial differences reflect distinct ecological pressures that may influence nutrient loading, turbidity, and zooplankton community structure. While no quantitative land-use measurements were undertaken, classification was guided by field observations and local knowledge. Figure 1 and Table 1.

Table 1: Location of the 20 water pans sampled; the first eleven pans represent sites located in areas influenced by agricultural activities, while the last nine represent pans situated in drier zones dominated by livestock and wildlife activities.

NO.	Water pans	Latitude	Longitude
1	M110	1° 3'53.34"S	35°45'21.42"E
2	M112	1° 2'10.70"S	35°43'37.80"E
3	M116	1° 3'23.02"S	35°43'27.30"E
4	M100	1° 2'19.74"S	35°43'1.23"E
5	M114	1° 0'9.14"S	35°38'22.15"E
6	M117	0°59'32.07"S	35°37'51.65"E
7	M115	1° 0'25.14"S	35°38'6.84"E
8	M118	0°59'33.47"S	35°35'8.84"E
9	M119	0°59'24.12"S	35°34'50.26"E
10	M120	0°59'0.15"S	35°31'58.85"E
11	M121	0°58'33.35"S	35°30'32.98"E
12	M225	1°10'53.90"S	35°44'2.53"E
13	M221	1°13'1.95"S	35°43'5.34"E
14	M222	1°13'45.90"S	35°42'19.79"E
15	M348	1°16'4.69"S	35°40'45.36"E
16	M391	1°17'58.30"S	35°39'26.57"E
17	M364	1°18'54.04"S	35°38'52.21"E
18	M392	1°22'4.68"S	35°36'18.80"E
19	M396	1°25'16.47"S	35°34'24.46"E
20	M398	1°14'47.16"S	35°41'43.07"E

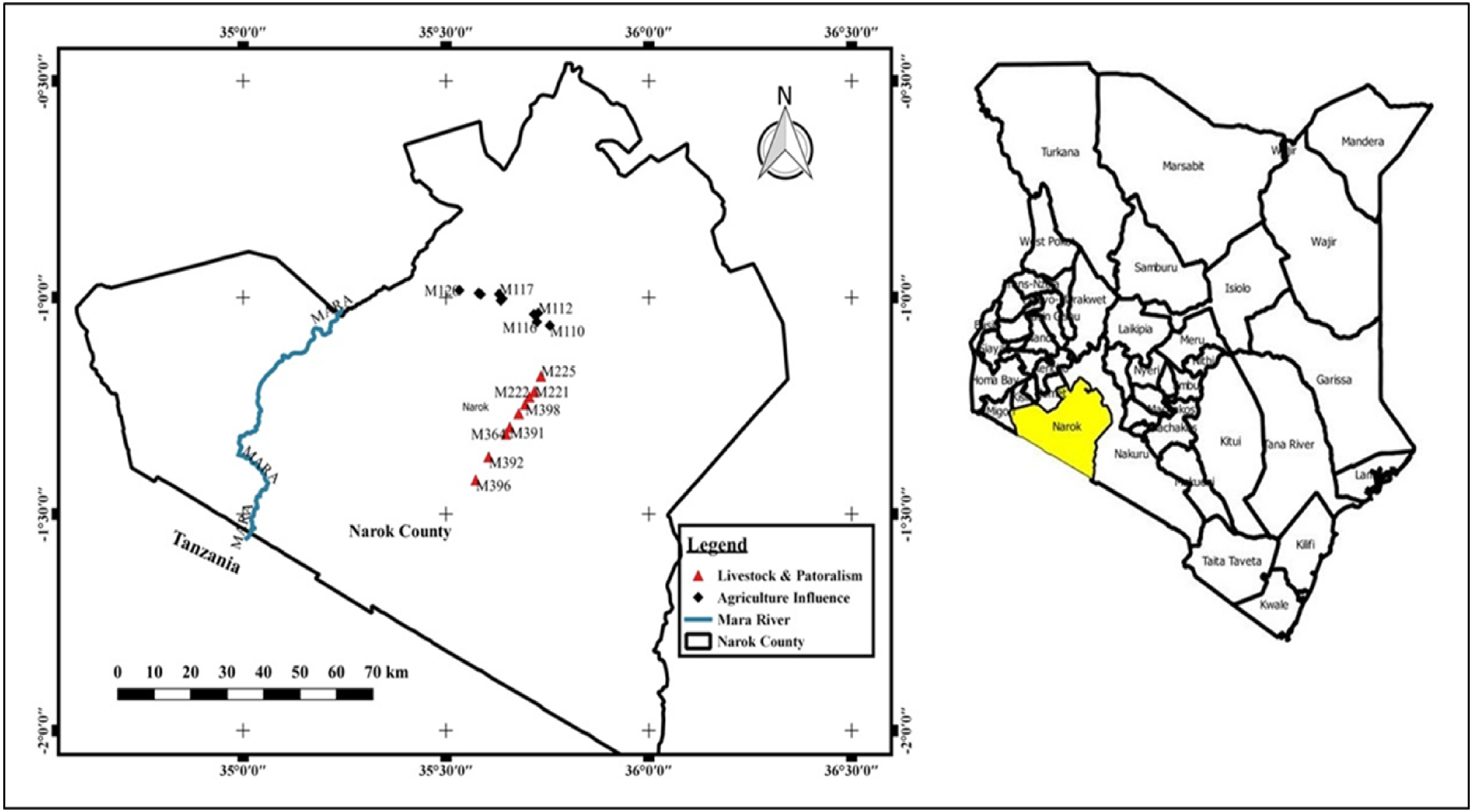

Figure 1: Map of Narok County indicating the sampling points for all the sites within Narok county.

Sampling Design

Sampling was conducted during three hydrological periods in 2023, with two sampling occasions in February (late dry season), two in June (early wet season), and two in July (post-rainy season). These six sampling events were selected to capture hydrologically driven variations in water quality and zooplankton community structure typical of semi-arid ecosystems. All twenty water pans were visited during each sampling event, providing repeated temporal observations across seasonal conditions. Within each pan, two sampling points were selected during every visit to account for spatial heterogeneity in water column characteristics. The points were randomly located within the open-water zone rather than fixed throughout the sampling period. Given that most water pans were shallow (<3 m) with irregular morphometry, the use of two random locations was considered sufficient, and traditional littoral–pelagic transects were not feasible. All water quality, nutrient, and zooplankton samples were collected from the surface mixed layer at approximately 0.1–0.5 m depth, where the influence of hydrological fluctuations on biological and chemical parameters is most pronounced.

Sampling and Sample Analysis

Physico-chemical Parameters

In situ measurements of water quality were conducted in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). At each sampling point, dissolved oxygen (DO), pH, temperature, and electrical conductivity (EC) were recorded in duplicate using a portable multiparameter probe (Model HI98194, Hanna Instruments). The probe was calibrated prior to every field excursion following the manufacturer's specifications. pH calibration was carried out weekly using standard pH 4.0 and 7.0 buffer solutions, while the DO sensor was calibrated using the air-saturation method immediately before field deployment. The probe was immersed approximately 10 cm below the water surface, and stabilized readings were recorded directly from the digital display.

Water Samples for Nutrients

Water samples for nutrient analyses were collected using clean 1-L plastic bottles that had been rinsed with sample water prior to collection. Samples were taken from a depth of approximately 0.5 m and immediately stored in ice-filled coolers before transportation to the Kenya Marine and Fisheries Research Institute (KMFRI) laboratory Kisumu research center. In the laboratory, samples were filtered through Whatman GF/C glass fiber filters with a nominal pore size of 0.7 µm. Filtered aliquots were used for analyses of soluble reactive phosphorus (SRP), nitrate (NO_3^-), nitrite (NO_2^-) whereas unfiltered portions were digested for total nitrogen (TN) and total phosphorus (TP). All analytical procedures followed APHA (2017) and Wetzel and Likens (2010). Total phosphorus was determined using the ascorbic acid molybdate method following persulfate digestion, with absorbance read at 810 nm using a HACH DR3900 spectrophotometer. Total nitrogen was quantified through alkaline persulfate digestion followed by colorimetric measurement. Nitrate was analyzed through the cadmium reduction method and read at 543 nm, while nitrite was measured at 543 nm. These nutrients were selected because of their importance in supporting phytoplankton growth and shaping zooplankton food environments.

Chlorophyll-a

Chlorophyll-*a* concentration was

used as a measure for phytoplankton biomass. A known volume of water (500 mL) was filtered through GF/C filters, after which pigments were extracted in 90% acetone for 24 hours at 4°C. Absorbance readings were obtained at 665, 645, and 750 nm using a HACH DR3900 spectrophotometer. Chlorophyll-*a* concentration (mg/m³) was calculated according to the equation by Jeffrey and Humphrey (1975), with turbidity correction applied using the 750 nm reading and path length accounted for during computation.

Zooplankton Sampling and Enumeration

Zooplankton was sampled from two randomly selected locations within each water pan during all six sampling events. At each location, 20 liters of water were collected using a clean plastic bucket and poured through 50 µm plankton net. This method was preferred over horizontal tows due to the shallow, irregular nature of the water pans, which limited the feasibility of net towing.

Preservation and Processing

The retained material was washed into labeled 500 mL containers. Samples were preserved immediately with 5% buffered formalin and transported to the KMFRI laboratory Kisumu research center for analysis. In the laboratory, samples were gently homogenized and concentrated to a known final volume ranging between 100 and 400 mL, depending on organism density. Subsamples of 2 mL were drawn using a calibrated dropper and transferred into a Sedgwick–Rafter counting chamber for enumeration. Each sample was analyzed in triplicate to reduce counting error, and mean values were used. Zooplankton were identified under a Leica compound microscope at 40× magnification using standard taxonomic keys, including Jeffries et al. (1984), Korovchinsky (1992), Koste and Shiel (1980), Pennak (1978), Segers (2007), and Shiel (2020). Abundance was calculated as individuals per liter using the formula by Lind (1979), which incorporates the mean number of organisms counted, the concentrated sample volume, the subsample volume, and the total volume of water filtered. The abundance was determined using the formula:

$$Abundance\ (ind./L) = \bar{N} \times 20 \times 2400 = \bar{N} \times 10$$

Where 400ML is the sample volume, 20L is the volume of the water filtered and 2mL is the subsample volume.

Data Analysis

Data analyses were conducted using SPSS version 26.0, PAST version 4.03, Microsoft Excel 2019, and R version 4.2.1. Prior to statistical analyses, normality and homogeneity of variance were evaluated using the Shapiro–Wilk tests, respectively. Where necessary, zooplankton abundance data were transformed using $\log_{10}$ transformations to stabilize variance. Descriptive statistics (mean ± standard deviation) were computed for all physico- chemical parameters. Differences among pans were examined using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. Relationships between environmental variables and zooplankton abundance and diversity were assessed using Pearson correlation coefficients. Zooplankton community structure was characterized using Shannon–Wiener, Simpson, richness, and evenness indices calculated through the vegan package in R. Spatial variation in zooplankton assemblages was explored using Principal Component Analysis (PCA) implemented through the prcomp function, and environmental vectors were fitted to ordination axes using the envfit function. Statistical significance was assessed at $p \leq 0.05$.

Results

Variations in physico-chemical parameters and Chl-*a*

Chlorophyll-*a* concentrations showed variations across the study sites, ranging from 19.08 ± 1.05 µg/L at site M118 to 176.61 ± 140.19 µg/L at site M396. The mean chlorophyll-*a* concentration was 84.21 ± 12.47 µg/L. ANOVA results confirmed statistically significant differences among sites ($F = 3.20$, $p = 0.0001$)

Total Nitrogen (TN) concentrations varied with the lowest value recorded at site M112 (393.00 ± 30.25 µg/L) and the highest at site M392 (2609.43 ± 52.47 µg/L). The mean TN concentration across all sites was 1237.45± 89.67 µg/L ($F = 7.27$, $p < 0.0001$).

Total Phosphorus (TP) concentrations ranged from 295.43 ±22.17 µg/L at site M117 to 1331.14 ±231.32 µg/L at site M398, with an overall mean of 748.53 ± 65.38 µg/L. These differences were statistically significant ($F= 5.66$, $p < 0.0001$).

Soluble Reactive Phosphorus (SRP), representing bioavailable phosphorus, ranged from 45.33 ± 0.01 µg/L at site M118 to 183.67 ± 7.07 µg/L at site M121. The mean SRP concentration was 67.93 ± 5.92 µg/L. Significant spatial variation in SRP was observed ($F = 3.67$, $p< 0.0001$).

Nitrate (NO_3^-) concentrations ranged from 20.13 ± 1.64 µg/L at M117 to 93.70 ± 14.36 µg/L at M225, with a mean value of 41.32 ± 3.07 µg/L. Nitrite (NO_2^-) concentrations varied from 4.76 ± 10.96 µg/L at M225 to 32.94 ± 4.71 µg/L at M392, averaging 18.17 ± 1.85 µg/L. Both nitrate and nitrite levels showed significant differences among sites (NO_3^-: $F = 3.55$, $p < 0.0001$; NO_2^-: $F = 5.14$, $p < 0.0001$.

pH values across all sites ranged from 6.70 to 9.30, with a mean of 7.58. The lowest pH (6.70 ±0.04) was recorded at site M221 in February, while the highest (9.30 ± 0.01) was observed at site M398 in July. A temporal increase in mean pH was noted from 7.42 in June to 8.21 in July due to photosynthetic activity and changing CO_2 concentrations.

Dissolved Oxygen (DO) concentrations ranged from 0.40 ± 0.10 mg/L at site M116 to 9.55 ± 0.01 mg/L at site M114, with a mean of 6.44 ± 0.23 mg/L across all sites. The observed spatial differences were statistically significant ($F= 4.295$, $p < 0.001$).

Electrical Conductivity (EC) values ranged from 79.83 ± 6.53 µS/cm at site M348 to 761.85 ±3.04 µS/cm at site M398, with an overall mean of 289.34 ±15.27 µS/cm. Spatial variation in EC was significant ($F = 5.687$, $p < 0.001$).

Water temperature ranged from16.40 ± 1.13 °C at site M116 to 26.20 ±4.81 °C at site M396, with an overall mean of 20.32 ± 0.38 °C. Temperature varied significantly between sites ($F = 2.523$, $p = 0.004$). These findings are summarized in Tables 2a, 2b, 3a, 3b where, Temp-Temperature, Cond-conductivity, DO-Dissolved Oxygen, TN-total nitrogen, TP-total phosphorus, SRP-soluble reactive phosphorus. Feb 2023 S.D*± Mean physico-chemical and biological variables in 11 water pans in Narok arid and semi-arid landscape.

Table 2a: Feb 2023 S.D*± Mean physico-chemical and biological variables in 11 water pans in Narok arid and semi-arid landscape.

Variables	Temp(°C)	Cond. (uS/cm)	DO (mg/L)	pH	TN(μgL^{-1})	TP(μgL^{-1})	NO_3^-(μgL^{-1})	NO_2^-(μgL^{-1})	SRP (μgL^{-1})	Chl-*a*(μgL^{-1})
M112	17.45 ±0.07	321.00±6.79	5.10±0.21	7.64±0.01	393±0.00	401.86±0.00	48.70±0.86	14.15±4.71	47.00±2.36	63.59±4.32
M116	16.40 ±0.85	230.30±8.20	0.40±0.10	6.88±0.01	1453.37±0.00	887.57±0.00	46.58±0.00	21.73±0.01	118.67±0.01	59.19±0.01
M100	18.85 ±0.07	419.05±17.32	5.90±0.15	7.45±0.07	637.84±180.50	610.43±101.02	55.82±14.78	15.76±5.87	54.50±15.32	82.66±1.38
M110	18.95 ±0.07	170.65±5.30	5.20±0.21	8.38±0.01	747.58±175.66	530.43±119.20	39.61±1.29	14.18±3.81	87.83±1.18	26.16±2.55
M114	18.50 ±0.07	151.50±1.13	2.00±0.17	7.33±0.01	848.9±62.15	440.43±66.67	34.91±2.79	19.02±3.84	47.00±2.36	32.36±1.80
M117	18.65 ±0.50	290.70±2.26	2.70±0.22	7.47±0.01	574.69±13.77	295.43±41.41	40.52±4.29	15.06±3.43	44.50±10.61	69.81±15.06
M115	22.40 ±0.14	210.15±1.77	6.30±0.26	7.30±0.006	871.79±139.19	723.29±64.65	29.61±1.71	14.30±1.93	58.67±4.71	92.20±0.15
M118	23.85 ±1.91	214.00±8.34	6.70±0.15	7.11±0.09	1053.37±0.00	1031.86±0.00	64.76±0.01	27.48±0.01	45.33±0.01	44.63±0.01
M119	20.75 ±0.07	366.30±17.54	8.20±0.41	7.25±0.07	1368.11±0.00	781.86±0.00	54.76±0.01	25.67±0.01	97.00±0.01	19.08±0.01
M120	23.95 ±0.78	164.00±3.514	7.10±0.23	7.04±0.01	878.37±45.78	926.86±233.35	53.55±9.42	15.48±1.03	65.17±4.95	38.87±0.84
M121	25.20 ±0.85	289.55±43.91	8.00±0.28	7.37±0.01	773.63±5.59	804.71±103.03	44.76±10.29	18.03±1.20	42.83±1.18	57.51±5.91

Table 2b: Feb 2023 S.D± Mean physico-chemical and biological variables in 9 water pans influenced by livestock and wildlife in Narok arid and semi-arid landscape

Variables	Temp(°C)	Condu. (uS/cm)	DO (mg/L)	pH	TN(μgL^{-1})	TP(μgL^{-1})	NO_3^- (μgL^{-1})	NO_2^- (μgL^{-1})	SRP(μgL^{-1})	Chl-*a*(μgL^{-1})
M225	19.60 ±0.01	130.45±9.55	7.50±0.61	7.00±0.44	1072.06±373.27	1004.72±163.65	93.70±14.36	32.94±4.71	162.00±2.36	51.31±27.90
M221	19.10 ±0.85	180.85±7.42	6.00±0.70	6.70±0.04	990.74±336.43	906.86±120.21	84.30±16.07	23.55±3.00	172.00±4.71	58.71±33.81
M222	20.25 ±0.64	567.75±33.59	7.60±0.57	7.61±0.06	974.16±105.32	799±175.77	87.33±16.93	23.55±1.71	133.67±9.43	28.75±15.56
M398	19.55 ±1.20	761.85±3.04	8.80±0.57	8.28±0.08	656.53±558.24	1331.14±231.32	50.51±4.29	20.06±0.21	183.67±7.07	41.15±33.54
M348	19.90 ±1.98	134.15±5.16	6.10±0.64	7.66±0.03	1002.32±62.52	941.14±150.51	63.55±5.14	19.76±1.07	123.67±11.79	73.28±7.37
M391	20.05 ±2.05	153.55±1.91	5.80±0.15	7.45±0.03	652.32±72.94	904.72±305.07	48.09±21.00	16.29±2.12	87.83±5.89	34.18±29.84
M364	23.70 ±3.39	450.05±93.27	6.90±0.65	8.08±0.02	846±149.61	973.29±165.67	68.55±26.78	20.67±1.50	122.83±3.54	95.66±35.06
M392	22.20 ±1.56	223.20±1.98	1.50±0.57	6.89±0.02	2609.43±52.47	1030.43±222.23	80.67±3.64	31.91±1.03	98.67±4.71	60.67±47.70
M396	26.20 ±4.81	223.20±28.71	8.50±0.01	8.73±0.01	1013.9±219.58	794±156.57	77.33±3.64	24.00±0.21	93.67±16.50	48.24±14.79

Table 3a: June-July 2023 S.D*± Mean physico-chemical and biological variables in 11 water pans influenced by agriculture in Narok arid and semi-arid landscape.

Variables	Temp(°C)	Condu. (uS/cm)	DO (mg/L)	pH	TN(μgL^{-1})	TP(μgL^{-1})	NO_3^- (μgL^{-1})	NO_2^- (μgL^{-1})	SRP(μgL^{-1})	Chl-*a*(μgL^{-1})
M112	16.65±1.13	289.17±12.39	9.08±2.61	8.26±1.34	457.4±189.00	370.43±124.44	34.25±11.97	11.37±8.20	104.22±5.36	33.53±12.57
M116	17.35±1.13	172.93±6.20	7.33±1.12	7.78±0.18	535.3±124.50	342.33±44.77	34.25±7.79	12.84±4.02	90.89±16.86	32.17±6.36
M100	17.62±1.18	182.33±13.07	7.6±2.36	7.85±0.27	416.88±102.93	327.1±81.43	32.74±5.63	8.43±1.27	94.78±5.85	47.86±6.82
M110	17.87±1.70	144.38±8.21	8.78±2.73	8.39±0.08	539.33±157.49	452.33±94.59	26.07±3.64	4.76±2.89	112.56±10.05	34.54±11.85
M114	19.67±2.91	156.07±6.73	9.55±0.01	7.87±0.24	516±124.26	366.62±176.16	33.55±6.99	10.02±1.27	73.67±14.81	54.35±17.20
M117	19.33±2.65	165.93±11.00	6.78±1.59	8.14±0.01	511.44±140.64	323.29±110.85	20.13±1.64	7.39±0.94	81.44±23.71	39.5±13.27
M115	21.28±1.64	153.05±22.46	8.92±5.65	7.66±0.32	516.7±193.71	352.33±143.32	34.56±12.21	11.93±5.93	76.33±5.24	34.6±7.78
M118	20.8±1.48	126.6±7.10	8.8±4.74	8.41±0.14	621.09±82.17	630.43±50.53	36.49±7.31	10.6±3.52	116.11±17.84	41.13±17.12
M119	21.78±1.38	248±13.61	8.2±4.77	8.26±0.18	634.42201.75	729±271.30	37.46±11.48	14.25±2.27	120.22±31.06	31.2±18.89
M120	20.95±2.20	113.27±5.54	8.05±3.16	9.21±0.32	631.44±52.10	548.52±61.18	37.91±14.01	8.7±7.16	117±35.63	35.14±16.58
M121	24±1.99	190.15±2.64	7.52±4.10	9.11±0.60	460.91±184.59	524.71±110.11	32.74±9.87	12.44±3.65	122.44±6.83	44.09±26.45

Table 3b: June-July 2023: S.D± Mean physico-chemical and biological variables in 9 water pans influenced by livestock and wildlife in Narok arid and semi-arid landscape. SD: Standard Deviation, Temp.: Temperature, Cond.: Conductivity, DO: Dissolved Oxygen, TN: Total Nitrogen, TP: Total Phosphorus, Nitrate, NO_2^-: Nitrite, SRP: Soluble Reactive Phosphorus, Chl-a: Chlorophyll-*a*

Variables	Temp(°C)	Condu. (uS/cm)	DO (mg/L)	pH	TN(μgL^{-1})	TP(μgL^{-1})	NO_3^- (μgL^{-1})	NO_2^- (μgL^{-1})	SRP(μgL^{-1})	Chl-*a*(μgL^{-1})
M225	18.73±1.81	146.83±25.37	6.08±4.84	8.49±0.03	822.67±217.39	705.67±92.41	49.91±19.16	21.73±3.37	118.11±28.98	53.04±29.63
M221	18.25±1.87	168.83±3.03	6.17±5.00	8.96±0.21	766.88±141.60	543.76±141.43	54.06±17.77	20.48±4.29	133.11±64.75	49.88±16.97
M222	19.28±1.76	386.83±25.10	4.72±3.84	9.13±0.01	904.25±186.26	597.10±128.53	51.63±15.17	20.52±5.51	119.78±36.22	124.29±39.78
M398	19.52±2.14	561±13.61	5.58±4.55	9.3±0.01	699.18±204.01	958.52±62.60	61.63±9.42	25.46±10.96	132±60.09	146.8±149.50
M348	20.2±2.25	79.83±6.53	7.43±0.11	9.3±0.01	771.61±172.05	739.48±109.96	50.72±17.63	23.4±3.24	138.67±59.65	41.66±21.93
M391	19.8±1.80	105.3±2.51	8.53±1.66	9.06±0.01	691.61±132.98	495.67±116.76	48.6±16.94	22.63±3.49	141.44±30.97	44.04±27.89
M364	21.85±2.21	160.42±13.04	8.88±3.43	8.65±0.01	765.47±315.86	534.24±97.23	56.27±15.02	18.7±1.32	135.89±57.55	54.44±21.42
M392	23.77±4.17	96.38±14.67	6.3±0.01	8.25±0.13	1071.79±404.83	549±188.06	52.13±8.57	19.85±1.92	114.78±32.59	75.95±48.01
M396	23.13±3.71	184.93±7.18	6±0.01	8.16±0.01	870.56±190.98	684.71±208.29	51.42±17.66	18.1±4.20	97±36.67	176.61±140.19

Variations in Zooplankton Distribution, Diversity and Abundance

i) *Variations in Zooplankton distribution and abundance among the taxonomic groups*

A total of 54,234 zooplankton individuals per liter (ind/L) were recorded across the 20 sampled water pans in Narok County. Zooplankton population was dominated by Rotifera, which contributed approximately 49% (25,864 ind/L) of the total zooplankton population. Copepoda followed with 26% (13,101 ind/L), while Cladocera represented 20% (10,934 ind/L) of the total abundance. Ostracoda formed the smallest proportion, accounting for 5% (4,335 ind/L) of the total individuals recorded (Figure 2). Rotifera were widely distributed across all sampling stations and contributed the highest numerical abundance. Copepoda and Cladocera had moderate abundances and were more evenly represented across sites, Ostracoda occurred in low numbers. Although numerical differences in total zooplankton abundance were observed among the sampled water pans, a one-way ANOVA showed no statistically significant differences $F(19,20) = 0.397$, $p = 0.975$), however, descriptive patterns showed that pans located in wetter zones tended to have higher zooplankton counts than those in drier areas (Fig 2).

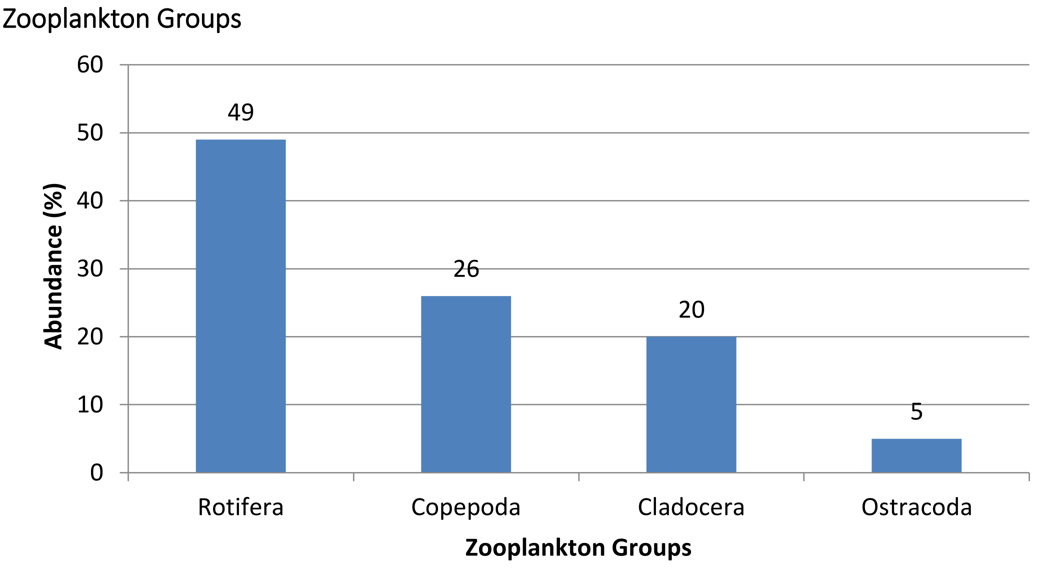

Figure 2: Abundance (%) per group during the study period

A total of 27 zooplankton taxa were identified from the water pans sampled in Narok County, representing four major groups: Copepoda, Cladocera, Rotifera, and Ostracoda. Cyclopoid recorded the highest total abundance (11,999 ind/L) and occurred in nearly all stations. Other dominant taxa included *Filinia* sp. (4,875 ind/L) and *Trichocerca* sp. (3,844 ind/L), moderate abundances were observed for *Moina micrura* (3,310 ind/L), *Asplanchna* sp. (3,244 ind/L), and *Keratella tropica* (3,180 ind/L. Among the cladocerans, *Bosmina longirostris* displayed the highest mean abundance (435 ind/L). Rotifera such as *Brachionus calyciflorus, B. falcatus, B. patulus, and B. plicatilis* were also widely distributed. Less abundant taxa included *Hexarthra* sp., *Encentrum* sp., *Lecane* sp., and *Lecane (Monostyla*) each recording mean abundances below 20 ind/L. The occurrence of Copepod nauplius larvae (mean 28 ind/L) and Calanoid (30 ind/L) indicated active reproductive processes and sustained recruitment within the water pans. Statistical analysis (one-way ANOVA, $F(19, 20) = 0.397$, $p = 0.975$) revealed no significant differences in zooplankton abundance among the 20 sampled pans as shown in Table 4.

Table 4: Zooplankton taxa identified during the study period

Taxa	Total abundance	Mean abundance	Count
Cyclopoida	11999	130.423913	92
Fillinia sp	4875	82.62711864	59
Trichocerca sp	3844	61.01587302	63
Moina micrura	3310	62.45283019	53
Asplanchna sp	3244	64.88	50
Keratella tropica	3180	40.76923077	78
Bosmina longirostris	3048	435.4285714	7
Brachionus calyciflorus	2472	53.73913043	46
Polyarthra sp	2266	37.14754098	61
Copepod nauplius larvae	2062	27.86486486	74
Brachionus falcatus	2000	57.14285714	35
Brachionus plicatilis	1972	51.89473684	38
Brachionus patulus	1831	73.24	25
Brachionus angularis	1776	32.29090909	55
Ostracorda	1538	29.01886792	53
Daphnia barbata	1448	21.29411765	68
Calanoida	1082	30.05555556	36
Euchlanis sp	932	51.77777778	18
Ceriodaphnia cornuta	802	57.28571429	14
Brachionus bidentata	514	27.05263158	19
Daphnia lumhorzti	478	478	1
Hexarthra sp	271	16.9375	16
Encentrum sp	189	12.6	15
Lecane sp	189	63	3
Lecane (Monostyla)	12	6	2
Daphnia barbata	10	10	1
Brachionus caudutus	7	7	1
Brachionus leydigi	1	1	1

ii)Variations in zooplankton diversity indices

Simpson's Diversity Index (D) values ranged from 1.85 to 9.38 in February and from 2.20 to 10.72 in July. Higher diversity was observed in M225 (9.38) and M222 (8.72), particularly in June, while the lowest diversity was recorded in M116 (1.85) in February.

Shannon's Diversity Index (H') also showed an increase with M225 rising from 1.76 in February to 1.96 in June/July in Table 5. Taxa richness significantly increased in June/July (16.43 ± 0.67) compared to February (14.21 ± 0.79), with a mean difference of −2.2 taxa ($p = 0.043$). Dominance was higher in February (0.28 ± 0.03) than in June/July (0.21 ± 0.02), but the difference was not statistically significant ($p = 0.10$).

Table 5: Diversity indices between the sites during the sampling period

Characteristic	N = 14[1]	N = 14[1]	Difference[2]	95% CI[2,3]	p-value[2]
Taxa (S)	14.21 ± 0.79	16.43 ± 0.67	-2.2	-4.3, -0.08	0.043
Individuals	4,533 ± 909	4,561 ± 718	-28	-2,416, 2,360	>0.9
Dominance (D)	0.28 ± 0.03	0.21 ± 0.02	0.07	-0.01, 0.14	0.10
Simpson's (1-D)	0.72 ± 0.03	0.78 ± 0.02	-0.06	-0.14, 0.02	0.13
Shannon (H')	1.76 ± 0.11	1.96 ± 0.07	-0.20	-0.47, 0.06	0.12
Evenness (E)	0.44 ± 0.03	0.45 ± 0.03	-0.01	-0.10, 0.08	0.8

c)Influence of water quality parameters on the diversity and abundance of zooplankton species

i)Influence of water quality parameters on the diversity of zooplankton

The analysis indicated that Total Nitrogen (TN) negatively correlated with species richness (-0.501), Shannon's diversity index (-0.320), and Simpson's index (-0.178), suggesting that higher TN concentrations reduced zooplankton diversity and evenness while slightly increasing dominance (0.173).

Total Phosphorus (TP) had a weak negative relationship on species richness (- 0.301) and Shannon's diversity index (-0.001), with a slight positive impact on evenness (0.141). Nitrates showed a weak positive correlation with individual numbers (0.080) and evenness (0.175) but a slight negative relationship on species richness (-0.337) and diversity (-0.063). Nitrites positively impacted individual abundance (0.218) and evenness (0.239). Soluble Reactive Phosphorus (SRP) significantly reduced dominance (- 0.301) while increasing evenness (0.117) and diversity (Shannon's index at 0.289). Chlorophyll- *a* (Chloro-*a)* positively influenced individual abundance (0.180), diversity (Shannon's at 0.131), and evenness (0.241) as presented in Table 6.

Table 6: Correlation analysis between water quality and zooplankton diversity indices

Variable	Ind/l	Taxa (S)	Individuals	Dominance (D)	Simpson's (1-D)	Shannon (H')	Evenness (E)
TN	0.043	-0.501	-0.047	0.173	-0.178	-0.320	0.035
TP	-0.033	-0.301	0.008	-0.068	0.057	-0.001	0.141
Ammonium	0.205	-0.321	0.168	0.114	-0.113	-0.158	0.030
Nitrates	0.080	-0.337	0.099	0.011	-0.019	-0.063	0.175
Nitrites	0.023	-0.238	0.218	-0.085	0.054	0.065	0.239
SRP	-0.158	0.209	0.083	-0.301	0.276	0.289	0.117
Chlorophyl-*a*	0.012	-0.026	0.180	-0.155	0.170	0.131	0.241

ii)Influence of water quality parameters on zooplankton abundance and distribution

The correlation analysis revealed weak associations ($r < 0.4$, $p > 0.05$) between zooplankton abundance and most physico-chemical parameters. This indicated that short-term variations in water quality did not strongly regulate zooplankton abundance across the sampled pans due to the combined influence of multiple interacting factors such as habitat heterogeneity, predation pressure, and hydrological variability. Although total nitrogen and total phosphorus showed positive but statistically insignificant correlations with zooplankton abundance ($r = 0.32$ and $r = 0.28$, respectively; $p > 0.05$), the scatterplots indicated considerable variability among sites. Dissolved oxygen (DO) and pH showed weak linear relationships with zooplankton abundance ($r < 0.3$) as shown in Fig. 3.

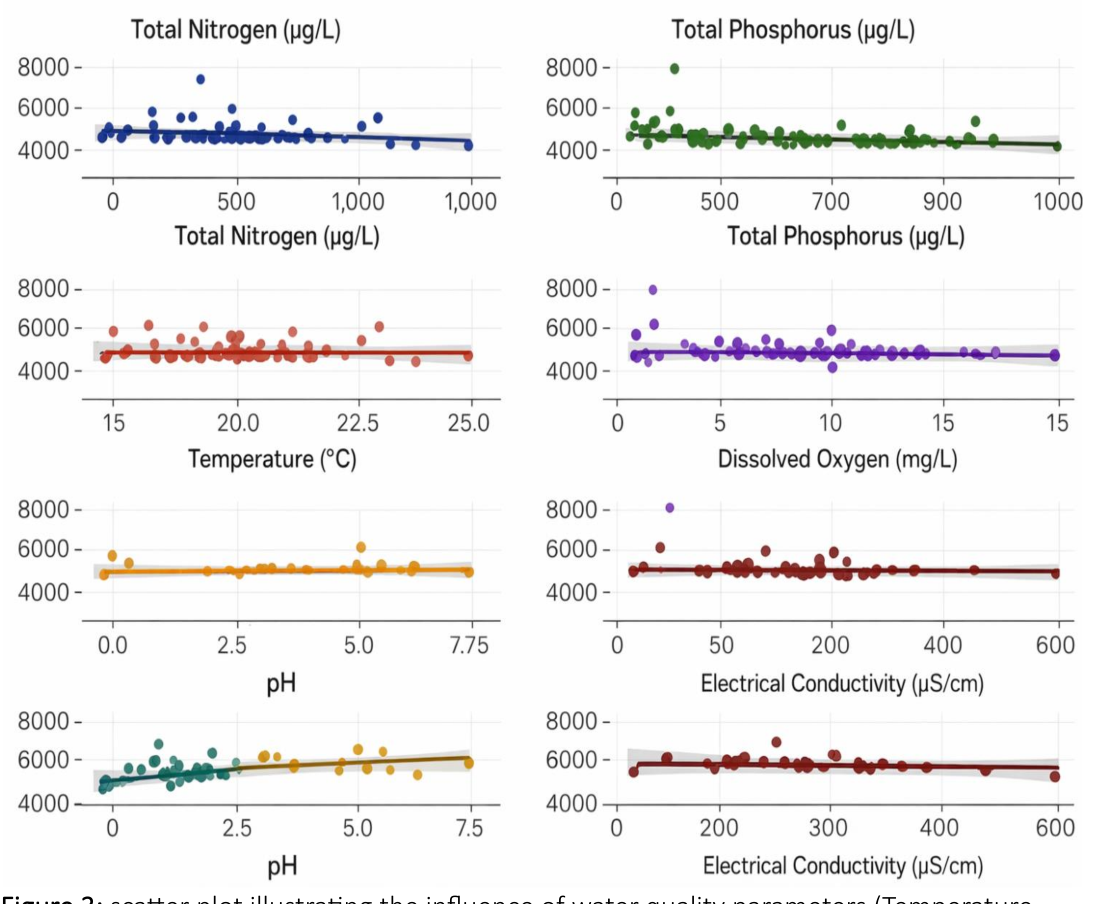

Figure 3: scatter plot illustrating the influence of water quality parameters (Temperature, DO, pH, EC, TN, TP and Chlorophyll-a on the zooplankton abundance.

Discussion

Water Quality Dynamics and Seasonal Variation

The physico-chemical characteristics of the water pans showed spatial heterogeneity, reflecting variations in hydrology, catchment land use, and seasonal rainfall dynamics. Chlorophyll-a concentrations ranged from 19.08 ± 1.05 µg/L (M118) to 176.61 ± 140.19 µg/L (M396), with a mean of 84.21 ± 12.47 µg/L, indicating high algal biomass across the systems. Higher concentrations during the wet season (June–July) suggested enhanced nutrient enrichment through surface runoff and erosion, which promoted phytoplankton growth. Similar seasonal patterns have been reported in tropical semi-arid water bodies, where rainfall pulses increased nutrient delivery and stimulate primary productivity (Abdul and Arunbabu 2025). The observed values are comparable to those reported for shallow eutrophic reservoirs but higher than those in more stable, perennial systems due to the ephemeral nature and limited flushing capacity of the pans.

Total nitrogen (TN) concentrations were high across sites, ranging from 393.00 ± 30.25 µg/L at M100 to 2,609.43 ± 52.47 µg/L at M392 (mean 1,237.45 ± 89.67 µg/L). TN levels increased during the dry season due to evaporation-driven concentration and reduced water exchange patterns consistent with findings in shallow, low-turnover water bodies (Zhao et al., 2025). Soluble reactive phosphorus (SRP) was higher during the wet season (mean 67.93 ± 5.92 µg/L), which indicated rapid mobilization from agricultural soils and livestock-grazing zones following runoff events. Similar dynamics have been documented in small-scale reservoirs where rainfall-mediated mobilization drives phosphorus pulses (Mng'ong'o, 2022; Weaver et al., 2020). Total phosphorus (TP) showed spatial variation (295.43–1,331.14 µg/L), with increased values in heavily grazed and erosion-prone catchments, supporting evidence that sediment re-suspension and land degradation contributed to phosphorus loading in semi-arid systems (Ngatia et al., 2023). Nitrate and nitrite concentrations (20.13–64.76 µg/L and 8.43–31.91 µg/L, respectively) reflected active nitrogen cycling driven by rapid nitrification in shallow oxygenated zones and denitrification in organic-rich sediments. Similar nitrogen transformation mechanisms have been described in temporary ponds and floodplain wetlands (Franco, 2023).

Temperature varied moderately (16.65–26.20 °C), influenced by pan morphology and shading, consistent with patterns observed in small reservoirs (Kariuki, 2021). Dissolved oxygen ranged from (0.40–9.55 mg/L), with hypoxic conditions observed in shallow turbid pans where organic matter decomposition exceeded photosynthetic oxygen production. Comparable diel oxygen fluctuations have been reported in nutrient-rich pans, (Mungenge et al., 2023). The pH ranged from slightly acidic (6.70 ± 0.04) to alkaline (9.30 ± 0.01), increasing during wetter months reflecting enhanced CO_2 uptake from phytoplankton photosynthesis. Similar seasonal alkaline has been observed in tropical eutrophic systems influenced by high algal biomass (Subramanian et al., 2025).

Electrical conductivity (EC) showed variation (79.83–761.85 µS/cm), which indicated varying degrees of mineralization, evaporation concentration, and livestock-driven ionic enrichment; these patterns are consistent with pastoral wetland systems (Cherotich, 2024). The significant site-level differences confirmed by ANOVA ($p < 0.001$) indicated the pans do not function as homogeneous habitats but rather reflect localized anthropogenic and ecological processes characteristic of semi-arid inland waters.

Zooplankton Community Structure and Dominance

A total of 54,234 zooplankton individuals per liter were recorded across the 20 water pans, comprising four major taxonomic groups: Rotifera (49%), Copepoda (26%), Cladocera (20%), and Ostracoda (5%). The strong dominance of Rotifera across all sites, particularly species of Brachionus, reflected their high reproductive rates, rapid turnover, and resilience to fluctuating environmental conditions, including elevated nutrient concentrations and hydrological stress. These traits enable rotifers to outcompete larger-bodied grazers under eutrophic and unstable conditions (Jana, 2024). The pattern is consistent with systems characterized by high nitrogen and phosphorus loads, where Rotifer dominance often signals eutrophication and organic enrichment (Rayori, 2023). The prevalence of Brachionus species has similarly been reported in nutrient-rich ponds where livestock inputs and runoff drive elevated algal productivity (Gichuki et al., 2020). Copepoda formed the second most abundant group, dominated by Cyclopoid (11,999 ind/L) with widespread distribution across sites.

Cyclopoids are known to thrive in nutrient- enriched shallow systems due to their omnivorous feeding strategies and tolerance to fluctuating dissolved oxygen conditions (Magouz et al., 2021). Calanoid, though relatively rare (30 ind/L), were restricted to lower-nutrient sites such as M115 and M177 emphasizing their potential use as indicators of better water quality and stable hydrological conditions. Similar niche partitioning has been reported in highland reservoirs where Calanoids persist in less disturbed waters with lower turbidity and higher oxygenation (Pinto et al., 2025). Cladocerans such as *Moina micrura* and *Bosmina longirostris* occurred in moderate abundances and were widely distributed. Their presence indicated active grazing pressure on phytoplankton and suggested a role in regulating algal biomass, particularly during post-rainfall nutrient pulses when phytoplankton blooms intensify. Comparable patterns have been documented in small tropical water bodies where Cladocerans track seasonal productivity peaks associated with runoff-driven enrichment (Mogaka, 2024). Ostracoda were least abundant (5%), reflecting their benthic feeding behavior and preference for habitats with accumulated sediments and low water column mixing. Similar habitat-restricted distributions have been observed in semi-arid wetlands where Ostracods occupy sediment–water interfaces rather than pelagic zones (Torricella et al., 2021).

Drivers of Zooplankton Diversity and Abundance

Correlation analyses revealed weak associations between zooplankton abundance and most physico-chemical parameters ($r < 0.4$, $p > 0.05$). TN negatively correlated with taxa richness (-0.501), Shannon's diversity index (-0.320), and Simpson's 1-D (-0.178), indicating that excessive nitrogen reduces species diversity and evenness while slightly increasing dominance, (0.173), (Geng et al., 2022) TP showed weak negative relationships with richness (-0.301) and Shannon's index (-0.001), and a slight positive effect on evenness (0.141). SRP, in contrast, reduced dominance (-0.301) while slightly enhancing diversity (0.289) and evenness (0.117). Chl-*a* showed weak positive correlations with abundance (0.180), Shannon's index (0.131), and evenness (0.241), suggesting that higher algal biomass moderately supports zooplankton diversity, (Meremo et al., 2022). These findings indicated that no single water quality parameter regulates zooplankton populations in the Narok water pans. Instead, interacting factors such as nutrient enrichment, hydrological stability, predation pressure, and habitat heterogeneity collectively influence community structure, (Emily et al., 2024). The observed weak correlations are consistent with ecological theory for small, dynamic freshwater systems, where non-linear responses to nutrient concentrations and environmental stressors are common, (Orr et al., 2024)

Seasonal and Spatial Patterns

Seasonal differences were evident in both water quality and zooplankton metrics. The wet season enhanced taxa richness and diversity while reducing dominance, reflecting the positive effects of increased water volume, habitat connectivity, and nutrient redistribution on ecological niches, (Shmidt et al., 2022). The dry season promoted accumulation of TN and TP, reduced water volumes, and favored rotifer-dominated assemblages, indicating nutrient enrichment and localized eutrophication, (Barjau-Aguilar et al., 2022). Spatially, pans in wetter zones showed higher total zooplankton counts and diversity indices than those in drier areas, emphasizing the role of hydrological environment in shaping aquatic communities.

Ecological Implications

The dominance of Brachionus and other opportunistic Rotifera provided strong evidence of widespread eutrophication in Narok water pans. The restricted occurrence of Calanoid at selected sites showed that some pans retained relatively good water quality, (Meremo et al., 2022), explaining their potential as reference systems for monitoring ecological health. Seasonal shifts in diversity emphasized the importance of rainfall and hydrological fluctuations in mediating community composition, resource availability, and recruitment, (Lundberg 2025). Weak but meaningful correlations between specific water quality parameters and zooplankton diversity explained the bio-indicator potential of zooplankton, (Rayori 2023). Higher total nitrogen concentrations were associated with reduced zooplankton diversity, whereas soluble reactive phosphorus and moderate chlorophyll-a levels were linked to greater community evenness and enhanced secondary productivity, (Suba et al., 2025). These findings provide a scientific basis for managing nutrient inputs, protecting riparian vegetation, and controlling livestock access to maintain ecological stability.

Conclusions

This study successfully established the seasonal and spatial variations in zooplankton community structure across the water pans of the semi-arid Narok Socio-Ecological Landscape and quantified the influence of key water quality parameters. The communities were characterized by high diversity but were heavily dominated by Rotifera (48.9% of total abundance), particularly the genus Brachionus, which is a strong indicator of eutrophic and polluted conditions. Seasonal shifts were clear: cooler, wetter periods favored the abundance of Rotifers, while Copepods and Ostracods were more prevalent in warmer, drier conditions. Further, the analysis revealed that eutrophication stress, rather than food availability strongly shaped the community; high concentrations of Total Nitrogen (TN) showed a negative correlation with species richness. This research indicated that the ecological health and sustainability of these vital water pans are significantly threatened by excessive nutrient loading from adjacent land-use practices, limiting their potential for biodiversity conservation and aquaculture.

Recommendations

The Narok County Department of Environment and NEMA should immediately establish and enforce a minimum 10-meter vegetated buffer around all permanent water pans, especially those adjacent to agricultural land. This structural measure is essential to intercept and filter surface runoff, thereby reducing the input of key eutrophication drivers. The Narok County Department of Agriculture must collaborate with extension services to train farmers in Best Management Practices (BMPs). Training should focus on soil testing to optimize fertilizer application rates and timings, minimizing the nutrient leaching, particularly of Soluble Reactive Phosphorus (SRP), into the pans during critical rainy periods. Empower local water resource user associations to implement basic, low-cost monitoring protocols. This should include seasonal tracking of key indicators like pH, DO, and simple zooplankton richness counts to detect early signs of ecological decline. WRUAs and the Narok County

Department of Water should promote construction of fenced-off watering points (e.g., using fortified troughs or single, hardened access ramps) to restrict direct livestock entry into the main body of the pan. This strategy minimizes bank erosion, sediment re-suspension, and direct fecal contamination, which contributes significantly to high Electrical Conductivity (EC) and sudden nutrient spikes. The County Department of Water should empower local WRUAs to implement basic, low-cost monitoring protocols. This should include seasonal tracking of key indicators like pH, Dissolved Oxygen (DO), and simple zooplankton richness counts. These protocols utilize the bio-indicator potential of zooplankton and enable the early detection of ecological decline, allowing for timely intervention. Conduct future studies that quantify the role of fish predation pressure and the quality/toxicity of phytoplankton (food source) to gain a comprehensive understanding of the top-down and bottom-up forces influencing zooplankton population crashes and successes in these specific semi-arid ecosystems.

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