SPATIOTEMPORAL ASSESSMENT OF NUTRIENTS IN THE STEELPOORT SUB-CATCHMENT OF THE OLIFANTS RIVER BASIN, SOUTH AFRICA

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Abstract. Nutrient enrichment is considered to be one of the most serious threats to freshwater ecosystems. The increasing agricultural and other human activities in the Steelpoort sub-catchment of the Olifants River Basin has led to serious impacts on water quality. The spatial and seasonal variability of nutrient concentrations in the Dwars, Spekboom and Steelpoort rivers in South Africa were analyzed. Four monitoring sites per each river were selected to assess the impact of human activities on nutrient levels in the rivers during the wet and dry seasons. The samples were analyzed to determine the concentrations of nitrates, nitrites, ammonia and ortho-phosphates. Trends in nutrient concentrations varied among the sites and rivers, and there were significantly higher levels of nutrients detected at sites with high human activities. Generally, higher concentrations of nutrients were recorded during the wet season in the Dwars and Steelpoort rivers and higher concentrations of nutrients were recorded in the Spekboom River during the dry season. The most likely cause of increasing nutrient enrichment are effluent from agricultural fields, partially treated and untreated sewage. Though nutrient levels recorded were low, some sites had concentrations that exceeded the recommended limits. It is therefore important that proper management measures should be implemented to reduce wastes discharged into the rivers.
Keywords: *land use, eutrophication, nutrients, pollution, water quality*

Introduction

Globally, water quality is declining due to increasing urbanization, mining, agricultural and industrial activities (Cheng et al., 2021; Addo-Bediako and Rasifudi, 2021; Varol et al., 2022). These activities, coupled with channel alteration and climate change are causing a decline in water quality in freshwater ecosystems, and are affecting the biotic communities (Liu et al., 2021; Ge et al., 2022). Nutrient enrichment is one of the major problems freshwater ecosystems are facing, usually caused by human activities (Romanelli et al., 2020). A number of studies have expressed concern about the impact of nutrient enrichment (eutrophication) on freshwater resources (e.g. Van Ginkel, 2011; Harding, 2015; Gqomfa et al., 2022). Nutrients, especially nitrogen and phosphorous generally originate from over fertilized agricultural soils through leaching and erosion processes (Trinh et al., 2015; Singkran, 2017) or from untreated domestic and industrial wastewaters (Cloern et al., 2014).

Nutrients can be stored temporarily in the groundwater and then transported into the stream via subsurface water or surface runoff that is induced by rainfall (Laurent and Mazumder, 2014; Zhou et al., 2017). High nutrient content can lead to eutrophication, may cause depletion of dissolved oxygen, and lead to increased autotroph biomass, species compositional shifts, reductions in biodiversity, potential production of algal toxins, and affect the taste and odor of water (Griffin, 2017). Assessment of the ecological status of rivers is important in managing river ecosystems and providing a precondition for economic growth and ecological integrity (Cao et al., 2019).

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In South Africa, nutrient enrichment in freshwater ecosystems is increasing due to increasing runoff from agricultural activities, industrial wastewater, and municipal sewage due to dysfunctional water waste treatment plants (Dabrowski and De Klerk, 2013). Due to the increasing nutrient levels in many rivers, there are concerns about severe ecological and economic consequences (Harding, 2015). The Olifants River Basin is one of the most polluted river systems in South Africa and has been systemically impaired by increasing agricultural, industrial and urban development, resulting in contamination of the water (Ashton and Dabrowski, 2011). Intensive and subsistence agriculture activities in the Steelpoort sub-catchment of the Olifants River Basin, in conjunction with industrial and other human activities are negatively impacting on the water quality of the rivers (Ashton and Dabrowski, 2011; Addo-Bediako, 2021). Though, there are a number of programs to monitor nutrient levels, there is relatively little published information on nutrient levels of freshwater ecosystems in the Steelpoort sub-catchment of the Olifants River Basin. Thus, the aim of this study was to assess the spatial and seasonal patterns in nutrient levels and to evaluate how nutrient levels are related to the land use in the river catchments.

Materials and methods

Study area

The Steelpoort River sub-catchment of the Olifants River Basin is located at the north eastern part of South Africa. The main rivers in the sub-catchment include Steelpoort, Dwars and Spekboom rivers. The rivers provide water for agricultural, mining and industrial activities. They also serve as a source of drinking water to a number of communities in the area. The Steelpoort River sub-catchment covers an area of 7,139 km^2. The elevation ranges from 1,500 m to 2,400 m, with the exception of the Steelpoort River valley, which is between 900 and 1,200 m. The mean annual rainfall for the area is between 630-1,000 mm. Rainfall usually occurs in the summer months, from October to March, with the highest rainfall usually in January. The mean daytime summer temperatures are between 19°C and 22°C, while the winter mean temperatures are between 13°C and 19°C (Stimie et al., 2001; SAWS, 2023).

Stream water sampling and chemical analysis

Twelve sampling sites were selected along the three main rivers in the Steelpoort River sub-catchment, the Dwars, Spekboom and Steelpoort rivers (*Table 1; Fig. 1*). Seasonal sampling was conducted during wet and dry seasons of 2019 and 2020. Stream water was collected in polyethene bottles from each of the 12 sites. Water samples collected from the streams were placed on ice and transported to the laboratory. They were filtered within 24 h of collection using 0.7-mm glass microfiber filters. The water samples were then preserved in polyethene bottles at 4°C prior to chemical analysis. The nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and ortho-phosphate (PO_4) levels were determined using a spectrophotometer (Merk Pharo 100 Spectroquant™) with Merck cell test kits. Physicochemical parameters such as water temperature, dissolved oxygen (DO), pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in situ using YSI multi-parameter instrument (Yellow Springs Instruments, Texas, model Model 554 Data logger).

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Table 1. *Characterization of selected sampling sites in the Steelpoort sub-catchment of the Olifants River Basin*

Sites	Latitude	Longitude	Description of the sites
DWS1	-24.8553	30.0103	Upstream, near mine water return dam and grazing area
DWS2	-24.8428	30.0867	Midstream, near mining and industrial areas (ferrochrome mine and smelter)
DWS3	-24.8317	30.0797	Midstream, area with agricultural coverage and pasture
DWS4	-24.8306	30.0794	Downstream, near the mouth, agricultural activities (crop production and animal grazing) and informal settlements
SPS1	-24.6936	30.3628	Upstream reach, agricultural and mining areas
SPS2	-24.6581	30.3386	Midstream, water treatment plant
SPS3	-24.6586	30.3244	Midstream, wastewater treatment plant
SPS4	-24.6419	30.3081	Downstream, near human settlement and grazing area
STS1	-25.1058	29. 8519	Upstream, near grazing area
STS2	-24.9942	30.0186	Midstream, near recreational site, site used for washing of clothes, cars and fishing
STS3	-24.8836	30.1192	Midstream, new residential development
STS4	-24.7339	30.5011	Downstream, near grazing area

DWS = Dwars River Sites, SPS = Spekboom River S STS = Steelpoort River Sites

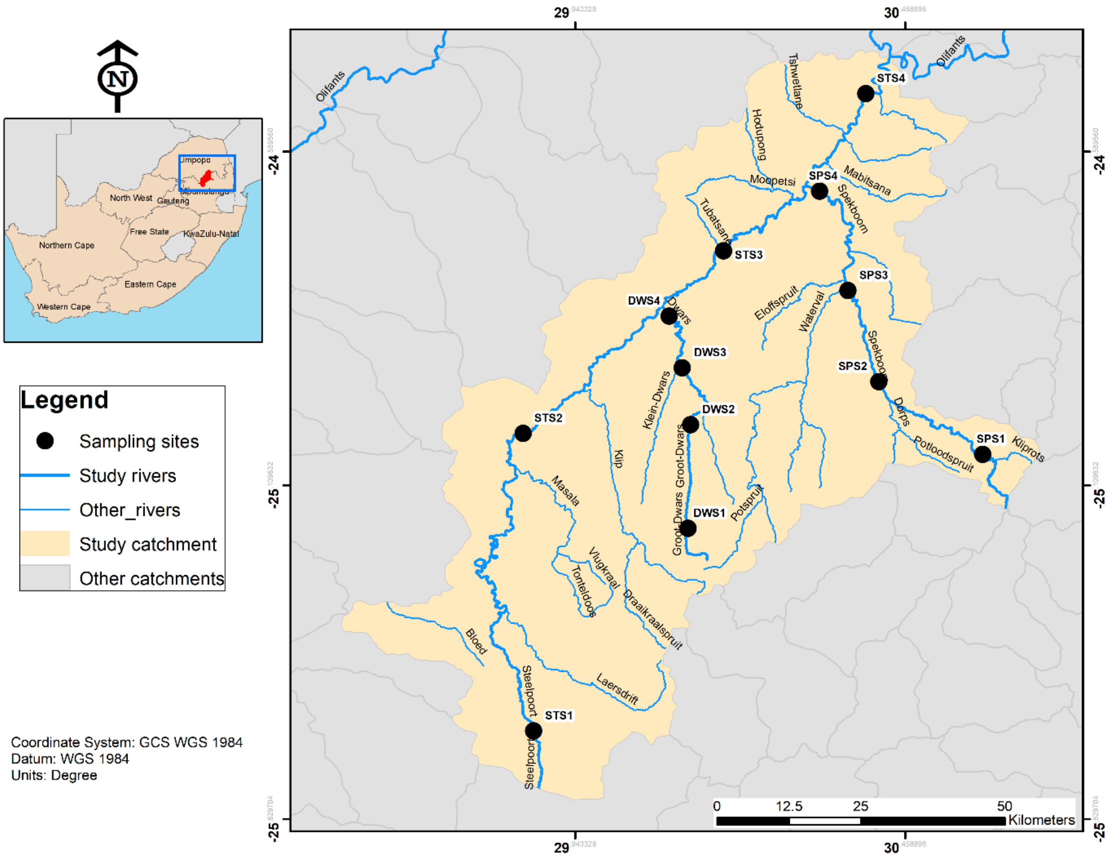

Figure 1. *Map of the study area, showing the sites of the Dwars, Spekboom and Steelpoort rivers (DWS = Dwars River Sites, SPS = Spekboom River S STS = Steelpoort River Sites)*

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Statistical analysis

The mean and standard deviation of the physicochemical parameters and nutrients were determined. One-way analysis of variance (ANOVA) was used to determine differences for mean concentrations of nutrients and dissolved oxygen among sites and seasons. The occurrence of a linear correlation between analyzed variables was tested using non-parametric Spearman Rank Correlation Analysis. The correlation determines the degree of a linear relationship between the different indicators. The level of significance considered for the interaction was 0.05. All statistical analyses were done using Statistica (Version 10).

Results

Physicochemical parameters

The water quality parameters showed variations among the rivers and along the rivers as shown in *Table 2*. Surface water temperature ranged from 17.6 to 22.2°C in the Dwars River, from 18.78 to 23.63°C in the Spekboom River, and from 17.4 to 25.75°C in the Steelpoort River. The lowest mean temperature was 18.8 in the Steelpoort River and the highest mean temperature was 21.7 in the Spekboom River (*Table 3*). The pH of the Dwars River ranged from 7.55 to 8.76, the pH of the Spekboom River ranged from 6.68 to 8.25, and the pH of the Steelpoort ranged from 7.80 to 8.85. The highest pH values were recorded during the wet season in all the rivers. The electrical conductivity values ranged from 282.4 to 559.6 uS/cm in the Dwars River, from 282.4 to 628.8 uS/cm in the Spekboom River, and from 232.9 to 372.5 uS/cm in the Steelpoort River. The TDS levels were between 96.5 and 385.5 mg/l in the Dwars River, between 193.6 and 436.5 mg/l in the Spekboom River, and from 181.6 to 240.5 mg/l. Generally, EC and TDS levels were higher during the wet season than the dry season in all the three rivers, with the highest mean EC and TDS of 515.8 uS/cm and 335.5 m/l respectively (*Table 3*).

The DO concentration in the Dwars River ranged from 5.32 to 8.65 mg/l, from 5.77 to 8.99 mg/l in the Spekboom River, and between 7.52 and 7.84 mg/l in the Steelpoort River. Dissolved oxygen levels fluctuated among the rivers and seasons, with the highest concentration of 8.99 mg/l at S2 in the Spekboom River during the dry season and lowest concentration of 5.32 mg/l at S3 of the Dwars River also during the dry season. The highest mean DO was 8.33 mg/l and the lowest was 6.15 mg/l (*Table 3*). Generally, the DO levels were higher during the dry winter season than in the wet summer season in all the three rivers (*Table 2*).

Spatiotemporal nutrient concentrations

The nutrient concentrations at the sites are shown in *Table 2* and the mean concentrations of nutrients recorded during the wet and dry seasons in each river are shown in *Table 3*. The levels of the nutrients fluctuated greatly among the rivers and between the seasons. Nitrate was recorded in all the sites during both the wet and dry seasons in the three rivers. Nitrate concentration showed an increase during the wet season in the Dwars and Steelpoort rivers, but showed an increase during the dry season in the Spekboom River. The highest mean concentration of 18.5 mg/l was recorded at DWS1 of the Dwars River during the wet season and the lowest concentration of 0.25 mg/l was recorded at STS1 in the Steelpoort River during the dry season. In the Dwars

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River, NO_2 was recorded at all sites during the dry season but only recorded at DWS1 during the wet season. In the Spekboom River, NO_2 was below detection level at all sites during the wet season but was detected at all sites during the dry season, with the highest mean concentration of 0.24 mg/l at SPS4. Whilst in the Steelpoort River, NO_2 was below detection level at all sites during the dry season, but was recorded at STS2 during the wet season with a mean of 0.065 mg/l. The highest concentrations of NO_2 were recorded during the dry season in the Spekboom River and during the wet season in the Dwars and Spekboom rivers.

Ammonia concentration was below detection level at all sites in the Dwars River during the wet season but was detected at all sites during the dry season with a mean concentration of 0.04 mg/l. In the Spekboom River, NH_3 concentration was below detection level at all sites during the wet season but was detected at all sites during the dry season, with the highest mean concentration of 0.09 mg/l. In the Steelpoort River, however, NH_3 was recorded at all sites during both wet and dry seasons except at S4 during the wet season. In general, the dry season had the highest levels of NH_3 in the Dwars and Spekboom rivers, but during the wet season, the highest level of NH_3 was in the Steelpoort River. Ortho-phosphate was only detected in the Dwars and Spekboom rivers at all sites during the dry season and was not detected in the Steelpoort River during both seasons.

Table 2. *Physicochemical parameters taken at each site of the three rivers*

Site	Temp	DO (mg/ℓ)	pH	EC	TDS	NO_3	NO_2	NH_3	Ortho-PO_4
DWS1-W	22.2	8.65	7.74	559.6	379	18.5	0.42	n.d	n.d
DWS2-W	17.65	6.68	7.93	514.5	385.5	17	n.d	n.d	n.d
DWS3-W	22.05	6.54	8.14	557.5	382.6	15.5	n.d	n.d	n.d
DWS4-W	21.75	7.63	7.55	282.4	194.7	0.55	n.d	n.d	n.d
DWS1-D	20.4	6.99	8.76	519.5	175.4	12.5	0.25	0.04	0.04
DWS2-D	17.6	5.95	8.2	491.3	181.9	10.4	0.03	0.04	0.05
DWS3-D	20.65	5.32	8.52	542	188.4	12.2	0.03	0.04	0.04
DWS4-D	19.8	6.33	8.35	307	96.5	4.6	0.02	0.04	0.04
SPS1-W	23.63	8.6	6.68	269.4	193.6	0.58	n.d	n.d	n.d
SPS2-W	21.8	8.53	8.16	414.1	277.3	0.3	n.d	n.d	n.d
SPS3-W	20.65	5.77	7.69	628.8	436.5	1.0	n.d	n.d	n.d
SPS4-W	20.65	7.49	7.92	305.2	215.2	0.9	n.d	n.d	n.d
SPS1-D	18.78	8.9	8.18	511.3	309.1	0.4	0.02	0.09	0.06
SPS2-D	21.5	8.99	8.12	485.1	251.2	0.9	0.03	0.03	0.09
SPS3-D	19.7	6.9	8.12	522.2	276.2	1.5	0.04	0.09	0.06
SPS4-D	20.75	8.53	8.25	544.6	272.6	3.9	0.24	0.2	0.11
STS1-W	25.75	7.515	8.65	232.9	198	0.45	n.d	0.45	n.d
STS2-W	21.4	6.9	8.85	293	211.3	0.5	0.065	0.4	n.d
STS3-W	20.25	6.95	8.6	331.5	240.5	1.3	n.d	0.45	n.d
STS4-W	19.1	7.41	7.9	309.2	237.9	1.05	n.d	n.d	n.d
STS1-D	18.45	7.825	8.65	372.5	226.8	0.25	n.d	0.2	n.d
STS2-D	19.8	7.8	8.0	267.6	181.6	0.3	n.d	0.1	n.d
STS3-D	19.35	7.84	7.8	291.7	208.3	0.55	n.d	0.15	n.d
STS4-D	17.4	7.5	8.45	325.4	239.1	0.8	n.d	0.1	n.d

DWS-D = Dwars River Sites during dry season, DWS-W = Dwars River Sites during wet season, SPS-D = Spekboom River Sites during dry season, SPS-W = Spekboom River Sites during wet season, STS-D = Steelpoort River Sites during dry season, STS-W = Steelpoort River Sites during dry season

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Table 3. *The mean ± standard deviation (SD) of physicochemical parameters measured in the Dwars, Spekboom and Steelpoort rivers of the Olifants River Basin*

Site	Temp (°C)	DO (mg/ℓ)	pH	EC µS/cm	TDS (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	NH_3 (mg/l)	Ortho-PO_4 (mg/l)
DWS-W	20.9 ± 2.2	7.37 ± 0.98	7.55-8.14	478.5 ± 132	335.5 ± 94	12.90 ± 8.3	0.11 ± 0.21	0.0	0.0
DWS-D	19.6 ± 1.4	6.15 ± 0.7	8.20-8.76	465.0 ± 107	160.6 ± 43	9.92 ± 3.7	0.08 ± 0.1	0.04 ± 0.0	0.04 ± 0.01
SPS-W	21.7 ± 1.4	7.60 ± 1.32	6.70-8.20	404.4 ± 162	280.7 ± 110	0.7 ± 0.31	0.0	0.0	0.0
SPS-D	20.2 ± 1.2	8.33 ± 0.97	8.11-8.25	515.8 ± 25	277.3 ± 24	1.68 ± 1.6	0.08 ± 0.11	0.10 ± 0.07	0.08 ± 0.02
STS-W	21.6 ± 2.9	7.19 ± 0.3	7.9-8.90	291.7 ± 42	221.9 ± 21	0.83 ± 0.42	0.2 ± 0.03	0.33 ± 0.2	0.0
STS-D	18.8 ± 1.1	7.74 ± 016	7.8-8.65	314.3 ± 45	214.0 ± 25	0.48 ± 0.25	0.0	0.14 ± 0.05	0.0
CCME			6.0-9.0			13.0	0.06	0.354	
SANS			6.5-9.5			11.0	< 0.9	< 1.5	
WHO	< 25.0		6.5-8.5	600	400.0	50.0	3.0	0.2	0.1

DWS-D = Dwars River Sites during dry season, DWS-W = Dwars River Sites during wet season, SPS-D = Spekboom River Sites during dry season, SPS-W = Spekboom River Sites during wet season, STS-D = Steelpoort River Sites during dry season, STS-W = Steelpoort River Sites during dry season

Differences in the nutrient and dissolved oxygen concentrations among the rivers

The NO_3 and NH_3 concentrations among the rivers differed significantly during the wet season ($F = 8.481$, $p < 0.005$; $F = 8.895$, $p < 0.005$ respectively) (*Fig. 2*), and during the dry season, NO_3, Ortho-PO_4 and DO differed significantly among the three rivers ($F = 105.87$, $p < 0.0001$; $F = 30.76$, $p < 0.0001$; $F = 10.45$, $p < 0.005$ respectively) (*Table 4*). The post-hoc tests showed that the NO_3 difference in mean concentration was between Dwars and Spekboom rivers ($p = 0.0002$) and between Dwars and Steelpoort rivers ($p = 0.0001$), the difference in NH_3 concentration was between Dwars and Steelpoort rivers ($p = 0.003$), between Spekboom and Steelpoort rivers ($p = 0.011$), the difference in ortho-PO_4 concentration was between Spekboom and Steelpoort rivers ($p = 0.033$), and the difference in DO concentration was between Dwars and Spekboom rivers ($p = 0.039$).

Table 4. *Results of analysis of variance among the rivers during wet and dry seasons*

Nutrients	df	MS	F	p-value
Wet season				
NO_3	2	196.14	8.481	0.008
NO_2	2	0.013	0.849	0.459
NH_3	2	0.141	8.895	0.007
Ortho-PO_4	2	-	-	-
DO	2	0.162	0.174	0.843
Dry season				
NO_3	2	105.87	19.94	0.0005
NO_2	2	0.009	1.154	0.358
NH_3	2	0.010	4.001	0.057
Ortho-PO_4	2	0.006	30.76	< 0.0001
DO	2	5.089	10.45	0.005

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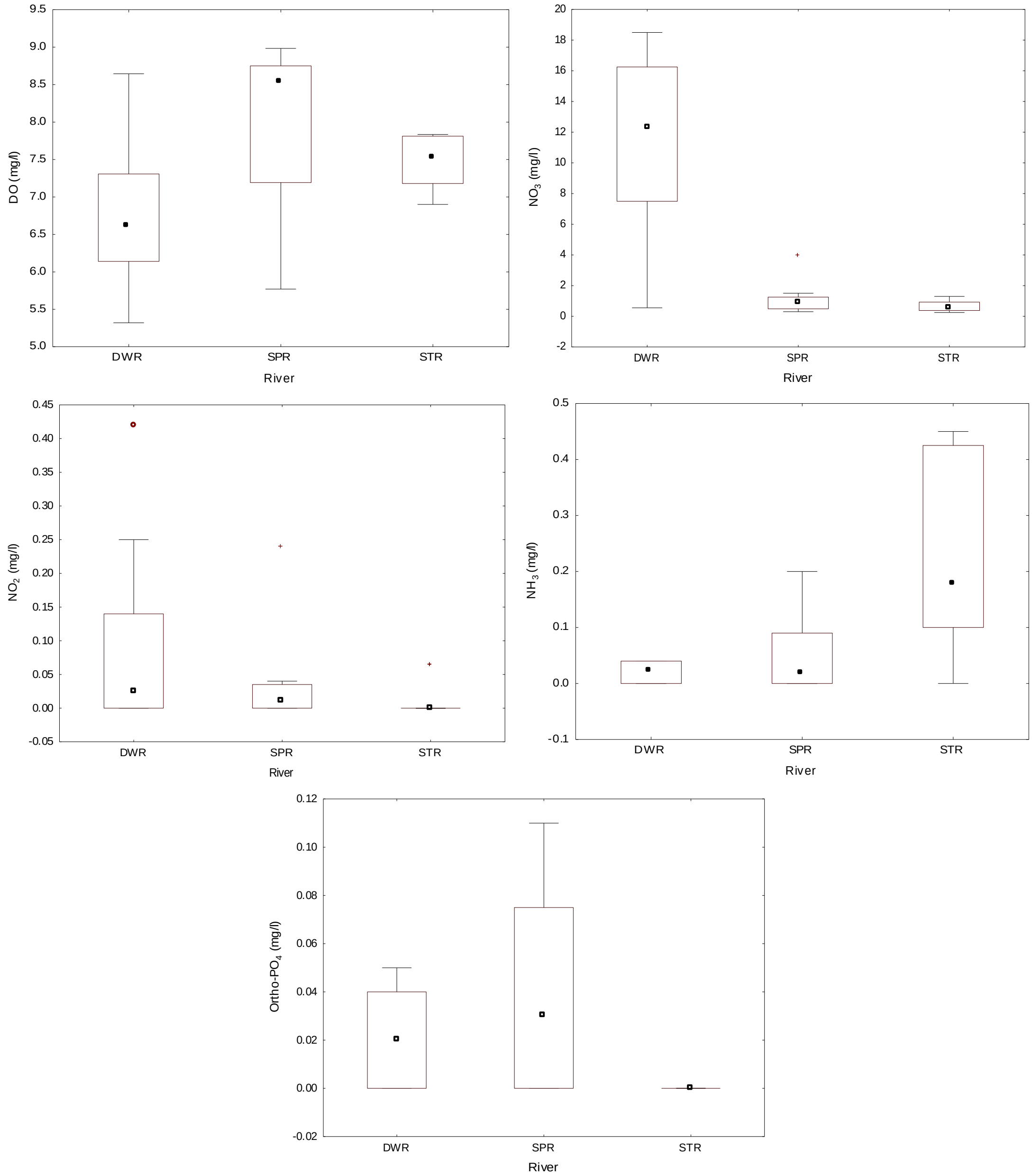

Figure 2. *Box and whisker plots for the nutrient and dissolved oxygen distribution in the Dwars, Spekboom and Steelpoort rivers (DWR = Dwars River, SPR = Spekboom River, STR = Steelpoort River)*

In the Dwars River, the highest concentrations of NO_3 was recorded at DWS1 (upstream) and the lowest at DWS3 (midstream), the highest mean NO_2 was at DWS1 and the lowest at DWS4 (downstream), however, the concentrations of NH_3 and ortho-PO_4 were similar at all reaches of the river, and the highest DO was at DWS1 and the lowest mean concentration was at DWS3. In the Spekboom River, NO_3, NO_2, NH_3, ortho-PO4 concentrations were highest at SPS4 (downstream), and the highest mean concentration of DO was at SPS2. In the Steelpoort River, the highest mean NO_3 was at STS3 and STS4, NO_2 was only detected at STS2. The concentrations of NH_3 and ortho-PO_4 were similar at all sites of the river, and the highest DO was at STS1, the highest mean concentration of

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NH_3 was at STS1. Ortho-PO_4 was below detection level at all sites and the highest mean DO was at STS1. There was a strong positive correlation between NO_3, and ortho-PO_4 (0.705), a significant correlation between NO_3 and NO_2, and a significant negative correlation between NO_3 and DO, thus, DO decreases with increasing NO_3 (*Table 5*).

Table 5. *Correlation matrix of water quality indicators in the wet and dry seasons in the Steelpoort sub-catchment of the Olifants River Basin*

	NO_3	**NO_2**	**NH_3**	**PO_4**	**DO**
NO_3	1.000000				
NO_2	**0.442885**	1.000000			
NH_3	-0.310360	0.043718	1.000000		
PO_4	0.279588	**0.704535**	0.073974	1.000000	
DO	**-0.503351**	0.005593	0.026450	0.024657	1.000000

Discussion

Physicochemical parameters

Water quality has a significant effect on the aquatic biota (Ali et al., 2016). The mean water temperature was found within the permissible limits of 25°C (WHO, 2011) at all the sites of the three rivers. The pH was slightly alkaline at all sites of the three rivers. The high values of electrical conductivity and TDS recorded in the present study were expected owing to the level of human activities in the catchments of the rivers. Conductivity and TDS attained their highest levels in the midstream (SPW3) of the Spekboom River during the wet season. An increase in conductivity and TDS in the Spekboom River can be attributed to anthropogenic discharges and runoff of wastewater into the river. The EC and TDS levels are usually increased by anthropogenic factors such as, land use changes, domestic, industrial, agricultural (intensive fertilization, irrigation) discharges (Canedo-Arguelles et al., 2013; Kaushal et al., 2018). High waste discharges into water bodies can make the water less suitable for its intended purposes (Islam and Islam, 2020), unfortunately, all these activities occur along the three rivers in the Steelpoort sub-catchment of the Olifants River Basin.

Dissolved oxygen concentration in water bodies is important in supporting aquatic life. In general, the DO was highest in the Spekboom River, followed by the Steelpoort River and then the Dwars River. From the results, with the decrease in water temperature during the dry winter season, the concentration of DO increased. Thus, the DO concentration reached its maximum value in the Spekboom River (8.99 mg/l) and the Steelpoort River (7.84 mg/l) during dry winter seasons. The high DO in dry winter season besides the decrease in temperature could be due to a decrease in the rate of oxygen consumption from aquatic organisms (Ali et al., 2016). However, in the Dwarf River, the highest DO (8.68 mg/l) was recorded during the summer wet season and the lowest DO concentration (5.32 mg/l) was recorded during the dry season. The low DO concentration in the Dwars River during dry winter season could be attributed to the high nutrient content (NO_3 and NO_2) and the slow-moving water.

Spatiotemporal stream nutrient concentrations

The higher NO_3 concentration in the Dwars and Steelpoort rivers during the wet season than dry season could be attributed to runoff from agricultural fields in the

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upstream of the river. High levels of NO_3 are normally due to improper disposal of solid waste, sewage and extensive use of chemical fertilizers (Garzon-Vidueira et al., 2020). The results of the study are consistent with other studies in the region which found higher NO_3 concentrations during the wet than dry seasons (Nyamangara et al., 2013; Edokpayi et al., 2015). Intense rainfall events usually lead to erosion and surface runoff transporting suspended materials into the water bodies that can increase nutrient load in rivers (Deng et al., 2021). The level of nutrients is usually high in areas such as recently fertilized fields and shallow nutrient enriched groundwater (Jiang et al., 2014; Orem et al., 2015). High NO_3 concentration during wet season can also be caused by nitrification process which causes a rapid decrease of NH_3 and an increase of NO_3 (Nguyen et al., 2019). Thus, there is seasonal variations in the transport of nitrates into water bodies.

In the Spekboom River, however, the NO_3 concentration during the dry season was higher than during the wet season. This could be due to partially treated sewage discharged into the river from the dysfunctional waste water treatment plant at site SPS3, which also affected the downstream of the river (SPS4). Wastewater discharge from rural and agricultural areas constitutes a constant source of pollution in many freshwater bodies. Despite the increasing nutrient pollution in some parts of the rivers, the NO_3 levels during both the dry and wet seasons were within the standard guideline values (CCME, 2012; WHO, 2011; SANS, 2015), however, the mean concentration of NO_3 exceeded SANS (2015) value in the Dwars River. Dorleku et al. (2019) reported that NO_3 at concentrations between 10 to15 mg/l can affect the water quality, aquatic biota and even humans. In infants, high NO_3 levels in drinking water can cause methemoglobinemia, a condition where the blood is unable to bind and carry oxygen to the cells (Nartey et al., 2012).

The NO_2 concentrations were consistently below the lower detection limit (<0.01 mg/L) at many sites. At sites where NO_2 was detected, the levels were below the guideline values of SANS (2015) and WHO (2011) of 0.9 and 3.0 mg/l respectively. The absence or low levels of NO_2 in the rivers could be attributed to the fact that NO_2 is a pervasive intermediate in the nitrogen cycle in nature. The highest NH_3 concentration was recorded in the Steelpoort River during the wet season. The levels of NH_3 exceeded the WHO standard guideline value of 0.2 mg/l, at the upstream and midstream sites (STS1, STS2, and STS3) of the Steelpoort River during the wet season and the NH_3 concentration exceeded the South African National Standard guideline of < 1.5 mg/l at SPS3 of the Spekboom River (SANS, 2015). The increase mainly during the wet season may be attributed to waste from farming activities and sewage entering the river through runoffs. The presence of high concentration of NH_3 usually indicates recent contamination by decaying organic matter, while the presence of NO_3 is indicative of late pollution (Gradilla-Hernández et al., 2020). High levels of NH_3 may trigger environmental problems, such as nitrous oxide emission and depleted oxygen in the water.

Ortho-phosphate is an essential nutrient for the development of organisms, and it is not categorized as a harmful or toxic element at low concentrations (Kumar and Puri, 2012). The natural source of phosphorus compounds in freshwater ecosystems is due to the dissolution of soil compounds, the decomposition of organic matter and the breakdown of microorganisms. Anthropogenic sources are related to domestic and industrial wastes, detergents, animal excrement and fertilizers (Griffin, 2017; Zhou et al., 2017). Ortho-phosphate was only recorded in the Dwars and Spekboom rivers during the dry season. There was not much fluctuation of ortho-PO_4 levels in the two

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rivers, with the highest recorded at SPS4 (downstream) of Spekboom River. During the dry season, the Spekboom River receives water discharge from the WWTP at SPS3 and could affect water downstream. Discharges from municipal and industrial wastewater treatment plants (WWTPs) are primary point sources of nutrients to receiving freshwater systems. Despite inputs being less diluted during the dry season, the decline in ortho-PO_4 concentration in the Dwars and Steelpoort rivers could also be attributed to algal growth (Causse et al., 2015; Nguyen et al., 2019).

The results are consistent with other studies which observed that land cover changes such as agricultural activities are a major driver of changes in water quality, mainly during the wet season (Mello et al., 2018; Alves et al., 2019). The enrichment of waters with ortho-phosphate and nitrogen compounds is an indication of runoff of enriched soils into the water bodies (Camara et al., 2019). The nutrients recorded in the rivers are mainly from agricultural runoff (wastes, pesticides and fertilizers), domestic (sewage and detergents) and industrial wastewater (Fernandes et al., 2021; Olive, 2021).

Conclusion

Pollution originating from human activities had a strong impact on nutrient levels (NO_2, NO_3, NH_3, ortho-PO_4) and DO in the three rivers. Concentrations of NO_2, NO_3, NH_3 and ortho-PO_4 in the Spekboom River were lower during the wet season, likely due to greater dilution from the higher rainfall. In contrast, NO_2, NO_3 concentrations were higher during the wet season in the Dwars River and NO_2, NO_3, NH_3, were higher in the wet season in the Steelpoort River. Thus, there is a clear separation among the dry and wet seasons, showing the strong influence of the seasonality on the variations of nutrients in the sub-catchment. The results suggest that large amounts of agricultural runoff reach the Dwars and Steelpoort rivers during the wet season, while in the Spekboom River, during the dry season, excess nutrients are received from the dysfunctional wastewater treatment plant in the midstream of the river. Excess nutrient in the rivers can reduce habitat availability, increase nuisance plant/algae growth, and decrease dissolved oxygen levels in the water. The implementation of good land use practices in the catchment is necessary to reduce erosion and nutrient discharge into the rivers. Furthermore, frequent monitoring to check the levels of nutrient pollution is needed for a swift action.

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