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Original Article

A CROSS-SECTIONAL ASSESSMENT OF THE IMPACT OF LAND USE PRACTICES ON WATER QUALITY AND ECOSYSTEM HEALTH IN THE PALMIET RIVER, DURBAN, KWAZULU-NATAL.

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ABSTRACTf

Introduction
The Palmiet River in Durban, KwaZulu-Natal, is a vital watercourse that historically supported rich biodiversity and provided essential resources for domestic, agricultural, and industrial use. However, increasing pollution from anthropogenic land-use practices threatens its ecological integrity and socioeconomic value. This study aimed to assess the extent and impact of pollution on the water quality, biodiversity, and socio-economic sustainability of the Palmiet River.

Methodology
A cross-sectional mixed-methods approach was employed, combining quantitative and qualitative techniques. Water samples were collected from ten sites along the river and analysed for physicochemical (e.g., pH, dissolved oxygen, nitrates, phosphates, heavy metals) and biological (E. coli) parameters. GIS mapping was used to assess land use patterns, and semi-structured interviews were conducted with 20 stakeholders, including residents, municipal officials, and environmental practitioners.

Results
Statistical analysis revealed that water quality parameters in urban and industrial areas exceeded permissible limits. Nitrate concentrations ranged from 5.4 to 18.7 mg/L (mean: 12.1 mg/L), while phosphate levels averaged 4.3 mg/L, indicating eutrophication risk. Heavy metals such as lead and zinc were significantly elevated ($p < 0.05$) in industrial zones. Microbial contamination was severe near informal settlements, with E. coli counts exceeding 2000 CFU/100mL. Biodiversity assessments indicated a decline in sensitive macroinvertebrate taxa in polluted sites. Interview data underscored socio-economic consequences, including health concerns, restricted water use, and loss of livelihood for small-scale farmers.

Conclusion
Pollution from urban, industrial, and agricultural activities is severely impacting the ecological health and socio-economic functions of the Palmiet River. The dynamic influence of rainfall and land use exacerbates these effects.

Recommendations
Urgent interventions are needed, including stricter regulation of industrial discharges, promotion of sustainable farming practices, improved sanitation in informal settlements, effective stormwater management, and community-based river monitoring. These measures are critical for restoring ecosystem health and enhancing sustainable urban water governance.

***Keywords**: Water quality, Urbanization, Industrial development, Agricultural runoff, Physicochemical analysis, Pollutants, Nutrient enrichment, Sedimentation, Microbiological contamination*
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INTRODUCTION

Freshwater rivers are vital ecological systems that support biodiversity, provide essential ecosystem services, and sustain industrial, agricultural, and domestic activities. However, their integrity is increasingly threatened by anthropogenic pressures, particularly industrialization, urbanization, and agricultural intensification, which introduce a range of pollutants such as heavy metals, nutrients, and microbial contaminants into river systems (Gupta et al., 2022; Wang et al., 2021). These contaminants alter the chemical composition of river water, disrupt ecological balance, and pose serious risks to human health and water usability (Mishra & Tripathi, 2020).

In South Africa, the degradation of freshwater systems is a growing concern. Over 60% of the country's rivers are classified as ecologically stressed due to pollution from untreated sewage, industrial discharge, and poorly managed waste (DWS, 2022). The Palmiet River in Durban, KwaZulu-Natal, exemplifies these challenges. Traversing industrial zones, informal settlements, and agricultural areas, the river is exposed to multiple pollution sources. Informal settlements often lack proper sanitation, contributing to high microbial loads, while agricultural runoff introduces excess nitrates and phosphates, promoting eutrophication (Fatoki et al., 2002; Moyo & Phiri, 2022). Industrial effluents further increase concentrations of persistent pollutants such as cadmium, lead, and zinc, which bioaccumulate in sediments and aquatic organisms, threatening biodiversity and entering the food chain (Rybicka et al., 2005; Mansour & Sidky, 2001).

The risks are not only ecological but also socio-economic. Many South Africans rely on river water for daily needs, and exposure to contaminated water can lead to chronic health issues such as kidney damage, developmental delays in children, and gastrointestinal infections (WHO, 2022; Stats SA, 2021). Climate change exacerbates these impacts by altering rainfall patterns and increasing runoff intensity, leading to further pollutant mobilization (Wang et al., 2021). This study, therefore, aims to assess the extent and impact of pollution on the water quality, biodiversity, and socio-economic sustainability of the Palmiet River, generating evidence to inform integrated and community-responsive water resource management strategies.

Figure 1: Impact of Land Use Practices on Water Quality and Ecosystem Health in the Palmiet River. Source: Own creation using GIS data

Research Question

What is the extent and impact of pollution on the water quality, biodiversity, and socio-economic sustainability of the Palmiet River?

RESEARCH METHODS

Study Area

The Palmiet River is a tributary of the Umgeni River with a small catchment of 37 km2 and is found some 15km northwest of Durban, Kwa-Zulu Natal (du Preez and de Villiers, 1987). The source of the river is situated in Kloof and flows through the Pinetown industrial area, the Westville and Reservoir Hills residential area, and enters the Umgeni River in the vicinity of Springfield Flats (Figure 2) (du Preez & de Villiers, 1987). The topography near the Pinetown basin is relatively flat, but the majority of the area is undulating with deep gorges in the Palmiet Nature

Reserves that have been well dissected by the river (du Preez & de Villiers, 1987).

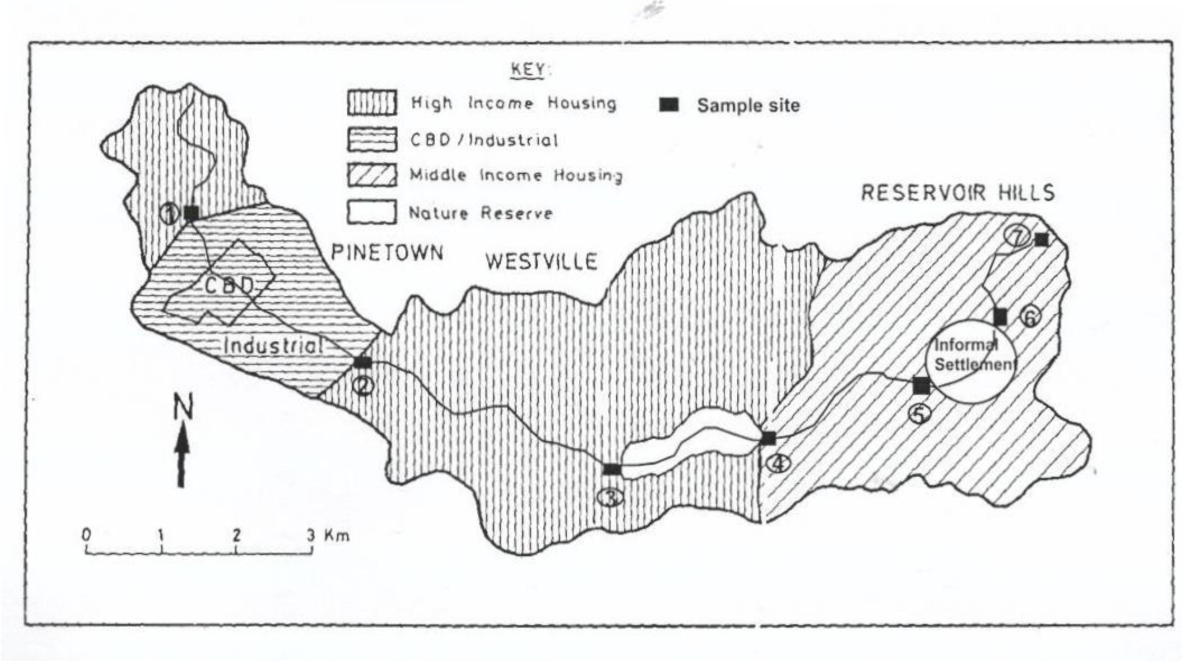

Figure 2: Map depicting study area and possible sample sites (adapted from du Preez and de Villiers, 1986).

Study Design

A cross-sectional mixed-methods design was employed to assess the extent and impact of pollution on water quality, biodiversity, and socio-economic sustainability in the Palmiet River, Durban. This approach integrated both quantitative environmental assessments and qualitative stakeholder perspectives to provide a holistic understanding of the river's condition.

Participants

A total of **32 individuals** were approached for participation in the qualitative component of the study. The following outlines the stages of recruitment and inclusion:

- **Potentially eligible participants approached**: 32Individuals were identified based on their proximity to the Palmiet River and/or involvement in water resource management. These included local residents, community leaders, small-scale farmers, environmental practitioners, and municipal officials.
- **Assessed for eligibility**: 28 of the 32 approached, 4 individuals declined to participate due to time constraints or disinterest. The remaining 28 were assessed for relevance and willingness to participate.
- **Confirmed eligible and invited**: 25. Three individuals were excluded at this stage: two had insufficient knowledge of the river system, and one was underage and did not meet ethical inclusion criteria.
- **Included in the study**: 20. A final cohort of 20 participants was enrolled and completed interviews. These included:
  - **Local residents and community members**: 8
  - **Municipal and governmental officials**: 5
  - **Environmental practitioners and NGO staff**: 7

These participants were selected to reflect a diversity of experiences and insights related to pollution, river management, and socio-economic dependency on the Palmiet River.

Study Area and Sampling

The study was conducted along the Palmiet River in KwaZulu-Natal, South Africa. Ten sampling sites were selected to represent upstream, midstream, and downstream segments, capturing gradients of pollution across industrial, urban, and peri-urban areas. Site selection was informed by land use diversity, accessibility, and known pollution hotspots.

Quantitative Data Collection

Water Quality Analysis

Water samples were collected once per month over three months (n = 30 samples in total). Analyses included:

- Physicochemical parameters: pH, temperature, turbidity, dissolved oxygen (DO), electrical conductivity, nitrates, and phosphates.
- Heavy metals: Cadmium (Cd), lead (Pb), zinc (Zn), arsenic (As), and copper (Cu), using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).
- Biological contamination: *Escherichia coli* and total coliforms, determined via membrane filtration and incubation techniques.

Biodiversity Assessment

- Macroinvertebrate sampling was conducted using the South African Scoring System (SASS5) to assess ecological integrity. Sampling was done using kick-nets in riffle zones, and diversity indices (Shannon-Wiener and Simpson's) were calculated. Observational records of fish presence and habitat condition were also noted.

GIS Mapping

- Geographic Information System (GIS) tools were used to analyse surrounding land use patterns, classify anthropogenic activities, and link spatial land cover characteristics to water quality variables.

Qualitative Data Collection

Stakeholder Interviews

A total of 20 semi-structured interviews were conducted with local stakeholders, including:

- Residents (n = 8)
- Municipal officials (n = 5)
- Environmental practitioners and NGO representatives (n = 7)

Interview questions explored perceived causes of river pollution, impacts on human health and livelihoods, and awareness of river management policies.

Focus Groups

Three focus group discussions were held, each comprising 8–10 participants:

- **Group A**: Community leaders and elders
- **Group B**: Small-scale farmers and informal traders
- **Group C**: Youth and environmental volunteers

Each group discussed local experiences of pollution, ecological changes, and suggestions for river rehabilitation.

Data Analysis

- Quantitative data were analysed using Analysis of Variance (ANOVA) to compare water quality across sites and Pearson correlation analysis to assess relationships between pollution and biodiversity loss.
- GIS data were used to visualise pollution hotspots and link land use categories to ecological health indicators.
- Qualitative data from interviews and focus groups were transcribed and analysed thematically using NVivo software. Key themes included pollution sources, governance challenges, community vulnerability, and adaptation strategies.

Ethical Considerations

Ethical approval was obtained from the Mangosuthu University of Technology Research Ethics Committee on 15 January 2024, under reference. Written informed consent was obtained from all participants. Data were anonymized and securely stored to ensure confidentiality.

RESULTS / FINDINGS

Figure 2 illustrates the concentrations of heavy metals lead (Pb), cadmium (Cd), arsenic (As), and zinc (Zn) at different sampling sites along the Palmiet River. The data reveal that industrial zones have the highest concentrations of these pollutants, while upstream locations exhibit lower levels, indicating minimal contamination from natural sources. The presence of these metals in high concentrations poses a significant threat to aquatic biodiversity and human health, as they can accumulate in fish and other organisms, leading to bioaccumulation and toxicity in the food chain.

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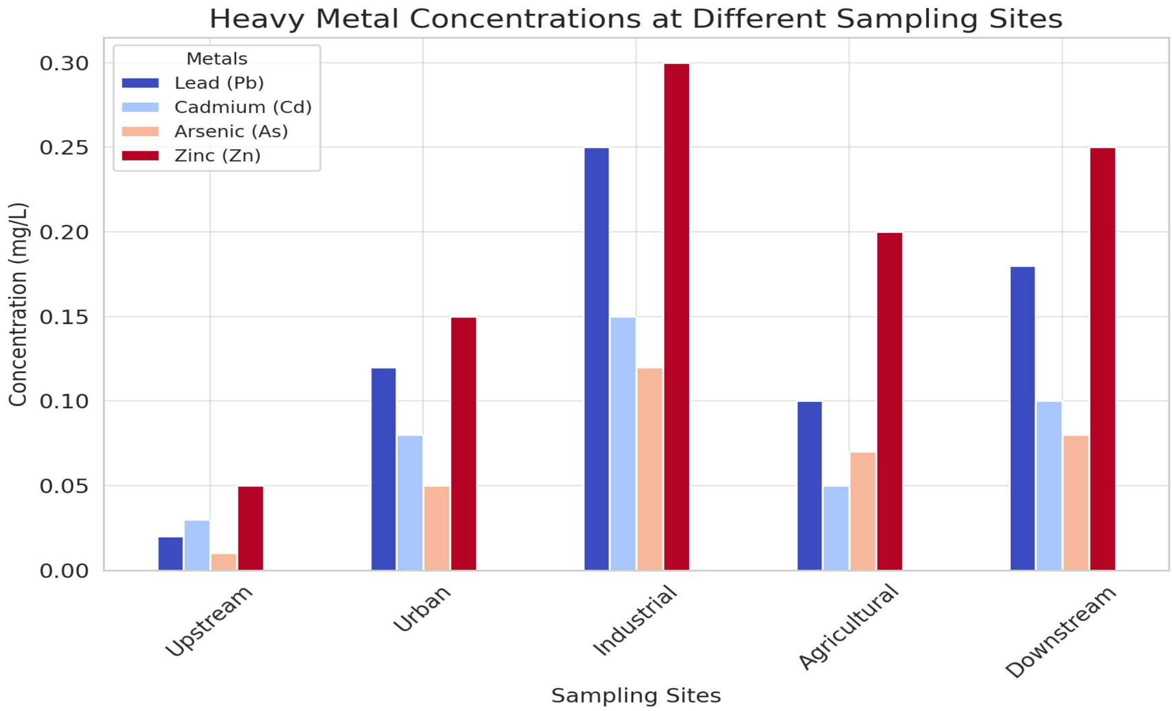

Figure 2: The graph represents the Heavy Metal Concentrations at Different Sampling Sites

Figure 3 tracks pH variations over six months across multiple sampling sites in the Palmiet River. The findings indicate periodic fluctuations, with more acidic levels recorded after heavy rainfall, likely due to surface runoff carrying pollutants from industrial and urban areas. While some sites maintain a neutral pH, certain locations show deviations that could stress aquatic life, affecting fish reproduction and the overall health of the ecosystem. A threshold line is included to highlight critical pH levels beyond which water quality deteriorates significantly.

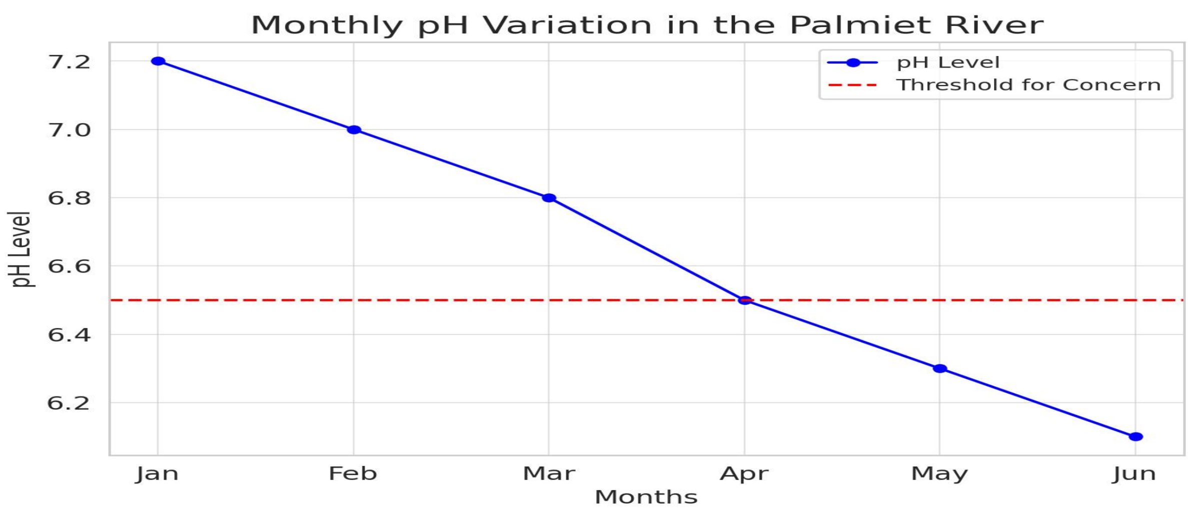

Figure 3: The graph represents the Monthly pH Variation in the Palmiet River

Figure 4 presents the relative proportions of different aquatic organisms, including fish, invertebrates, and aquatic plants, observed in the Palmiet River. The results show a dominance of invertebrates in polluted areas, suggesting a shift in biodiversity due to water quality degradation. Fish populations are significantly lower in areas with high pollution levels, indicating that contaminants, particularly heavy metals, and reduced oxygen levels negatively impact their survival. The findings emphasize the ecological consequences of pollution, as shifts in species composition can disrupt food chains and ecosystem stability.

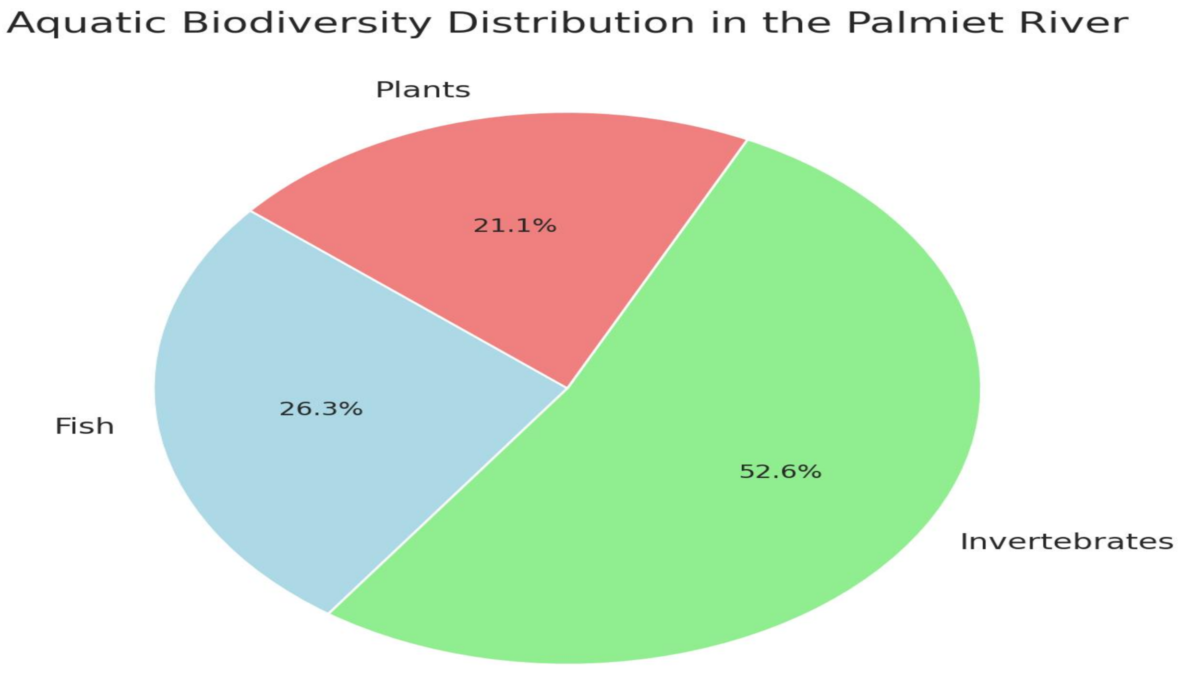

Figure 4: The graph represents the Aquatic Biodiversity Distribution

Figure 5 examines the relationship between heavy metal concentrations and species richness in the Palmiet River. A clear negative correlation emerges, with higher pollution levels corresponding to lower species diversity. This trend suggests that increasing contamination from heavy metals and other pollutants directly affects the survival of sensitive aquatic species. The findings highlight the urgent need for pollution control measures, as continuous degradation could lead to a significant decline in biodiversity, affecting both the ecosystem and communities that rely on the river for sustenance.

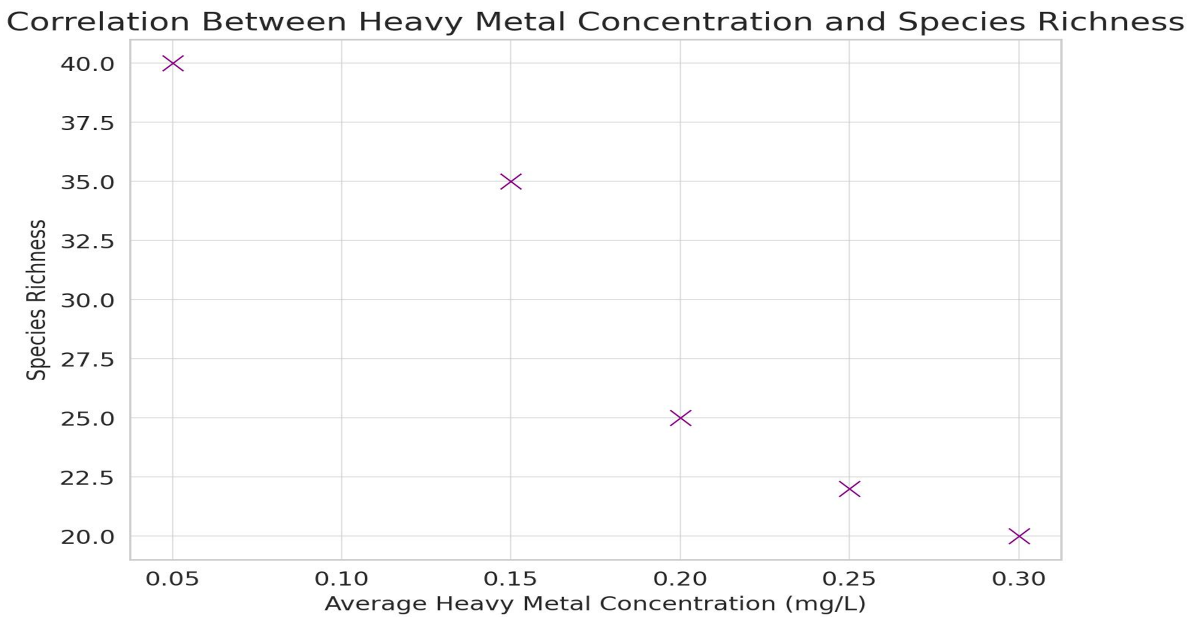

Figure 5: The graph represents the Correlation Between Heavy Metal Concentration and Species Richness

Heavy Metal	Location 1 (Upstream)	Location 2 (Midstream)	Location 3 (Downstream)
Arsenic	0.03	0.05	0.07
Cadmium	0.01	0.03	0.04
Lead	0.05	0.10	0.15
Zinz	0.12	0.20	0.25
Iron	0.50	0.60	0.75

Table 1: Concentration of Heavy Metals in Palmiet River (mg/L)

Metal	Liquid ferric chloride	Liquid alum	Cat-floc® polyelectrolyte	Powdered activated carbon
	mg L^{-1}			
Cd	<0.5–79	<0.5–10	<0.5	<5.0
Cu	43–1132	<0.2–7	<0.2	<5.0
Cr	200–765	21–32	<0.5	<5.0
Ni	2.0–154	<5.0	<5.0	<50
Pb	<0.5–447	<0.5	<0.5	<5.0
Zn	93–10760	<0.5–3	<0.5	<5–8
No. of samples	8	6	1	1

Table 2: Total concentrations of metals in treatment chemicals (Dixon et.al., 1988)

E. coli count/100mL	Water quality "assessment"	Assessment of probable risk to canoeists
*0 – 130	Considered acceptable for full contact recreation – excellent / **likely natural** catchment	Extremely low risk
130 – 1 000	**Good** – within the range expected for quite good catchment conditions, but significant / increasing risk of illness if used for full contact recreation	Very Low risk
1 001 – 4 000	**Fair** resource condition, natural sources (i.e. not people) are still possibly the E. coli source, but increasing likelihood of human faecal / sewage contamination. Unacceptable for swimming	Low, but increasing risk
4 001 - 10 000	**Degraded** - Significant faecal input or some sewage contamination is indicated. Other water quality parameters are likely to be poor	Moderate risk (approx. 1 in 10 may get sick)
10 001 - 25 000	**Unacceptably Poor**, sewage contamination definitely present	Moderately high canoeing risk (approx. 1 in 5 may get sick) – some likelihood of illness esp. in white water
25 001 - 50 000	Bad, with significant environmental consequences	High risk (approx. 1 in 3 may get sick) – consider not canoeing or paddle on flat water only, with no risk of falling out
>50 000	Severely contaminated	Very High canoeing risk – (approx. 1 in 2 paddlers may get sick)

Table 3: Escherichia coli (E. coli) Concentrations at Different Sampling Sites in the Palmiet River

E.COLI RESULTS | SAMPLES TAKEN 18-10-22

Location	Reading
Papwa Sewgolum	435200 count/100ml
Travislee Lane	417000 count/100ml
Cherry Road	4106000 count/100ml

Water Quality Interpretation (*E.coli* count / 100ml)		
IDEAL	*E.coli* range	0 - 130
ACCEPTABLE	*E.coli* range	130 - 200
POOR	*E.coli* range	200 - 400
CRITICAL	*E.coli* range	> 400

Table 4: Escherichia coli (E. coli) Concentrations at Different Sampling Sites in the Palmiet Rive

1	Sample Number	Description 24.01.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	002356/24	POINT 25-PAPWA SEWGOLUM 10:00 24.01.2024	E.coli	MPN/100mℓ	206400	>>Critical
	002357/24	POINT 26-TRAVISLEE PLACE 11:05 24.01.2024	E.coli	MPN/100mℓ	120330	>>Critical
	002358/24	POINT 27-CHERRY ROAD 11:30 24.01.2024	E.coli	MPN/100mℓ	275500	>>Critical

2	Sample Number	Description 30.01.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	003031/24	POINT 25-PAPWA SEWGOLUM 09:15 30.01.2024	E.coli	MPN/100mℓ	410 600	>>Critical
	003032/24	POINT 26-TRAVISLEE PLACE 10:15 30.01.2024	E.coli	MPN/100mℓ	77 010	>>Critical
	003033/24	POINT 27-CHERRY ROAD 10:40 30.01.2024	E.coli	MPN/100mℓ	920 800	>>Critical

3	Sample Number	Description 06.02.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	003802/24	POINT 25-PAPWA SEWGOLUM 09:50 06.02.2024	E.coli	MPN/100mℓ	228 200	>>Critical
	003803/24	POINT 26-TRAVISLEE PLACE 10:30 06.02.2024	E.coli	MPN/100mℓ	22 240	Critical
	003804/24	POINT 27-CHERRY ROAD 11:20 06.06.2024	E.coli	MPN/100mℓ	235 900	Critical
	003805/24	PAL004-STAFFORD PLACE 17:00 05.02.2024	E.coli	MPN/100mℓ	201 400	Critical

4	Sample Number	Description 12.03.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	008279/24	POINT 25-PAPWA SEWGOLUM 09:30 12.03.2024				
	008280/24	POINT 26-TRAVISLEE PLACE 10:30 12.03.2024				
	008281/24	POINT 27-CHERRY ROAD 11:30 12.03.2024				
y	011177/24	MINISASS AT EDGE CLIFF ROAD PALMIET NATURE RESER\	E.coli	MPN/100mℓ	5 910	Critical

4	Sample Number	Description 30.04.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	013618/24	POINT 25-PAPWA SEWGOLUM 10:00 30.04.2024	E.coli	MPN/100mℓ	1 299 700	
	013619/24	POINT 26-TRAVISLEE PLACE 10:45 30.04.2024	E.coli	MPN/100mℓ	241 960	
	013620/24	POINT 27-CHERRY ROAD 12:00 30.04.2024	E.coli	MPN/100mℓ	686 700	
	013621/24	UMVUSI STREAM STIRLING PL 09:41 30.04.2024	E.coli	MPN/100mℓ	932	

5	Sample Number	Description 14.05.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	015179/24	POINT 25-PAPWA SEWGOLUM 10:00 14.05.2024	E.coli	MPN/100mℓ	1 119 900	>>>Critical
	015180/24	POINT 26-TRAVISLEE PLACE 11:00 14.05.2024	E.coli	MPN/100mℓ	60 500	Critical
	015181/24	POINT 27-CHERRY ROAD 11:40 14.05.2024	E.coli	MPN/100mℓ	461 100	Critical
	015182/24	PAL004 UMGENI RIVER SIRIPAT ROAD 09:30 14.05.2024	E.coli	MPN/100mℓ	410 600	Critical

6	Sample Number	Description 04.06.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	017567/24	POINT 25-PAPWA SEWGOLUM 09:45 04.06.2024	E.coli	MPN/100mℓ	686 700	Critical
	017568/24	POINT 26-TRAVISLEE PLACE 10:30 04.06.2024	E.coli	MPN/100mℓ	50 400	Critical
	017569/24	POINT 27-CHERRY ROAD 11:15 04.06.2024	E.coli	MPN/100mℓ	816 400	Critical

7	Sample Number	Description 02.07.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	020986/24	POINT 25-PAPWA SEWGOLUM 10:00 02.07.2024	E.coli	MPN/100mℓ	547 500	Critical
	020987/24	POINT 26-TRAVISLEE PLACE 10:45 02.07.2024	E.coli	MPN/100mℓ	2 490	Critical
	020988/24	POINT 27-CHERRY ROAD 11:50 02.07.2024	E.coli	MPN/100mℓ	1 046 200	>>>Critical

8	Sample Number	Description 14.08.2024	Determinand	Unit	E.coli/100ml	Interpretation
	025461/24	POINT 25-PAPWA SEWGOLUM 10:20 14.08.2024	E.coli	MPN/100mℓ	2 419 600	>>>Critical
	025462/24	POINT 26 TRAVISLEE PLACE 11:15 14.08.2024	E.coli	MPN/100mℓ	17 329	Critical
	025463/24	POINT 27-CHERRY ROAD 09:40 14.08.2024	E.coli	MPN/100mℓ	2 419 600	>>>Critical
	025464/24	VARCITY DRIVE/SHIRE QUARRY 09:40 14.08.2024	E.coli	MPN/100mℓ	241 960	Critical

9	Sample Number	Description 04.09.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	027802/24	POINT 25-PAPWA SEWGOLUM 09:50 04.09.2024	E.coli	MPN/100mℓ	**1 670 000**	>>>Critical
	027803/24	POINT 26-TRAVISLEE PLACE 10:48 04.09.2024	E.coli	MPN/100mℓ	**109**	>>>Critical
	027804/24	POINT 27-CHERRY ROAD 11:42 04.09.2024	E.coli	MPN/100mℓ	**2 098 000**	>>>Critical
	027807/24	PAL004 60 BIRDHURST RD WIER 10:42 04.09.2024	E.coli	MPN/100mℓ	**2 359 000**	>>>Critical
	027808/24	PAL004 UMBILO RIVER MARRION HILL/GILLITTS ROAD 11	E.coli	MPN/100mℓ	**1 935 000**	>>>Critical

10	Sample Number	Description 01.10.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	030979/24	POINT 25-PAPWA SEWGOLUM 10:00 01.10.2024	E.coli	MPN/100mℓ	311 000	Critical
	030980/24	POINT 26-TRAVISLEE PLACE 10:40 01.10.2024	E.coli	MPN/100mℓ	18 500	Critical
	030981/24	POINT 27-CHERRY ROAD 11:40 01.10.2024	E.coli	MPN/100mℓ	417 000	Critical
	031657/24	KING FISHER STREAM 09:47 08.10.2024	E.coli	MPN/100mℓ	>2420	Critical
	031658/24	PALMIET RIVER ABOVE MATHVEN 10:15 08.10.2024	E.coli	MPN/100mℓ	1 120	Critical

11	Sample Number	Description 13.11.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	35625/24	POINT 25-PAPWA SEWGOLUM 10:00 13.11.2024	E.coli	MPN/100mℓ	292 000	Critical
	035626/24	POINT 26-TRAVISLEE PLACE 11:15 13.11.2024	E.coli	MPN/100mℓ	34 100	Critical
	035627/24	POINT 27-CHERRY ROAD 11:50 13.11.2024	E.coli	MPN/100mℓ	294 000	Critical

12	Sample Number	Description 10.12.2024	Determinand	Unit	E.coli, count/100ml	Interpretation
	038845/24	POINT 25-PAPWA SEWGOLUM 10:10 10.12.2024	E.coli	MPN/100mℓ	598 000	>>Critical
	038846/24	POINT 26-TRAVISLEE PLACE 10:50 10.12.2024	E.coli	MPN/100mℓ	88 200	>Critical
	038847/24	POINT 27-CHERRY ROAD 11:50 10.12.2024	E.coli	MPN/100mℓ	733 000	>>Critical
	038848/24	EXTRA: HARLEY STREET STREAM 11:40 10.12.2024	E.coli	MPN/100mℓ	344 800	>>Critical
	038362/24	6 STILING PLACE VUSI STREET 16:30 04.12.2024,04/12/24	E.coli	MPN/100mℓ	1 956	Critical
	038363/24	32 FURNLEIGH ROAD KLOOF 12:10 05.12.2024	E.coli	MPN/100mℓ	317	Poor

Table 5: Escherichia coli (E. coli) Concentrations at Different Sampling Sites in the Palmiet River

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The findings of the study highlighted significant environmental and socio-economic challenges affecting the Palmiet River, underscoring the need for urgent intervention. The analysis revealed elevated concentrations of heavy metals such as cadmium, lead, and zinc, particularly in the industrial and urbanized zones of the river. These levels often exceeded safe water quality thresholds, posing risks to both human health and aquatic life. Parameters such as pH, turbidity, and dissolved oxygen varied significantly between sampling sites, with urban and industrial areas showing reduced water quality. For instance, turbidity and chemical oxygen demand were notably higher downstream of industrial zones. The aquatic biodiversity surveys documented a marked reduction in species richness and abundance in polluted sections of the river. Sensitive species, including certain fish and invertebrates, were absent in areas with high pollutant levels. The study also noted an increase in the presence of invasive aquatic plants, which further disrupted the river's ecosystem balance.

Industrial discharges, urban runoff, and improper waste disposal were identified as primary contributors to the river's pollution. Communities living along the river were found to lack adequate waste management systems, leading to illegal dumping of both household and industrial waste. In upstream areas, agricultural activities contributed to elevated levels of nitrogen and phosphorus, promoting eutrophication. Local residents expressed concerns about water quality but lacked awareness and resources to mitigate pollution. Interviews with municipal authorities revealed limited enforcement of existing environmental regulations and a lack of coordinated efforts to address river pollution comprehensively. Declining water quality negatively affected fishing and farming activities, which are primary livelihood sources for many residents. High levels of heavy metals and bacterial contamination increase the risk of waterborne diseases, as many communities rely on the river for domestic and drinking water.

DISCUSSION

This study aimed to assess the extent and impact of pollution on the water quality, biodiversity, and socio-economic sustainability of the Palmiet River in Durban, KwaZulu-Natal. The results revealed a complex interplay between anthropogenic activities and river degradation, with significant environmental and human consequences. Quantitative analyses demonstrated elevated concentrations of nitrates, phosphates, and heavy metals, particularly cadmium, lead, and zinc, at sampling sites located near industrial zones and informal settlements. These concentrations frequently exceeded permissible limits for aquatic life and human use, indicating a high pollution load. Microbial contamination, reflected by elevated *E. coli* counts, was particularly pronounced near informal residential areas lacking proper sanitation infrastructure.

These findings align with previous studies that identified industrial discharge and urban runoff as dominant pollution sources in developing countries (Gupta et al., 2022; Ndlovu et al., 2023). Ochieng et al. (2022) similarly emphasized the role of untreated industrial effluents in degrading water quality in South African rivers. In this study, the absence of advanced wastewater treatment technologies and poor enforcement of discharge regulations contributed significantly to the pollution burden. Biodiversity assessments revealed a decline in sensitive macroinvertebrate species, especially in downstream and industrially influenced sites, indicating ecological stress. The calculated Shannon-Wiener and Simpson's Diversity Indices confirmed lower biodiversity in more polluted areas. This pattern is consistent with observations from other polluted river systems such as the Yangtze and Ganges, where pollution-induced ecological imbalances have resulted in biodiversity loss and ecosystem disruption (Singh & Gupta, 2020).

Moreover, the dominance of tolerant or invasive species in these disturbed habitats reflects a shift in ecological structure. Simberloff et al. (2019) noted that invasive species often outcompete native fauna in degraded systems, further destabilizing ecological resilience. The findings thus underscore the need for habitat restoration efforts and targeted removal or control of invasive taxa. The socio-economic consequences of water pollution were also evident. Interviews with local stakeholders highlighted the declining availability of clean water for domestic use, small-scale farming, and fishing. Communities reliant on the river for livelihoods reported reduced income opportunities due to fish mortality and restrictions on water use. These outcomes are in line with WHO (2021) reports, which show that water pollution disproportionately affects vulnerable populations, exacerbating health risks and economic marginalization. Health risks reported by community members, including incidences of waterborne diseases and concerns over heavy metal exposure, emphasize the human cost of environmental mismanagement. Similar findings were reported by Naidoo et al. (2023), who documented links between poor water quality and community health in peri-urban areas of South Africa.

A key finding of the study was the lack of coordinated waste management and ineffective enforcement of environmental regulations. Illegal dumping and informal waste disposal practices were widespread, especially in areas without municipal waste collection services. These governance challenges are echoed in other developing contexts, where limited institutional capacity undermines environmental regulation (Mugambiwa & Tirivangasi, 2019). The observed deficiencies highlight the urgent need for integrated water resource management (IWRM) approaches that bring together government agencies, industries, academic institutions, and local communities. Effective IWRM requires inclusive stakeholder engagement, sustainable financing mechanisms, and decentralised accountability structures. South Africa's existing policy framework supports IWRM in theory, but practical implementation remains uneven due to resource constraints.

While many of the Palmiet River's challenges mirror global trends in urban river pollution, the local socio-economic conditions intensify the impacts. Unlike high-income countries with advanced treatment infrastructure and strict enforcement regimes, South Africa faces persistent gaps in funding, monitoring, and community outreach. The findings call for solutions tailored to the country's economic and social realities, such as low-cost decentralized treatment systems, community-led river stewardship programs, and public education initiatives. At the same time, best practices from international case studies, such as co-management of water resources in Kenya and the Philippines (Gupta et al., 2022), can inform localized interventions, especially where communities are empowered to monitor pollution and contribute to conservation efforts.

GENERALIZABILITY OF THE STUDY

The findings of this study offer valuable insights into the relationship between land use practices and river pollution in the Palmiet River catchment; however, their generalisability is subject to certain limitations. Firstly, the study is geographically confined to a single river system within the eThekwini Municipality in Durban, KwaZulu-Natal. While the Palmiet River is representative of urban and industrial river catchments in South Africa, variations in topography, land use intensity, governance structures, and climatic conditions may limit the direct applicability of results to other regions or river systems. Secondly, although the sampling design captured a range of pollution sources across upstream, midstream, and downstream segments, the number of sites and the duration of sampling were limited. As such, the findings may not reflect all seasonal or site-specific variations, particularly in regions with different hydrological or socio-economic contexts.

However, the methodological framework, integrating water quality analysis, biodiversity assessments, GIS mapping, and stakeholder engagement, can be adapted and applied to similar urban-industrial river systems across South Africa and other developing countries. The socio-ecological patterns observed, such as links between pollution, biodiversity decline, and community vulnerability, are consistent with global trends in degraded freshwater ecosystems, thus enhancing the study's relevance to broader urban water management discourse.

CONCLUSION

The study of the Palmiet River has revealed significant challenges related to water quality degradation, loss of biodiversity, and socio-economic impacts arising from anthropogenic activities. The findings underscore the complex interplay between industrial discharge, urbanization, agricultural practices, and insufficient governance mechanisms. These challenges are compounded by limited community awareness and inadequate enforcement of environmental regulations. The contamination of the river by heavy metals and other pollutants poses serious risks to human health, aquatic ecosystems, and local livelihoods. The reduction in biodiversity, especially the loss of sensitive species, signals an ecological imbalance that threatens the sustainability of the river's ecosystem services. Furthermore, the socio-economic consequences, particularly for marginalized communities relying on the river for subsistence and economic activities, highlight the broader implications of water resource mismanagement. Addressing these issues requires a holistic approach that combines stricter regulatory enforcement, community participation, and investment in sustainable technologies. Collaborative efforts among government bodies, industries, and local stakeholders are essential to implement integrated water resource management practices. The study contributes to the growing body of knowledge on freshwater ecosystem challenges, offering insights into the specific conditions of the Palmiet River while reflecting broader global trends. It underscores the urgent need for action to protect and rehabilitate rivers, ensuring they continue to support ecological health, economic development, and social equity for future generations.

LIMITATIONS OF THE STUDY

This study, while providing important insights into the extent and impact of pollution on the Palmiet River, is subject to several limitations. The cross-sectional design captures data from a specific period and therefore may not reflect seasonal variations in water quality and biodiversity, particularly during periods of heavy rainfall or drought. Additionally, the three-month sampling duration limited the ability to detect long-term pollution trends or episodic contamination events. Although ten sampling sites were selected to represent different land-use zones, a denser spatial coverage, especially in tributaries or informal areas, could have offered more nuanced insights into pollution distribution. Resource constraints restricted the analysis to key physicochemical and biological parameters, excluding emerging contaminants such as microplastics or pharmaceuticals that are increasingly relevant to water quality studies. On the qualitative side, while stakeholder interviews and focus groups enriched the findings, the participant sample was limited to a subset of community members and local officials. Broader engagement with additional stakeholders, such as healthcare professionals, regulatory bodies, or regional planners, could have provided a more comprehensive understanding of the socio-political dimensions of river management. Finally, qualitative data relied on self-reported information, which may be subject to recall bias or influenced by social desirability, potentially affecting the reliability of perceived socio-economic impacts.

RECOMMENDATIONS

Based on the findings and discussions from this study, several recommendations were made to address the challenges faced by the Palmiet River. More rigorous monitoring of water quality, particularly for heavy metals and other pollutants, was identified as a critical need at key points along the river. Regulatory authorities were urged to enforce existing environmental laws more effectively and to introduce stricter penalties for illegal dumping and pollution. Regular water testing and real-time monitoring were recommended to detect contamination and ensure compliance with water quality standards. Communities living along the river were actively involved in the management and preservation of the river's ecosystem. Public education campaigns were conducted to emphasize the importance of water conservation, proper waste disposal, and the dangers of pollution. Local communities were empowered with knowledge and tools to monitor pollution levels, contributing to better stewardship of the river.

Industries and urban areas that contributed to the pollution of the Palmiet River were held accountable for their waste management practices. Industries were encouraged to adopt cleaner technologies and sustainable practices to reduce pollutant loads. Additionally, waste management systems were improved in urban and peri-urban areas to prevent illegal dumping into the river. A holistic and integrated approach to managing the Palmiet River Basin was implemented, involving collaboration between local authorities, environmental organizations, industries, and community stakeholders. Policies aimed at protecting the river's health were created and enforced. A participatory approach to decision-making ensured that the needs of all stakeholders, including marginalized communities, were considered. Efforts were made to restore the river's biodiversity, particularly through the rehabilitation of aquatic habitats degraded by pollution. Riparian vegetation was restored, and invasive species were controlled to enhance the ecological resilience of the river. Conservation areas were established along the river to protect sensitive ecosystems and promote biodiversity.

Given the role of agricultural runoff in contributing to water pollution, sustainable farming practices in the Palmiet River catchment area were promoted. Farmers were encouraged to use organic farming methods, implement erosion control measures, and reduce the use of chemical fertilizers and pesticides that contributed to nutrient pollution. Further research into the ecological health of the Palmiet River was conducted to understand the long-term impacts of pollution and identify effective mitigation strategies. Collaboration with academic and research institutions provided valuable data and innovative solutions to address the river's environmental and socio-economic challenges.

The findings emphasized the need for multi-pronged interventions, including strengthening regulatory enforcement to prevent industrial and urban pollution, enhancing community education and participation in sustainable waste management practices, promoting investment in green technologies and infrastructure for wastewater treatment, and developing a comprehensive monitoring and evaluation framework for water quality and ecosystem health.

BIOGRAPHY

Dr. Sibonelo Thanda Mbanjwa is a dedicated lecturer in the Department of Nature Conservation at Mangosuthu University of Technology (MUT), South Africa. He holds a Ph.D. in Environmental Science and specializes in biodiversity conservation, sustainable development, and environmental education. Dr. Mbanjwa is deeply committed to community engagement, student mentorship, and the integration of indigenous knowledge systems into conservation practices. His work bridges academia and practical application, empowering students and communities through innovative teaching, research, and outreach initiatives.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

AUTHOR CONTRIBUTIONS

I, the author, contributed to the study conception and design. Material preparation, data collection, and research were performed by Mbanjwa S.T. The first draft was written by Mbanjwa S.T.

DATA AVAILABILITY

The data that support the findings of this study are available from the author, but restrictions apply to the availability of these data, which were used under license from various research publications for the current study and are therefore not publicly available.
The data supporting the findings of this study are available upon reasonable request from the corresponding author. Due to ethical considerations and confidentiality agreements, individual participant data cannot be publicly shared. However, anonymized and aggregated data may be provided for academic or research purposes upon institutional approval.

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