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Assessment of selected natural wetlands for treating wastewater contaminants from adjacent human activities

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Abstract: Wetlands function as natural wastewater treatment systems but are increasingly degraded by human activities and climate change. This study evaluated the capacity of selected natural wetlands to reduce wastewater contaminants from adjacent human activities. Water samples were collected at predetermined input and output points during dry and wet seasons and analyzed for physicochemical parameters, heavy metals, and microbiological indicators. pH ranged from 6.66 to 7.6, and the temperature from 24 to 27.3 °C. Turbidity decreased markedly from 84 to 9 NTU in the dry season and from 42 to 8 NTU in the wet season. Heavy metals also declined between the input and the output, including copper (0.81-0.72 mg/L in the dry season; 0.46-0.27 mg/L in the wet season), lead (1.16-0.84 mg/L; 1.01-0.89 mg/L), silver (0.50-0.30 mg/L; 0.59-0.25 mg/L), and zinc (0.50-0.24 mg/L; 0.48-0.28 mg/L). Nutrients and microbial indicators showed similar reductions. Approximately 80% of the measured parameters were higher at the wetland input than at the output. These wetlands, located upstream of the Vaal River, significantly reduce pollutant loads, highlighting their importance for water quality protection and the urgent need for conservation.

Keywords: *Heavy metals, Microbiological parameters, Physicochemical parameters, Wastewater treatment, Wetlands.*

1. Introduction

Wetland systems are important natural water purification systems [1, 2]. By intercepting stream channels and/or surface runoff, they influence the flow and quality of water. According to Pandiarajan and Sankararajan [3], dense wetland vegetation reduces the rate of flowing water. This allows suspended materials in the water to settle on the wetland surface. Subsequently, the accumulated sediment binds to the roots of wetland plants [4]. Through the aforementioned purification strategy, wetlands take up, transform, or recycle excess nitrogen and phosphorus, which pose a eutrophication threat to receiving surface water bodies [5]. To further improve water quality, some pollutants, such as heavy metals, bind to wetland soil particles [6].

As stated by Kadlec and Wallace [7], 87% of the global wetland area has been lost over the past 300 years. In South Africa, wetland loss and degradation are high, with approximately 50% of the original wetland area lost through anthropogenic activities [8]. The main contributing human activities include urbanization and infrastructure development, human settlements, pollution from industrial effluent and agricultural runoff, mining activities, land use changes, and poor land management, such as overgrazing and poor burning methods (Ibid). Wetlands are significantly degraded by increasing pollutant inputs and the introduction of non-native species [9, 10]. Recently, climate change has been reported as the primary direct driver of wetland degradation and loss [11].

Wetlands cover only about 6% of the Earth's surface, and an estimated 95 percent of these wetlands are freshwater [12, 13]. Anthropogenic activities, including agriculture, livestock, and urbanization,

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continue to threaten freshwater ecosystems worldwide [14]. Freshwater quality is determined by its qualitative characteristics, compliance with water guidelines, and its appropriateness for agricultural, domestic, industrial, and recreational uses [15]. As a result of human impact, several water quality monitoring studies have reported on changes in water physicochemical parameters and heavy metals content of freshwater systems over seasons [16, 17]. Water quality guidelines are issued at national and international levels by governments and water management institutions and are used as a basis for regulation and standard setting worldwide.

Although affected by human activities, the water quality improvement capacity of wetlands prevents contamination of the open downstream water. Consequently, there is a reduced risk to human health and the ecosystem at large [18]. Research on the conservation and management of wetland systems supports two United Nations Sustainable Development Goals adopted at the United Nations (UN) General Assembly in 2015: SDG 6 (clean water and sanitation) and SDG 15 (life on land) [19]. As stipulated in SDG 6 and 15, water-related ecosystems should be protected and restored, and there should be a reduction in the degradation of natural habitats. Effective protection and management of wetlands align with SDG 6 by providing and improving clean water and sanitation for all by 2030. The wastewater treatment potential of natural wetlands should be assessed to establish the state of the wetlands in relation to their reported wastewater treatment potential. Most studies on the wetland purification potential have been done on constructed wetlands [20-22].

Natural wetlands in the Vaal region extend through agricultural areas, industries, and human settlements. These pollution sources have been reported as causes of wetland loss and degradation [8] and affect the potential of wetland systems in treating wastewater that passes through them. Nonetheless, natural wetlands have been proven to treat municipal wastewater worldwide, including in South Africa [23, 24]. Downstream of the selected Vaal wetlands in the present study lies the Vaal River, which has been implicated in eutrophication and water quality problems [25]. Effective purification by wetlands upstream of the Vaal River could help reduce pollution levels in the Vaal River. The importance and value of wetlands are not clearly understood; thus, they are largely ignored [18]. Moreover, limited research has been conducted to determine the capability of natural wetlands in treating wastewater contaminants. The present study aimed to assess the potential of selected natural wetlands in the Vaal region, South Africa, in treating wastewater contaminants from adjacent human activities.

2. Materials and Methods

2.1. Study Area

The present study was conducted at three selected wetlands in the Vaal region, namely Tshirela, Sebokeng, and Sharpeville (Figure 1). Sampling sites were located using a Garmin Nüvi 1310 (Garmin, USA) global positioning system (GPS).

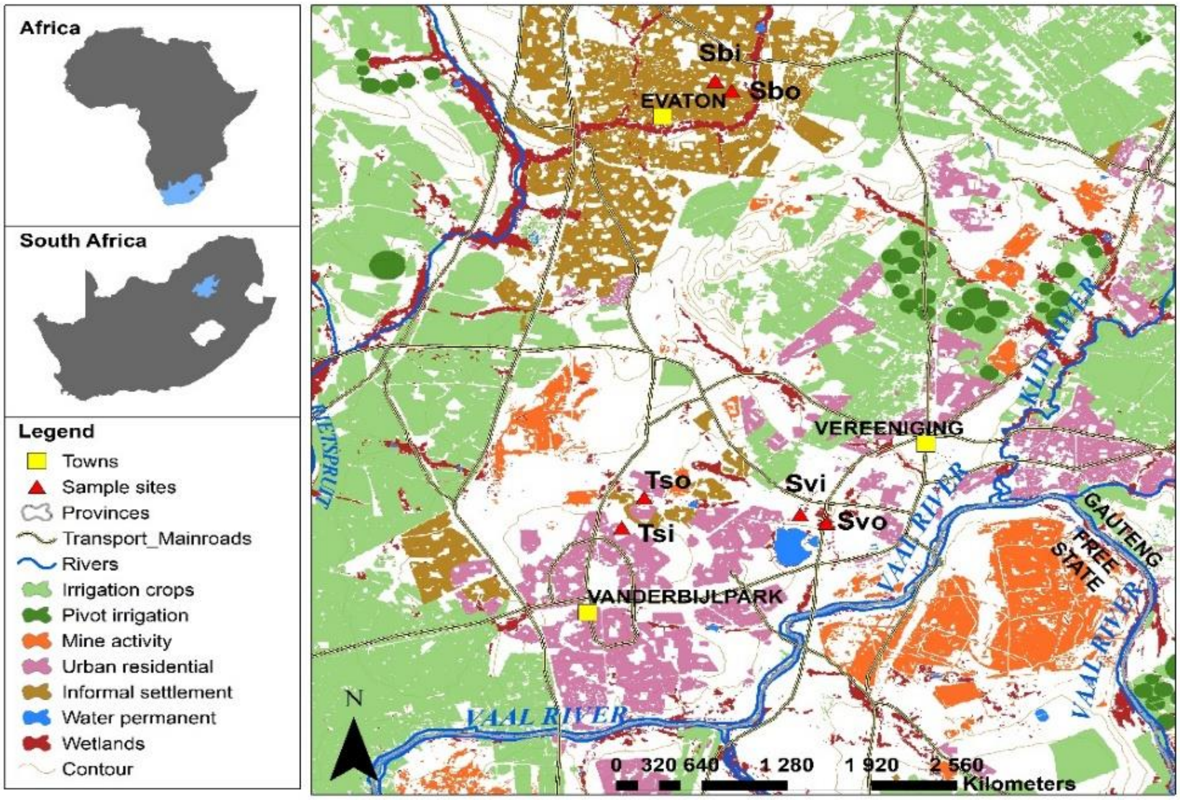

Figure 1.
Map showing selected wetland systems in the Vaal region: Tshirela (Ts), Sebokeng (Sb), and Sharpeville (Sv). Sampling sites are denoted by input (i) and output (o).

2.2. Wetland Description

Inland wetland systems in the present study are Palustrine wetlands, dominated by scrub–shrub vegetation that comprises reed beds, marshes, shrublands, bogs, and fens [26]. As seen during field observations, *Phragmites australis* was the most dominant species. Further field observations showed that wetlands in this study were influenced by adjacent human activities. In particular, Tshirela wetland was affected by nearby Mittal industrial effluent, domestic activity (observable sewage and stormwater runoff that enters the wetland), local activities and businesses (schools, clinics, taverns, sporting facilities), animal grazing, and illegal dumping. Anthropogenic impacts on the Sebokeng wetland result from domestic (residential area) and industrial activities (ceramic and metal industries), and local businesses such as shopping malls, schools, poultry farms, and butcheries. Sharpeville wetland is largely affected by activities from nearby infrastructure developments, domestic activities (direct effluent from some wastewater treatment plants), and local businesses (schools and shopping centers). Moreover, these wetlands do not directly discharge into open surface water but are located upstream of the Vaal River.

2.3. Sampling

Water samples were collected during the dry and wet seasons. Seasonal sampling allows for a comprehensive assessment of water quality variations, identification of seasonal trends, and potential pollution sources [27]. Sampling was conducted in duplicate, at the input (upstream) and output (downstream) points along the wetland systems to assess variability in experimentation. Water samples were collected aseptically in 1 L sterile Schott bottles using two sampling techniques [28]. The direct sampling technique was used at sampling sites where the water was easily accessible. A dip sampling technique was applied using a rope, where access to the water was limited. Water samples were placed in cooler boxes on ice, transported to the laboratory, and analyzed within 8 hours of collection. Microbiological tests, including heterotrophic plate count for raw water matrices, particularly for coliform analysis, have shorter holding times [29].

2.4. Water Quality Analysis

Total water quality ranges (TWQR) of South Africa were used as water quality guidelines to inform the physical, chemical, and biological state of the sampled wetlands [15]. These ranges serve as regulatory and management objectives for water quality, as they determine whether water parameters will cause adverse effects on water suitability for use or human health. The following analyses of physicochemical properties, heavy metals, and microbial levels of the sampled wetlands were conducted in duplicate.

2.4.1. Physicochemical Analysis

On-site, the physical properties (temperature and pH) of the water samples were measured using a 914 pH/conductometer (Metrohm, South Africa), following manufacturer instructions. At the laboratory, a commercial turbidity meter (2100P, HACH, USA) was used to measure turbidity. Chemical parameters (nitrates, phosphates) and heavy metals (copper, lead, silver, zinc) were determined spectrophotometrically using Nanocolor 500D photometer test kits (Macherey-Nagel, Germany).

2.4.2. Microbial Levels in Water

2.4.2.1. Heterotrophic Plate Count

Heterotrophic plate count (HPC) bacteria were enumerated by plating 10-fold serial dilutions up to 10^{-5}. The diluent (100 µL) was then spread onto Nutrient Agar (NA) plates (Merck, South Africa). An antifungal, nystatin (100 µg/mL), was added to NA plates to inhibit fungal growth. The plates were incubated at 37°C for 24 hours. Afterwards, colonies were counted, and the total number of HPC bacteria was expressed as CFU/mL.

2.4.2.2. Indicator Organisms

Aliquots of water samples (100 µL) were filtered through 0.45 µm pore size GN-4 Metricel® membrane filters (PALL Corporation, USA) using an MZ-1C diaphragm pump following the membrane filtration technique as described by Van Wyk et al. [30]. Subsequently, membrane filters were individually placed onto mFC agar medium (Merck, SA) containing rosolic acid to inhibit bacterial growth other than fecal coliforms and bile salts to inhibit non-enteric bacteria [31]. The agar plates were incubated at 45 °C for 24 hours.

For enumeration of total coliforms in water samples, m-Endo Agar was used, following the aforementioned membrane filtration method and subsequent incubation procedures. Too numerous to count (TNTC) colonies were observed for undiluted samples. The samples were at a ratio of 1:5 (sample water: sterile distilled water) and subsequently filtered. The number of colonies on mFC and m-Endo Agar was counted and expressed as CFU/100 mL.

2.5. Data and Statistical Analysis

Microsoft Excel 2019 was used to standardize raw data, calculate means, and standard deviations for physicochemical parameters, heavy metals, and microbiological parameters. SPSS software (version 21.0) evaluated significant differences between parameters at input and output, as well as between two sampling seasons. A p-value of less than 0.05 was considered statistically significant.

3. Results and Discussion

3.1. Water Parameters in Wetland Systems

The selection of parameters in the present study was based on their previous application as assessment tools in water analysis for various uses [32-34]. The nutrients (nitrates and phosphates) have been used primarily as indicators of organic and nutrient pollution. Table 1 summarizes the measurements (mean ± standard deviation) for physicochemical parameters, heavy metals, and microbiological parameters for dry and wet seasons at selected wetlands in the Vaal region. Field observations indicated that animal grazing (pigs and cattle) was largely observed in the wetland systems. Physicochemical, heavy metals, and microbiological parameters were compared to the target water quality range [15] for livestock watering (Table 1). The statistical analysis conducted was instrumental in presenting key findings revealed by the dataset and summarizing the information. The statistical analysis showed that a p-value of ≤ 0.05 indicates a significant difference between parameter values at the input and output points. If a p-value is greater than 0.05, the results are considered not statistically significant.

3.1.1. Physicochemical Parameters

Mean pH values of water samples at the input and output for both dry and wet seasons varied from 6.66 to 7.6 (Table 1). Water pH reflects its alkalinity (>7) or acidity (<7), and water samples in the current study exhibited circumneutral pH values [35]. At Tshirela and Sharpeville wetlands, cattle grazing was observed at the input, within the wetlands, and downstream. Animal grazing is a threat to wetland integrity as it removes wetland vegetation cover and contributes to wetland pollution [36]. Nevertheless, the water is unlikely to be harmful to the animals as it falls within acceptable limits for livestock water quality [37] and South African water quality guidelines for livestock watering [15]. Higher pH values were observed at the inputs than at the outputs, and the differences were statistically significant (Table 1). The significant difference indicates that the pH of the water is significantly reduced as it passes through the wetland systems. Water temperatures at the inputs and outputs varied between 24 and 27.3 °C, respectively. However, the values were within the expected ranges during the sampling seasons.

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Table 1.
Mean ± standard deviations of physicochemical, heavy metals, and microbiological parameters at selected wetlands in the Vaal region during the dry and wet seasons.

Parameters	**TWQR – livestock watering**	**Dry season**						**Wet season**					
		Tshirela		**Sharpeville**		**Sebokeng**		**Tshirela**		**Sharpeville**		**Sebokeng**	
		Input	**Output**	**Input**	**Output**	**Input**	**Output**	**Input**	**Output**	**Input**	**Output**	**Input**	**Output**
Physicochemical parameters													
Temperature	N/A	25±0	25±0	27.3± 0.64	26± 0.28	26.2± 0.28	24.9± 0.14	25.2± 0.14	24.2± 0.28	24.15± 1.20	24.4± 1.56	24± 1.13	24.9± 0.85
pH	N/A	7.17± 0.01	6.92±0	7.11± 0.08	7.37± 0.02	7.22± 0.02	7.14± 0.01	6.66± 0.04	7.44± 0.02	7.3±0	7.37±0	7.6± 0.04	7.33± 0.34
Turbidity (NTU)	N/A	84± 4.24	3.0±0	14± 1.41	9.0±0	30±0	8.0±0	42± 8.49	2.0±0	11±0	8.0± 1.41	7.0± 1.41	4.0± 1.41
Phosphates (mg/L)	N/A	1.34± 0.09	0.72± 0.03	1.2± 0.09	0.66± 0.23	1.48± 0.64	0.59± 0.01	0.9± 0.01	0.31± 0.04	1.44± 0.50	0.4±0	1.39± 0.11	0.58± 0.08
Nitrates (mg/L)	0 – 100	1.13± 0.81	0.38±0	0.46± 0.03	0.21±0	0.85± 0.01	0.2± 0.03	0.47± 0.02	0.23± 0.04	0.26± 0.02	0.19±0	0.55± 0.06	0.19± 0.04
Heavy metals													
Copper (mg/L)	0 – 1	0.81± 0.07	0.11± 0.01	0.16± 0.03	0.72± 0.064	0.24± 0.04	0.135± 0.02	0.35± 0.04	0.13± 0.01	0.46± 0.04	0.27± 0.06	0.33±0	0.17± 0.03
Lead (mg/L)	0 - 0.1 (a) 0 - 0.5 (b)	<0.10	<0.10	1.16± 0.04	0.835± 0.05	1.04± 0.03	0.78± 0.07	0.49± 0.02	<0.10	1.01± 0.01	0.66±0	0.89± 0.01	0.72± 0.19
Silver (mg/L)	N/A	0.505±0.09	<0.20	<0.20	0.295± 0.04	<0.20	<0.20	0.59± 0.01	<0.20	0.25± 0.01	<0.20	<0.20	<0.20
Zinc (mg/L)	0 – 20	0.5±0.03	<0.10	<0.10	0.24± 0.06	<0.10	<0.10	0.48± 0.06	0.28± 0.04	<0.10	<0.10	<0.10	<0.10
Microbiological parameters													
HPC (10^3 CFU/mL)		135± 20.51	2± 1.41	19± 6.37	2± 1.41	2± 0.71	17± 0.24	42± 7.78	20± 6.36	194± 15.56	43± 12.02	36± 12.02	7.0± 2.12
Total coliforms (CFU/100mL)		988± 3.54	510± 28.28	983± 10.61	500± 70.7	903± 31.82	980± 14.14	305± 35.34	208± 31.82	465± 21.21	355± 7.07	847± 7.07	778± 24.75
Faecal coliforms (CFU/100mL)	0 – 200	535± 21.21	343± 3.53	598± 67.18	365± 7.07	680± 113.14	688± 24.75	210± 28.28	48± 17.68	303± 45.96	248± 17.68	698± 3.54	670±0

TWQR, target water quality ranges [15]: (a) cattle, (b) pigs

The maximum mean turbidity values (input: output) recorded were 84.9 NTU in the dry season and 42.8 NTU in the wet season (Table 1). As shown in Figure 2, higher turbidity values were observed at the inputs than at the outputs. Statistically, the differences were not significant. Turbidity, often referred to as the optical clarity of water, depends on suspended particles, dissolved inorganic, and organic matter content within the water environment [38]. High turbidity observed at the wetland input could result from diffuse or point source pollution from domestic, agricultural, and industrial activities in the area [39]. In studies by Nsanzabaganwa et al. [21] and Yu et al. [22] on constructed wetlands, vegetation was associated with high removal efficiency of turbidity in wetland systems.

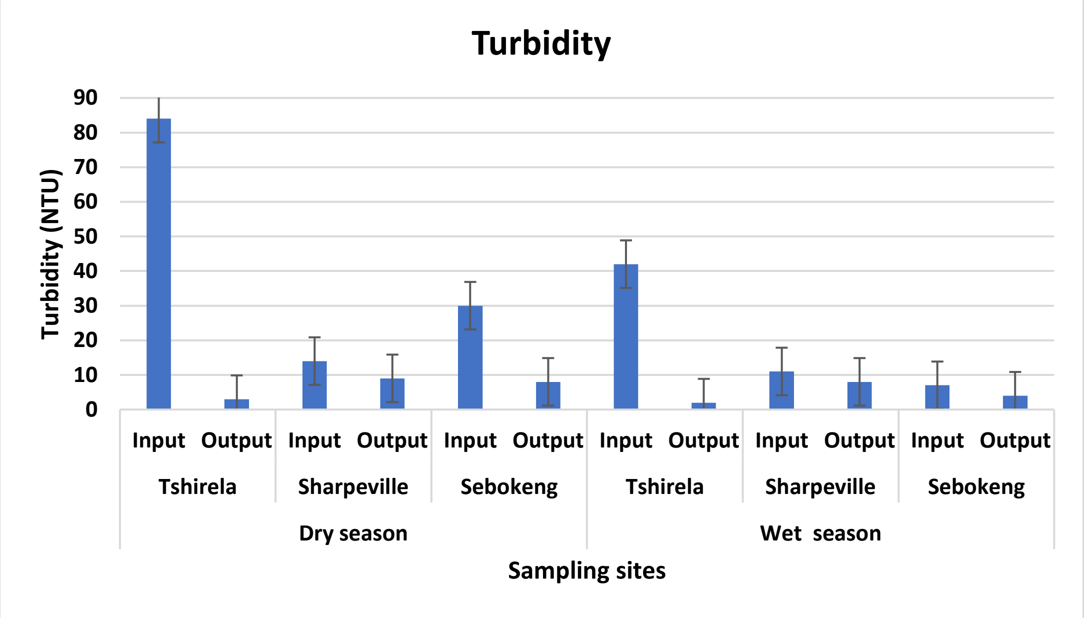

Figure 2.
Turbidity levels at the selected wetlands during dry and wet seasons.

Elevated nutrient levels were also observed at the input than at the output (Figure 3). For phosphates, the maximum recorded mean values (input: output) for dry seasons were (1.48: 0.23 mg/L) and for the wet season (1.44: 0.58 mg/L). For nitrates, the maximum recorded mean values (input: output) for dry seasons were (1.13: 0.38 mg/L) and for the wet season (0.55: 0.23 mg/L). Human activities that include illegal dumping, stormwater runoff, industrial effluent, sewage discharges, and animal waste from cattle grazing result in high nutrient concentrations in water entering wetland systems [40]. Nutrient runoff from anthropogenic sources can be effectively mitigated through plant uptake and microbially mediated processes within wetland systems [41]. Over-enrichment of surface water environments with nutrients (eutrophication) impairs water quality [42]. By regulating nutrient concentrations through plant assimilation and microbial activity, wetland ecosystems play a critical role in controlling accelerated eutrophication. This function is particularly important for protecting drinking water sources, maintaining the ecological integrity of recreational water bodies, and sustaining aquatic life (Ibis).

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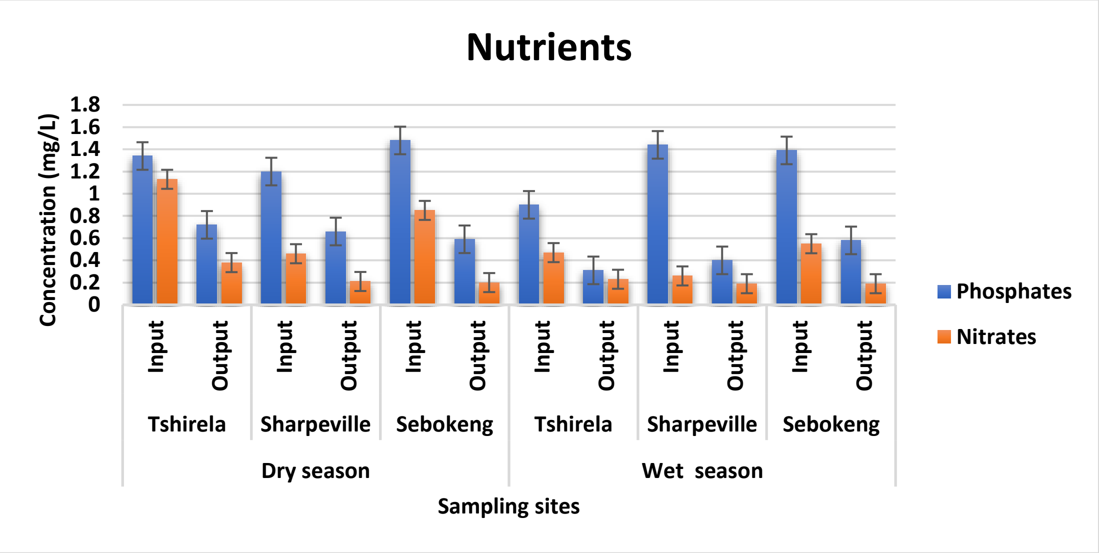

Figure 3.
Nutrient levels at the selected wetlands in the Vaal region during dry and wet seasons.

Heavy metals are referred to as any metallic chemical elements that have relatively high density and are toxic or poisonous at low concentrations [43]. Their presence in water is detrimental to the environment and public health (Ibis). The maximum mean values (input: output) for the heavy metals during the dry season were copper (0.81:0.72 mg/L), lead (1.16:0.84 mg/L), silver (0.50:0.30 mg/L), and zinc (0.50:0.24 mg/L). For the wet season, copper (0.46:0.27 mg/L), lead (1.01:0.72 mg/L), silver (0.59: <0.20 mg/L), and zinc (0.48:0.28 mg/L) Table 1. Between both seasons, higher values were observed at the input than at the output (Figure 4). As stated by Oladimeji et al. [44], heavy metals are the most common environmental pollutants from industrial, mining, and agricultural activities. The occurrence of heavy metals in the present study could result from observed agricultural runoff, industrial, and domestic activities around the wetland systems. Nonetheless, measurements for copper, lead, and zinc were generally within the TWQR limits for livestock watering [15].

In descending order on the ATSDR's Substance Priority List ranked in 2022, heavy metals studied in this research ranked high: Lead (2), Zinc (72), Copper (120), and Silver (227), and could pose the most substantial probable risk to human health due to their potential for human exposure and known toxicity [45]. The dominant heavy metals in this study, Copper and Lead, have also been measured in high concentrations in other wetland water quality studies [46, 47]. These studies implicated domestic sewage, industrial effluent, and mine tailings as primary sources. In the present study, high concentrations of copper and lead were observed in Sebokeng and Sharpeville wetlands. From field observations, the two wetlands were heavily impacted by industrial and domestic human activities. Unregulated discharges of heavy metals could threaten the environment, humans, animals, and plants' health [47]. Therefore, mitigating the release of heavy metals into receiving water bodies is essential for environmental protection and public health.

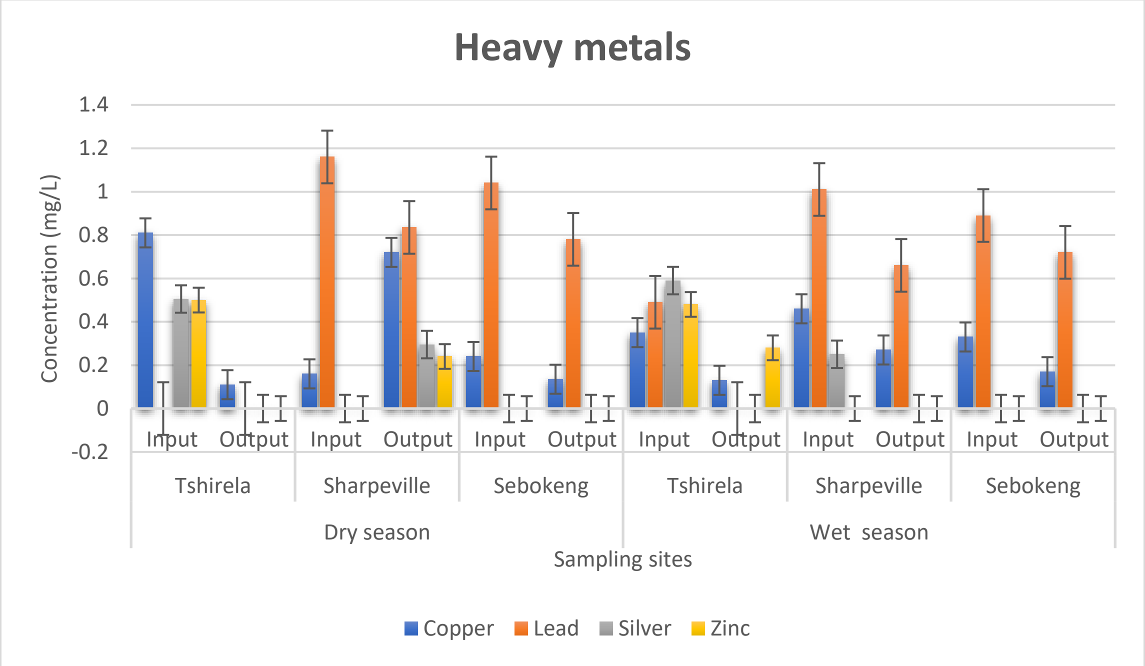

Figure 4.
Heavy metal concentrations at the selected wetlands in the Vaal region during dry and wet seasons.

3.1.2. Microbiological Parameters

Assessment of indicator bacteria levels in water is a common approach for quantifying the potential pathogen loads in ambient water bodies [48]. In the present study, the maximum microbial levels (input: output) for the dry season were as follows: HPC (135 x 10^3: 17 x 10^3 CFU/mL), total coliforms (988, 980 CFU/100 mL), and faecal coliforms (680, 688 CFU/100 mL). For the wet season, HPC (194 x 10^3: 43 x 10^3 CFU/mL), total coliforms (847, 778 CFU/100 mL), and faecal coliforms (698, 670 CFU/100 mL). As mentioned by Turpie et al. [18], wetlands have the capability to remove various pathogens from water passing through. In a study by O'Geen and Bianchi [49], water that passed through the wetland from irrigational activity was analyzed for microbial pathogens. Lower concentrations and loads of microbes were observed downstream of the wetland systems. Similar results were seen in the current study, where higher microbial levels were observed at the input at Tshirela and Sharpeville wetland systems (Figures 5 and 6). However, this was not observed at the Sebokeng wetland during the dry season. Higher microbial levels at the output could be associated with field observations that showed sewage from overflowing manholes that directly entered the Sebokeng wetland towards the output sampling site. Wetland features such as vegetation, sedimentation, and hydrology play a pivotal role in reducing the levels of microbial pathogens in wetland systems [50]. Although cattle and pigs were seen grazing and drinking water within the wetlands during field analysis, microbiological parameters were outside the target water quality range (TWQR) for livestock farming [15].

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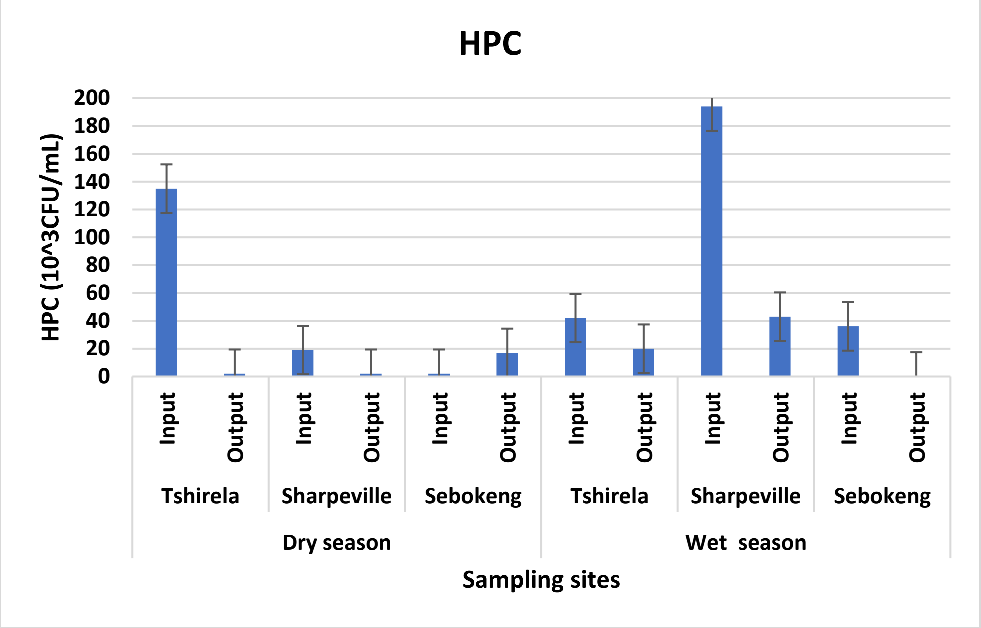

Figure 5.
Heterotrophic plate count (HPC) in selected wetland systems during the dry and wet seasons.

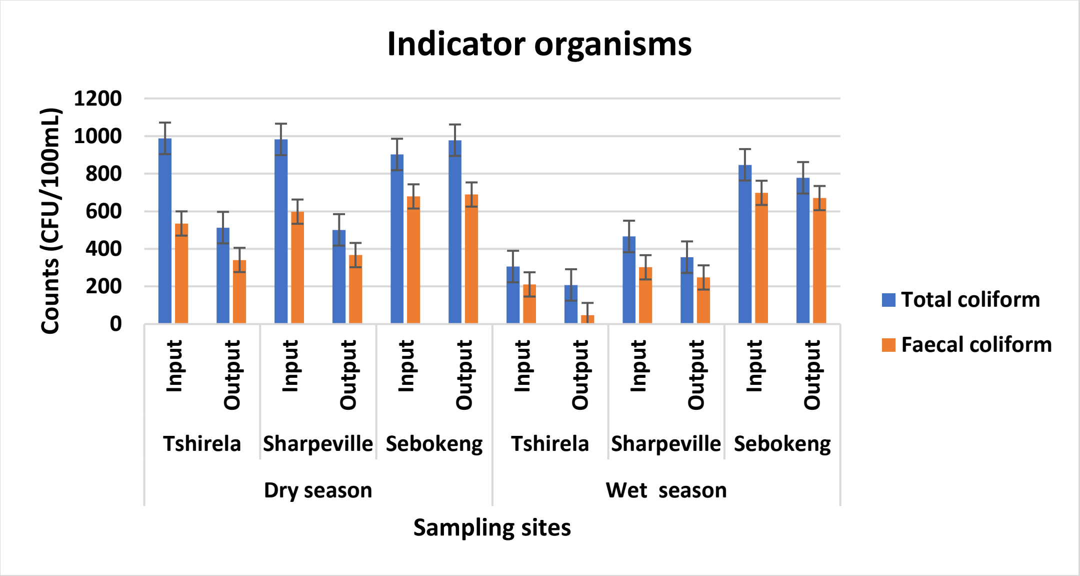

Figure 6.
Total coliforms and faecal coliform levels in selected wetland systems during the dry and wet seasons.

Previous studies have stipulated that microbes (total and fecal coliforms) in the present study have been used to determine water quality and could affect human health through drinking water [51, 52]. It is thus critical to reduce microbial levels before they reach surface water environments, which are drinking water resources. However, Urakawa and Bernhard [53] stipulated that microbial indicators are important in wetland management. Their sensitivity to environmental pollutants is critical as it enables them to swiftly effect a response to changes in environmental conditions. By monitoring microbial indicators, the health and functioning of wetlands can be determined. Although the previously mentioned fecal indicators, including *Escherichia coli*, are critical to understanding and evaluating water quality, they are the second leading cause of wetland water quality impairment [54]. Thus, it is imperative to determine their presence and diversity in such water environments. Findings from the present study showed that FC values exceeded the safe limit for livestock farming [18]. With some cattle seen during field analysis, this could be worrisome. Ingesting water with high fecal coliform counts can lead to several health issues in livestock.

3.2. Spatial and Temporal Trends

For most of the measured parameters (80%), higher concentrations were recorded at the input sampling points compared to the output points. Elevated contaminant levels are likely attributable to upstream and adjacent anthropogenic activities. High population growth, growing industrialization, and urbanization often lead to increased discharge of wastewater effluent [55]. These require treatment before discharge into open aquatic systems. Findings from the present study indicate that wetland systems play a significant role in reducing contaminant concentrations in the water as it flows through them. This could be said for all the parameters in the wetlands, except for HPC in the Sebokeng wetland, during the dry season, where higher concentrations were observed at the output than the input.

The results of this study also suggest that land use determines the water quality of adjacent wetland streams. High concentrations of heavy metals were observed at wetlands characterized by industrial activities. The widespread application of heavy metals in industries has led to their distribution in the environment [56]. It is vital to safely dispose of and manage these industrial by-products to prevent environmental contamination, thereby protecting human and ecological health (Ibis). Fluctuations in concentrations of various parameters were observed in the dry and wet seasons. Thus, no apparent seasonal trend was observed. This observation conforms to the findings by Murray-Tortarolo et al. [57]. The author stipulated that due to climate change from the mid-twentieth century, there has been no consistent reconciliation of seasonal trends over longer time periods.

4. Conservation and Protection of Wetland Systems

Wetlands are destroyed because their value is poorly understood [18]. Moreover, the economic benefits and services provided by wetlands are frequently overlooked by governments, developers, private industry, and other land users. It is imperative to conserve and manage wetlands to ensure their continued provision of ecosystem services and benefits to humanity [58]. Furthermore, understanding the water treatment characteristics of wetlands and other services they provide can bring recognition and a balance between conservation and activities that could degrade and destroy them [59]. Holistic approaches and strategies should be recognized and prioritized to conserve wetlands and mitigate the adverse impact on wetland systems. Some activities that should be implemented to conserve wetlands are presented in Figure 7.

Figure 7.
Wetland conservation activities for communal benefits.

Networking platforms such as forums, seminars, and workshops should be created between researchers, non-governmental organizations, relevant government institutions, private institutions, and communities for effective communication of knowledge and research findings [60]. On such platforms, all stakeholders could network and discuss salient issues related to the conservation, rehabilitation, and development of wetland systems. As stated by Van der Duim and Henkens [61] and Ranjbar et al. [62], education and awareness are also important components of successful wetland conservation. Capacity-building programs should be created through institutional mechanisms to provide training to local communities, policymakers, and other stakeholders for the overall sustainability of any program [60]. Most importantly, it is vital to foster dialogue and collaboration with local communities to implement wetland management strategies. Hands-on participation of local stakeholders, particularly the community, is vital for effective wetland conservation [61].

Initiatives such as organized wetland clean-up campaigns, barricading, and establishing protective buffer zones on the wetlands play a crucial role in maintaining their ecological integrity [63]. These measures could collectively discourage activities that may contaminate these water resources and contribute to reducing pollution from indiscriminate waste disposal. Agroecological methods and carefully managed recreational activities not only serve to improve the local economy and livelihoods of the communities but also serve to conserve the wetlands [64]. Wetlands, as an ecosystem type, are not formally protected by law, but their alteration is regulated by domestic policies and legislation [65]. Stakeholders and governance structures, including government, non-governmental organizations (NGOs), and the community, should collaborate for effective policy implementation around the protection of wetlands [66]. Furthermore, legal action should be taken against those responsible for wetland degradation [63]. Enforcing pollution control measures, such as the Polluter Pays Principle, should be imposed to regulate the discharge of pollutants into wetland systems.

5. Conclusion

Globally, natural wetlands have proven successful in removing pollutants from surrounding human activities and improving water quality. Findings from the study further indicated that wetlands have the potential to reduce the levels of contaminants that enter wetland systems. The Vaal River, downstream of the inland wetlands, is used for agricultural, bathing, and recreational purposes. According to TQWR, the water parameters of the wetland were within permissible limits for cattle farming, as observed during the field analysis. The integrity and well-being of natural inland wetlands are affected by adjacent and surrounding industrial, agricultural, and domestic activities. The present study suggests that wetlands should be given considerable attention in land-use planning and regulation. Trends observed during field analysis, such as dumping, cattle farming, industrial effluents, and agricultural runoff, should be avoided or controlled. If these are not controlled, existing in-stream water quality problems in the Vaal River and South Africa as a whole will be exacerbated. Proper and efficient management strategies should urgently be implemented to conserve, protect, and restore wetlands, thus to sustain their social and economic services.

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Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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