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Land use impacts on the water quality of the Palmiet River, Durban, KwaZulu-Natal, South Africa

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ABSTRACT:

Landuse and seasonality impacts of the physico-chemical, nutrient and microbiological properties (total dissolved solids , dissolved oxygen , biological oxygen demand, chemical oxygen demand, conductivity, pH, ammonia , phosphorous , sodium , potassium , E. coli and total coliforms) of the Palmiet River, Durban, South Africa, are presented. Pollution associated with landuse is the principal factor governing water quality. The sanitary state of the river, particularly in the vicinity of the informal settlement is highly contaminated. These impacts of the Palmiet River on the Mgeni River, into which it flows, are minimal although marked wet season increases in E. Coli concentrations in the Mgeni were measured.

Key words: *Land use, water quality, physico-chemical, Palmiet, E. Coli*

1. INTRODUCTION

The quality of water, even in pristine environments, is impacted on by a number of factors [1], due to the complex interplay of landscape ecology and hydrology at different spatial and temporal scales. With the ever quickening pace of development, the chemistry of the majority of fluvial systems is controlled by numerous natural and anthropogenic factors through diffuse or point pollutants [2]. In recent years, a rapid decline in fresh water in terms of quantity and quality has been attributed primarily to unsustainable land use practices [3]. In fact, most human activities pose as potential threats to pollute and contaminate water. Sources of pollutants include industries, urban infrastructure, agriculture, transport, mine discharges, domestic discharges and pollution incidents [4]. In particular, the development of land has been shown to have significant impacts on the movement and accumulation of sediment, pollutants and nutrients in streams. These impacts have noticeable repercussions on the chemistry and consequently, quality of stream water [5-9].

Consequently, comprehensive study of the water quality of all fluvial systems is essential, particularly those within heavily utilized catchments. In this vein, this study attempts to account for seasonal pollutant loading in relation to natural causes and anthropogenic land use of the Palmiet fluvial system. In addition, the influence of the Palmiet River on the waters of the Mgeni River, into which it flows, is explored at the confluence of these two rivers.

2. STUDY SITES AND RESEARCH METHODS

2.1 Study area

The Palmiet River, located in the Durban Metropolitan area, KwaZulu-Natal province, South Africa, has its source in the Kloof escarpment (Fig. 1). This river is a tributary of the Mgeni River which is the lifeblood of the key developed areas of the province of KwaZulu-Natal. However, the Palmiet River is unique in that it flows through a myriad of land use zones in the highly developed Durban-Pinetown region and is consequently exposed to potentially serious degradation. Approximately 6 km of the river passes through a natural reserve but it is otherwise bordered industries and residential suburbs (Fig. 1). In the upper reaches of the catchment, the river flows through the Pinetown-New Germany CBD/industrial area. It then traverses a residential sector in the Pinetown-Westville area, through the Palmiet Nature Reserve, and ultimately joins the Mgeni River in vicinity of Springfield. One kilometer upstream of its confluence with the Mgeni River, is a densely populated informal settlement, the Palmiet Slum Settlement (PSS). The Pinetown-New Germany industrial area has been subject to intense industrial development over the past two decades and constitutes an important industrial hub in KwaZulu-Natal. The residential sector in the Pinetown-Westville area comprises of housing categorized mainly in the high to middle income groups [10]. The topography of the catchment is steep and undulating; with the exception of the Pinetown basin area which is relatively flat. Since this is a summer rainfall area, peak discharge is experienced in the summer months between October and March with a substantial decrease in the winter months of April to September [11].

2.2 Materials and methods

Six sampling sites were systematically chosen before and after each land use type along the Palmiet River to study the influence of land use on water quality (Fig. 1). Further sampling was conducted in the Mgeni River just upstream and downstream of the Palmiet-Mgeni confluence to assess the impact of the former on the water quality of the latter. Land use and sampling site identification was made using topographic maps, Google Earth® images and aerial photographs followed by site visit ground truthing (Fig.1). Field surveys were conducted on a monthly basis through the summer and winter seasons. All samples were collected in clean high density polyethylene bottles, labeled and stored on ice prior to analysis.

The samples were analyzed within a twenty four hour period. Physical and chemical components of the water samples were analyzed at the University of KwaZulu-Natal chemistry laboratory whilst microbiological analysis was conducted at Talbot and Talbot Laboratories (Pty) Ltd. The composite analyses included total dissolved solids (TDS), conductivity, pH, ammonia, phosphorous, sodium, potassium, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), *Escherichia coli* (*E. coli*) and total coliforms.

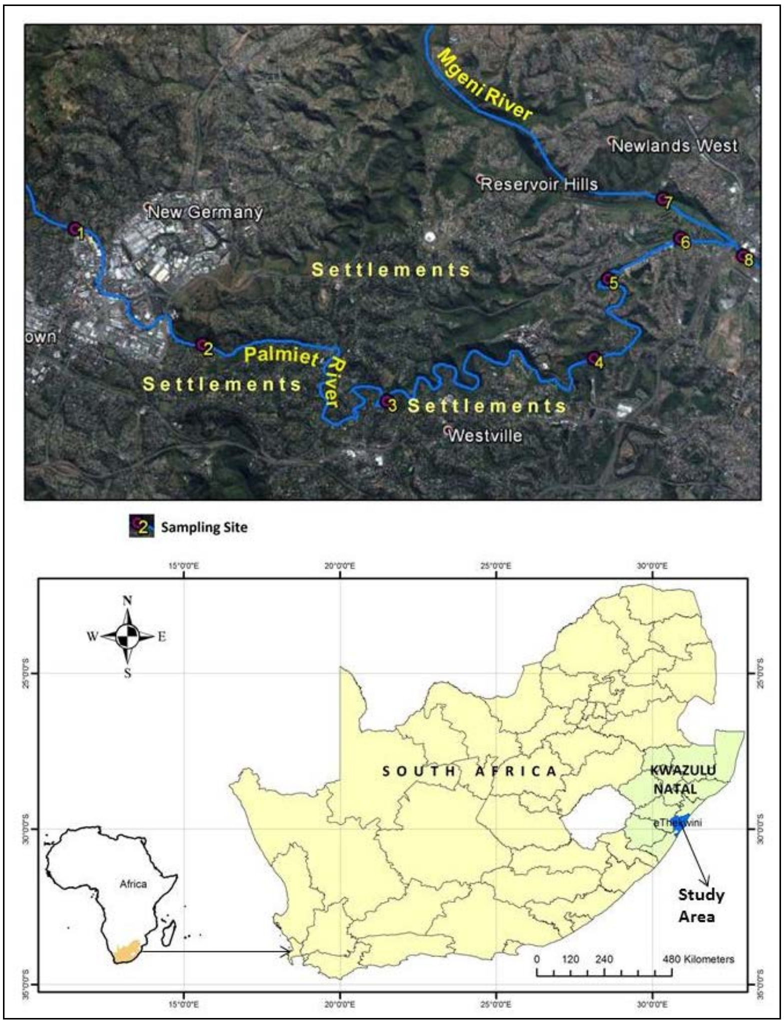

Fig. 1: Google Earth® image of the Palmiet River (in light blue), the Pinetown-New Germany CBD/ industrial area through which the river flows and the Mgeni River (in red) into which the Palmiet flows. Sampling sites along the rivers are numbered 1 – 8.

Analysis of phosphorous was attained through atomic adsorption inductively coupled plasma (ICP) analysis, which permits the simultaneous determination of several elements in a sample and is based on the use of emitted, absorbed or scattered light to identify the concentration of an atomic or molecular species in a chemical system [12]. Analysis of sodium and potassium cation concentrations was quantitatively determined using a Jenway PFP7 flame photometer. Concentrations of dissolved oxygen were determined using the Winkler method [12] whilst BOD concentrations were obtained by aerobic decomposition of organic matter within a BOD incubator as outlined by Tomar [13]. The COD of the sample was measured by the oxygen corresponding to the organic matter susceptible to oxidation by chromic acid as outlined by Tomar [13].

3. RESULTS AND DISCUSSION

The variations of parameters defining water quality measured during summer and winter seasons are illustrated in Tables 1 and 2 respectively. *Statistical analysis*: single factor Analysis of Variance (ANOVA) was employed to assess any significant differences in the measured parameters of both seasons (Table 3).

Table 1: Variations of water quality parameters for summer

Site no.	**TDS**	**Cond. (µs/cm)**	**pH**	**$^*NH_4^+$**	**P**	**DO**	**BOD**	**COD**	**Na**	**K**	**Total Coliforms****	***E.coli*****
1	1.0	1.53	8.16	3.31	0.000	1.39	<1.0	21.0	6.95	0.12	96.0	56.0
2	2.0	5.16	10.93	5.29	0.000	0.00	<1.0	24.0	8.47	1.50	147.0	27.0
3	0.0	0.97	8.23	4.45	0.000	0.00	2.0	<20.0	6.13	0.00	53.0	17.0
4	1.0	1.07	8.07	3.55	0.000	4.03	2.0	<20.0	4.14	0.00	110.0	5.0
5	1.0	1.39	9.91	4.69	0.000	14.62	<1.0	<20.0	4.62	1.21	83.0	21.0
6	3.0	5.74	8.72	5.68	0.000	8.00	<1.0	<20.0	0.63	0.12	195.0	122.0
7	0.0	0.69	7.78	3.74	0.000	0.07	2.0	<20.0	2.97	0.00	184.0	25.0
8	1.0	2.09	9.49	4.52	0.016	8.00	2.0	<20.0	3.79	0.00	173.0	98.0

(* determined as NH_4^+ concentration;** measured as colonies per 100 ml; all other units in mg/l)

Table 2: Variations of water quality parameters for winter

Site no.	**TDS**	**Cond. (µs/cm)**	**pH**	**$^*NH_4^+$**	**P**	**DO**		**COD**	**Na**	**K**	**Total Coliforms****	***E. coli*****
1	4.0	8.69	9.040	5.02	0.000	4.03	1.0	<20.0	3.86	2.73	1880.0	490.0
2	3.0	8.20	8.110	4.22	0.000	17.26	2.0	21.0	4.00	1.28	180.0	10.0
3	2.0	7.73	9.080	4.29	0.532	4.03	1.0	35.0	0.00	1.06	390.0	150.0
4	2.0	7.82	8.890	2.68	0.682	5.36	3.0	<20.0	0.00	0.63	1000.0	300.0
5	3.0	8.02	8.520	3.31	0.328	22.55	1.0	<20.0	0.00	0.41	1020.0	160.0
6	4.0	8.42	8.850	3.55	0.396	10.65	1.0	<20.0	17.78	1.35	1630.0	220.0
7	2.0	3.96	8.500	3.55	0.489	10.65	1.0	<20.0	14.44	1.06	820.0	110.0
8	2.0	3.91	7.870	3.87	0.622	9.33	1.0	<20.0	14.44	1.06	790.0	120.0

(* determined as NH_4^+ concentration;** measured as colonies per 100 ml; all other units in mg/l)

Table 3: Single factor ANOVA for significant seasonal changes in the water quality of the Palmiet River.

Variable	Rejection level (α)	*fcalc*	*fcrit*	H0
TDS*	0.05	8.929	4.965	Rejected
Conductivity*	0.05	36.818	4.965	Rejected
pH	0.05	0.261	4.965	Accepted
Ammonia	0.05	1.620	4.965	Accepted
Phosphorous*	0.05	8.096	4.965	Rejected
DO	0.05	2.299	4.965	Accepted
BOD	0.05	0.172	4.965	Accepted
COD	0.05	0.514	4.965	Accepted
Sodium	0.05	0.085	4.965	Accepted

Potassium	0.05	3.016	4.965	Accepted
Total coliforms*	0.05	10.975	4.965	Rejected
*E. coli**	0.05	6.913	4.965	Rejected

(* significant differences observed with *f*calc > *f*crit and the alternate hypothesis H_1 accepted)

3.1 Physico-Chemical Characteristics

3.1.1 Total dissolved solids (TDS)

TDS reached a maximum in winter (Tables 2 and 3) but displayed a significant seasonal variation (Table 3). Slight increases in TDS concentrations occur at sites 2, 4 and 6 (Table 2) in summer, and sites 1, 5 and 6 (Table 3) in winter. The winter increase at site 4 (Table 2) is attributed to biogeochemical processes occurring within the nature reserve whilst industrial effluent emanating from the Pinetown industrial area has created increases in TDS concentrations at site 2 (Table 2). High TDS levels recorded during winter at site 5 (Table 2) is associated with effluent discharge emanating from a large construction company as well as from the Palmiet Slum Settlement (PSS). Site 1 (Table 2) is a partly transformed wetland of middle to high income housing and, hence the high TDS recorded here.

3.1.2 Conductivity

The electrical conductivity (EC) was significantly higher in winter. Anomalous increases in conductivity at sites 2 and 6 (Fig.1 and 2) in summer and sites 1 and 6 **(** Fig. 1 and 2) in winter is related to corresponding increases in seasonal TDS which, in turn, is related to the introduction of soluble inorganic material by runoff and human activities associated at these sample locations.

3.1.3 pH

The river water was found to be slightly alkaline during both seasons reaching higher levels in summer (maximum of 10.93 at site 2) although no significant differences in pH were found to occur between the summer and winter (Table 3). The variability of pH within each season is marginal with a slight increase in alkalinity at sites 2 and 5 (Figure 2) in summer. This increase at site 2 (Fig. 2) is related to industrial effluent discharges into the river from the Pinetown industrial area. Discharges from a construction factory situated just upstream of the informal settlement accounts for the elevated alkaline condition at site 5 **(**Figure 2) particularly since some liming of the un-tarred track had occurred a few months earlier. The pH of most naturally occurring fresh water in South Africa ranges between 6 and 8. In most instances, pH values recorded in this study frequently exceeded this range and is related to potentially eutrophic conditions[14] within the system.

3.1.4 Dissolved Oxygen (DO)

The highest DO levels were generally recorded in winter, reductions in some cases were observed in summer (Site 2; Table 1 and 2) and may be attributed to increased primary productivity and biotic respiratory requirements together with increased organic decomposition, as well as the warmer temperatures of the water in summer [14]. DO concentrations remain fairly consistent at all sites in both seasons, distinct peaks occurs in winter at site 2 (Table 2) and site 5 in summer and winter (Table 1 and 2), reflecting the influence of the nature reserve on the system.

3.1.5 Biological Oxygen Demand (BOD)

Although the BOD in winter was found to be marginally higher than in summer no statistically significant seasonal differences were observed (Table 3). Generally low BOD levels (less than 2.0 mg O_2/L) were recorded at all sites (Table 2 and 3) with the exception of site 4 (Table 2) (situated downstream of the nature reserve). Here, levels peaked at 3.0 mg O_2/L in winter, indicative of an abundance of organic matter decomposition within the reserve during the dry winter season [15]. Low values for BOD, predominantly at sites 1, 5 and 6 (Table 2 and 3) are indicative of the prevalence of large amounts of non-biodegradable pollution.

3.1.6 Chemical Oxygen Demand (COD)

The highest COD level occurred during winter with no statistically significant seasonal differences observed (Table 3). Most sites have shown consistent levels of COD and with the exception of site 2 in summer (Table 1) (situated downstream of the industries) as well as site 3 (below the residential area) in winter (Table2). These increases can be accounted for by industrial and urban discharges respectively. Hence the high COD levels at site 3 (Table 2) correlate well with high concentrations of phosphorous and ammonia measured here. An increase in COD during summer at Site 2 (Table 1) relative to the other sites is also related to the high levels of ammonia prevalent at this site.

3.2 Nutrients

3.2.1 Ammonia

The highest concentrations of ammonia were recorded in summer with no significant differences to that obtained in winter (Table 1, 2, 3). Increasing levels of ammonia recorded at sites 2 and 6 (Tables 1) in summer is directly related to activities at industrial site 6 [14] (Table 1. An increase in ammonia during winter, site 1 (Figure 2) (a modified wetland) is reflective of wetland biochemical wetland processes as well as leaching of nitrogenous matter from garden fertilizers[14] from the expansive surrounding residential area (Figure 2). The concentrations of ammonia recorded at all sample locations along both the Palmiet and Umgeni Rivers, have to a great extent exceeded the water quality standards for aquatic ecosystems as outlined by DWAF [14], thus rendering these habitats potentially unsafe for aquatic life.

3.2.2 Phosphorous

Trace amounts of phosphorous were detected in winter and none detected in summer. The increasing levels of P at sites 3 and 4 (Table 2) in winter, indicate their association to residential and nature reserve sources respectively as a consequence of possible P loading due to the mineralization and leaching of fertilizers and decomposition of organic matter [14] within these respective areas. An increase in phosphorous at site 6 in winter (Table 2) preceded by a decrease in at site 5 in winter (Table 2), can be attributed to loading from the PSS as well as fertilization and irrigation in the adjacent golf course during the drier winter period.

3.2.3 Sodium

Generally high levels of sodium ions were recorded during summer with an anomalous increase emanating from the PSS was recorded at site 6 in winter (Table 2) (situated beyond the informal settlement) (Figure 1).Notwithstanding the latter, the quantified amounts of sodium at all sample sites complied with the acceptable standard range of 0-100 mg/L as stipulated by DWAF[14] during both the summer and winter seasons.

3.2.4 Potassium

Acceptable levels of potassium in natural waters should range ideally less than 10 mg/L [16], a target level satisfied at all sampling sites. The levels of potassium ions were found to be higher in winter whilst elevated levels of potassium were recorded at sites 2 and 5 in summer (Table 2) and, site 1 in winter (Table 3) caused by increased summer runoff from the Pinetown industrial area while an increase at site 6 is due to contamination from the informal settlement. Increase in levels of potassium at site 1 in winter (Table 2) is considered to be derived from bio-geochemically induced soil leachates of this transformed wetland. The nature reserve shows a drop in potassium levels during winter, and this is due to filtration processes in this densely vegetated area [17].

3.3 Pathogens

3.3.1 Total coliforms

The total coliform count was found to be significantly higher in winter (Table 3 and attributed to the concentrating of pollutants during low fluvial flow. At site 6 (Table 2, Figure 2), direct discharge of faecal contaminated surface runoff from the PSS area enters the river, increasing coliform counts. Site 1 (Figure 2, Table 1) (the transformed wetland site) which is associated with an abundance of birdlife shows a higher coliform count than the residential area situated at site 3 (Figure 2, Table 1). High coliform counts are often a common characteristic of residential areas, nature reserves and informal settlements as evident in sites 3, 4, 5 (Figure 2) respectively. The acceptable standard total coliform count in water suitable for human consumption and domestic use is 0-5 colonies per 100 ml [14]. The counts recorded in this study greatly exceeded this standard at all sample locations for both seasons. This graphically illustrates the severity of contamination in the Palmiet River.

3.3.2 E. coli

The *E. coli* count was also found to be significantly higher in winter peaking at the PSS, the reclaimed wetland (Site 1) and the nature reserve (Site 4). The other area of concern is residential area of Westville. Levels at all sites were higher than the target levels stipulated by DWAF [14]. Consumption of waters infested with *E. coli* can cause illness and possibly death in humans and animals, especially in children under five years of age [18]. The presence of *E. coli* at all sample locations in both seasons therefore render the sanitary quality of the water source as unacceptable.

3.4 Influence of the Palmiet River on the water quality of the Mgeni River

Chemical analysis of water quality variables along the Mgeni River upstream and downstream of the Palmiet-Mgeni confluence (Sites 7 and 8 respectively) shows slight variations, indicative of the limited impact of the Palmiet River on the water quality of the Mgeni River. This is mainly attributable to the size of the Palmiet River in relation to the Mgeni River, such that the

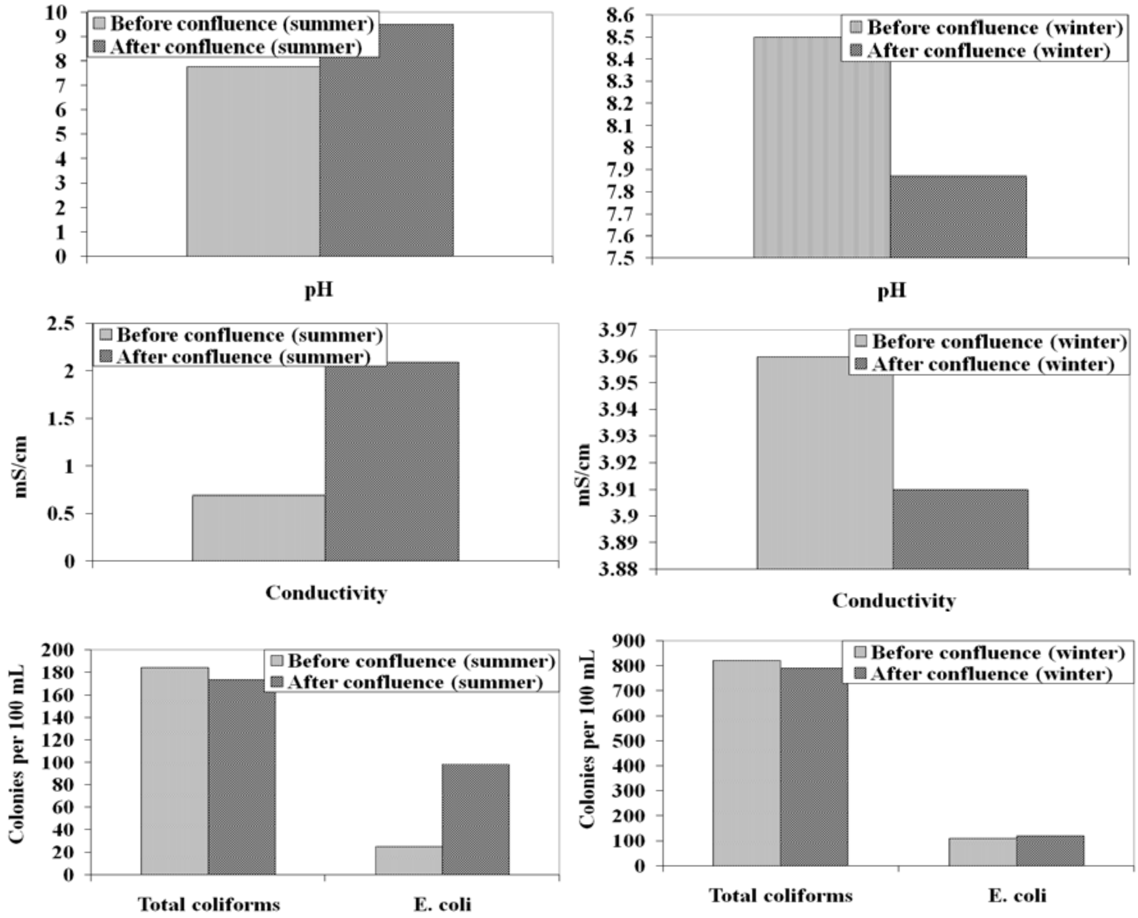

Fig. 2 Seasonal profiles of water quality variables before and after the Palmiet- Mgeni River confluence along the main Mgeni River.

relatively limited discharge and carrying capacity of the Palmiet River shows no noteworthy influence on the water quality of the Mgeni River after the confluence, with the exception of *E. coli* in summer. The sudden peak in *E. coli* after the confluence of the Mgeni River in summer can be related to high summer runoff flushing considerable amounts of faecal matter in the vicinity and downstream of the PSS. It is difficult to accurately quantify the effects of the Palmiet on concentrations of DO, BOD and COD in the Mgeni River as these parameters are highly variable with temperature, water turbulence and volume and, biological productivity [14].

4. CONCLUSION

A diverse variety of activities characterize the Palmiet River and its associated catchment. These are primarily due to human development utilization of the catchment over the past three decades and accounts for the spatial and temporal variability of water quality parameters. As wide range of physical and chemical parameters, as well as microbiological indicators were assessed in this study and demonstrates that intensification of anthropogenic activities and processes have caused a general deterioration of nutrient and microbiological water quality across all land use types. The range of chemical parameters in a water profile has been shown to be modified by the diluting and concentrating effects of tributary inflows, precipitation input, or as a consequence of specific physico-chemical characteristics governing elements persistence in the water column [19]. Such effects form the basis to explain the seasonal variations of the variables measured in this study. The presence of lower dissolved compounds in summer is attributed to dilution following high fluvial discharge in this rainy season.

Specific land use types are shown to affect the river's water quality in different ways. Combined ammonia and phosphorous concentrations emanating from the different land use types were typically high, with the levels of ammonia and phosphorous causing hypertrophic conditions thus rendering sections of the river as unsuitable aquatic habitats. Disturbingly high amounts of pathogenic microbes and non-biodegradable materials particularly associated with the informal settlement characterize the lower catchment of the Palmiet. Whilst the nature reserve displays a limited purifying capacity with regard to certain physico-chemical parameters, the stress placed on the ecosystem as a consequence of a combination of anthropogenic activities negatively impacts the sanitary quality of the system across all other land use types.

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