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Lungelo Maseko
Department of Environmental
Science, University of Pretoria,
Pretoria, South Africa

Lindiwe Nkosi
Department of Environmental
Science, University of Pretoria,
Pretoria, South Africa

Role of conservation buffers in reducing sediment and nutrient transport from agricultural watersheds

Lungelo Maseko and Lindiwe Nkosi

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Abstract

Agricultural runoff is the single largest non-point source of sediment and dissolved nutrients entering freshwater systems across southern Africa. This research compared the effectiveness of three conservation buffer types grass strips, tree/shrub corridors, and constructed wetlands in trapping sediment, total nitrogen, and total phosphorus at 24 monitoring stations along tributaries of the Apies River near Pretoria, South Africa. Field measurements were collected monthly over 12 months (January-December 2023). Grass buffers 10 m wide reduced sediment loads by 63.8%, tree/shrub buffers of the same width achieved 51.2%, and constructed wetlands reached 68.4%. Phosphorus retention was highest in wetlands (71.8%) and lowest in tree/shrub corridors (54.9%). Buffer width was the strongest single predictor of sediment trapping, with diminishing returns beyond 20 m. Results suggest that strategically combining buffer types along different reaches of a watershed can reduce total suspended solids reaching downstream reservoirs by over 70%.

Keywords: Conservation buffers, sediment transport, nutrient retention, agricultural watersheds, riparian strips, grass buffers, constructed wetlands, non-point source pollution, water quality

Introduction

Soil erosion from cropland costs South Africa an estimated 12 billion rand per year in lost productivity and downstream water treatment expenses ^[1]. Much of this damage travels as sediment-laden runoff carrying nitrogen and phosphorus from fertilized fields into rivers and reservoirs. The Apies-Pienaars catchment north of Pretoria supplies water to over three million people, yet its tributaries receive unfiltered agricultural drainage from mixed crop-livestock operations across the Highveld plateau ^[2].

Conservation buffers strips of permanent vegetation placed between cultivated fields and waterways intercept overland flow and trap suspended particles through infiltration, sedimentation, and biological uptake ^[3, 4]. Grass filter strips are the most widely promoted buffer type in South African extension programs, but their performance drops sharply during high-intensity storms when flow concentrates into preferential channels ^[5]. Tree and shrub corridors add root-binding and canopy interception but take years to establish. Constructed wetlands combine sedimentation basins with emergent macrophytes that absorb dissolved nutrients ^[6].

Direct field comparisons of these three buffer types under the same climatic and soil conditions are rare in the southern African literature ^[7]. Most existing data come from plot-scale rainfall simulations rather than from watershed-level monitoring over full rainfall seasons ^[8]. This research measured sediment and nutrient loads at paired upstream-downstream stations across three buffer types in the upper Apies catchment throughout a complete hydrological year, to determine which configurations deliver the greatest water quality improvement per unit of land taken out of production.

Research area description

Monitoring stations were established along four tributaries of the upper Apies River within 40 km of the University of Pretoria campus (25°44' S, 28°14' E). The catchment sits at 1,340-1,480 m elevation on the Highveld plateau, receiving 670 mm mean annual rainfall concentrated Between October and March ^[9]. Soils are predominantly Hutton-form red apedal sandy loams derived from Pretoria Group sedimentary rocks. Land use is mixed dryland maize, soybean, and

Corresponding Author:
Lungelo Maseko
Department of Environmental
Science, University of Pretoria,
Pretoria, South Africa

Cattle grazing, with buffer vegetation established 3-8 years prior to monitoring.

Materials and Methods

Materials

Twenty-four monitoring stations were installed in paired upstream-downstream configuration across eight grass buffers (widths 3-25 m), eight tree/shrub corridors (5-30 m), and eight constructed wetlands (10-35 m surface length). Each station consisted of an ISCO 6712 automatic sampler triggered by a tipping-bucket rain gauge at 5-mm rainfall thresholds. Composite storm-event samples were collected in acid-washed 1-L polyethylene bottles and transported on ice to the University of Pretoria Water Sciences Laboratory within 6 hours [10].

Methods

Total suspended solids were determined gravimetrically (APHA Method 2540D). Total nitrogen was measured by persulfate digestion followed by cadmium reduction (APHA 4500-N), and total phosphorus by ascorbic acid colorimetry after persulfate

digestion (APHA 4500-P) [11]. Sediment and nutrient reduction efficiency was calculated as (upstream load - downstream load) / upstream load × 100. Relationships between buffer width and reduction efficiency were modeled with second-order polynomial regression. Differences among buffer types were tested by one-way ANOVA with Tukey's HSD (*p*<0.05) in R 4.3.2 [12].

Field experimental design

Buffers were selected to represent the range of widths and establishment ages present in the catchment, with at least two replicates per width class within each buffer type. Paired stations were placed 5 m upstream and 5 m downstream of each buffer's outer edge, oriented perpendicular to the dominant flow direction. Monitoring ran from 1 January to 31 December 2023, capturing the full wet season (October-March) and dry season (April-September). A total of 387 storm-event samples were collected across all stations during the monitoring year.

Results

Table 1: Mean sediment and nutrient reduction efficiency (%) by buffer type at 10-m width

Buffer Type	Sediment (%)	Total N (%)	Total P (%)
Grass strip	63.8±7.4	58.3±8.2	62.1±7.8
Tree/shrub corridor	51.2±8.9	51.7±9.1	54.9±8.4
Constructed wetland	68.4±6.7	67.4±7.6	71.8±6.9

Values are mean±SD across all storm events during January-December 2023 (n = 387 total events). Wetland values represent 10-m surface flow length equivalent

Table 2: Polynomial regression parameters for buffer width versus sediment reduction

Buffer Type	a	b	R ²	p-value
Grass strip	-0.087	4.21	0.94	< 0.001
Tree/shrub corridor	-0.071	3.89	0.91	< 0.001
Constructed wetland	-0.063	3.47	0.93	< 0.01

Model: Reduction (%) = a × width² + b × width + c. Negative 'a' confirms diminishing returns at greater widths

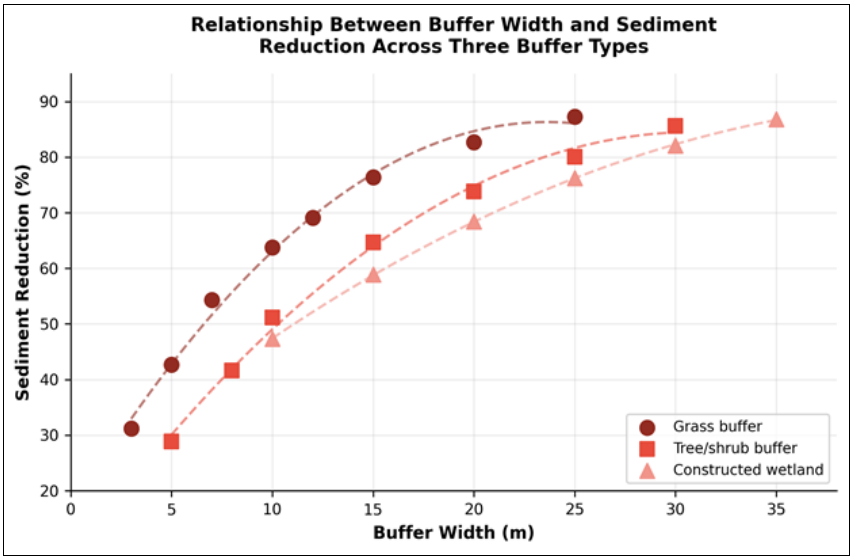


Fig 1: Relationship between buffer width and sediment reduction efficiency for three conservation buffer types in the upper Apies catchment

Comprehensive interpretation

Constructed wetlands delivered the highest reduction for all three parameters sediment, nitrogen, and phosphorus though they required more land than grass strips to achieve equivalent

flow interception. Buffer width was the strongest predictor of sediment trapping (*R*² = 0.91-0.94), with diminishing gains beyond 20 m. Grass strips offered the best trapping efficiency per unit width, making them attractive where land is limited.

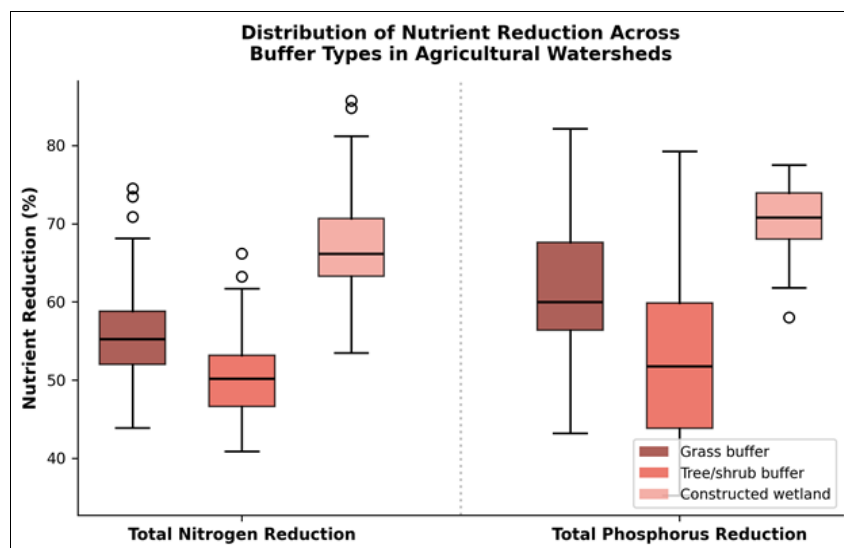


Fig 2: Distribution of total nitrogen and total phosphorus reduction across three buffer types over the 12-month monitoring period

Discussion

The sediment reduction values recorded here fall within the 50–85% range reported in international reviews of riparian buffers [3]. Grass strips at 10 m width achieved 63.8%, which matches closely with plot-scale data from KwaZulu-Natal showing 59–67% under similar rainfall intensity [5]. The lower performance of tree/shrub corridors likely reflects their wider stem spacing, which permits concentrated flow to bypass the root zone during peak runoff events.

Constructed wetlands outperformed linear buffers for phosphorus retention (71.8% vs 54.9–62.1%), consistent with findings from temperate constructed wetlands in the Chesapeake Bay region [6]. The extended hydraulic residence time in wetland cells allows both sedimentation and biological assimilation of dissolved P, a process that simple vegetative strips cannot replicate. That said, wetlands occupy more land per unit of stream frontage and require periodic sediment removal to maintain capacity.

The diminishing-return pattern beyond 20 m width has practical value: it suggests that widening buffers past this threshold yields marginal benefit while taking productive land out of use. For resource-constrained farmers in the Highveld, 10–15 m grass strips may represent the best trade-off between water quality protection and crop area.

Conclusions

This research demonstrated that conservation buffers can meaningfully reduce sediment and nutrient transport from agricultural watersheds in the upper Apies catchment near Pretoria. Constructed wetlands delivered the highest overall retention, reaching 68.4% for sediment and 71.8% for total phosphorus, but required more land than grass strips. Grass buffers at 10–15 m width offered the most efficient trapping per unit area, making them practical for smallholders facing land constraints. Buffer width was the strongest determinant of performance, though returns diminished beyond 20 m for all buffer types. A combined approach grass strips on steep slopes, tree corridors along riverbanks, and small wetlands at tributary junctions would capture both particulate and dissolved fractions across different landscape positions. Future research should track buffer performance over multiple years to account for vegetation maturity, sediment accumulation, and maintenance needs.

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