

Evaluating runoff water quality from green roofs compared to conventional roofs

Évaluation de la qualité de l'eau de ruissellement des toits verts comparée à celle des toits conventionnels

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RÉSUMÉ

Cette étude évalue la qualité du ruissellement provenant d'une toiture végétalisée extensive âgée de 10 ans (GR) et d'une toiture traditionnelle en céramique (CR) durant l'hiver sec à São Paulo (climat Cwa). Trois événements pluviométriques supérieurs à 40 mm, représentant toutes les pluies significatives de 2024, ont été analysés. Les échantillons de ruissellement ont été caractérisés pour l'azote (NH_4^+ , NO_2^- , NO_3^- , NTK, N total), le phosphore, la matière organique (DBO, COT), le pH et les matières en suspension (MES). La GR a présenté des concentrations plus élevées en nitrate, azote total et phosphore que la CR, suggérant une libération persistante de nutriments dans un système ancien en période de faible activité végétale. Le COT a diminué au fil de la saison, tandis que les variations du ratio DBO/COT indiquent des changements dans la biodégradabilité de la matière organique. Les MES sont restées très faibles sur la GR, confirmant la capacité de filtration du substrat. Ce travail constitue la première référence pour la qualité du ruissellement hivernal d'une GR âgée au Brésil.

ABSTRACT

This study investigates runoff water quality from an extensive 10-year-old green roof (GR) compared with a conventional ceramic roof (CR) during the dry winter season in São Paulo, Brazil (Cwa climate). Three rainfall events (>40 mm) occurring in 2024 were monitored, representing all significant winter storms. Runoff was analyzed for nitrogen species, phosphorus, organic matter (BOD, TOC), pH and total suspended solids (TSS). The GR showed higher concentrations of nitrate, total nitrogen and phosphorus relative to the CR, indicating continued nutrient release in aged systems under low vegetation activity. TOC progressively decreased over the season, whereas BOD/TOC ratios suggested shifts in organic matter quality. The CR exhibited greater first-flush effects after long dry periods, whereas TSS remained consistently low in the GR, highlighting effective particulate retention. This dataset provides a first reference for dry-season runoff quality from an aged GR in Brazil, contributing to the characterization of nutrient and carbon dynamics in subtropical conditions.

KEYWORDS

Green roofs, Nutrients, Rainwater reuse, Runoff, Water quality

1 INTRODUCTION

Urbanization increases impervious areas and diminishes natural infiltration, intensifying storm runoff volumes and pollutant transport. Conventional roofs rapidly convey rainfall to drainage systems with little retention capacity, increasing hydraulic load and pollutant wash-off (Maniquiz-Redillas et al., 2022). Green roofs (GRs) have emerged as a nature-based solution capable of mitigating these impacts through retention, delayed discharge, and partial pollutant filtering. Their adoption is expanding in Brazil, especially in São Paulo—a city that regularly faces dry winter periods, water scarcity, and summer storm peaks, making rainwater harvesting an attractive complementary water source (Gobatti & Leite, 2023; Osawa et al., 2025).

However, uncertainties remain regarding the water quality of aged GR runoff, particularly under dry-season conditions, when antecedent dry periods can prolong surface pollutant accumulation and vegetation activity is reduced. Most available Brazilian studies evaluated newly installed roofs or rainy-season behavior, leaving little understanding of (i) aged systems (>10 years), (ii) runoff quality under seasonal drought, and (iii) direct comparison with conventional ceramic roofs.

This study addresses this gap by monitoring and comparing runoff quality from a >10-year-old extensive GR and a conventional tile roof (CR) during the dry winter season in São Paulo (Cwa climate). The objective is to characterize nutrient dynamics, organic matter behavior, pH and suspended solids. To our knowledge, this represents the first dry-season dataset from an aged GR in Brazil, contributing valuable baseline information for future benchmarking of long-term performance.

2 METHODS AND METHODOLOGY

The study was conducted at the University of São Paulo, located in São Paulo, Brazil, a region characterized by a humid subtropical climate. This climate is marked by hot summers, dry winters, and average annual precipitation of 1,654 mm, distributed over approximately 139 rainy days. Climatological data from 1990 to 2020 indicate a mean annual temperature of 20.4°C, with seasonal variations ranging from a minimum of 16.4°C to a maximum of 26.1°C (INMET, 2021). The rainy season spans from October to March, while the dry season occurs during the winter months.

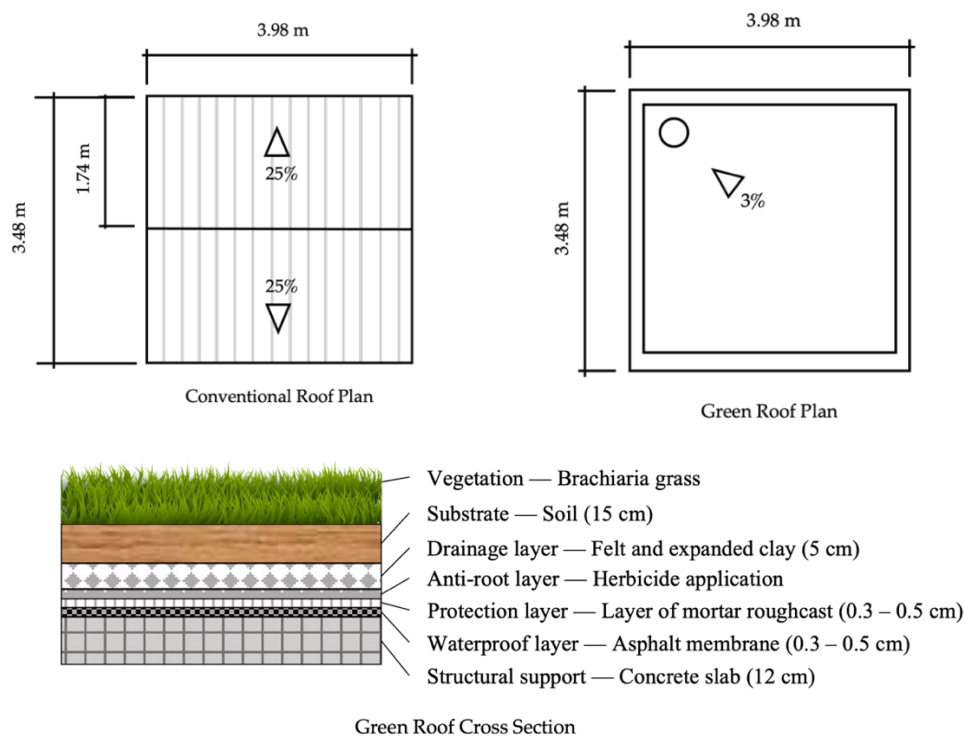


Figure 1 – Green roof (GR) and conventional roof (CR): frontal photo, plan with slope and drainage, and layer schematic with thicknesses

The GR pilot system was built in 2011 and covers an area of 11.42 m² with a gentle 3% slope. Its multilayer structure includes an asphalt waterproofing membrane, a mechanical protection layer (mortar and felt), an anti-root barrier, a drainage layer of expanded clay, and a 15 cm soil substrate. Originally composed of vegetable soil, the substrate was later enriched with worm humus to increase its organic matter content. The roof is vegetated with *Brachiaria decumbens*. The CR shares the same base structure but is finished with ceramic tiles, a traditional material in Brazil. This roof has a steeper slope of 25° and a surface area of 8.92 m². Runoff was collected from only one side, resulting in an effective monitored area of 4.46 m². Additional construction and design details of both prototypes are illustrated in Figure 1.

Water samples were collected from both the GR and the CR during three rainfall events that occurred in the dry season of 2024. These events were selected as they represent the most significant precipitation occurrences during this typically dry period in São Paulo. Meteorological data, including precipitation depth, rainfall event duration, air temperature, and rainfall intensity, were obtained from a local meteorological station.

Runoff samples were collected using an autosampler that captured the first hour of runoff during each rainfall event, providing insight into the initial stages of the runoff, commonly referred to as the "first flush" (Castro et al., 2020).

The water quality parameters analyzed in the runoff samples included:

- pH, Total Suspended Solids (TSS), BOD, TOC, Total Phosphorus (TP), Nitrate (NO₃⁻), Nitrite (NO₂⁻), Ammoniacal Nitrogen (NH₃-N), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN).

Samples were sent to a certified external laboratory, where standard analytical methods were employed to ensure accuracy and reliability of the results.

3 RESULTS AND DISCUSSION

The monitored events revealed distinct differences in runoff quality between the GR and CR. The green roof consistently exhibited elevated concentrations of TKN, nitrate, and TP, likely resulting from substrate aging and ongoing biogeochemical transformations. Conversely, the GR generally functioned as a sink for ammoniacal nitrogen, except during short antecedent dry periods conducive to ammonification. Furthermore, the GR effectively reduced TSS concentrations and contributed to pH stabilization. While both roof types occasionally presented elevated levels of BOD, TOC, and nutrients, the green roof showed a consistent capacity to enhance runoff water quality relative to the conventional system.

Rainfall events occurred under long antecedent dry conditions, characteristic of São Paulo's winter. The first event followed a short dry spell, while the second and third followed more than 30 days without significant rainfall. These differences influenced pollutant mobilization intensity.

Nutrient behaviour differed between systems. Across events, the GR consistently presented higher total nitrogen and nitrate concentrations than the CR, suggesting internal nutrient cycling and release from substrate organic matter. Ammoniacal nitrogen peaked during the first event and decreased as dry periods lengthened, while nitrate increased later in the season. TP was also higher in GR runoff than in CR runoff, though within ranges expected for aged systems reported in literature.

Organic matter patterns also reflected seasonal influence. The GR presented higher TOC early in the season, declining by August. BOD varied over time in both roofs, with the CR showing pronounced first-flush responses after long dry periods. While both roofs generated organic carbon loads, temporal dynamics indicated stronger internal processing in the GR and wash-off dependence in the CR.

Suspended solids behaviour clearly distinguished systems. TSS in the GR remained consistently below detection, indicating effective substrate filtration, while the CR exhibited an acute TSS peak following prolonged dry conditions. pH remained mostly neutral to slightly acidic, with the GR showing a slightly more variable range due to substrate leaching.

Collectively, results indicate that even after more than a decade in operation, the GR continues to regulate particulate matter effectively while releasing moderate nutrient and organic carbon loads, especially under extended drought. CR runoff was chemically less enriched but prone to episodic sediment flushing.

Rainfall scarcity did not prevent runoff generation, demonstrating that rainwater harvesting remains feasible in winter, although water quality characteristics differ from rainy-season behaviors described in previous Brazilian

studies. Comparison with literature shows this aged GR produced lower nutrient loads than newly installed systems, but greater nitrate and phosphorus than most year-round monitoring, reinforcing the importance of seasonal context. The diversity in climates, roof configurations, and methodologies across Brazilian studies further highlights the need for long-term and regional monitoring to establish national performance references.

4 CONCLUSION

This study highlights the nuanced behavior of nutrients and organic matter in runoff from an aged green roof compared to a conventional ceramic-tiled roof in a humid subtropical environment. The green roof exhibited higher levels of specific nutrients due to internal substrate processes but also demonstrated an ability to mitigate ammoniacal nitrogen, stabilize pH, and reduce suspended solids. Although occasional nutrient peaks were observed, the green roof showed notable potential to improve urban runoff quality. These findings reinforce the importance of appropriate design and maintenance practices to optimize green roofs as effective components of sustainable urban water management systems.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the research support provided by the Engineering Departments of Civil Construction, the Department of Hydraulic and Environmental Engineering of the Polytechnic School of the University of Sao Paulo and the Hydraulic Technological Center Foundation (FCTH).

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