

A Mixed-Methods Approach to Assessing Ecosystem Service Regulation in Higher Education Campuses: The Pontificia Universidad Javeriana Cali Case

Une approche mixte pour évaluer la régulation des services écosystémiques dans les campus universitaires : le cas de l'Université pontificale Javeriana de Cali

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RÉSUMÉ

Le projet analyse les services écosystémiques régulateurs générés par l'infrastructure verte et bleue du campus de l'Université Javeriana de Cali. À travers l'imagerie satellite et des mesures de terrain, il évalue comment les zones végétalisées et les systèmes aquatiques réduisent la température de surface et atténuent les îlots de chaleur urbains. L'étude inclut l'analyse du NDVI, de la température de surface (LST) et de leur évolution dans le temps. Des mesures microclimatiques autour des zones humides permettent d'identifier l'effet du type de surface, de l'ombrage et de la distance au plan d'eau sur la température locale. Le projet examine également le stockage de carbone à travers des équations allométriques adaptées aux forêts tropicales. Grâce à l'intégration de données spatiales, climatiques et biologiques, le campus est présenté comme un laboratoire vivant permettant d'évaluer l'efficacité des Solutions fondées sur la Nature (SfN) à petite échelle urbaine. Ces résultats constituent une base scientifique solide pour orienter la planification écologique du campus. Ils démontrent aussi le potentiel reproductible de ces approches dans d'autres institutions urbaines.

ABSTRACT

This study evaluates three key regulating ecosystem services: water regulation, thermal regulation, and carbon sequestration within the campus of Pontificia Universidad Javeriana de Cali. The campus' ecological infrastructure, composed of wetlands, a constructed lagoon, and dense tropical vegetation including bamboo provides an ideal setting to assess multifunctional Nature-based Solutions (NbS). A mixed-methods approach was applied, integrating GIS-based analysis, satellite remote sensing, biophysical modeling, and field measurements. Runoff was modeled using hydrological simulations and the campus monitoring system. Thermal regulation was assessed through LST data complemented by on-site temperature measurements; and carbon storage was estimated using allometric equations and tree inventory data. Results show clear spatial variability in ecosystem service provision, highlighting areas with strong multifunctional potential for climate adaptation. The study also underscores the benefits of combining remote sensing, modeling, and field data to evaluate ecosystem services at a campus scale, offering a framework applicable to similar urban institutional environments.

KEYWORDS

Nature-based Solutions (NbS), ecosystem services, water regulation, thermal regulation, carbon sequestration

1 INTRODUCTION

The case study is located on the campus of Pontificia Universidad Javeriana de Cali, a 45-hectare institution in southern Cali, Colombia. The campus combines built areas with extensive green and blue spaces that provide key ecosystem services (Fraga *et al.*, 2022). A central feature is the constructed lagoon system connected to internal wetlands, which supports stormwater regulation, infiltration, biodiversity, and flood mitigation under the city's tropical monsoon climate. These water bodies are complemented by diverse tropical vegetation, notably bamboo (*Guadua* spp.), which offers dense canopy cover, rapid biomass production, and strong contributions to carbon storage and microclimate regulation (Gratani *et al.*, 2006). Together, the aquatic and vegetative systems form a multifunctional ecological infrastructure that enhances thermal comfort, air quality, and overall environmental performance (Venter *et al.* 2020). This configuration makes the campus an ideal living laboratory for evaluating small-scale Nature-based Solutions and their potential applicability in similar urban contexts.

2 MATERIALS AND METHODS

2.1 Water regulation

The methodology combines data processing, hydraulic modeling, and field verification. The rainfall series was cleaned in Python to standardize time steps and extract events with at least ten minutes of continuous precipitation. System geometry was digitized from a topographic TIFF, and infiltration, roughness, and storage losses were parameterized in SWMM based on technical literature and Colombian standards. Ten rainfall events recorded by the campus rain gauge were compared with the water-level sensor installed in the lake behind the “Lagos” (Illustration 1) building at Pontificia Universidad Javeriana Cali.

2.2 Thermal regulation

The thermal regulation potential of NbS within the University campus was assessed through a mixed-method approach combining remote sensing data analysis and temporal trend evaluation. This methodology focused on quantifying the surface temperature reduction effect provided by green-blue infrastructure over time.

2.2.1 Satellite remote sensing method

Using Landsat satellite imagery, two key variables were extracted for the 2000–2024 period: Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI). These indices were generated in Google Earth Engine to ensure consistent temporal analysis and normalization despite climate variability. The analysis focused on computing changes in surface temperature (Δ LST) together with variations in NDVI to assess the cooling effect produced by vegetation and aquatic systems. The study followed the methodology from the article “Using satellite imagery to investigate Blue-Green Infrastructure establishment time for urban cooling”, which links long-term NDVI trends with reductions in surface temperature.

Using the approach of Tzavali *et al.* (2023), the Cooling Establishment Time (CET) was defined as the year when a statistically significant and sustained decrease in Δ LST occurred, together with a stable or increasing NDVI trend—indicating when Nature-based Solutions (e.g., bamboo planting or wetland restoration) began effectively mitigating urban heat. Pre- and post-intervention periods were then identified to assess temporal changes in Δ LST, and moving average smoothing was applied to both NDVI and Δ LST time series to reduce variability and highlight long-term ecological cooling patterns.

Spatial distribution maps of Δ LST were created to identify cooling hotspots. The campus was analyzed using a 900-meter buffer zone, allowing detection of local effects surrounding the lagoon, wetlands, and vegetation clusters. Zones near green infrastructure showed a higher incidence of negative Δ LST, suggesting localized cooling.

2.2.2 Onsite surface temperature monitoring

To assess the wetlands' role in mitigating urban heat on the Javeriana University Cali campus, outdoor air temperature was measured around four wetlands located near the Lagos and Acacias buildings. Each wetland included four sampling points (Illustration 1) classified by surface type (hard/soft) and shade level (none/partial/full). Measurements were taken from 9:00 a.m. to 3:00 p.m. using the *FlirOne* thermal imaging camera app, calibrated with a thermohygrometer through one-minute readings. All data (temperature, time,

surface type, shade, and images) were compiled into a database. The analysis examined thermal patterns by comparing mean and median temperatures, creating box plots, and using bar charts to evaluate temperature differences with distance.



Illustration 1 Maps of the campus wetlands and location of the sampling areas

2.3 Carbon sequestration

Initially, the study considered using i-Tree Eco to estimate tree-related environmental benefits; however, the tool was unsuitable because more than half of the campus tree species were unrecognized and local environmental data was unavailable. Therefore, allometric equations were selected as an alternative method to estimate biomass and carbon stock.

Three model types were evaluated—using DBH (Diameter at Breast Height) only, DBH with wood density, and DBH with wood density plus height. Due to limited wood-density information, the DBH-only model was chosen. Equations appropriate for tropical dry and premontane humid forests were applied, and above-ground biomass estimates were converted to carbon using a standard 50% biomass-to-carbon factor. To convert this carbon value into CO₂ equivalent (CO₂e), a factor of 3.67.

This approach expresses carbon storage in standard climate impact units. Carbon capture over time was estimated using species-specific DBH growth rates from i-Tree (fast: 1.09 cm/yr, moderate: 0.84 cm/yr, slow: 0.58 cm/yr). Using these rates and maximum species heights, biomass accumulation was modeled over time, incorporating growth slowdowns after trees reach 80% of their maximum height. This allowed identifying species with the highest long-term sequestration potential and those still in early growth stages.

3 RESULTS

3.1 Water regulation

Across the ten analyzed rainfall events, the lake's water level showed no significant variation, even during high-intensity storms. This stability is attributed to the downstream gate, which functions as a fixed hydraulic control and keeps the internal water level nearly constant. Thus, under the current configuration, the water level is governed by the outlet control rather than rainfall variability.

3.2 Thermal regulation

3.2.1 Onsite surface temperature monitoring

The Acacias wetland plot shows a clear increase in the difference between surface and air temperature as the distance from the wetland grows (see illustration 2). Close to the wetland (5.7 m and 1.9 m), thermal contrasts remain low due to the wetland's cooling influence and the presence of softer or shaded surfaces. At intermediate distances (9.3 m), temperature differences become more noticeable, reflecting a weakening of the cooling effect. The highest contrast occurs at 35.7 m, where an unshaded hard surface produces the most pronounced

temperature differential, signaling a localized micro-heat island.

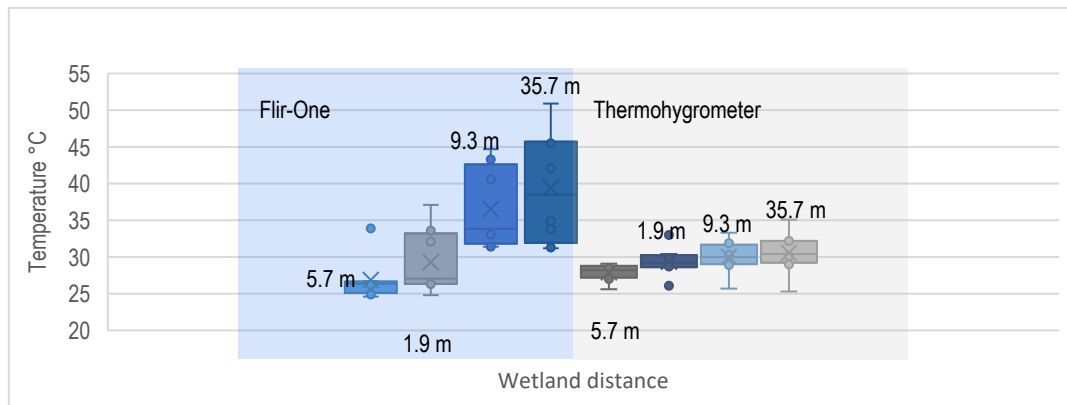


Illustration 2 Temperature boxplots based on FLIR One and thermohygrometer readings, categorized by wetland distance

3.3 Carbon sequestration

Carbons sequestration rate varies according to the species, the most common specie in the field is the *Caesalpinia peltophoroides Benth* (common name “Acacia Amarilla”) followed by *Mangifera indica L.* (“Palo de mango”) and *Ficus benjamina L* (“Caucho Benjamin”). The campus has the potential to capture 13-14 Co2eqTon in 4 years (see Illustration 2).

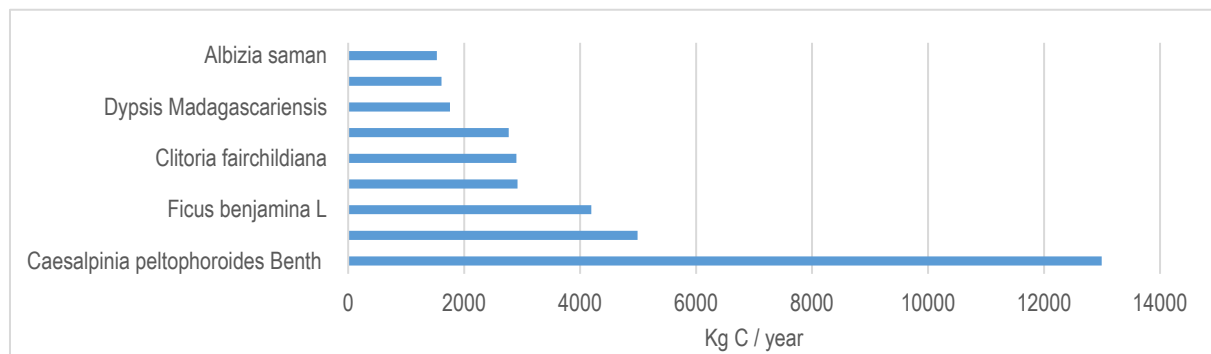


Illustration 3 Total carbon sequestration by species (Year 4)

4 CONCLUSIONS

The integrated assessment of water, temperature, and carbon on the Javeriana Cali campus shows that the green-blue infrastructure provides measurable regulating benefits. The lagoon maintains stable water levels even during intense rainfall, reflecting consistent hydraulic performance and the interaction between ecological components and engineered structures. Vegetation and wetlands produce a detectable cooling effect, reducing surrounding land surface temperatures. Additionally, the campus vegetation demonstrates meaningful carbon-sequestration potential, particularly in fast-growing or high-biomass species.

LIST OF REFERENCES (only for scientific papers)

- Fraga JPR, Okumura CK, Guimarães LF, Arruda RN de, Becker BR, de Oliveira AKB, et al. Cost-benefit analysis of sustainable drainage systems considering ecosystems services benefits: case study of canal do mangue watershed in Rio de Janeiro city, Brazil. *Clean Technol Environ Policy* 2022; 24:695–712. <https://doi.org/10.1007/s10098-021-02221-w>.
- Gratani L, Varone L. Carbon sequestration by *Quercus ilex L.* and *Quercus pubescens Willd.* and their contribution to decreasing air temperature in Rome. *Urban Ecosyst* 2006;9:27–37. <https://doi.org/10.1007/s11252-006-5527-2>.
- Tzavali, A. & Paravantis, John & Mihalakakou, Giouli & Fotiadi, Aleksandr & Stigka, Eleni. (2015). Urban heat island intensity: A literature review. 24. 4537-4554.
- Venter ZS, Krog NH, Barton DN. Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. *Sci Total Environ* 2020; 709:136193. <https://doi.org/10.1016/j.scitotenv.2019.136193>.