

Sustainability Strategies Based on Water Footprint Calculation in a University Campus

Kattya Intriago-Mejía

Escuela Superior Politecnica del Litoral

Denisse Nieto-Anchundia

Escuela Superior Politecnica del Litoral

Bethy Merchan-Sanmartín

betgumer@espol.edu.ec

Escuela Superior Politecnica del Litoral

Research Article

Keywords: Sustainability proposals, evapotranspiration, environmental impact, water resource, efficiency, circular economy.

Posted Date: August 3rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10204338/v1>

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Additional Declarations: No competing interests reported.

SUSTAINABILITY STRATEGIES BASED ON WATER FOOTPRINT CALCULATION IN A UNIVERSITY CAMPUS

Authors:

Intriago-Mejía, Kattya^a [kainmeji@espol.edu.ec]; Nieto-Anchundia, Denisse^a
[dnieto@espol.edu.ec]; Merchán-Sanmartín, Bethy^{*a,b} [betgumer@espol.edu.ec]

Affiliations:

^a Facultad de Ingeniería Ciencias de la Tierra, Escuela Superior Politécnica del Litoral, ESPOL, Campus
Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador;

^b Geoscience Institute, Federal University of Pará, Belém, 66075-110, Brazil.

*Corresponding author:

Bethy Merchan-Sanmartín

E-mail: betgumer@espol.edu.ec

<https://orcid.org/0000-0001-5103-0355>

Tel: +593 95 895 0980

Abstract

This article seeks to determine the Water Footprint by processing primary and secondary information and to propose sustainability strategies on a university campus that support its identification and reduction. The methodology was: i) Analysis of primary and secondary data. ii) Comparison of the results with other universities. iii) Proposal of strategies to reduce the water footprint in the most critical areas of the campus. ESPOL, with a water footprint of 75.11 per capita, despite having a relatively high value compared to some other universities, remains within what is considered “normal.” The proposed sustainability strategies were: a) effectively raising awareness among everyone, not only students; b) efficient water management through smart irrigation and reuse; c) fostering an environmental culture and responsible resource management on campus. Implementing these strategies will help the university become more sustainable and reduce water use in areas under the most significant pressure on water resources.

Keywords

Sustainability proposals, evapotranspiration, environmental impact, water resource, efficiency, circular economy.

1. INTRODUCTION

The concept of the water footprint was proposed by Arjen Y. Hoekstra in 2002, who introduced it as a tool to link consumption with global water use; it was later revised by Chapagain and Hoekstra in 2004 [1], who indicate that it is an indicator that measures the total volume of freshwater used to produce goods and services, considering both direct and indirect use [2], [3]. This encompasses concept several components for its determination, and its importance lies in the environmental impact they have.

Its components are: blue water footprint (surface and groundwater), green water footprint (rainwater incorporated into products), and grey water footprint (the water required to dilute pollutants) [4], [5]. These three elements contribute to the “*direct part*” of the total calculation; additionally, the “*indirect part*” must be considered, which refers to the water required for the production of a good, object, or service and is generated by the production of all the elements present in the area under study [6], such as, for example, a university campus.

The water footprint in universities enables quantification of direct and indirect water use. It is measured as a sustainability metric derived from ISO 14046, the first international standard in force for its assessment [7]. Similarly, “*The Water Footprint Assessment Manual: Setting the Global Standard*” was developed as a complement to the Global Water Footprint Standard launched by the Water Footprint Network in 2011, to provide scientific rigor, transparency, and comparability in water use assessment [8].

The value obtained when calculating the water footprint represents the total volume of water used, both directly and indirectly, to produce goods and services. It enables assessment of the pressure that human activities exert on water resources [9]. This value must be interpreted within the context of local water availability and the capacity of ecosystems to regenerate this resource. A high water footprint may indicate unsustainable water use, whereas a low one may reflect efficient management or lower demand [9], [10].

In this context, high value indicates intensive use of water resources, which may place pressure on local water sources and contribute to water scarcity. On the other hand, a low value suggests effective water management, although a low water footprint does not always reflect sustainable practices if water quality is overlooked [11]. Therefore, interpreting the water footprint requires an analysis that considers both the quantity and quality of the water used [11], [12]

At Escuela Superior Politécnica del Litoral (ESPOL), a “Sanitary Sewerage Master Plan” [13] had already been completed, which served to diagnose the situation and analyse future wastewater production and treatment demands. It proposes the sustainable use of effluents for garden irrigation, promoting a circular economy. Similarly, a “Drinking Water Master Plan” was developed,

which analysed drinking water consumption between 2017 and 2020, finding that average consumption was 37% compared to a 63% loss rate [14].

Although the advantages of responsible water use are widely recognized, most university campuses lack detailed information on their water footprint and do not have strategies to reduce it [15]. At the ESPOL, despite ongoing efforts, a comprehensive assessment of its Water Footprint (WF) has not yet been conducted, which limits decision-making aimed at promoting sustainability within its facilities.

This lack of data prevents identifying critical consumption areas, establishing intervention priorities, and generating environmental awareness among the university community. Thus, the central problem lies in the lack of quantified, context-specific information on the Water Footprint at ESPOL, which would enable the design of effective water sustainability strategies on campus. In this way, it is planned to calculate it through the analysis of primary and secondary information to propose sustainability strategies that reduce the impact of water consumption on the university campus.

2. MATERIALS AND METHODS

Since complete data from 2023 is available, the analysis is carried out for that year. Below, Fig. 1 presents the methodological scheme:

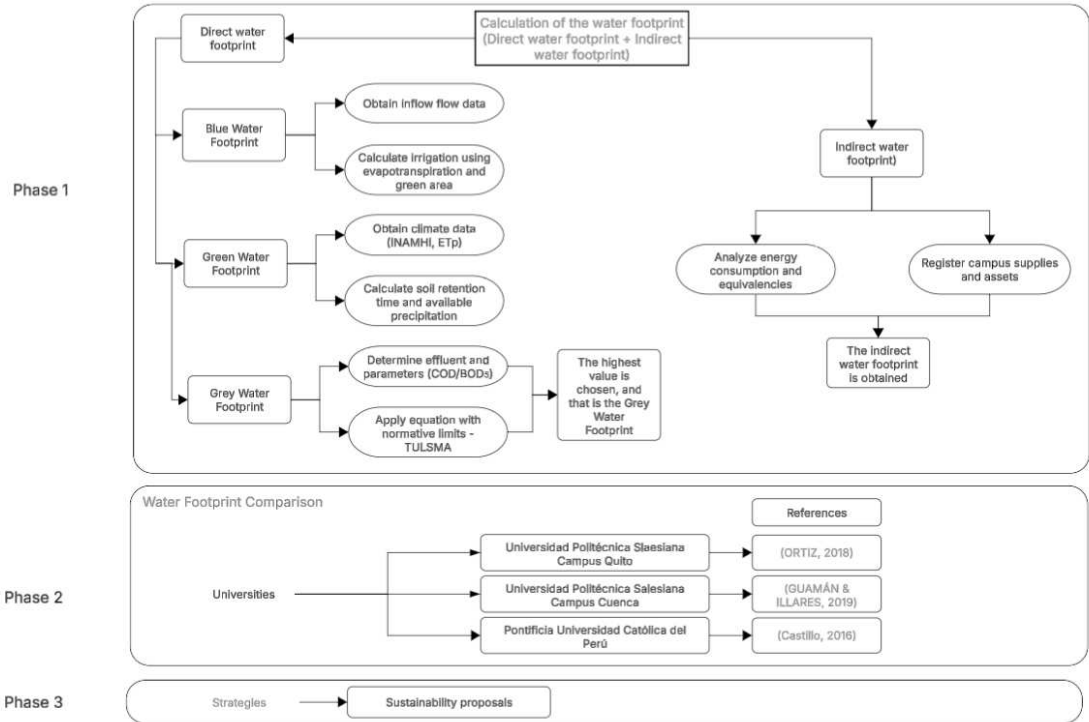


Fig. 1 Methodological scheme

2.1. Phase 1: Calculation of the Water Footprint

In Phase 1, the Total Water Footprint was obtained, comprising the direct and indirect water footprints. The direct water footprint includes the values of the grey, green, and blue water footprints, with potable water flow as a key factor. The indirect water footprint encompasses the water consumption involved in the production of the inventory of university supplies and goods, as well as the total energy consumption.

2.1.1. Blue Water Footprint

In this section, the blue water footprint was calculated by summing the water consumption that does not return to the sewage system, which in this case corresponds to 10% of the potable water inflow to the university (water consumption) [16], plus the irrigation water footprint (WF irrigation), where the latter is calculated using Equation 1.

$$WF_{\text{irrigation}} = ET_{\text{blue}} \times \text{ESPOL green area} \quad \text{EQUATION 1}$$

Where:

- ET_{blue} : is the crop evapotranspiration supplied by irrigation water. This value is obtained from FAO (Food and Agriculture Organization of the United Nations) data and programs such as CROPWAT, considering the sector, crop, and soil [8]. Through the crop water requirement module analyzed over one year, this value is obtained by converting units (mm → m³/ha).

2.1.2. Green Water Footprint

In this section, the green water footprint was calculated. Its calculation considered the water stored in the soil, evapotranspiration, and water incorporated into green areas. The evapotranspiration value was taken from a study conducted in the engineering area of ESPOL in 2022, which indicates that the maximum evapotranspiration value is 3.64 mm/day [17]. The evapotranspiration value is expressed in mm/day, so it must be converted to m/year before multiplying by the total green area of 96,429 m².

Next, for soil storage, Table 1 was used, which includes the Water retention capacity (Sa); the annual average value of 140 mm/m was taken. This value must be converted to meters and then multiplied by the total green area mentioned in the previous paragraph.

Parameters	Average values	Maximum values
ET (mm/day)	5.494	5.6
Water retention capacity (Sa)	9.6 (140 mm/m)	9.6 (140 mm/m)

Root depth (D)	60 cm	60 cm
Allowable depletion (da)	29.4 mm	26.94 mm
Irrigation interval (i)	5 days	4 days
Net Sheet (dn)	27.47	27.47

Table 1. Irrigation agronomic scheduling [18]

Finally, the incorporation of water into plants (Plantae) was considered, which is calculated following the steps below according to the methodology [8]:

1. Obtain the total precipitation volume by multiplying the total green area of the campus by the annual precipitation (1,565 mm [19]).
2. Calculate the available water, which is assumed to correspond to 70% of the total precipitation volume and is used by the plants, because not all precipitation becomes water available for plants. Water is lost through runoff, soil infiltration, evaporation, and other processes.
3. Determine the water incorporation rate, assuming 75% of the available water is incorporated by plants, including grass, into their tissues.
4. Finally, the water stored in the soil, evapotranspiration, and incorporation into green areas are summed to obtain the total Green Water Footprint.

2.1.3. Grey Water Footprint

In this section, the value of the grey water footprint was determined using Equation 2.

$$WF_{grey} = \frac{Effl * C_{effl} - Abstr * C_{act}}{C_{max} - C_{nat}} \quad \text{EQUATION 2}$$

Where:

- $Effl$: Effluent value, considered to be 80% of the flow entering the campus, is the annual value.
- C_{effl} : Effluent concentration, which in this case was analyzed using the COD and BOD₅ values obtained from this and other publications.
- $Abstr$: value of the flow entering the campus, annual.
- C_{act} : Concentration of pollutant of the previously mentioned inflow, which, according to Interagua regulations, in Guayaquil, must be zero.
- C_{max} : Maximum permitted discharge concentration of pollutant. According to Table 9 of the *Texto Unificado de la Legislación Secundaria del Ministerio del Ambiente de Ecuador* (TULSMA), the discharge limit to a freshwater body for COD is 200 mg O₂/l, while for BOD₅ it is 100 mg O₂/l.
- C_{nat} : Natural concentration of pollutant in water found in the environment (freshwater), 20 mg O₂/l [8].

In this case, two studies were analyzed in different sectors of the campus (Admissions, MBR Engineering), where the Grey Water Footprint was taken as the higher value.

2.1.4. Indirect Water Footprint

Finally, this section considered the water footprint generated by annual energy consumption, supplies (*tangibles necessary for everyday activities, such as paper, folders, printer ink, towels, etc.*), and furniture and equipment present on campus (*desks, chairs, computers, printers, etc.*). Table 2 presents energy consumption values from 2019 to 2023, with 2023 of primary interest.

MONTH	2019	2020	2021	2022	2023
JANUARY	1,050,000	1,108,800	499,800	554,400	953,400
FEBRUARY	1,163,400	1,100,400	508,200	575,400	963,600
MARCH	982,800	781,200	550,200	680,400	886,200
APRIL	1,062,600	441,000	445,200	735,800	870,000
MAY	1,226,400	478,800	504,000	835,800	1,058,400
JUNE	1,226,400	462,000	541,800	806,400	1,054,200
JULY	1,134,000	462,000	567,000	722,400	1,066,800
AUGUST	1,071,000	449,400	567,000	886,800	1,016,400
SEPTEMBER	970,200	483,000	617,400	819,000	1,014,000
OCTOBER	907,200	529,200	672,000	869,400	1,142,400
NOVEMBER	1,134,000	567,000	701,400	1,208,400	1,054,200
DECEMBER	1,155,000	483,000	709,800	1,120,200	1,203,600
TOTAL kWh	13,083,000	7,345,800	6,883,800	9,710,400	12,436,200

Table 2. Electricity consumption kWh – Gustavo Galindo Velasco Campus

Thus, Table 3 shows the Water Footprint equivalencies of energy sources, which, for the study site, correspond to hydroelectric energy.

Primary energy carriers	Average water footprint (m³/GJ)
Wind energy	0
Uranium	0.09
Natural gas	0.11
Coal	0.16
Solar active space heat	0.27
Crude oil	1.06
Hydropower	22.3

Table 3. Water Footprint Equivalencies of Energy Sources[8]

On the other hand, for the Water Footprint generated by supplies (*paper, bathrooms*) and goods (*furniture, equipment*), the inventory of items available on campus in the year of analysis was used. The sum of all these values gives the total Water Footprint.

2.2. Phase 2: Comparison with Other Universities

In Phase 2, the values of blue, green, grey, indirect, and total water footprints obtained from previous studies of four other South American universities were compared. These were: Universidad Politécnica Salesiana Quito Campus [20],

Parameters	Value	Unit
Annual rainfall	1.565	m
Total green area	96,429	m ²
Total precipitation volume	150,911.40	m ³
% Available water	0.7	
Available water	105,638	m ³
% Incorporation into the plant	0.75	
Incorporation of water	79,228.48	m ³
Total Green Water Footprint	220,844.10	m ³

Table 6. Water incorporation in plants data

On the other hand, in obtaining the Grey Water Footprint value, the BOD₅ and COD parameters were evaluated in both the Admissions and the Engineering areas. Table 7 and Table 8 summarize the resulting values.

Admissions							
COD							
Year	Effl [m ³ /year]	Ceffl [mg/l]	Abstr Q [m ³ /year]	Cact [mg/l]	Cmax [mg/l]	Cnat [mg/l]	WF _{grey} [m ³ /year]
2018	271,079	298	338,849	0	200	40	504,885
2019	223,119	298	278,899	0	200	40	415,560
2020	172,451	298	215,564	0	200	40	321,190
2021	183,568	298	229,460	0	200	40	341,895
2022	148,343	298	185,429	0	200	40	276,289
2023	205,642	298	257,052	0	200	40	383,007
BDO							
Year	Effl [m ³ /year]	Ceffl [mg/l]	Abstr Q [m ³ /year]	Cact [mg/l]	Cmax [mg/l]	Cnat [mg/l]	WF _{grey} [m ³ /year]
2018	271,079	105	338,849	0	100	20	355,791
2019	223,119	105	278,899	0	100	20	292,844
2020	172,451	105	215,564	0	100	20	226,342
2021	183,568	105	229,460	0	100	20	240,933
2022	148,343	105	185,429	0	100	20	194,700
2023	205,642	105	257,052	0	100	20	269,905

Table 7. Water Footprint Values in Admissions for BOD₅ and COD

Engineering - MBR							
CDO							
Year	Effl [m ³ /year]	Ceffl [mg/l]	Abstr Q [m ³ /year]	Cact [mg/l]	Cmax [mg/l]	Cnat [mg/l]	WF _{grey} [m ³ /year]
2018	271,079	36	338,849	0	200	40	60,993
2019	223,119	36	278,899	0	200	40	50,202
2020	172,451	36	215,564	0	200	40	38,802
2021	183,568	36	229,460	0	200	40	41,303
2022	148,343	36	185,429	0	200	40	33,377
2023	205,642	36	257,052	0	200	40	46,269
BDO							
Year	Effl [m ³ /year]	Ceffl [mg/l]	Abstr Q [m ³ /year]	Cact [mg/l]	Cmax [mg/l]	Cnat [mg/l]	WF _{grey} [m ³ /year]
2018	271,079	18	338,849	0	100	20	60,993
2019	223,119	18	278,899	0	100	20	50,202
2020	172,451	18	215,564	0	100	20	38,802
2021	183,568	18	229,460	0	100	20	41,303
2022	148,343	18	185,429	0	100	20	33,377
2023	205,642	18	257,052	0	100	20	46,269

Table 8. Water Footprint Values in Engineering-MBR for BOD₅ and COD

As mentioned earlier, the higher Water Footprint value between BOD₅ and COD was used to calculate the average of the values obtained in Admissions and Engineering for the analysis. In this case, the results are presented in Table 9.

Year	WF _{grey} ESPOL [m ³ /year]
2018	282,939
2019	232,881
2020	179,996
2021	191,599
2022	154,833
2023	214,638

Table 9. Grey Water Footprint Values 2018 – 2023

For the Indirect Water Footprint, the values shown in Table 10 were obtained, including paper supplies, bathroom supplies, furniture, equipment, and energy.

Indirect Water Footprint - 2023	
Raw Materials	WF [m ³ /year]
Paper supplies	289.63
Bathroom supplies	182.31
Furniture and fixtures	2,104.58

Equipment	11,653.40
Energy	998,370.15
Total	1,012,600.06

Table 10. Indirect Water Footprint Value

In Phase 2, Fig. 2 was developed for analysis and to establish an appropriate range of Water Footprint (WF) values. This figure compares three other Latin American universities, each with the following populations: Pontifical Catholic University of Peru Campus (35,915), Salesian Polytechnic University Cuenca Campus (7,725), Salesian Polytechnic University Quito Campus (7,648), and ESPOL (20,804).

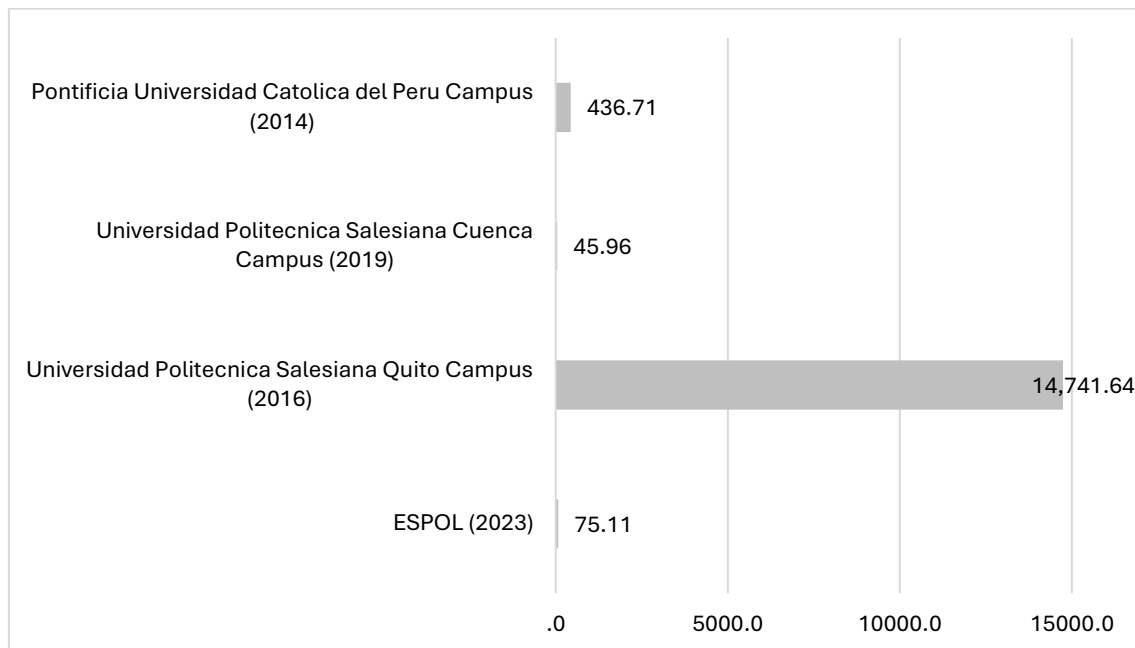


Fig. 2 Comparison of Total Water Footprint per capita (m³/year/person)

Finally, in Phase 3, sustainability strategies were proposed to reduce the calculated Water Footprint, such as:

1. Using irrigation systems with moisture sensors and drip irrigation ensures that only the necessary amount of water is applied to green areas, optimizing water use and reducing waste.
2. Reusing greywater from sinks or showers for irrigation and cleaning outdoor areas reduces demand on the public water supply, contributing to the sustainability of the water cycle.
3. Replacing conventional bulbs with LED (Light Emitting Diode) technology. Installing motion sensors and using energy-efficient electrical equipment helps reduce energy consumption, thereby reducing the indirect water footprint associated with electricity generation.
4. Promoting environmental education programs on responsible water and energy use among the university community, raising awareness of

sustainable habits. Continuous sustainability education enhances the effectiveness of strategies in the short-, medium-, and long-term.

5. Using natural ventilation instead of artificial systems and thermal insulation to minimize the water footprint associated with energy consumption.

6. Incorporating sustainable construction criteria in university buildings, such as green roofs, vertical gardens, and natural lighting, improves energy efficiency and rainwater management.

The strategy of implementing relative humidity sensors, air and soil temperature sensors, and soil moisture content monitoring has proven helpful in controlling irrigation water volume, detecting anomalies in drip emitters, and pressure variations. Compared to other studies using traditional irrigation systems, this method achieved approximately 15% water savings. Drip irrigation and automated systems not only reduce water consumption but also maintain or improve crop productivity [23], [24].

Natural ventilation systems and adapting spaces to reduce artificial ventilation have advantages such as lowering energy costs, improving occupant wellbeing by reducing respiratory issues caused by stale air, and decreasing operational costs. This benefits environmental impact reduction and the water footprint associated with energy consumption [25]. Also, LED lights with motion sensors that gradually reduce luminosity consume less than half as much energy and have a longer lifespan, thereby reducing pollution [26].

4. DISCUSSION

The proposed sustainability strategies are premised on determining the total Water Footprint (WF) value. Significantly, identifying the critical points of water consumption will facilitate reducing this aggregate value. This value is vitally because the results presented in this article establish an initial baseline value (75.11 / per person). At ESPOL, the most substantial contribution to the Water Footprint was identified as deriving from energy consumption. This finding underscores that electricity usage constitutes a critical factor in the campus's overall water impact. This information guides the pursuit of a more sustainable approach on the university campus, encompassing not only reduced water consumption but also optimised energy use and sustainable waste management.

The integration of innovative technologies, such as sensors for irrigation control and automated drip systems, maximises water use efficiency, facilitates the detection of operational failures, and yields savings of up to 15%. Similarly, implementing natural ventilation and using LED lighting with motion sensors reduces energy consumption, operational costs, and environmental impacts.

Concurrently, these measures enhance occupant comfort and reduce the Water Footprint.

The Water Footprint (WF) value determined for ESPOL is notably low when benchmarked against other universities, which reported significantly higher values, such as the Salesian Polytechnic University of Quito (14,741.64 / per capita) and the Pontifical Catholic University of Peru (436.71 / per capita). This comparison was conducted while accounting for various influencing factors, including the study year, institutional population, and resulting WF per capita.

The primary limitations encountered in the WF calculation for ESPOL originated from the availability and precision of the input information. Across the broader context of Latin American (LATAM) universities, there is a general insufficiency of available data, making it challenging to identify and retrieve relevant indexed, peer-reviewed publications. Furthermore, a methodological constraint was sourcing population data for the benchmark universities from different years, which often did not align temporally with the Water Footprint assessment year used for ESPOL.

5. CONCLUSIONS

This study determined the Water Footprint using primary and secondary data to propose sustainability strategies for reducing it on a university campus.

Determining the Water Footprint is key to identifying areas and processes with the highest water consumption, both in academic and administrative activities.

This information not only allows optimization of water use and reduction of operational costs but also promotes a culture of sustainability among students, faculty, and staff. Calculating the Water Footprint helps identify critical points of water consumption and pollution on campus, facilitating the implementation of concrete actions to reduce it.

The following sustainability strategies are proposed to reduce the impact of water consumption:

1. Use low-consumption sprinklers that adjust water output based on soil moisture and employ moisture sensors to ensure watering occurs only when necessary. Implement drip irrigation systems in green areas and gardens to significantly reduce water waste.
2. Promote the installation of systems to capture and reuse greywater from bathrooms, kitchens, and laundry for irrigation and outdoor cleaning.
3. Replace conventional bulbs with low-energy LED lights, use motion sensors in low-traffic areas to light only when needed, and promote the use of low-energy-labeled appliances and electronic devices.
4. Provide environmental education and awareness for students and staff, encouraging sustainable habits.

- 314 5. Implement responsible waste management and select materials with a
315 lower water footprint.
316 6. Apply natural ventilation and thermal insulation in buildings to reduce the
317 need for heating or air conditioning, indirectly decreasing the water
318 footprint associated with energy consumption.
319 7. Plan the campus and new constructions using sustainable criteria,
320 incorporating green infrastructure and passive lighting and ventilation
321 systems.

322 Implementing these strategies will not only reduce the campus' Water Footprint
323 but also strengthen a sustainability culture, contributing to the university's
324 environmentally responsible development.

325 **6. FUNDING STATEMENT**

326 No applicable. This study received no funding.

327 **7. ETHICS AND CONSENT TO PARTICIPATE DECLARATIONS**

328 Not applicable

329 **8. CONSENT TO PUBLISH DECLARATION**

330 Not applicable

331 **9. CLINICAL TRIAL NUMBER**

332 Not applicable.

333 **10. DATA AVAILABILITY STATEMENT (DAS)**

334 All data generated or analysed during this study are included in this published
335 article and its supplementary information files.

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