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Botanical Garden-Focused Blue Infrastructure Strategies at Balıkesir University's Çağış Campus*

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Abstract

This study investigates how blue infrastructure supports the natural water cycle to enhance ecosystem resilience and climate adaptation, proposing spatial analyses, ecological design strategies, and a holistic model for sustainable campus planning. The research area selected is the Botanical Garden of Balıkesir University's. The research is based on a four-stage methodological approach. In the first stage, climatic, topographic, and geological data were generated in ENVI-met simulation model and Geographic Information System environment. Subsequently, Landsat data from 1993 and 2024 were processed using the controlled classification method to obtain land use/cover maps. In the final stage of the method, design proposals for the blue infrastructure within the botanical garden boundaries were made, utilising the results of all analyses. In addition, the results of all analyses, design proposals related to the blue infrastructure within the botanical garden boundaries were made. It is anticipated that this study will contribute to the implementation of sustainable blue infrastructure designs at the Balıkesir University Botanical Garden, thereby mitigating the effects of climate change and enhancing the efficient use of rainwater.

Keywords: *Sustainable landscape planning, blue infrastructure, nature-based solutions, Geographic Information Systems*

*This study is not included in the study group that requires TR Index Ethics Committee Approval.

1. Introduction

Climate change is causing water crises on a global scale and contributing to the daily depletion of water resources. The depletion of water resources has negatively impacted ecosystems, the services they provide, and natural resources (DeNicola et al., 2015; Brown & Berry, 2022). The United Nations World Water Development Report (2020) states that global water consumption has increased sixfold over the last century and that this increase continues at an annual rate of approximately 1% (Wang et al., 2022). This situation not only leads to numerous adverse outcomes such as loss of biodiversity, drought, flooding, and negative impacts on human health, but also seriously threatens the functioning of human systems (Wu et al., 2023). Goal 15: Life on Land, under the United Nations' 2030 Sustainable Development Goals (SDGs), emphasises the need to protect, restore and sustainably manage water ecosystems and wetlands in sub-goals 15.1 and 15.3. In line with these objectives, it has been specifically stated that land degradation, desertification and drought must be combated by 2030, and that the comprehensive protection of natural ecosystems is a critical element in achieving sustainable development goals (UN Department of Economic and Social Affairs SDG, 2025). Sustainable Development Goal 6.2 (SDG 6.2) aims to ensure universal and equitable access to safe and affordable drinking water for all by 2030 (UN Turkey SDG, 2025). However, by 2030, water scarcity is expected to affect a large part of Turkey, and by approximately half of that time, the problem is expected to reach quite serious proportions (Lehner et al., 2001; Polat, 2023; Ayanoğlu & Demirel, 2023). For this reason, resources must be used rationally through sound decision-making. If sufficient improvements and investments are not made in our country and globally in the context of the water crisis, and if sufficient attention is not paid to the issue throughout this process, it is anticipated that living standards for all living beings will deteriorate further (Mengü & Akkuzu, 2008).

Ecological planning and design principles based on the natural structure of the landscape and ecological processes play a significant role in creating climate-resilient and sustainable cities today. This approach requires urban systems to be considered not only in physical terms but also in terms of their ecological and socio-climatic dimensions. Thus, the regeneration capacity of urban ecosystems is preserved, and spatial development models compatible with natural cycles are supported. In this context, landscape design is considered not only as an urban aesthetic tool but also as a planning discipline that ensures sustainability and the continuity of ecosystem services. Functions such as rainwater management, microclimatic balance, biodiversity and strengthening ecological connectivity make landscape systems fundamental components of blue-green infrastructure (Mat et al., 2009; Demiroğlu et al., 2017). In order to achieve sustainability in the decision-making process for natural resources and ecosystems, another ecosystem-based planning method based on the principle of protecting natural resources has emerged as blue-green infrastructure planning, which aims to achieve a balance between conservation and use (Parlak & Atik, 2020; Karlı & Artar, 2021; Ortaçeşme & Altunbey, 2022). Blue-green infrastructure, recognised as a nature-based approach, leverages the natural capacity of ecological infrastructure systems to sustain or enhance them by incorporating elements of natural systems without causing harm, restoring, or advancing them, thereby producing high-quality, durable, and cost-effective infrastructure (Kutay & Oğuz, 2020; Uy & Tapnio, 2021; Büyükbayraktar et al., 2022; Kamer & Arslan, 2022). Furthermore, these systems play a significant role in reducing the urban heat island effect to reasonable levels by mitigating peak temperatures caused by urbanisation and climate change (Avdan & Jovanovska, 2016; Ünal & Akyüz, 2018). Examples of blue-green infrastructure methods include green walls, rainwater ditches, green roofs, rain gardens, porous pavements, infiltration ditches, and filter strips. The most recommended green infrastructure technology is the rain garden system, which is effectively used in the treatment of rainwater runoff (bioretention systems) (Alyaseri et al., 2017). Rain gardens function like small sponges, using a soil-based medium to absorb rainwater into the ground, remove pathogens, and play an effective role in reducing nutrients, organic components, and various heavy metals present in rainwater runoff (Malaviya et al., 2019). These applications help mitigate the effects of climate change, increase the amount of usable water, support the reuse of rainwater, and contribute to energy efficiency (Ünal & Akyüz, 2018).

One of the most important application areas of blue-green infrastructure systems is botanical gardens (Bowler et al., 2025). Botanical gardens are not only strategic core areas of blue-green infrastructure systems due to their scientific research, education and plant conservation functions, but also because of their capacity to produce multidimensional ecosystem services such as ecological restoration, carbon sequestration, rainwater management, regulation of soil moisture balance and microclimatic improvement. These areas function as the intersection point of natural and artificial ecosystems, directly contributing to the restructuring of the hydrological cycle, the support of groundwater recharge, and the sustainability of biotic diversity (Sanusi & Jalil, 2021; Dushkova et al., 2025). Additionally, botanical gardens are considered important nature-based laboratory areas for strengthening urban ecological connectivity, increasing carbon storage potential, and testing the feasibility of climate-adaptive landscape strategies. In this respect, botanical gardens play a critical role as multifunctional green infrastructure nodes that serve not only to protect biological diversity but also to create sustainable urban ecosystems (Konaklı & Önder, 2011; Karaşah & Var, 2016). When considered specifically in the context of university campuses, botanical gardens form the spatial counterpart of the sustainable campus vision, offering an integrated system design in terms of energy, water and biodiversity management. Thus, these areas fulfil both ecological restoration and environmental education functions and become one of the most concrete examples of blue-green infrastructure-focused planning approaches that strengthen the applicability of the sustainable campus model (Tanfer & Yener, 2020; Ardalı & Köksal, 2022).

This study aims to develop and plan blue infrastructure strategies and present different design proposals, focusing on the botanical garden located at Balıkesir University's Çağış Campus. Furthermore, the study aims to evaluate the role of the botanical garden in sustainable campus planning and within the framework of nature-based solutions.

2. Materials and Metodology

The Materials and Methodology section comprises the subsections Materials and Methodology. The Methodology subsection further encompasses Obtaining Climatic and Geographical Data, Land Use/Land Cover Change Analysis and Accuracy Assessment, Examination of Soil Analyses, Proposing Blue Infrastructure Measures, and Evaluating Results, each of which is discussed in detail.

2.1. Materials

The research area selected for this study is the Botanical Garden of Balıkesir University. The Botanical Garden at the Çağış Campus of Balıkesir University has been assessed as an area with high blue infrastructure potential due to its topographical features and ecological diversity. Furthermore, the campus's recreational use opportunities and its structure, which is conducive to the applicability of ecologically based planning approaches, were decisive factors in selecting this area. The Çağış campus is the university's main campus, located approximately 17 km from the city centre of Balıkesir, on the Bigadiç road, within the boundaries of the Çağış and Paşaköy neighbourhoods, covering a large area of 5,000 acres. The botanical garden selected as the research area (Figure 1) is located within the boundaries of the Altıeylül district of the Çağış Campus and covers an area of 19.19 hectares.

Figure 1. Balıkesir University Botanical Garden location map

The district of Atıeylül has a mild and warm climate influenced by the Mediterranean climate. According to the Köppen-Geiger climate classification, this climate is defined as 'Csa' type, which is dry and hot in summer and rainy and cool in winter. The botanical garden generally takes the shape of a rectangle extending from the north/north-west to the south/south-east. Images of the study area are shown in Figure 2.

Figure 2. Photographs of the area of Balıkesir University Botanical Garden

2.2. Metodology

The method of this study, which aims to develop blue infrastructure strategies with the goal of a sustainable campus at Balıkesir University Çağış Campus Botanical Garden, consists of five stages.

2.2.1. Obtaining Climatic and Geographical Data

The first stage of the methodology involved generating climatic and geographical datasets for the study area using Geographic Information Systems (GIS) and the ENVI-met microclimate simulation model. Within this framework, spatial analyses were conducted to produce slope, elevation, aspect, and geological maps, while land surface temperature distributions for 1993 and 2024 were analyzed using the ENVI-met model. In addition, long-term precipitation data were obtained from the Balıkesir Regional Directorate of Meteorology. Due to the unavailability of earlier records for the Çağış region in the institutional archive, the precipitation analysis was limited to the 2000–2024 period, representing the longest continuous dataset available for the study area. These precipitation data were organized into tables and subsequently interpreted to evaluate rainfall variability and its implications for stormwater management strategies within the botanical garden design.

The ENVI-met microclimate simulation model was used in the study to examine changes in land surface temperatures between 1993 and 2024. ENVI-met is a three-dimensional microclimate simulation model widely used to analyze environmental conditions at the local scale, particularly within urban and landscape environments. The model allows the detailed examination of microclimatic parameters such as surface temperature, air temperature, humidity, wind flow, and radiation interactions between vegetation, buildings, and ground surfaces. Due to its high spatial and temporal resolution, ENVI-met is particularly effective in assessing small-scale thermal environments and surface temperature variations within specific landscape areas (Yeo et al., 2021; Mutlu & Yılmaz, 2024). In this study ENVI-met microclimate simulations, the analysis was conducted for 13:00 (1:00 PM) in July, which generally corresponds to the period when surface temperatures reach their highest levels during the daytime due to maximum solar radiation and accumulated heat on urban surfaces during the summer season. Selecting this time period allows for a more accurate assessment of peak thermal conditions within the study area. Table 1 presents the input parameters used in the ENVI-met model for the study area.

Table 1. ENVI-met model input data

Location	Climate type	Simulation time	Simulation duration	Spatial resolution
Balıkesir/Çağış	Transition ecosystem	July	24 hours	2m x 2m x 2m

For the creation of the elevation, slope and aspect map, DEM data obtained from the United States Geological Survey Earth Explorer (https://earthexplorer.usgs.gov/) database was used. Slope values were classified into five categories (0–5%, 5.1–10%, 10.1–15%, 15.1–20%, and >20%), where slope is expressed as percent rise. This classification is based on slope groups that are widely used in the literature and are accepted for the assessment of environmental processes such as soil erosion, surface runoff, land use planning, and vegetation distribution. Furthermore, data obtained from the General Directorate of Mineral Research and Exploration (MTA) was utilised to reveal the geological characteristics of the study area, and a geological map was created with the assistance of GIS.

2.2.2. Land Use/Land Cover Change Analysis and Accuracy Assessment

Remote Sensing (RS) techniques and Geographic Information Systems (GIS) were used together to analyse land use/cover changes between 1993 and 2024.

Remote sensing enables the accurate determination of spatial and temporal changes in land cover by providing objective and repeatable data production, allowing for temporal comparisons of satellite images covering large areas (Zhang et al., 2022; Hu et al., 2025). This method allows for the reliable discrimination of different land classes, such as agricultural areas, forest cover, settlement areas, and water surfaces, based on their spectral characteristics. GIS, on the other hand, ensures that the classification results obtained from remote sensing data are effectively used in spatial analysis, querying, statistical evaluation, and mapping processes. Thus, the integration of UA and GIS enables both the monitoring of long-term changes and the detailed presentation of the spatial distribution of these changes (Das & Angadi, 2022; Kumar et al., 2024).

In this study, spatial and temporal changes in land use were analysed using Landsat satellite images from 1993 and 2024 obtained from the U.S. Geological Survey Earth Explorer database. For both years, Landsat satellite images from May, one of the periods when vegetation development is most intense and pronounced, were used in the analyses. The characteristics of the satellite images used are shown in Table 2.

Table 2. Characteristics of satellite images

Satellite	Sensor	Pathh-Row Values	Date	Data Source
Landsat 5	TM	180-033	1993/05/20	Landsat 4-5 TM C2 Level-2
Landsat 8	OLI-TIRS	181-032	2024/05/25	Landsat 8 OLI/TIRS C2 Level-2

At this stage, the study area has been divided into four main land use/cover classes: pastures, settlement areas, forested areas, and agricultural areas, utilising Landsat satellite imagery. During the classification process, the supervised classification method, which is widely used in the literature and is based on statistical principles, was preferred. Within this scope, the Maximum Likelihood method was applied as the classification algorithm.

The Maximum Likelihood algorithm calculates the probability of pixel values belonging to each class by considering the statistical distribution properties (probability density functions) of each class, thereby assigning the pixels to the class with the highest probability value. This approach demonstrates strong performance in distinguishing between classes that exhibit similarity across spectral bands, thereby achieving a high level of accuracy (Liu et al., 2011; Sun et al., 2013).

Accuracy assessment is considered an important evaluation stage in classification processes (Avcı et al., 2023). The primary objective of performing accuracy analysis on classified maps is to quantitatively determine how accurately pixels are assigned to their respective land use classes. However, before conducting an accuracy assessment, potential sources of error must be identified (Farhadpour et al., 2024). During the accuracy assessment process, it is generally assumed that the differences between the classified image and the reference data are primarily caused by classification errors. In this study, an error matrix was generated to evaluate the accuracy of the supervised classification results, and previously selected reference pixel points were utilized. The error matrix approach is one of the most commonly used methods in accuracy assessment studies (Güzel & Yeşil, 2025).

Within the scope of the study, 40 reference points were determined for each of the four land use classes (pastures, settlement areas, forested areas, and agricultural areas). Accordingly, 160 points were assigned for a single year and a total of 360 points for images representing two different years. The comparison between reference points and previously generated classification points was conducted using the Spatial Analyst Tools in ArcMap 10.8. Producer’s and user’s accuracy values were subsequently derived using the Error Matrix method, which is frequently employed in classification accuracy analysis. Producer’s accuracy represents the ratio of correctly classified pixels in a given class to the total number of reference pixels for that class. User’s accuracy was calculated as the proportion of correctly classified pixels relative to the total number of pixels classified within the same category. Overall accuracy was determined by dividing the total number of correctly classified pixels by the total number of reference pixels (Altıner, 2022).

2.2.3. Examination of Soil Analyses

Three different soil samples taken from the field were analysed by experts at the Balıkesir University Science and Technology Application and Research Centre laboratories to obtain data on the permeability of the soil structure in the study area. The results obtained were used to interpret the soil structure. The main reason for taking samples from three different locations was to cover different micro-environmental conditions that would represent the basic physical characteristics of the study area. The samples taken were selected to reflect the soil structure prevailing throughout the garden, the effects of vegetation cover, and the heterogeneity within the area. In this study, soil samples were taken from a depth of 16–20 cm. The reason for this is that the specified depth range reflects the active soil layer representing the root zone, free from the effects of the surface organic layer, and that the hydraulic properties determining the movement of water within the soil profile are largely shaped within this horizon.

2.2.4. Proposing Blue Infrastructure Measures and Evaluating Results

At this stage of the method, design criteria for blue infrastructure in the botanical garden were determined. Following the evaluation of all analyses conducted within the scope of the study, design proposals were made for incorporating blue infrastructure applications into the design. Blue infrastructure applications were addressed under headings such as rain gutters, rain gardens, rainwater plant strips, permeable surfaces, etc. Figure 3 illustrates the methodological flowchart of the study.

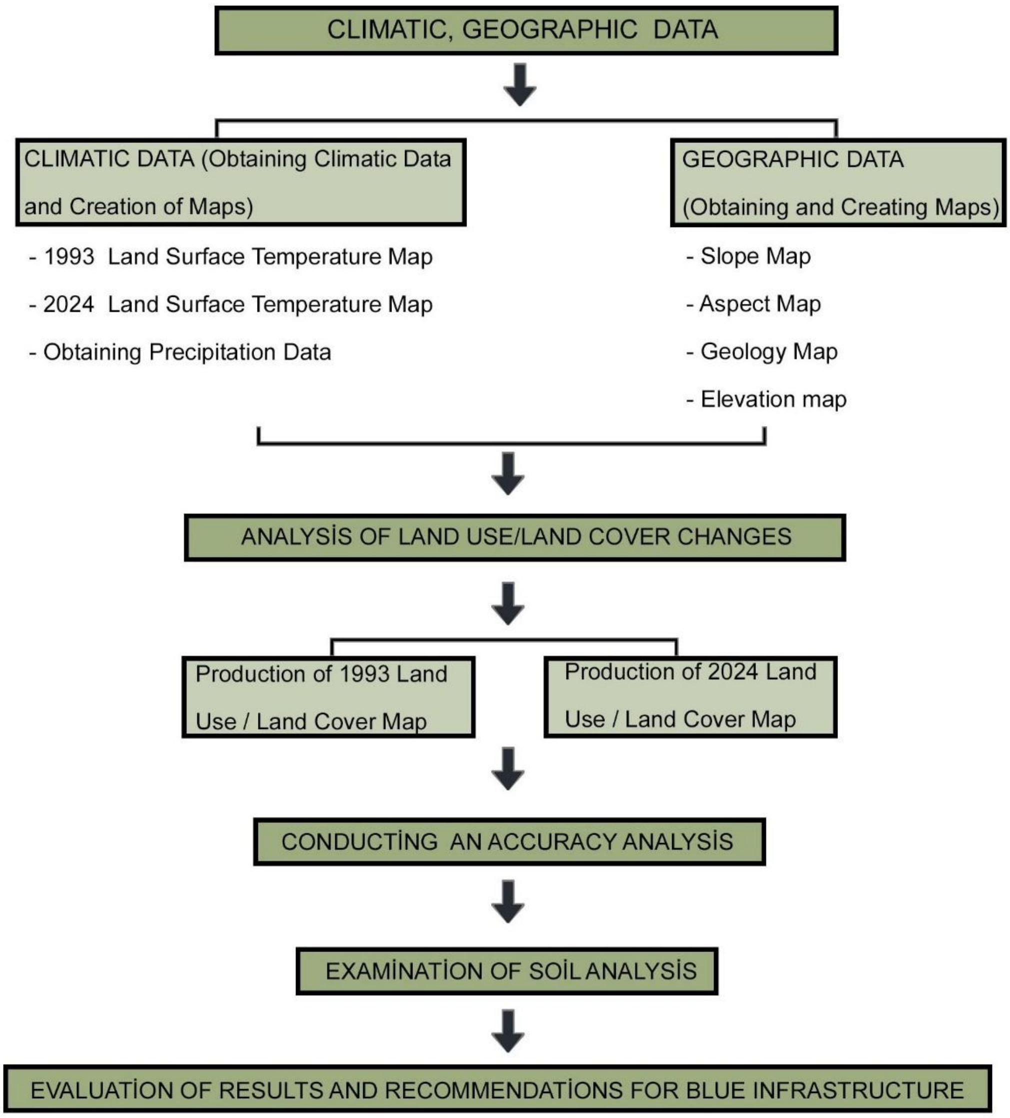

Figure 3. Method flow diagram

3. Findings and Discussion

In this section, the headings "Evaluation of Analyses" and "Evaluation of the Design" are presented and discussed.

3.1. Evaluation of Analyses

This section presents findings regarding the climatic and geographical structure of Balıkesir University's Çağış Campus and its surroundings. The findings encompass slope, elevation, aspect, geology, precipitation, ground surface temperature, temporal changes in land use, and soil analysis evaluations. A large part of the Çağış Campus is located within a slope range of 0.5% to 10% (Figure 4). When the elevation map of the study area is examined, the broader landscape shows an elevation range between 115 m and 397 m, indicating a heterogeneous topographic structure. The botanical garden site itself is situated between 150 m and 200 m, representing a mid-elevation zone within the regional topographic gradient. This moderate elevation range provides suitable conditions for nature-based stormwater management strategies, enabling the integration of rain gardens and rain trenches (bioswales) that can capture, convey, and infiltrate surface runoff while supporting diverse planting compositions within the botanical garden design.

This area, which has a gently and moderately sloping topography, provides advantages in terms of infrastructure design. An examination of the aspect characteristics of the Botanical Garden (Figure 4) reveals that the area consists largely of south and south-west facing slopes, which brings with it increased temperature and water requirements during the summer months. In contrast, small areas facing north and northeast provide microclimatic diversity within the garden. This allows for the diversification of plant species with different ecological requirements and provides important clues for both the management of heat island effects and water efficiency strategies for the botanical garden.

The geological structure of the area in which Balıkesir University Çağış Campus is located (Figure 4) consists of two main units. Quaternary-aged alluvial deposits, which cover most of the campus, consist of loose sediments and possess high permeability and weakly consolidated structures, making them important for groundwater recharge and drainage. These units also have limited bearing capacity and may require ground improvement works. The Miocene sandstone–limestone formations observed in extensive areas to the east and west of the settlement are lithological units that exhibit more solid, impermeable–semi-impermeable properties. The limestone texture can facilitate karstic void formation and groundwater flow.

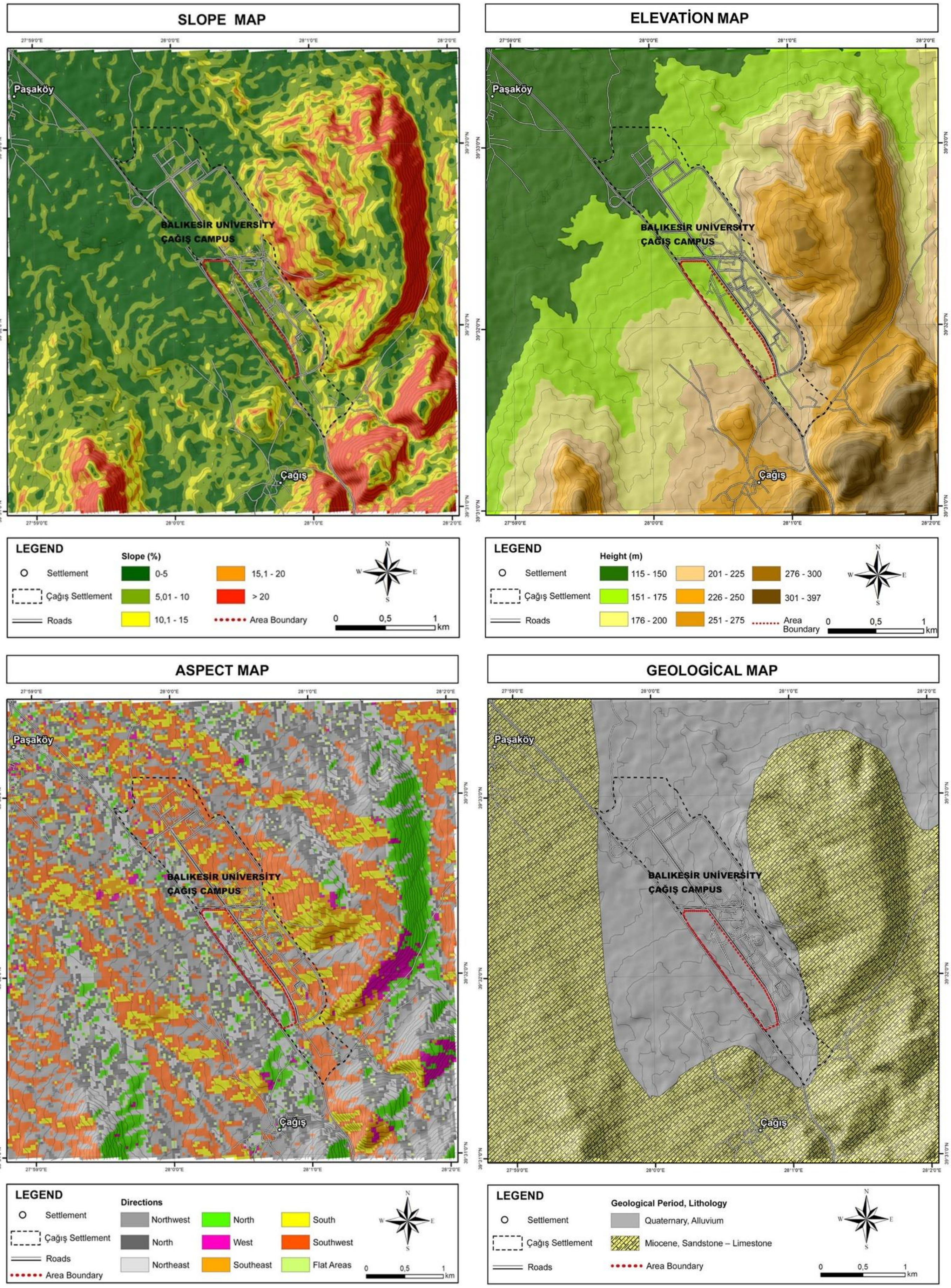

Figure 4. Slope, elevation, aspect and geology map of the study area and its immediate surroundings

According to the monthly and annual average precipitation data obtained from the Balıkesir Regional Directorate of Meteorology, the annual average precipitation values recorded in the Çağış region between

2000 and 2024 indicate significant interannual variability in precipitation magnitüde (Figure 5). The values range from approximately 11.68 mm to 28.16 mm, demonstrating fluctuations in rainfall conditions over the study period. Such variability suggests that the hydrological response of the landscape, particularly surface runoff generation, may vary depending on annual precipitation patterns. In this context, the integration of nature-based stormwater management strategies, including rain gardens and rain trenches, offers an effective approach to regulate runoff dynamics within the botanical garden area. These systems function by promoting infiltration, temporary water retention, evapotranspiration, and biofiltration, thereby reducing runoff pressure on conventional drainage systems while enhancing the ecological and hydrological performance of the landscape.

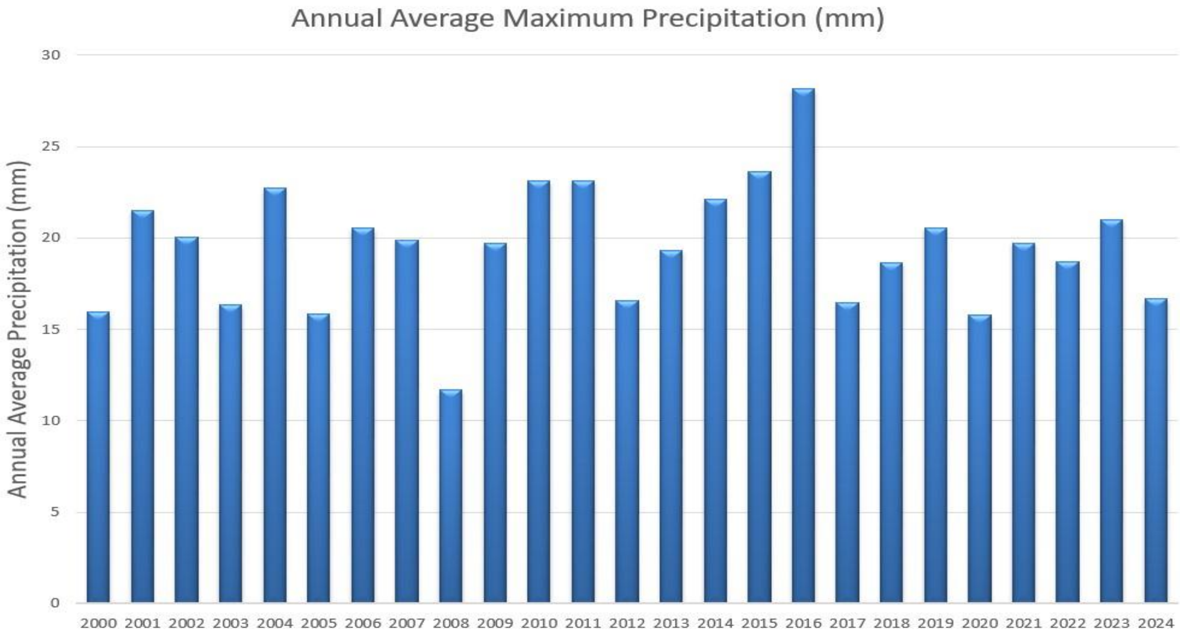

Figure 5. Annual average preciptation in the Çağış region (2000-2024)

Surface temperature maps for the Balıkesir University Çağış Campus and its surroundings for the years 1993 and 2024 are shown in Figure 6. The study compares surface temperature values between 1993 and 2024. The comparative analysis clearly reveals that significant changes have occurred in the thermal characteristics of the study area over the examined period. The simulation results for 1993 indicate that surface temperatures were generally lower and exhibited a more spatially homogeneous distribution. The dominance of blue and light green tones on the map suggests that cooler surface conditions prevailed across a large portion of the study area. This pattern can be associated with more favorable microclimatic conditions during that period, which were likely related to lower building density, higher vegetation cover, and a greater proportion of permeable surfaces.

In contrast, the simulation results for 2024 demonstrate a considerable increase in surface temperatures throughout the study area. The widespread presence of yellow, orange, and red tones indicates a substantial rise in thermal values. According to the simulation outputs, surface temperatures range from a minimum of 16.98 °C to a maximum of 50.09 ° Higher temperature values are observed particularly along linearly built-up areas and on impermeable surfaces where development is more dense. These surfaces tend to absorb greater amounts of solar radiation and store heat, subsequently releasing it into the surrounding environment and contributing to the observed increase in surface temperatures.

Climate change, along with the gradual replacement of agricultural land in the study area by built-up areas over time, are significant factors contributing to the increase in surface temperatures. Surface temperature analyses reveal that temperature increases are more pronounced in areas where impervious surfaces are concentrated and green space continuity is weakened. These areas stand out as zones where natural infiltration of rainwater is restricted and microclimatic stress is heightened.

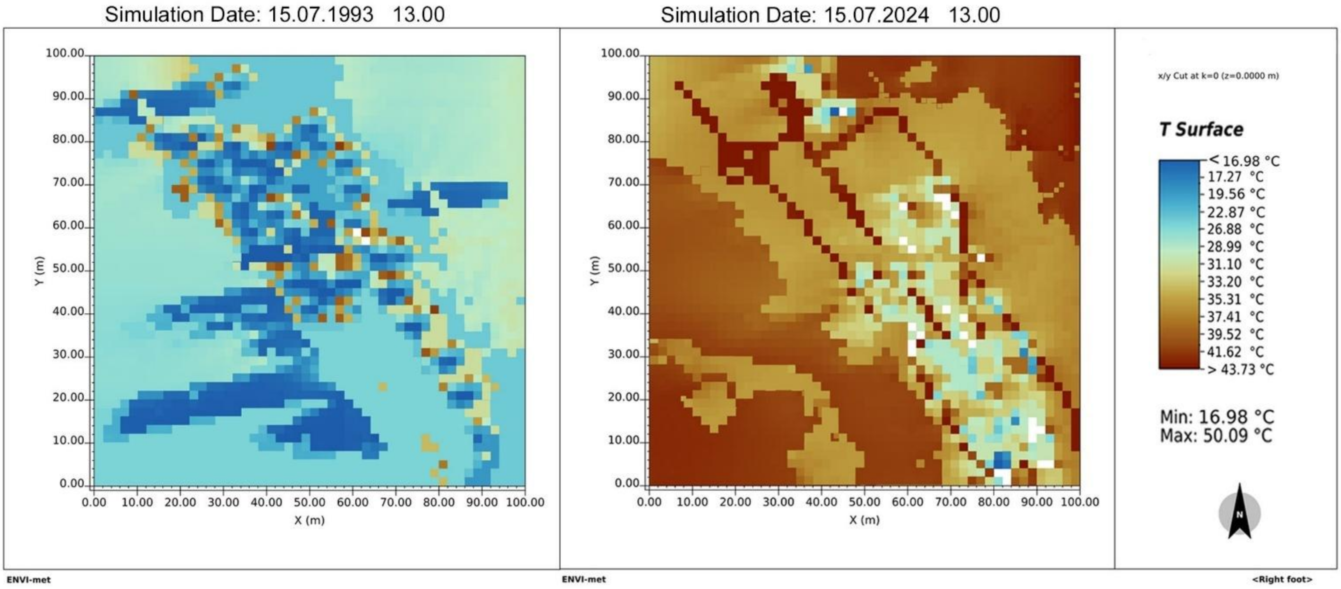

Figure 6. Land surface temperature maps of the study area and its immediate surroundings in 1993 and 2024.

When examining the temporal changes in land cover/use in the study area between 1993 and 2024, it is observed that areas previously designated for agricultural use have gradually transformed into residential areas over time (Figure 7). This situation has led to an increase in residential density within and around the campus. Although the increase in residential areas has increased the spatial distribution and area potential of Balıkesir University, it has led to the narrowing of agricultural areas and a decrease in ecosystem integrity. While the total size of green areas in the study area was 172.760.97 m² in 1993, this area has decreased to 90.074.95 m² as of 2024. Accordingly, it has been determined that approximately 82.686.02 m² of green space has been converted into built-up areas, resulting in a decrease of approximately 47.9% in the amount of green space. This significant loss of green space highlights the risk of reduced surface permeability and weakened natural infiltration processes for rainwater. This significant reduction in green spaces poses a risk of decreased surface permeability and a weakening of natural rainwater infiltration processes. However, the absence of older records of precipitation and temperature data in institutional archives means that all analyses including LULC analyses are limited to the 2000–2024 period, which may raise certain questions. However, the fact that the main campus buildings such as the Faculty of Economics and Administrative Sciences, the Faculty of Medicine, the Faculty of Tourism, the Faculty of Architecture, the Faculty of Health Sciences, the Faculty of Sports Sciences, Faculty of Theology and Faculty of Law, were largely established after the year 2000, indicating that the process of spatial development and intensive urbanisation took place primarily within this period.

In this context, limiting the analysis period to the years 2000–2024 provides a methodologically acceptable framework for representing land-use changes within the study area and the associated hydrological/environmental processes. Therefore, when interpreting the findings, this data constraint must be taken into account, and it should be borne in mind that the results are limited to the period covered by the dataset, particularly with regard to climate parameters.

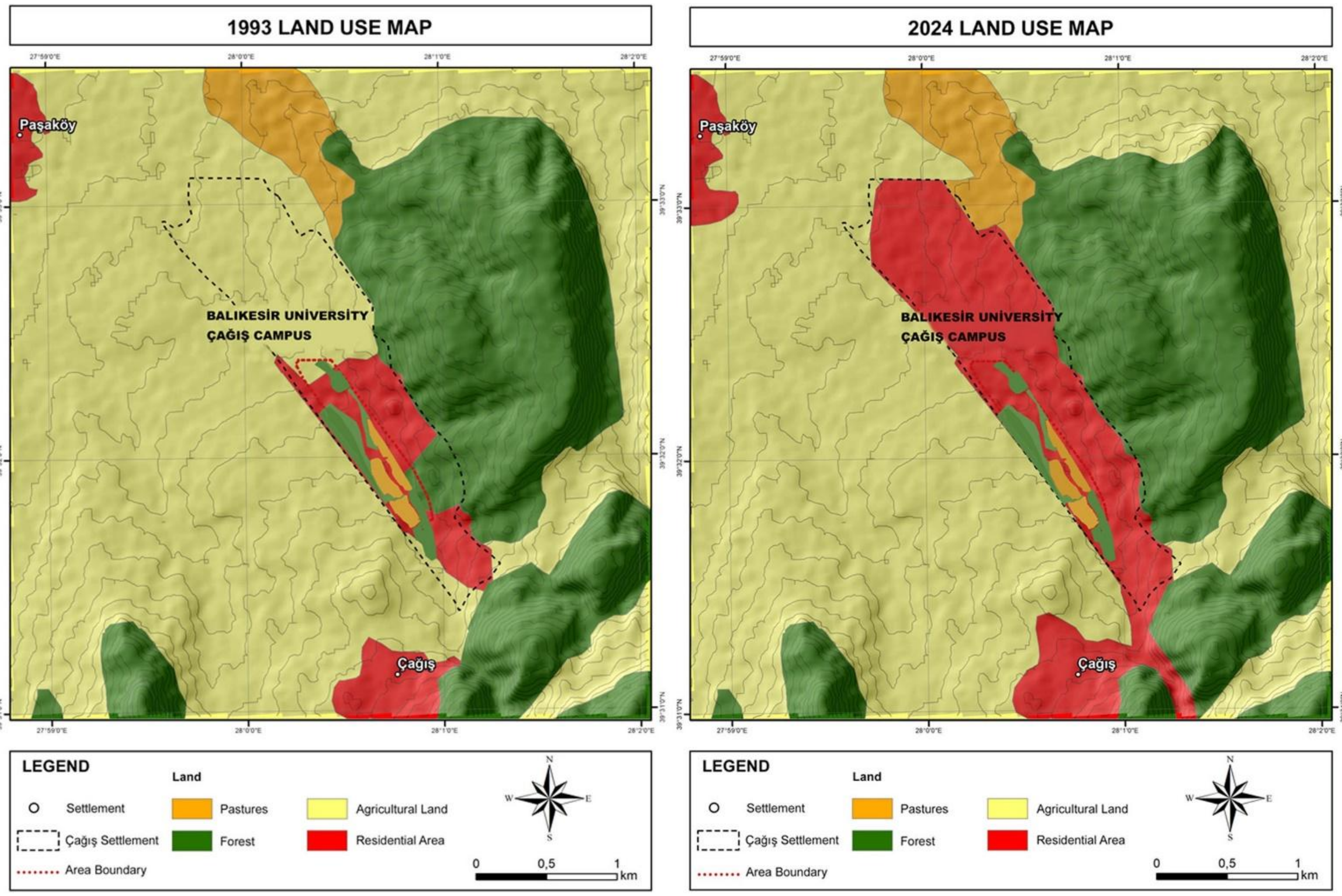

Figure 7. Land use maps of the study area and its immediate surroundings for 1993 and 2024

The accuracy analysis of the land use classification results for the years 1993 and 2024 was conducted (Table 3 and Table 4). According to the results, for the year 1993, 135 out of a total of 160 reference pixels were correctly classified, resulting in an overall accuracy of 84.3%. For the year 2024, 149 out of 160 reference pixels were correctly classified, yielding an overall accuracy of 93.1%. These findings indicate that the classification results for 2024 demonstrate a higher level of accuracy compared to those of 1993.

Table 3. User and producer accuracy in 1993

1993	Pastures	Settlement	Forested	Agricultural	Producer accuracy	User accuracy
Pastures	30	0	1	4	96.77 %	75 %
Settlement	0	34	3	3	87.18 %	85 %
Forested	1	4	35	0	83.33 %	87.5 %
Agricultural	0	1	3	36	83.72 %	90 %
Total	31	39	42	43		

Table 4. User and producer accuracy in 2024

2024	Pastures	Settlement	Forested	Agricultural	Producer accuracy	User accuracy
Pastures	38	0	2	0	100 %	95 %
Settlement	0	35	1	4	97.22 %	87.50 %
Forested	0	0	40	0	89.95 %	100 %
Agricultural	0	1	3	36	90 %	90 %
Total	38	36	46	40		

Within the scope of the study, three different soil samples taken from the field were analysed in the laboratories of the Balıkesir University Science and Technology Application and Research Centre to obtain data on soil permeability, and the results for the samples are shown in Table 5. The soil parameters analysed in the study were selected to evaluate the hydro-physical properties, chemical balance and ecological functionality of soil systems: clay content, texture class, pH, electrical conductivity (EC), organic matter, lime ($CaCO_3$), phosphorus (P_2O_5), potassium (K_2O), calcium (Ca), sodium (Na), and water saturation ratio, were selected to evaluate the hydro-physical properties, chemical balance, and ecological functionality of soil systems. These parameters are components that directly affect processes such as water holding capacity, drainage properties, nutrient cycling, and soil productivity (Mengel & Kirkby, 1987). Clay content and texture class play a decisive role in infiltration rate and surface runoff, while pH and EC are critical in terms of ion exchange capacity and nutrient availability (FAO, 2015).

The results obtained reveal that the soil samples from the study area exhibit significant differences in terms of water permeability depending on their clay content (Table 5). The high clay content in the first (40%) and second (42%) samples caused a decrease in infiltration rate and limited drainage capacity, while the 36% clay content in the third sample exhibited a more balanced infiltration and drainage capacity. This situation demonstrates that the speed of water movement through the soil profile is inversely proportional to the clay content. Similarly, studies conducted by Brady and Weil (2016) have shown that water retention capacity increases in soils with high clay content, but permeability decreases. Furthermore, this inverse relationship between clay content and water permeability becomes more pronounced in soils with a loamy-clayey texture and varies depending on soil porosity and aggregate stability (Rawls et al., 1982). In this context, it was concluded that the third sample in the study area had the most suitable profile in terms of hydraulic conductivity due to its lower clay content (36%), while the first two samples exhibited high water retention capacity but limited drainage.

Plant residues on the soil surface are one of the most significant factors in preventing erosion and increasing infiltration (Yılmaz & Alagöz, 2008). When the analysis results are examined, the 2–3% organic matter content determined in the soil increases porosity, thereby improving water retention capacity, and also strengthens aggregate stability, supporting the sustainability of the infiltration process. Again, according to the data obtained from the soil analysis results, the fact that the three samples taken were found to be under neutral–slightly alkaline pH conditions contributes to the maintenance of ion balance and colloidal stability; this situation makes it possible for water permeability to continue without deterioration.

Table 5. Analysis results of soil samples obtained from the study area

Parameter	Sample 1	Sample 2	Sample 3
Clay (%)	40	42	36
Soil Class	Clay	Clay	Clay Loam
Water Saturation (%)	116 → Heavy Clay	72 → Clayey	60 → Clay Loam
pH	8.03 → Alkaline	7.83 → Slightly alkaline	7.79 → Slightly
EC (µS/cm)	400 = Salt-Free	665 = Salt-free	524 = Salt-Free
Organic Matter (%)	0.25 = Extremely Low	0.75 = Very low	0.47 = Extremely Low
Lime (%)	21.59 = Very Calcareous	43.20 = Very calcareous	48.84 = Very Calcareous
Phosphorus (kg/da)	7.21 = Medium	7.56 = Medium	3.05 = Low
K2O (Potassium,	98.17 = Low	171.73 = Medium	81.51 = Low
Ca (mg/kg)	6512 = Very High	8693 = Very high	7941 = Very High
Na (mg/kg)	132 = Medium	126 = Medium	124 = Medium
YSTK(Weak	80–100 mm/m	90–140 mm/m	80–100 mm/m

3.2. Evaluation of the Design

In order to effectively manage water in the working area and ensure sustainability, various design proposals have been put forward for rain gardens, rain ditches and rainwater collection, which are important elements of blue infrastructure systems. Additionally, studies on the subject were examined to determine the suitability of site selections in the designs. In terms of land use, Dylewski et al. (2014) stated in their work entitled 'Low Impact Development Handbook for the State of Alabama' that rain gardens and rain swales can be implemented in gardens, along roadsides, along roads, at intersections or in other areas for the purpose of renovation and redevelopment. According to the Bąk and Barjenbruch (2022), it is recommended to avoid locating stormwater management practices such as rain gardens and swales in areas with high groundwater levels and above groundwater systems. In terms of land use, it has been decided that rain gardens and rain ditches in the study area will be designed in suitable areas of the botanical garden. Rain gardens and ditches in botanical gardens are planned to be designed in such a way that they do not obstruct pedestrian circulation or compromise safety, and collect rainwater naturally flowing from walkways and hard surfaces.

Dylewski et al. (2014) state that the suitable slope range for blue infrastructure systems such as rain gardens and bioswales is between 2% and 12%. Slopes exceeding 12% are considered unsuitable. This is because excessive slope increases surface runoff velocity, preventing adequate water retention and therefore limiting effective infiltration. The optimal slope is generally accepted to be around 5%. Since the slope of the study area ranges between 5% and 10%, it can be considered suitable for the implementation of rain gardens and bioswales.

When the elevation analysis is examined, the study conducted by Hassan et al. (2025) indicates that areas with low to moderate topography are suitable for the implementation of rain gardens and bioswales, whereas areas with high elevation are considered less suitable. According to the elevation maps of the study area, the site ranges between 151 and 200 m. This indicates that the area has a low to moderate topographic elevation, suggesting that it is suitable for the application of rain gardens and bioswales.

According to Suppakittpaisarn et al. (2025), southern, southeastern, and eastern aspects are generally preferred for the placement of rain gardens. Areas that receive sufficient sunlight are considered more suitable, as many of the plant species used in rain gardens require adequate solar exposure for healthy growth. Based on this consideration, the southeastern part of the botanical garden was selected as the most appropriate location for the placement of rain gardens.

Furthermore, based on the results obtained from the soil samples, areas corresponding to all three samples were considered in the planning process. However, a larger portion of the design area was allocated to the zones where the third sample was collected, as it exhibited the most suitable soil profile in terms of hydraulic conductivity.

As a result of the analyses and field studies carried out, the rain gardens within the botanical park have been divided into three different areas.

In determining these areas, the application areas within the scope of the Sponge City Project carried out by the İzmir Metropolitan Municipality were examined on site, and information obtained from meetings with project officials was evaluated. Furthermore, scientific reports and guidance documents published by the European Environment Agency (EEA) were taken into account, and the buffer zone distances were determined accordingly. These areas were classified and presented in Figure 8. In the first zone (base), it is recommended to select plants that are resistant to water and, after absorption, resistant to arid conditions to prevent the accumulation of sudden rainwater. The other zones are spaced at 60 cm intervals. In the second zone, which serves as a transition area between the first and third zones, the use of semi-arid plants is recommended. The third zone is the buffer zone where drought-adapted plants are recommended.

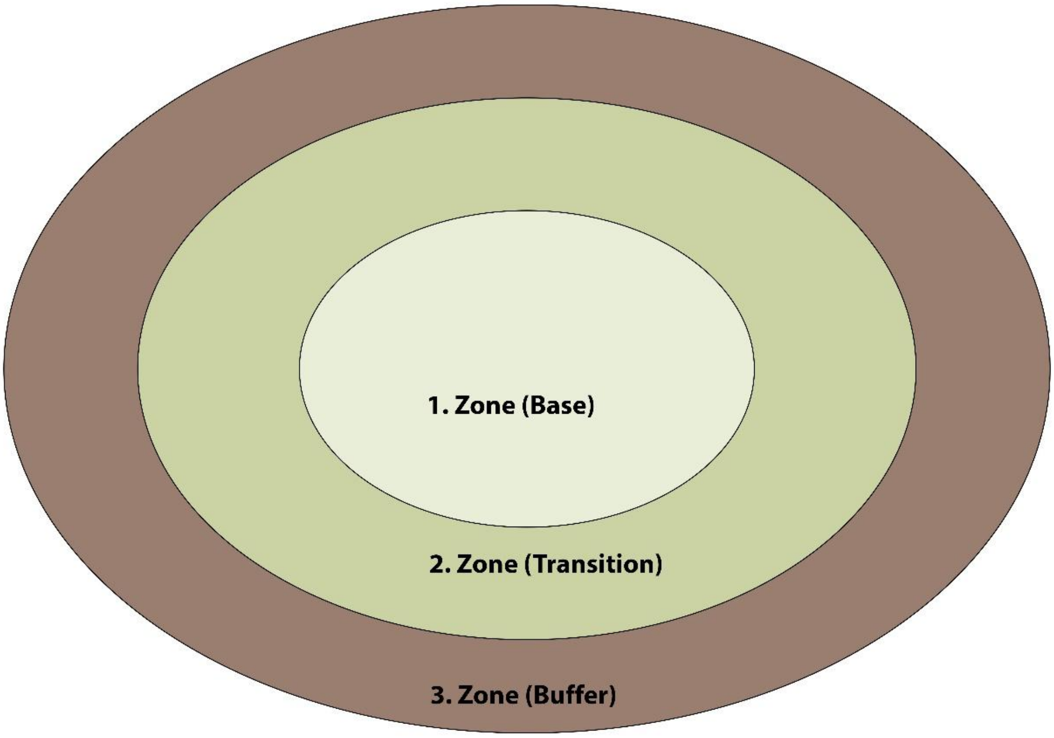

Figure 8. Rain garden plan illustration

Within the scope of the study, impermeable surfaces were first identified in the blue-green infrastructure applications created within the botanical garden, and these surfaces were made permeable to facilitate the flow of water into the ground (Figures 9, 10,11,12). The use of materials such as the carrier layer and sub-base reservoir within the permeable surface layer proposed in the designs ensures that water seeps into the soil after being stored. These systems, which reduce infrastructure pressure, aim to enhance the environmental quality of the region. The rain garden and rainwater ditch works designed for the area and shown in the detailed drawings aim to provide an ecological approach that enables water recycling (Figures 9 and 10). The designed rainwater ditches and rain gardens are expected to provide benefits in terms of water recovery and increased biodiversity. However, the fact that the area is located within the university campus in a densely populated area in terms of student population has influenced the design of the recreation area. Consequently, urban furniture designed in accordance with sustainable strategies in the designated area has ensured that rainwater is collected directly into the tank via the designated line, meeting the water needs of the existing landscape and the living creatures there. Considering all the parameters of the design, the aim is to integrate Balıkesir University's Çağış Campus into blue infrastructure systems and sustainable campus strategies.

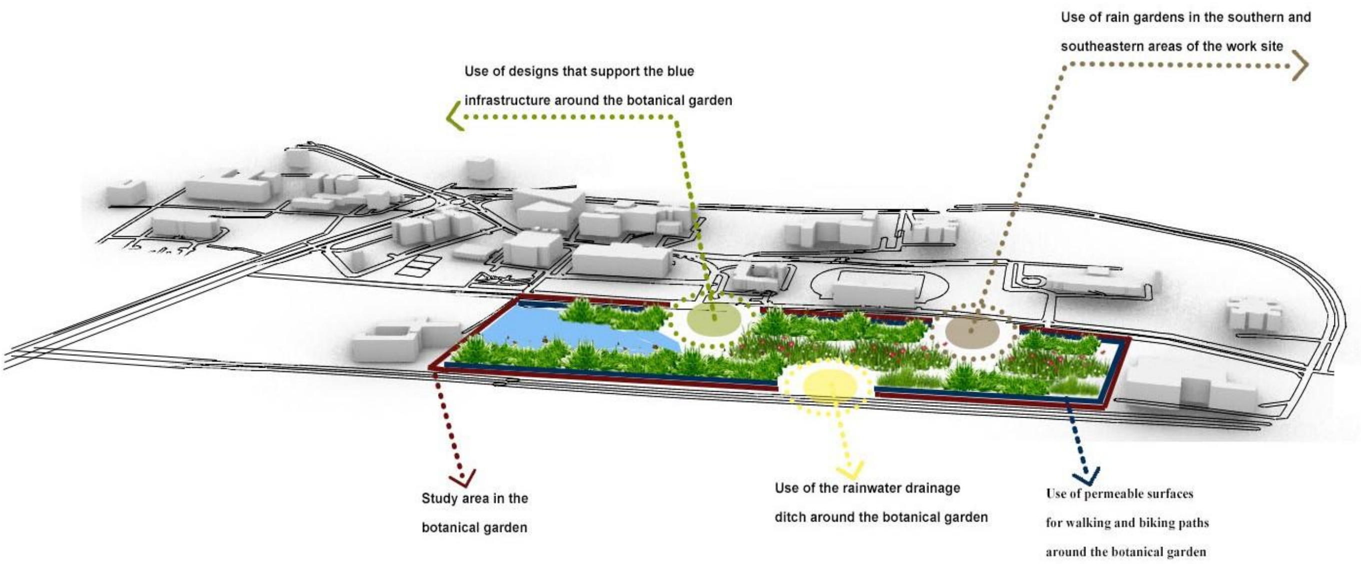

Figure 9. Blue infrastructure belonging to the study

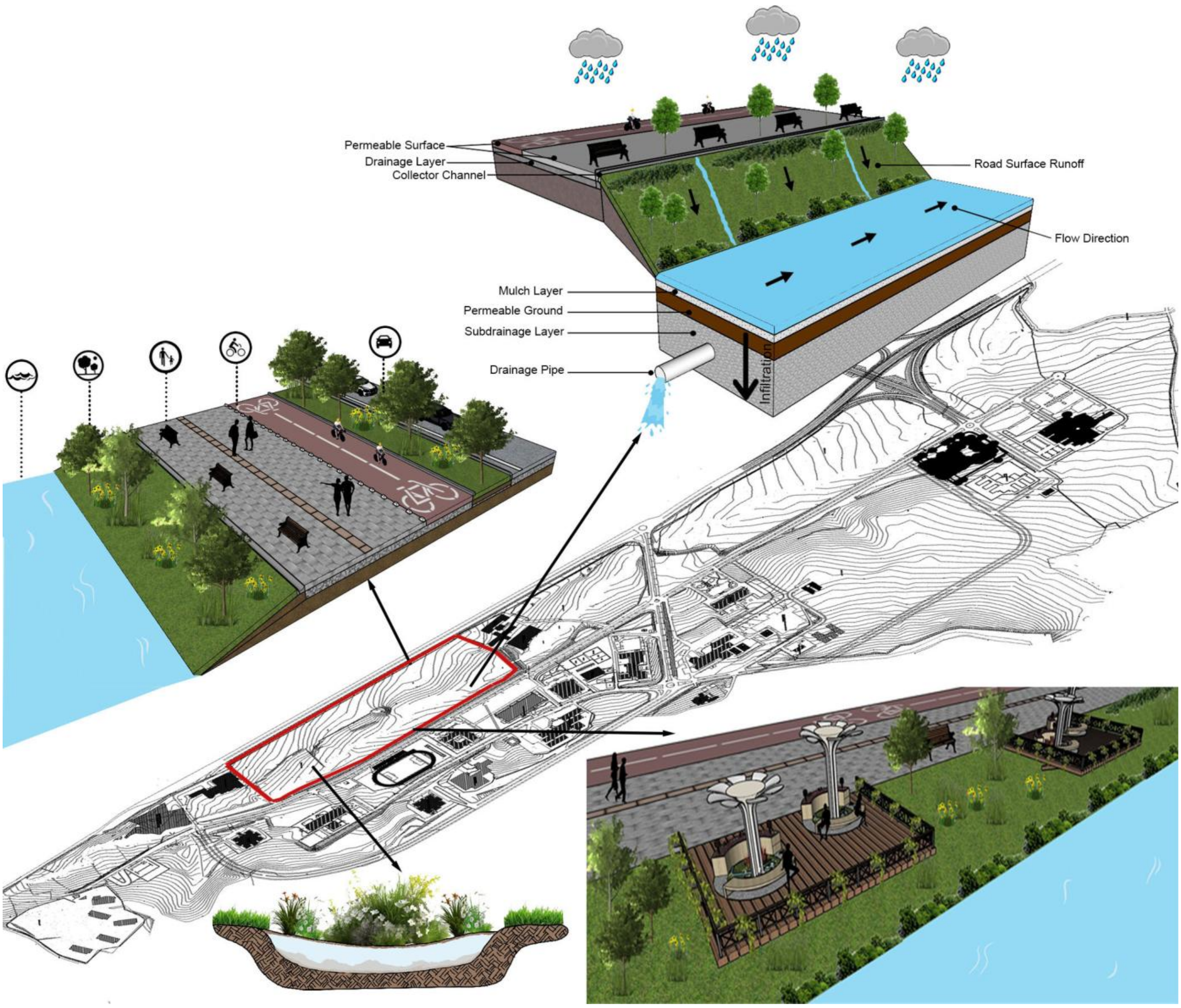

Figure 10. Redesign of the study area and its immediate surroundings

The rain gardens proposed within the scope of this study are a natural-based application that collects and filters rainwater, allowing it to seep into the ground. Rainwater is collected in a pit created within the garden, meeting the water needs of plants that provide both environmental and aesthetic benefits. Subsequently, the ponding method is expected to prevent the sudden overflow of water accumulated in the pit. It is anticipated that rainwater, absorbed gradually, will be naturally filtered through the soil and plants, removing contaminants (heavy metals, solids, etc.). Thanks to this working principle, rain gardens will ensure water recycling and management as well as the replenishment of groundwater. The aim is for rain gardens to enable not only a cycle but also an ecological design that increases biodiversity and prevents flood risk.

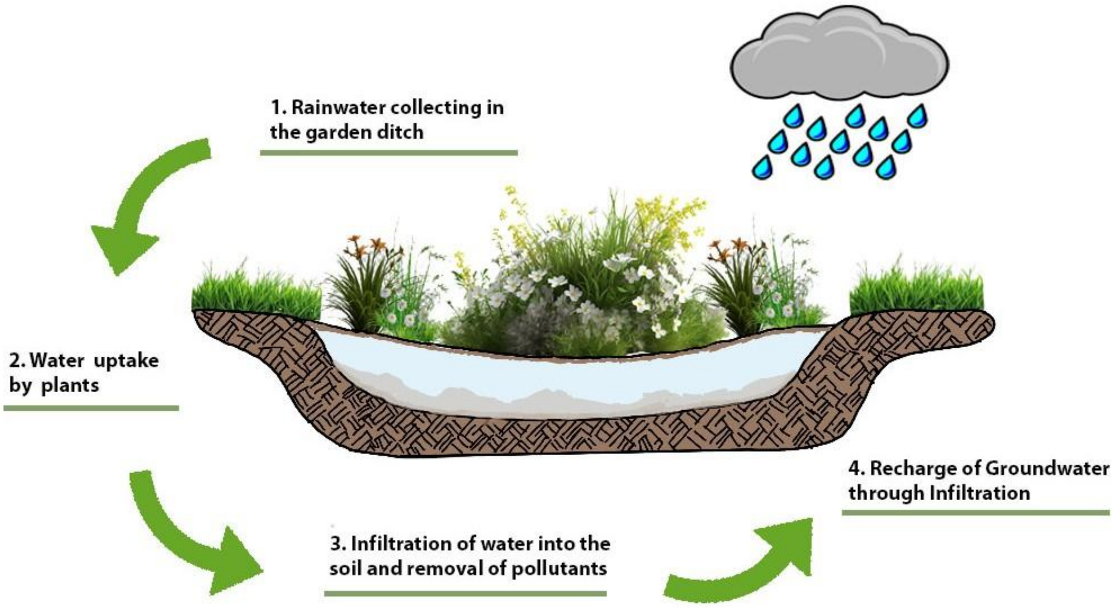

Figure 11. Rain garden detail illustration

In addition to rain gardens, the designed rain ditches are expected to collect surface water from impervious surfaces (roofs, roads, etc.) in gently sloping rain pits (Figure 11). These channels, which enable the purification and reuse of groundwater, initiate the biofiltration process of the collected water by directing surface runoff. The drainage pipe installed to prevent potential flooding accelerates water discharge, ensuring that water separated from contaminants mixes with the groundwater. Rainwater ditches are considered useful for achieving solutions that provide hydrological and ecological benefits.

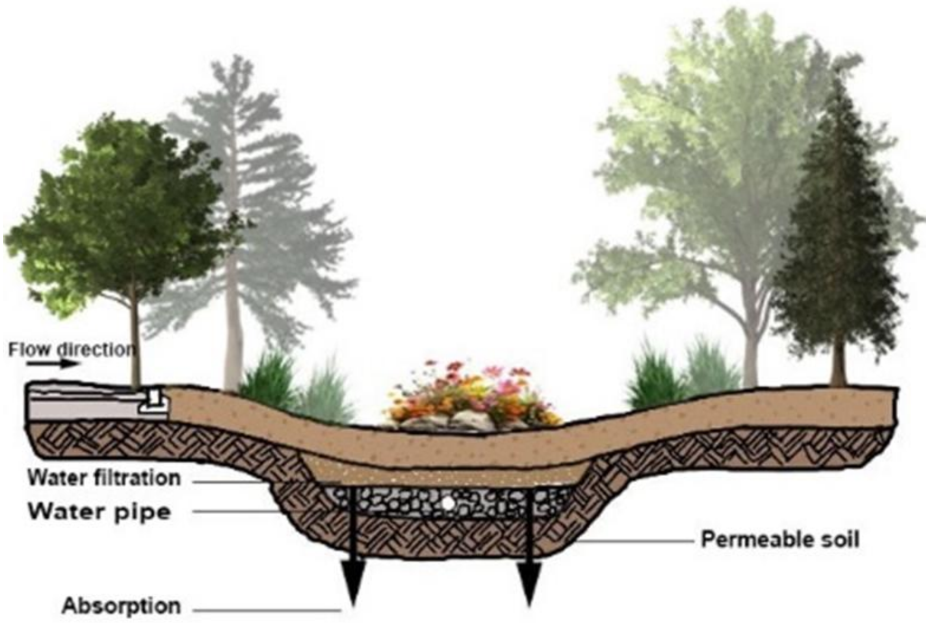

Figure 12. Rainwater drainage ditch detail illustration

This study presents an integrated approach for planning blue infrastructure systems within campus environments. The model is based on spatial and climatic analyses derived from environmental datasets including climate conditions, topography, geological structure, and land cover characteristics. These analyses inform the development of blue infrastructure design strategies that are incorporated into campus landscape planning. By addressing surface temperature variations and hydrological responses, the model seeks to improve microclimatic comfort and enhance water management within the landscape. Consequently, the model highlights the potential of blue infrastructure systems to improve microclimatic conditions and support sustainable landscape planning in botanical gardens and campus areas.

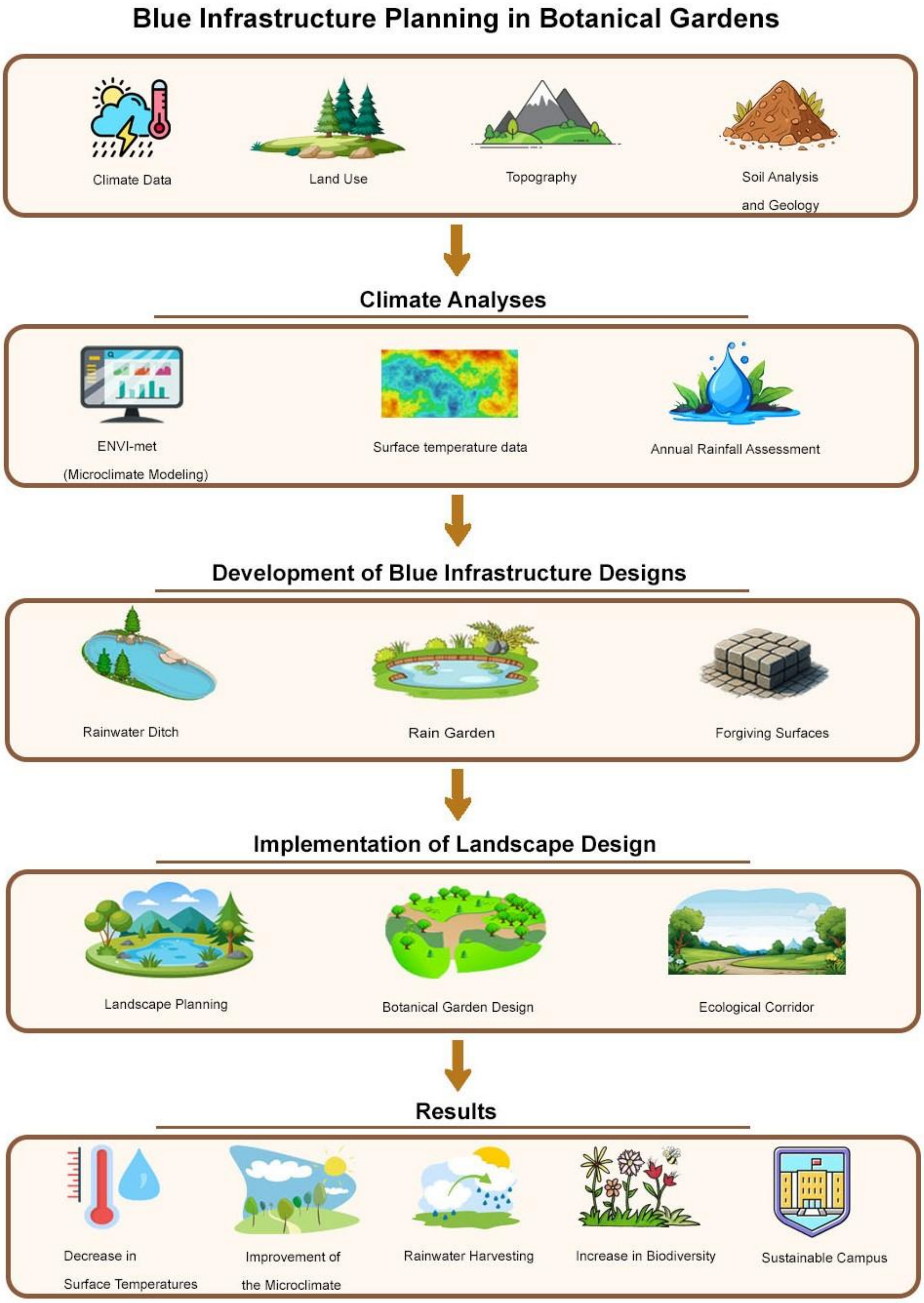

Figure 12. Conceptual diagram illustrating the blue infrastructure planning model proposed in the study.

4. Conclusion

The combined geographical and climatic analyses revealed that the area where Balıkesir University Botanical Garden is located has a high ecological resilience capacity, largely preserved hydrogeological permeability, and a landscape system with distinct microclimatic differences. Soil analyses obtained from the study show that the area has medium-high water permeability, which creates a suitable hydrological environment for the applicability of blue infrastructure systems. The fact that slope values are mostly between 5–10% and that the aspect is predominantly southeast minimises erosion potential by allowing surface runoff to flow naturally. Between 2000 and 2024, the annual average precipitation recorded in the Çağış region shows significant interannual variability. Values range approximately between 11.68 mm and 28.16 mm, indicating irregular rainfall patterns during the study period. Such variability suggests that the hydrological response of the area, particularly surface runoff formation, may change depending on annual precipitation regimes. This condition highlights the importance of blue infrastructure practices for effective stormwater management and retaining water within the landscape. The comparison of surface temperature values between 1993 and 2024 also reveals notable changes in the thermal characteristics of the study area. Simulation results for 1993 indicate generally lower surface temperatures and a more homogeneous spatial distribution. In contrast, recent analyses demonstrate an increase in surface temperatures. These findings emphasize the importance of blue infrastructure elements in regulating microclimatic conditions and improving thermal comfort within the campus landscape.

In this context, the rain gardens, rain swales, vegetated buffer zones, and permeable surface systems proposed for the study area are considered not only as engineering solutions that enhance hydrological efficiency but also as concrete components of a nature-based planning approach. Based on the analyses and observations obtained, the study area has the potential to support a wide range of ecosystem services, from water management to soil stability, from reducing the heat island effect to preserving plant diversity.

The rain garden and rainwater harvesting ditch applications developed within the scope of this study have been evaluated as effective blue infrastructure components that reduce surface runoff by improving rainwater management in the settlement. However, in sustainable landscape planning, blue infrastructure systems must contribute not only to the channelling and storage of water, but also to the support of ecosystem services and the restoration of natural processes. Therefore, the nature-based solutions approach provides a comprehensive framework that transforms blue infrastructure into an ecological and multidimensional planning tool. Within this scope, it is recommended that nature-based approaches such as biofiltration basins, permeable surface coverings, vegetated buffer zones, natural sedimentation basins, and green drainage systems integrated with ecological corridors be implemented in the study area. These systems enhance the sustainability of groundwater resources by maintaining hydrological balance; they also strengthen ecosystem resilience against climate change and provide multiple environmental benefits such as microclimatic comfort, biodiversity, and carbon storage.

Blue infrastructure systems play a critical role in sustainable campuses. They are effective in producing climate-resilient infrastructure solutions on campuses and restoring the natural water cycle. This study, which aims to develop design proposals for infrastructure systems in the Botanical Garden at Balıkesir University's Çağış Campus, has evaluated the management and efficient use of rainwater. The aim is to convert impermeable surfaces in the botanical garden into permeable surfaces, enabling water to collect in the soil's accumulation horizon. The designed rainwater ditches and rain gardens are expected to facilitate the effective use of water in the area and contribute to the preservation of biodiversity. Rain gardens and rainwater harvesting ditches are important landscape applications in terms of landscape planning and efficient water use, as they are systems that prevent rainwater from flowing uncontrollably over the surface. Botanical gardens are multifunctional institutions of strategic importance in the conservation of biodiversity and the preservation of species, the conduct of scientific research, and the creation of ecosystem services and blue-green infrastructure. Furthermore, with the deepening of the climate crisis, increasing the number of botanical gardens and protecting existing ones is of great importance. In this context, it is anticipated that all analyses and designs carried out within the scope of this study will contribute to the structuring, protection, and planning efforts of the Balıkesir University Botanical Garden.

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