Master Thesis

Methodology for Selecting Potential CO2 Sink in Macaronesia Island: The Case of Gran Canaria.

submitted by

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Abstract

Carbon dioxide (CO_2) accounts for 80% of the greenhouse gas emissions in the atmosphere. One of the several ways to mitigate CO_2 emissions is through afforestation, which prevents catastrophic environmental consequences. The mean average emission per tourist in the Canary Islands on their way to the islands is 0.48 Tn. Like most urban cities, the island of Gran Canaria faces the problem of CO_2 due to anthropogenic and human activities. Vegetation coverage significantly influences the distribution of temperature. The correlation between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) of Gran Canaria, using satellite images from Landsat 8 and Sentinel-2, revealed a strong inverse relationship within all land use types, with an R^2 value of 0.39. Land suitability analysis is a prerequisite for optimum utilization of available land resources. This study developed a suitability map for afforestation based on land use land cover, topographic, meteorologic, and socio-economic factors. Eight factors, including distance from settlements, land use, distance from the road, distance from water, elevation, slope, precipitation, and temperature, were employed according to previous studies, expert consultation, and land suitability mapping experience. After the criteria decision and data acquisition, maps of each criterion were created and transformed using the Suitability Modeler of ArcGIS Pro. The current study results show that 87% of the total area is suitable for afforestation and reforestation projects in Gran Canaria. Instead of using reactive methods to lessen the effects, the study recommends a proactive approach to climate adaptation through nature-based solutions. The next stage will be to design a forest repopulation project, considering the kind of tree species needed, the methods needed to implement it, and the management guidelines pertaining to the initial years of installation and growth of the new trees. The most crucial technical choice is which forest species to choose, as it will determine whether or not the repopulation effort is successful. The new revegetated space's ability to sequester carbon dioxide will primarily rely on the productivity of the land used for forest repopulation, the species chosen, and the introduced planting density.

Keywords: GHG emissions, GIS, Gran Canaria, Afforestation, Reforestation, Land Suitability Analysis

1. Introduction

Global atmospheric CO_2 concentrations have more than doubled in the past 40 years (MacKinon et al., 2008), primarily driven by human activities such as fossil fuel combustion and increased demand for energy, posing a significant threat to the climate and ecosystems of the planet. Nature-based solutions (NbS) are gaining popularity as an integrated approach to address climate change and biodiversity loss (Seddon et al., 2020; Chausson et al., 2020), as well as supporting sustainable development goals (Gómez Martín et al., 2020; Maes et al., 2019). NbS are actions broadly classified as protecting, restoring, or managing natural and semi-natural ecosystems, sustainable management of working lands and aquatic systems, or creating new ecosystems.

Climate change is one of the significant problems facing the globe now, described as notable variations in the long-term averages of meteorological variables, such as temperature and precipitation (WMO, 1996). Recent decades have demonstrated that increased human activity has changed the composition of the global atmosphere, leading to notable changes in the global climate (IPCC, 2007). Since 1750, there has been a 150%, 40%, and 20% increase in the concentration of greenhouse gases such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), respectively (IPCC, 2014). Carbon dioxide emissions, which comprise the most significant amount of greenhouse gases (Sathaye et al. 2006), increased from 22.15 billion metric tons in 1990 to 36.14 billion metric tons in 2014 (Abeydeera et al. 2019). Since 1975, the average global temperature has risen at a pace of 0.15–0.20 °C and is predicted to increase to 1.4–5.8 °C by 2021 (Arora et al. 2005). In January 2024, the worldwide surface temperature was 1.27°C higher than the average for the 20th century, which was 12.2°C, higher than the previous record set in January 2016 by 0.04°C. The Global Annual Temperature Outlook from NCEI indicates a 22% probability that 2024 will be the warmest year ever recorded and a 99% chance that it will be among the top five. Greenhouse gas (GHG) emissions, mainly CO_2 from the combustion of fossil fuels, and non-CO_2 GHGs such as nitrous oxide, methane, and CFCs contribute to global warming. The atmospheric concentration of CO_2 increased from 315.98 ppm in 1959 to 424 ppm in 2022. In May 2023, carbon dioxide hit a new record of 424 ppm. Fossil fuel emissions contributed little to CO_2 emissions before 1750 but did so quickly when industrialization progressed. Most greenhouse gases in the atmosphere are made up of CO_2, which comes from industrial operations and fossil fuels (65%), forestry, and other land uses (11%), and methane (16%), nitrous oxide (6%), and fluorinated gases (2%), (IPCC, 2014). Since 1751, the global CO_2 emissions have been around 1.5

trillion metric tons, with regional differences in the emission. With approximately 514 billion metric tons of CO_2 emissions, Europe is the most significant contributor to CO_2 emissions, followed by Asia and North America, with a combined CO_2 emissions record of 457 billion metric tons apiece (Malhi et al. 2021). China has been the second-largest contributor to CO_2 (200 billion metric tons) emissions since 1751, with the United States accounting for 399 billion metric tons, or 25% of all emissions. The European Union generated 22% of CO_2 emissions in history. Due to its low per-capita emissions, Africa only contributes 3% of the world's cumulative CO_2 emissions. Ultimately, Climate change will become a severe issue in the twenty-first century, with detrimental externalities affecting developed and developing nations (Malhi et al. 2021).

Carbon sequestration transfers and safely stores atmospheric CO_2 into other long-term carbon pools that would otherwise be released into the atmosphere (Lal, 2007). Carbon sinks are areas where carbon is stored. Terrestrial carbon sinks include natural forests, forest plantations, wetlands, and soil biome. Woodwell (1978) suggested that terrestrial vegetation is the primary source of atmospheric carbon dioxide and constitutes a significant carbon source in the global carbon balance, primarily through deforestation and other physical processes. Most of the terrestrial vegetation in the northern hemisphere, remarkably temperate and boreal forests, may act as CO_2 sinks (Pan et al., 2011), and one of the best ways to deal with growing CO_2 levels is through afforestation (Bastin et al., 2009).

Additionally, (Francisco, 2010) highlighted the effects of carbon sequestration by urban vegetation. Hence, mitigating these emissions by afforestation is crucial to prevent catastrophic environmental consequences. Carbon sequestration can lower global emissions from fossil fuels by 5–15% (Lal, 2004). Capturing and storing atmospheric CO_2 is crucial for mitigating climate change and achieving sustainable development. Accurate information on the present condition and the dynamic and spatial distribution of carbon sources and sinks must be made available to managers and policymakers to reduce the consequences of greenhouse gases (Wang et al., 2009). Reducing CO_2 sources or increasing sinks is one way to lower net greenhouse gas emissions from the forest ecosystem, which is a massive carbon sink (De Jong et al. 2000). By increasing the amount of forest land, it would be feasible to offset the carbon dioxide emissions in urban areas significantly (Richards & Stokes, 2004). Carbon can be stored (sequestered) in three ways, Giri et al. (2017): i) Terrestrial sequestration or carbon sinks, ii) Geological sequestration, iii) and Ocean

Sequestration. We can also distinguish between direct and indirect carbon sequestration in terrestrial ecosystems. Direct carbon sequestration can occur i) through tree carbon deposition (Clark et al., 2023); ii) through forest soil carbon deposition (Hagedorn et al., 2001); iii) through understory plant carbon deposition (Nam et al., 2024); iv) and humus carbon deposition (Zhang et al., 2023). On the other hand, indirect carbon sequestration primarily manifests as carbon storage in forest products produced by harvesting forest trees and processing them into wood products to replace cement, steel, and other building materials or energy sources (Zhang et al., 2023). Forests are the primary terrestrial ecosystem, representing 46% of the global total stock (Hu et al., 2022).

Developing effective and sustainable carbon sequestration strategies is essential for mitigating climate change. Identifying the best and worst places to put a specific purpose, such as future land use, is the main emphasis of Land Suitability Analysis (LSA) (Collins et al., 2001). Multiple factors must be considered simultaneously to determine the ideal sites for reforestation. Thus, we combined a Geographic Information System (GIS) and the Multicriteria Evaluation (MCE) approach in this study. MCE is relevant because it enables the evaluation of several options (or choice possibilities) considering relevant priorities and objectives or criteria (Voogd, 1982; Keeny & Raiffa, 1993). MCE is mainly concerned with how to combine different information (data layers) from several criteria to generate a single index of evaluation, and it has been used extensively for land suitability modeling (Carver, 1991; Jankowski & Richard, 1994; Thapa & Murayama 2008; Apud et al., 2020). The social, economic, and environmental domains interact intricately to create the landscape (McHarg, 1969). Accounting for the primary natural elements, physical and biological processes, and society's social and cultural values, MCE seeks to enhance natural resource management while obtaining the most significant benefits from each other disciplines (Spósito, 2018).

In the context of climate change, the selection of potential CO_2 sink areas in urban areas is driven by the urgent need to mitigate the accumulation of atmospheric CO_2 (Government of Las Palmas, 2022). Urban areas, typically characterized by high emissions due to dense populations and industrial activities, present unique opportunities for carbon sequestration. Integrating CO_2 sinks in urban planning can significantly offset carbon emissions, enhance air quality, and contribute to achieving carbon neutrality goals (Chen et al., 2022). Strategically identifying and developing urban CO_2 sinks—such as parks, green roofs, urban forests, and wetlands—can transform cities into active players in climate action. These green spaces not only sequester CO_2 but also improve urban microclimates, reducing the urban heat island effect and increasing the resilience of cities to climate impacts (Demuzere et al., 2014).

Additionally, urban vegetation can play a crucial role in carbon storage and sequestration through photosynthesis, thereby converting CO_2 into biomass. Moreover, promoting urban CO_2 sinks aligns with sustainable urban development strategies, fostering biodiversity and enhancing the well-being of urban residents. Therefore, the deliberate selection and cultivation of CO_2 sinks within urban areas are vital for mitigating climate change impacts and moving towards sustainability in urban development.

Island ecosystems such as the Macaronesia archipelago offer unique opportunities for carbon capture due to their specific characteristics and vulnerabilities. The islands of the Macaronesia archipelago are remote, minimizing human disturbance. In the Macaronesia region, (Vergílio et al., 2016) accessed the changes in carbon storage on Pico Island (Azores, Portugal) between 1998 and 2013. Using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Carbon Storage and Sequestration model (Bañolas et al. 2020) assessed carbon sequestration by the seagrass *Cymodocea nodosa* (Ucria) in Gran Canaria, Cruz-Pérez, et al. (2023) calculated the carbon footprint linked to vehicles on the three high-capacity roads on the island of Tenerife. Blue carbon maps are scarce, and deep-water seagrasses have been understudied. To address this problem, (Montero-Hidalgo et al., 2023) mapped and assessed blue carbon storage and sequestration by *Cymodocea nodosa* in the Canarian archipelago using the local carbon storage capacity and high spatial resolution (20 m/pixel) seagrass distribution maps for 2000 and 2018. On the terrestrial ecosystem, (Rocafull Pérez, 2022) estimated the distribution, area occupied, and the total amount of carbon accumulated in the biomass of *Opuntia maxima* and *Opuntia dilleniitwo,* two invasive species on Tenerife. The case of Gran Canaria in the Canary Islands provides valuable insights into implementing carbon sequestration solutions in vulnerable island ecosystems with a history of carbon increase.

The Municipal Building Ordinance of Las Palmas de Gran Canaria requires that at least 60% of the surface be planted with tree species (Government of Las Palmas, 2018). Creating a network of carbon sinks involves the afforestation or reforestation of the urban and peri-urban periphery of the major cities in Gran Canaria with wooded areas adapted to the bioclimatic conditions and the edaphic characteristics of the relief. Plans for revegetation have already been undertaken in some sectors or are now in progress in the area behind the Lasso, La Mayordomía, or the area between El Zardo and Siete Puertas surrounding the former San Lorenzo Dam (Government of Las Palmas, 2023). Therefore, the overall objective of this study is to select a suitable urban network of carbon sinks in Gran Canaria. The project aims to enhance the capacity of land ecosystems to absorb and store greenhouse gases, particularly carbon dioxide (CO_2), from the atmosphere. The specific objectives are to i) analyze the evolution of Green House gas emissions, ii) analyze the relationship between temperature and vegetation, iii) identify suitability criteria for afforestation and reforestation maps, iv) create suitability maps for each criterion identified, v) produce a map of carbon sink networks, i.e., suitable forests in and around urban areas.

2. Materials and Methods

2.1 Study area

This study area is focused on the island of Gran Canaria in the Canary Islands of Spain. We further analyzed the potential CO_2 sink of seven urban areas: Gáldar, Arucas, Tamaraceite, Telde, Vecindario, Maspalomas, and La Aldea. These pilot areas were selected based on their population, historical uniqueness, and tourist attractions. Gáldar was the first capital of Gran Canaria, chosen by the island’s early rulers (Guanarteme). Galdar, Tamaraciete (Las Palmas), and Telde are populated and most robust in activities on the island, where businesses and transportation thrive. La Aldea is the least populated of all, with the beautiful and less disturbed Guigui beach in the western part of the island. Figure 3 and Figure 4 illustrate the location of the pilot areas and their respective land cover type.

Gran Canaria is one of the seven islands in the Canary Islands of the Macaronesia archipelago (Figure 1). Macaronesia comprises four oceanic archipelagos: the Azores, Canary Islands, Cape Verde, and Madeira. The Azores and Madeira are autonomous regions of Portugal, the Canary Islands are autonomous regions of Spain, and Cape Verde is a sovereign nation. In 2022, Macaronesia had a total population of 3,259,294: 2,172,944 (66.67%) in the Canary Islands, 593,149 (18.20%) in Cape Verde, 253,259 (7.77%) in Madeira and 239,942 (7.36%) in the Azores. The total area of the Azores, Madeira, Cape Verde, and the Canary Islands are 2,333 km^2, 801 km^2, 4,033 km^2, and 7,492 km^2, respectively.

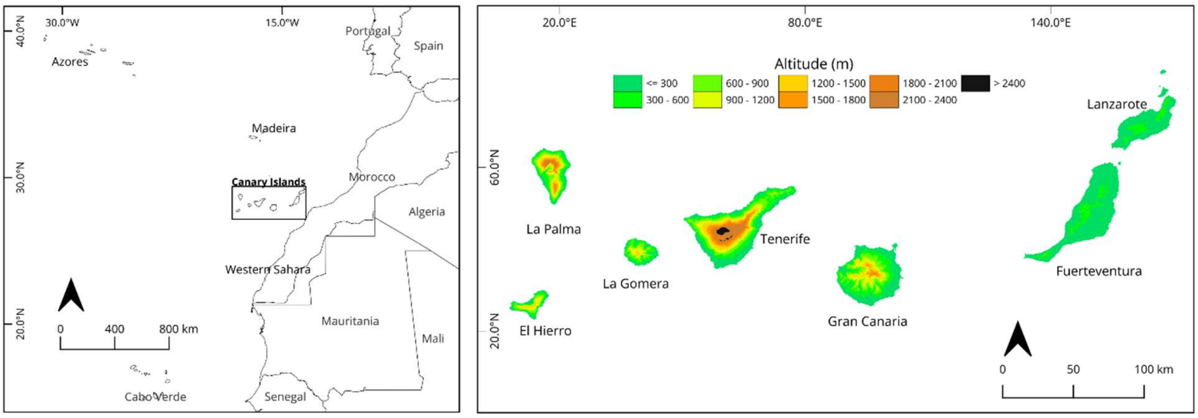

Figure 1: The Canary Islands

The Macaronesia region is globally recognized for having the highest endemic biodiversity among European insular regions (Fernández-Palacios, 2011), comparable to renowned island ecosystems such as Hawaii, Galápagos, New Zealand, New Caledonia, and Madagascar. Over 28,100 terrestrial species have been identified in an area slightly larger than 15,000 km^2 spread across 39 islands (Fernández-Palacios, 2011). While most endemisms are specific to individual archipelagos, the Macaronesia archipelago boasts endemic species across multiple islands, illustrating the interconnected nature of these isolated ecosystems. While fragments of potential natural vegetation remain in the Azores, almost replaced by conifer plantations and cattle rangelands, and in Cape Verde, where landscape transformations induced by desertification and the introduction of alien species are pervasive, it is still feasible to reconstruct their original distribution. Despite a considerable latitudinal difference of approximately 25º between these regions, Macaronesia shares, to some extent, a common biogeographic history (Fernández-Palacios, 2011). This shared history is evident through the emergence of similar biotic elements and analogous (vicariant) taxa that have historically contributed to the formation of closely related ecosystems (Santos-Guerra, 1983). There are, however, notable differences in structure and function, primarily attributed to climatic variations (AEMET, 2012).

The Canary Islands is one of the 16 autonomous regions of Spain consisting of seven major islands (La Palma, La Gomera, El Hierro, Tenerife, Gran Canaria, Fuerteventura, and Lanzarote) from left to right with a total area of 7,492 km^2. Tenerife is the largest (2,034 km2) of all the islands, and El Hiero is the smallest (268.7 km2). The distance between the Canary Islands (Fuerteventura) and the African coast (Stafford Point, Western Sahara) is 96 km. The most populated islands are

Tenerife (927,993 inhabitants) and Gran Canaria (852,688 inhabitants), and the least populated are La Gomera (21,798 inhabitants) and El Hierro (11,423 inhabitants) (INE, 2022). The land use type of Gran Canaria is illustrated in Figure 2.

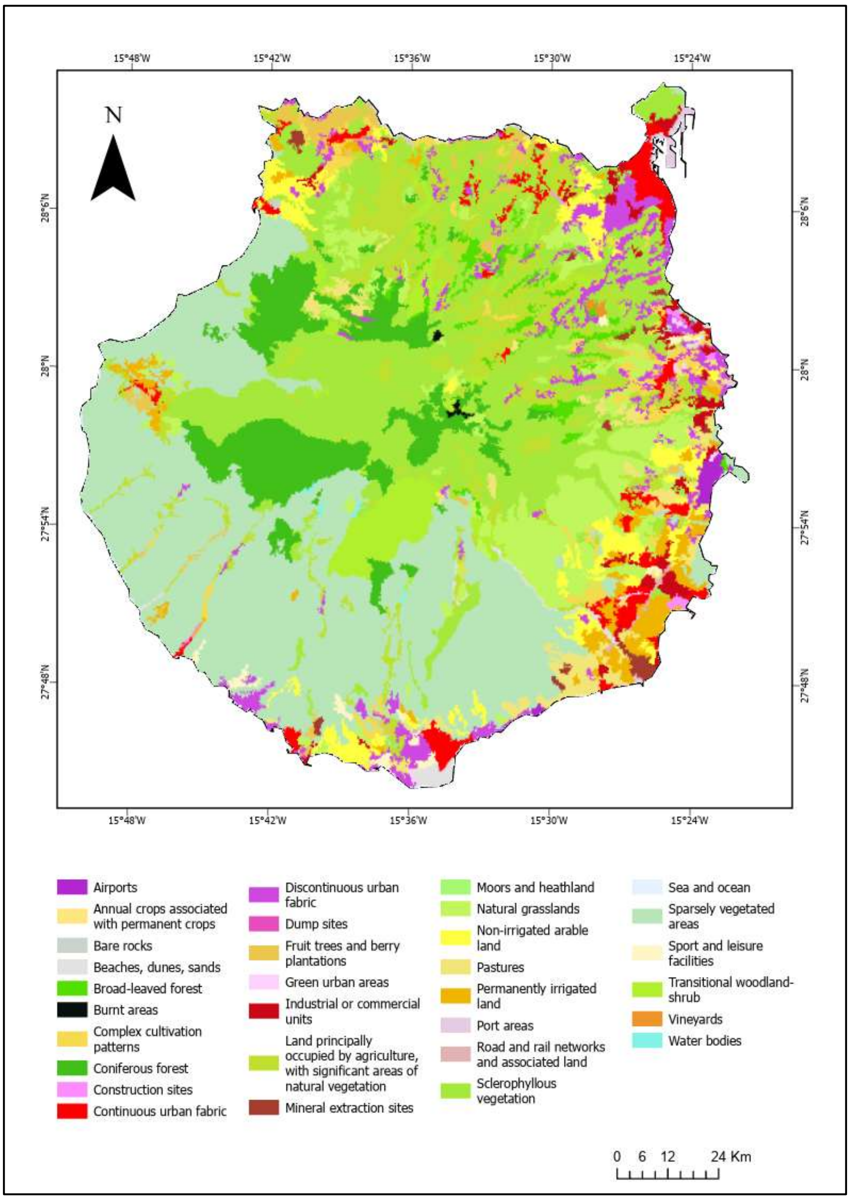

Figure 2: Gran Canaria Land Cover

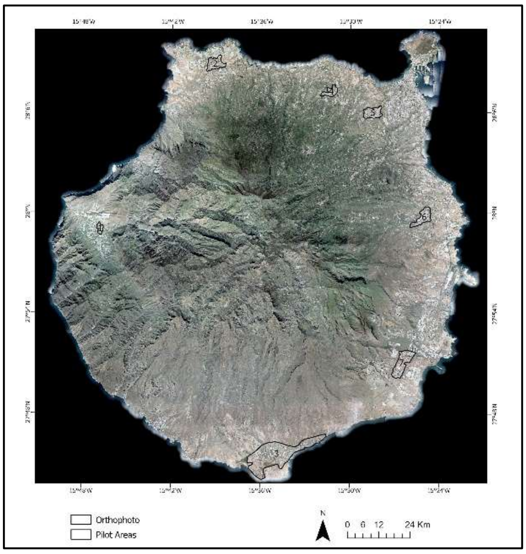

Figure 3: Location of the Pilot Areas

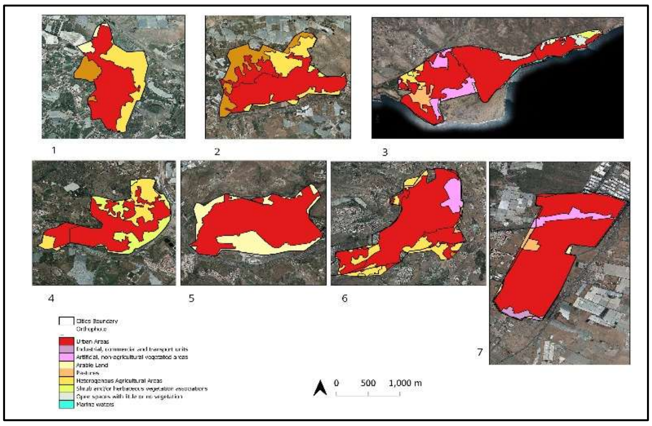

Figure 4: The Pilot Areas and Land Cover

1. La Aldea 2. Galdar 3. Maspalomas 4. Arucas 5. Tamaraciete 6. Telde 7 Vecindario

Gran Canaria, approximately 45 km in circumference, with a maximum elevation of 1950 m asl (Pico de las Nieves) in its geometric center, is the third largest island in terms of surface area (1,532 km^2), is characterized by its unique biological endemism, subtropical climate, and volcanic geology. The island's volcanic nature and subtropical climate contribute to its biological endemism. The island records a mean annual rainfall of 148mm, with an average temperature of 24°C throughout the year. The mean average emission per tourist in the Canary Islands on their way to the islands is 0.48 Tn, compared to only 0.26 Tn in the case of the Balearic Islands (Carrillo et al., 2022). Spain received five million international tourists in February, 15.9% more than in 2023. In the first two months of 2024, tourists increased by 15.6% (INE, 2024). The Spanish economy emitted 304.4 million tonnes of greenhouse gases in 2022, 3.1% more than in 2021. These emissions have decreased by 26.9% since 2008 to 22.7% of emissions corresponded to households.

The Canary Islands' economy has experienced significant shifts due to tourism activity, particularly with the implementation of tourism moratoria to enhance the quality of accommodation supply (Inchausti-Sintes & Voltes-Dorta, 2019). The concept of ultraperiphericity highlights the challenges faced by regions like the Canary Islands, where agrotourism has been identified as a crucial element in diversifying and improving the competitiveness of the agricultural sector, suggesting that a complete abandonment of agriculture for tourism may not be necessary (López & García, 2006). While the Canary Islands have focused on developing the tourism sector, particularly high-end tourism, agriculture need not be entirely abandoned. Integrating agriculture with tourism through concepts such as agrotourism and leisure farming can provide a balanced approach to economic development, leveraging the benefits of both sectors (Liu & Yen, 2010; López & García, 2006; Murthy, 2014). Therefore, it is not a matter of abandonment but rather a strategic diversification and integration of the agricultural sector with the burgeoning tourism industry to ensure sustainable economic growth and social welfare in the Canary Islands.

2.2 Methodology

The evaluation criteria for each land use appropriateness in this study were chosen after a thorough literature review, expert consultation, and professional suitability mapping experience. To determine which of these criteria are most frequently employed in a GIS-based MCE, the most pertinent and frequently applied criteria in land use suitability and site selection were gathered and derived through literature research. The procedure of searching and selecting literature was based on several reliable research archives, such as Google Scholar, Research Gate, Web of Science, and Science Direct. Land use suitability, evaluation criteria, site selection, land use planning, and MCE/MCDA were among the significant keywords used in the search queries.

After an initial examination of the relevant literature, which included over 50 papers, a lengthy set of criteria was created for each land use, and a list of 8 criteria was derived after two rounds of pre-testing with three professionals in related fields. When evaluating the possible expansion of production forests, stakeholders consider that the accessibility and settlement factors are significant. Following the MCE methodology of Apud et al., 2020, we followed the six main steps: i) determining site issues and goals, locating sources and data that are currently available; ii) formulating a criterion (or relevant factors to be evaluated); iii) ordering and weighing the criteria; iv) using geographic information systems (GIS) to analyze the data; v) and evaluation of outputs and results. The Methodology for the Suitability analysis is illustrated in Figure 5.

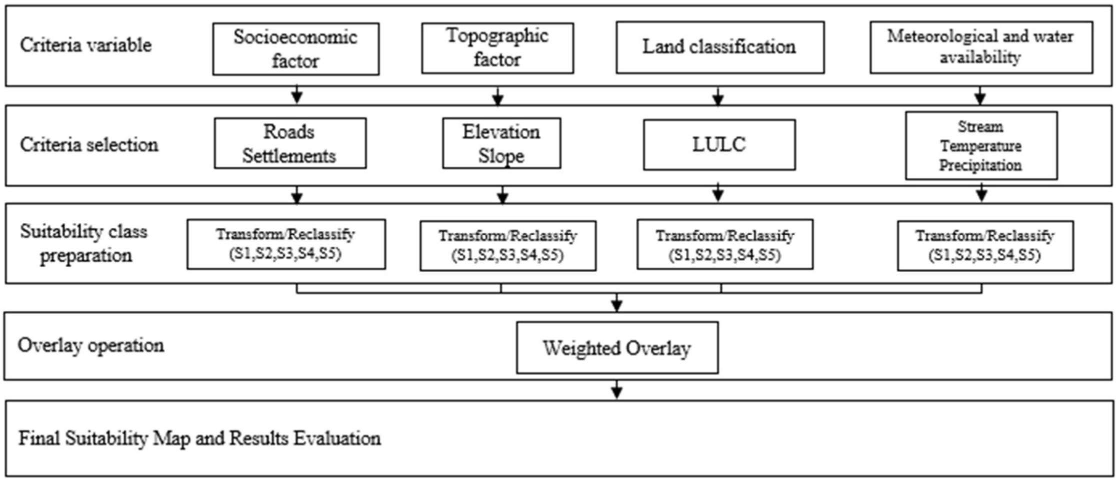

Figure 5:Methodological Flowchart

The approach designed is predicated on identifying and aggregating diverse elements to assess and scrutinize the area by integrating different geographical information strata to generate an all-encompassing assessment index, in this case, a network of carbon sinks through afforestation. Five types of assessment criteria—highly suitable, suitable, moderately suitable, poorly suitable, and not suitable—are advised (Jahn et al., 2006). The model identifies spatial priorities for afforestation and reforestation, considering the unique problem of CO_2 emissions across Gran Canaria. Priority sites for localization must be situated where advantages are maximized to improve the function and value of afforestation.

2.2.1 Data Acquisition and Processing

Data Requirement	Spatial Data	Source
Administrative Boundaries	Polygon	IDE Canaries
GHG Emissions	.xls	Government of the Canary Islands
Orthophoto	Raster (.jp2)	SITCAN
Corine Land Cover	Raster	Copernicus Land Monitoring Service
Elevation/Slope	Raster (GeoTIFF)	Open Topography
LST	Raster (GeoTIFF)	Rslab
NDVI	Raster (GeoTIFF)	GEE

Settlements	Polygon	SITCAN
Average Annual Precipitation	Raster (GeoTIFF)	SITCAN
Avg Annual Air Temperature	Raster (GeoTIFF)	SITCAN
Road	Polyline	Open Street Map
Waterways	Polyline	Open Street Map

Table 1: Data Requirements

This study uses data from several open sources, including government agencies, educational institutions, and non-governmental organizations (Table 1). The 2018 Corine land Cover raster was obtained from the Copernicus Land Monitoring Service. The administrative layers of Gran Canaria were downloaded from IDE Canarias, which contains 21 municipalities. The shapefile of the seven case-study areas was extracted following the urban limit extent of Google Maps. The elevation data was obtained from open topography, and the slope was derived from the DEM using the Spatial Analyst tool in ArcGIS Pro. The evolution of GHG emissions by sector and gas type was obtained from the Ecological transition unit of the Government of the Canary Islands (Gobierno de Canaries, 2023).

The 2021 Orthophoto of the island of Gran Canaria was obtained from a digital color photogrammetric flight of 20 cm/pixel carried out between February 13, 2021, and May 7, 2021. The Landsat 8 Land surface temperature dataset for Gran Canaria, acquired from the Rslab, was utilized for analysis. The dataset covers the duration of July 1 to August 31, 2021, comprising ten individual datasets. To assess the quality LST data, an initial preprocessing step was performed to mitigate the impact of cloud cover. Subsequently, statistical analysis and comparison with ground-based measurements, where available, were conducted to evaluate the accuracy and reliability of the LST dataset. For the NDVI, 438 Sentinel-2 surface reflectance satellite images were obtained for the period between January 2018 and December 2023 (i.e.,73 images per year with a temporal resolution of 5 days) from the Google Earth Engine platform. These satellite images were atmospherically corrected. These were filtered using the SCL (Scene Classification Layer) quality band, removing saturated or defective pixels, dark area pixels, cloud shadows, water areas, clouds, and cirrus (Caparros-Santiago et al., 2023). Overlapping orbits cover the study area. The maximum value was chosen to represent a 5-day period in the overlapping area between tiles. NDVI time series were subsequently generated at a spatial resolution of 10 m using the red band (0.65 µm–0.68 µm) and the near-infrared band (0.78 µm–0.90 µm).

2.2.2 Suitability Map

The suitability maps were created using GIS, and locations appropriate for the establishment of suitable sites for afforestation and reforestation projects were identified through multicriteria analysis. Before creating the different criterion maps, we standardized the data on the components chosen to align them with assessment standards. The suitability criteria were reclassified, transformed, and weighted accordingly using the Suitability Modeler in ArcGIS Pro (Caparros-Santiago et al., 2023) (Appendix I). For environmental factors associated with land use, five assessment criteria—highly suitable, suitable, moderately suitable, poorly suitable, and not suitable—are advised (Jahn et al., 2006). Every vector dataset was transformed into a raster, reorganized, and assigned a code between 1 and 5. A rating of 1 indicates a low rating, while 5 denotes a high rating. Expert understanding of the field and guidelines for creating sustainable green spaces informed the weights assigned to the various elements. The Suitability Modeler, a new tool in ArcGIS Pro, was used to develop the suitability map for locating new sites for afforestation in Gran Canaria.

	Criteria	**Class**	**Rank**	**Weight**
1	Settlement	<214	5	
		264-314	4	
		314-364	3	
		364-414	2	
		>464	1	
2	LULC	Marginal spaces and previous restoration land	5	
		Agricultural land, Deforested forests	5	
		Crops	5	
		Rangeland	2	
		Built Area	1	
3	Slope (Degree)	0.1 **- 11.8**	5	

		11.9 **- 23.7**	4	
		23.8 **- 35.5**	3	
		35.6 **- 47.3**	2	
		47.4 **- 59.1**	1	
4	Elevation (Meters)	4.9 - 43.1	5	
		43.2 **- 88.1**	4	
		88.2 **- 140.7**	3	
		140.8 **- 203.8**	2	
		203.9 - **378**	1	
5	Proximity to Road (Meters)	0-50	5	
		50-100	4	
		100-200	3	
		200-400	2	
		>400	1	
6	Proximity to River(Meters)	0-50	5	
		50-100	4	
		100-200	3	
		200-400	2	
		>400	1	
7	Temperature	16-22	5	
8	Precipitation			
9	Soil **Type**	Loamy soil: Medium texture	4	
		Clayey Soil: Heavy texture	3	
		Sandy Soil: Light texture	2	

Based on the previous criteria, the focus is on utilizing forests as effective carbon sinks and identifying locations for afforestation or reforestation projects. To fulfill this purpose, we also integrated the priority criteria given by the Government of Las Palmas (City Hall of Las Palmas, 2024). These include: i)Agricultural land that is estimated to cease soon to be usable, ii) Deforested

Forest lands that are not intended for silvopastoral uses (mainly livestock) or that house or constitute ecosystems of interest, prioritizing those that have scarce coverage and are exposed to soil degradation, iii) Marginal spaces between forestry, agricultural and urban uses that can harbor wooded masses, and iv) L

and previously intended for other uses and requiring restoration work (quarrying, rubbish, etc).

3.0 Results

3.1 CO2 emissions of Gran Canaria

The GHG emissions of Gran Canaria (also referred to as GEI - Gases de Efecto Invernadero in Spanish) have been measured since1990 up to 2021. Since 1995, the regional government of the Canary Islands has measured the total emissions in units of $CO_{2\text{-eq}}$ (Gg CO_2-eq) using the same sectors as the Intergovernmental Panel on Climate Change (IPPC) recommendations and EMEP/CORINAIR. The sectors include agriculture, energy processing, industrial processes, product use, waste treatment, and disposal, and transportation which are the total of all the sectors. The GHG emissions increased and peaked in 2005, reaching 19,813 Gg $CO_{2\text{-eq}}$. These emissions dropped to 13.626,00 Gg $CO_{2\text{-eq}}$ between 2005 and 2014, 28% more than the 1995 emission. From 2014 to 2019, the overall emissions increased from 13,626 Gg $CO_{2\text{-eq}}$ to 13,901 Gg $CO_{2\text{-eq}}$ and decreased to 11,711 Gg $CO_{2\text{-eq}}$ in 2020 due to the COVID-19 pandemic.

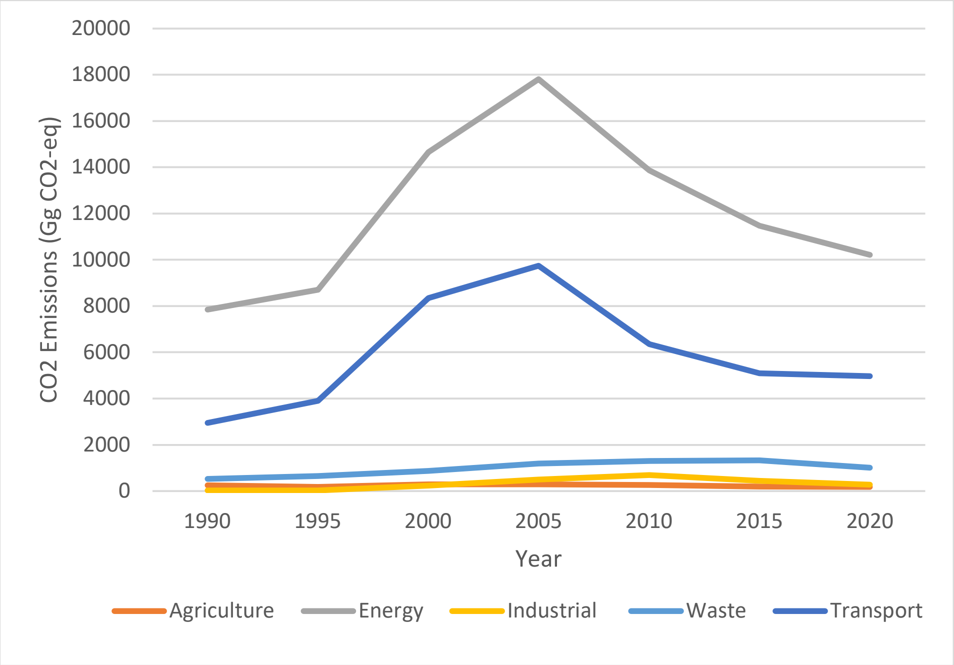

Figure 6: Canary Islands GHG emissions by category. Source: Canary Islands Energy Yearbook. Spanish System of Inventories of Emissions of Pollutants into the Atmosphere (CRF nomenclature). Ministry for the Ecological Transition and the Demographic Challenge (data as of June 2021)

Figure 6 illustrates that CO_2 contributed 87% of the total average emissions in the Canary Islands, followed by methane, which has 9% of the emissions. HF Cs, N2O, PF Cs, and SF6 account for the remaining 4% of the GHG emissions in the Canary Islands. These emissions were driven mainly by energy processes (62%) and transportation (30%) sectors, accounting for approximately 92% of GHG emissions. Waste emissions account for 5.1%; the lowest was from agriculture (1.18%) and industrial processes (1.80%).

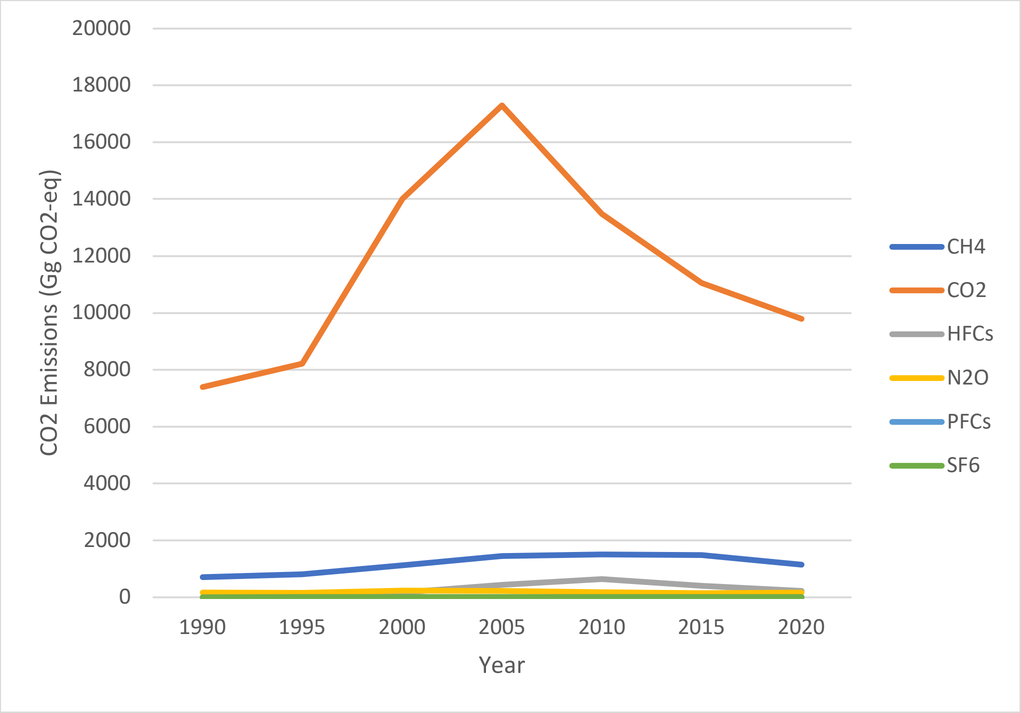

Figure 7: Canary Islands GHG emissions by type of gases.

Source: Canary Islands Energy Yearbook. Spanish System of Inventories of Emissions of Pollutants into the Atmosphere (CRF nomenclature). Ministry for the Ecological Transition and the Demographic Challenge (data as of June 2021)

In 2022, Spain's emissions increased due to a more carbon-intensive energy mix, influenced by geopolitical factors and the post-pandemic economic recovery (Barrutiabengoa et al., 2024). In the same year, the Spanish economy emitted 304.4 million tons of greenhouse gases into the atmosphere, a 3.1% increase from 2021. Since 2008, these emissions have dropped by 26.9%. Homes accounted for 22.7% of the emissions. Emissions sources include combustion from power plants, vehicles, and industry as well as deforestation., Furthermore, the Spanish National Statistics Institute (INE) released the Spanish Air Emission Accounts, which show that 2022 greenhouse gasses (GHG) and CO_2 emissions increased by 3.1% and 4.5%, respectively. This increase is explained mainly by the recovery of the economy following the pandemic and the move toward a more carbon-intensive energy mix. Droughts and geopolitical circumstances caused this shift, but it was also somewhat counteracted by a decline in energy intensity, or the amount of energy utilized per GDP unit, due to high energy prices (Barrutiabengoa et al., 2024). The well-established downward trend of emission intensities—emissions per unit of GDP—was extended in 2022 by the fall in non-CO_2 carbon intensities. The energy sector accounts for 926,100 kt CO_2 eq (27.41%), followed by the domestic transport sector (23.77%). Land Use, Land use change, and forestry contributed a negative emission value of 236,401.52 kt CO_2 eq (-7%). The total emissions from the European Union (EU-27) (UNFCCC) were 3,374,743 kt CO_2 eq in 2022 (European Environment Agency, 2024). Germany contributed to the highest emissions (749,965 kt CO_2 eq), followed by Italy (410,289 kt CO_2 eq) and France (395,674 kt CO_2 eq). Spain was ranked 5th with a contribution of 294,201 kt CO_2 eq (4.30%) by the total GHG emissions in the EU. Comparing the total 2021 GHG emission from the Canary archipelago with the 2022 EU-27 emissions, the total emissions from the canaries represent approximately 0.00038%. The overall CO_2 emissions grew until 2005, reaching 24,609.9 Gg CO_2-eq, as shown in Figure 7. The total emissions between 2005 and 2014 dropped to 16,230.8 Gg CO_2-eq. Although this was a decline of 8.4% from 2005, it was still 2.3% more than in 1995. Total emissions increased between 2014 and 2017, reaching 18,474.8 Gg CO_2-eq, or 2.2% since 2014 and 4.6% since 2017.

3.2 Relationship between mean LST and mean NDVI

An informative visual interpretation of the spatial pattern of the thermal variation and vegetation cover in Gran Canaria is illustrated in Figure 8. In the LST image of Gran Canaria, the beaches have a lower temperature compared to inland areas. It is clear that higher temperatures are associated with urban buildings and significant transportation arteries composed of non-porous materials, such as metal, asphalt, and concrete (Lo et al. 1997). In contrast, the temperature of water bodies, crops, parks, and green land is lower. Embalse de Soria, Embalse de Excusabaraja, and Embalse de Ayaguarees in the west-central part of the island show a cooler temperature. For the NDVI image, built-up or core urban areas have low values. However, the Embalse de Soria and Embalse de Excusabaraja water bodies also have low values due to the absence of vegetation. High values are also detected within cropland, parks, and green land due to relatively high levels of green biomass.

In this study, we conducted a regression analysis between LST and NDVI to evaluate the influences of urban land use and land cover. Previous studies have discussed the relationship between LST and NDVI. For instance, Gorgani et al. (2013) studied the correlation between LST and NDVI in the Urban area of Mashhad and examined the relationship between thermal behavior and vegetation cover. Using seven land-use/cover types (commercial, industrial land, residential, farmland, grassland, pasture, forest, and water) at various scales, (Weng et al.,2004) examined the relationship between LST and NDVI, with strong inverse correlation results.

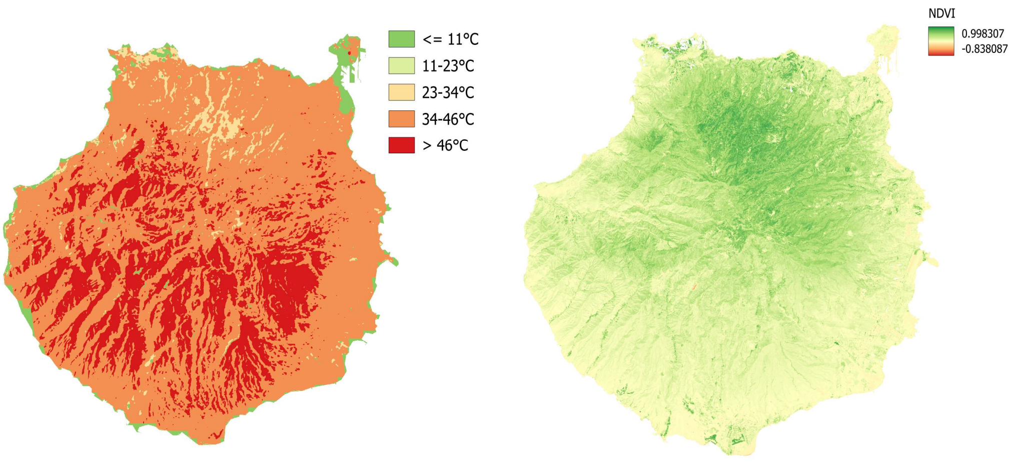

Figure 8: a LST *b. NDVI*

Water bodies, such as rivers, lakes, and ponds, exhibit favourable correlations between temperature and NDVI levels (Yue et al., 2007), which also appear low. The distribution of the 2021 NDVI for Gran Canaria is illustrated in Figure 8b. The NDVI value of Gran Canaria ranged from -0.83 to 0.99. Parks and agricultural areas with the densest vegetation have the higher values, whereas suburbs with bare soil and no vegetation cover have the lowest value. A typical instance is the Maspalomas dunes in the southern part of the island. The lowest temperatures are seen in vegetated places like parks, and the highest are found in suburban areas with bare soil.

The land surface temperature of Gran Canaria ranges from 11 °C to 46 °C. Changes in land use have a significant impact on the local temperature regime. The temperature was lower when the vegetation body was compared to other places, including built-up areas. In the northeastern region of Gran Canaria, areas with no vegetation cover, such as parks, universities, and agricultural fields, have lower LST values than built-up or suburban areas. Figure 9 illustrates the regression coefficient between LST and NDVI Gran Canaria. The regression coefficient from NDVI to LST and the correlation between NDVI and LST is, with an R^2 value of 0.39, indicating an inverse correlation between LST and NDVI. Higher land surface temperatures are found in areas with lower NDVI values and vice versa. The results also suggested that compared to areas with little vegetation cover, such as developed areas, areas with more vegetation cover (greater NDVI) may have higher evapotranspiration rates and encourage latent heat exchange between the land surface and atmosphere.

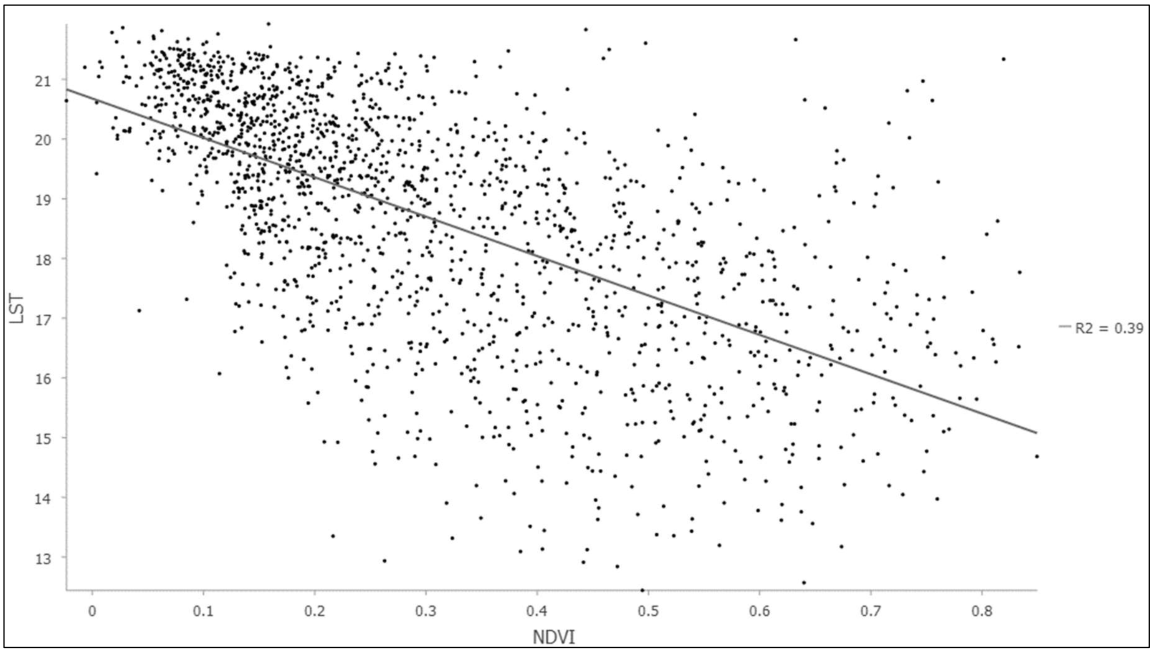

Figure 9: Relationship between Gran Canaria Average 2021 LST AND 2021 NDVI

3.3 Land Suitability Analysis

The elevation of Gran Canaria ranges from -28 to 1958m, and we distinguished the different types of reliefs into five classes. The elevation class between -28 and 250 consists of marshy depressions, water bodies, and densely populated regions. Populations are spread across the island, with the east being the least densely populated. The areas between 250 and 500 meters are elevated and mostly covered by vegetation. According to field observations backed by literature, elevated land is uneven and difficult to navigate on foot, and it may be favorable for reforestation. One of the deciding factors that guarantees green infrastructure stability is the slope factor, which occasionally relies on the altitude in a specific area. Gran Canaria has a range of slopes from 0 ° to 80°. Low slopes are found around the coastal settlements in the north, east, and south, and steep slopes can be found towards the center and on the eastern part of the island. An essential component of the accessibility of socio-community facilities in general, and green spaces in particular, is the road network. Afforestation sites that are 150, 300, 450, and 600 meters away from roadways were most suitable. At the same time, those that are farther away were less suitable, as illustrated in the road suitability map in Appendix I.

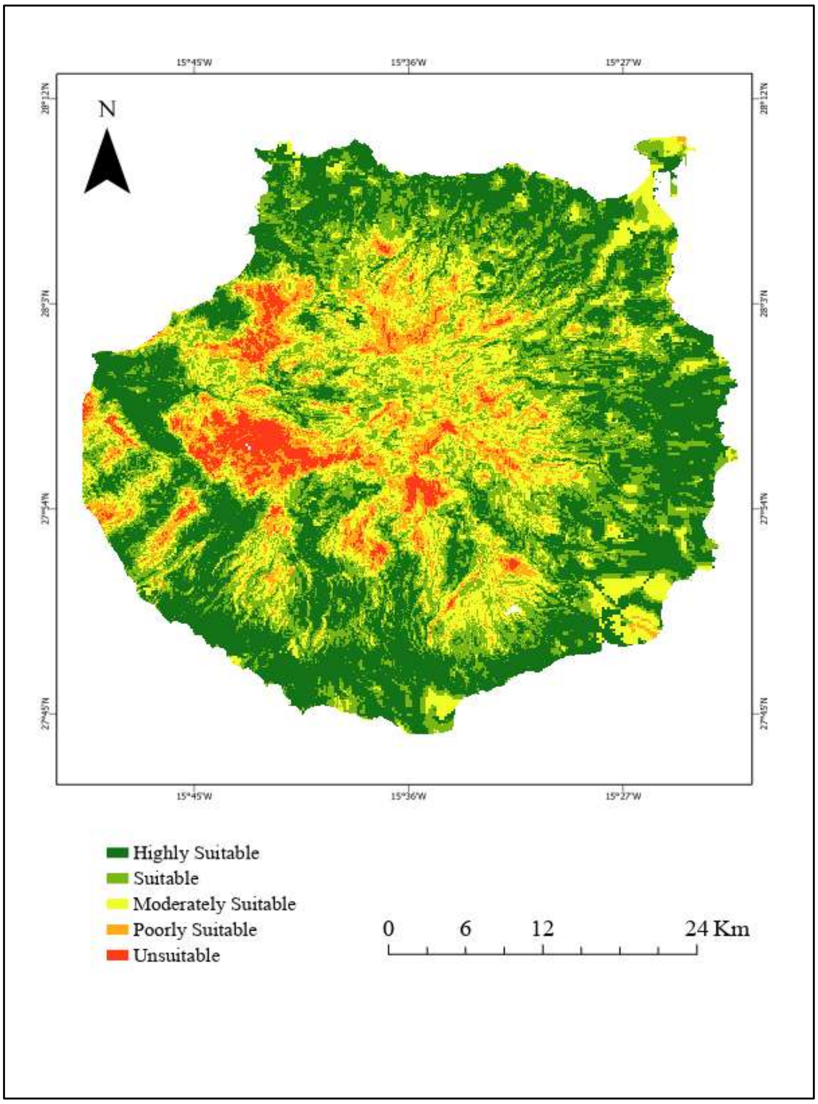

Figure 10: Final Suitability Map

According to the Land Suitability analysis (Figure 10), Gran Canaria is well suited for afforestation and reforestation projects. According to the criteria defined, 22.35% of the study area is highly suitable, as it is located in densely populated areas at medium elevations. The suitable areas cover a total area of 439.61 km2 (28.2%) of the study area. The moderately suitable areas account for

36.45% of the study area, and the poorly suitable and unsuitable areas account for 5.88 and 7.12%, respectively. The proximity of the appropriate areas makes it easy for residents to access them. In distant sites, the island's bus transportation makes it easy to access any site from any point on the island.

Suitability Class	**Pixel Count**	**Area (km^2)**	**Percentage**
Highly Suitable	9420	348.34	22.35
Suitable	11888	439.61	28.20
Moderately Suitable	15362	568.08	36.45
Poorly Suitable	2477	91.60	5.88
Unsuitable	3003	111.05	7.12
Total		1558.68	100.00

Table 2: Area Under Each Suitability Class

Table 4 illustrates the suitability ranking and areas covered by seven pilot study areas: Arucas, Maspalomas, La Aldea, Vecindario, Telde, Tamaraciete, and Galdar. Compared to the overall suitability map of Gran Canaria, the seven pilot study areas exhibit unique suitability for afforestation potential. Each area is classified into three suitability categories: Moderately Suitable, Suitable, and Highly Suitable, suggesting the need for more urban green infrastructures within the pilot areas. Maspalomas, with the highest surface area, illustrate a balanced distribution with suitable land areas of 36.91%, slightly dominant over Moderately Suitable 33.92% and Highly Suitable 29.18%. In contrast, La Aldea has a suitable land area of 63.02% and a highly suitable area of 37.81. These findings further suggest that while development is generally positive in areas like Telde and Tamaraciete with more suitable land areas, other areas, such as Vecindario and Galdar, would need more focused approaches to maximize land usage. The suitable distribution guides future land-use planning and development projects by highlighting the potential and limitations across the pilot study sites.

	Suitability Class	Area	Percent
Arucas	Moderately Suitable	0.58	44.00
	Suitable	0.51	39.00
	Highly Suitable	0.22	17.00

Maspalomas	Moderately Suitable	4.77	33.92
	Suitable	5.19	36.91
	Highly Suitable	4.10	29.18
La Aldea	Suitable	0.37	63.02
	Highly Suitable	0.22	37.81
Vecindario	Moderately Suitable	1.79	46.76
	Suitable	1.28	33.40
	Highly Suitable	0.77	20.04
Telde	Moderately Suitable	0.33	14.06
	Suitable	1.46	62.48
	Highly Suitable	0.55	23.43
Tamaraciete	Moderately Suitable	0.26	11.68
	Suitable	1.57	71.76
	Highly Suitable	0.37	16.69
Galdar	Moderately Suitable	1.35	62.61
	Suitable	0.51	23.69
	Highly Suitable	0.29	13.54

Table 3: Suitability Class and Area Covered by the Seven Pilot Areas

4.0 Discussions

There are various kinds of greenhouse gases (GHGs). The principal ones are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) because of their relative emission levels (Voigt et al., 2017). The increase in global temperature can be attributed to two main sources of greenhouse gas emissions: naturally occurring GHGs (CO_2, CH_4, N_2O, and O_3) and human-induced GHG emissions (CO_2, CH_4, N_2O, CHF_3, SF_6, HFCs, PFCs, and CFCs) linked to rapid industrialization and population growth (Wright & Nance 2012). In 2017, the amount of carbon dioxide, methane, and nitrous oxide that Spain released into the atmosphere rose by 3.8%, 0.9%, and 4.1%, respectively (INE, 2018)- considering the current state of CO_2 emissions in Gran Canaria to be addressed with the implementation of afforestation and reforestation projects (Government of Las Palmas, 2023).

A multicriteria analysis technique that incorporates environmental and social aspects has been used in several studies to find potential locations for green spaces (Ustaoglu & Aydınoglu, 2020; Gelan, 2021; Linh et al., 2022). The components and the resulting criteria in such an approach vary based on the research area and theme (Nguyen et al., 2021). Certain criteria related to the location and spatial layout of the region that is more likely to support green spaces are very precisely defined in the field of planning (Linh et al., 2022). As a result, over a dozen criteria have been mentioned and applied in various ways in earlier research in the field (Ustaoglu & Aydınoglu, 2020; Gelan, 2021). The selection of the criteria is predicated on a review of the literature that considers several global studies that have examined land suitability analysis based on GIS modelling. A table with a list of factors was created from this search (Table 2), illustrating the most frequent criteria that surfaced throughout the many studies. If they address a similar goal, the cases chosen as references offer direction for this study as well as suggestions on the weights, ranks, and criteria to consider. Using remote sensing and GIS techniques, this study established a network of carbon sinks in Gran Canaria, which is part of the forest repopulation project of the Government of las Palmas Gran Canaria, to create a network of carbon sinks that involves the afforestation or reforestation of much of its rustic and peri-urban periphery with wooded areas adapted to the bioclimatic conditions and the edaphic characteristics of the relief.

Urban and peri-urban forests encompass a comprehensive view of all trees and related plants, including street tree plantations, urban parks, cemeteries, trees in private gardens, and other urban tree sites. They also comprise forest ecosystems and woodlands. The woodland portion of the urban and peri-urban forest is crucial because it offers several essential ecosystem services, including preserving drinking water, storing carbon dioxide, inhibiting soil degradation, and providing outdoor recreation areas (Nieder et al., 2018). Sustainable forest resource management and the ongoing provision of ecosystem services to present and future generations are also essential for urban and peri-urban forestry to be effective. Along with maximizing the positive effects on nearby populations, it should aim to reduce any drawbacks that can restrict the recreational use of urban and peri-urban woods, such as allergy exposure and the perception of increased criminal risk. Long-term planning is crucial to guarantee the sustainability of ecosystem services and the advantages of urban and peri-urban forestry (Cueva et al., 2022). The emphasis on forests and trees as essential elements sets urban and peri-urban forestry apart from other urban green space designs. By connecting the tree-dominated aspects of urban and peri-urban green structures and spaces, urban and peri-urban forestry can be an integrative, nature-based solution. It is also strongly associated with the green infrastructure planning method, which emphasizes the importance of considering the whole network of green and blue areas (such as wetlands, rivers, and lakes) within a city or metropolitan area. This necessitates shifting our attention from specific areas to this broader network. This is because numerous ecosystem services can be produced via a network of green and blue areas that is interconnected and functional. Urban environments are ecosystems, or more accurately, socio-ecological systems, and they can withstand the effects of climate change if they have trees and other vegetation (UNECE, 2021). The land suitability analysis will also fulfill the three strategic objectives to prevent and reduce the impact of climate change in three ways i) adapt the territorial and urban model to the effects of climate change, ii) reduce greenhouse gas emissions, and iii) improve resilience to climate change. The research objective aligns with the Government of Spain's indicators: 05-Green surface, 11-Parks and green area equipment, 45-Greenscape regeneration, and 54-Greenhouse gas emissions by Inhabitant (Government of Las Palmas, 2023).

Working with Spanish data requires changing the number format from decimal to a point format, which is different from the original English version, which may be difficult. Also, data acquisition in Spanish requires more attention in translation. For instance, the Spanish databank refers to the GHG as GEI (Gases de Efecto Invernadero). The data we found were based on the municipalities, not the selected pilot cities. This research adds to the body of evidence supporting the validity of multiple criteria in land suitability analysis for afforestation and reforestation. It is also important to note that MCDA based on expert opinion and weighted overlay technique may be biased by the researchers, particularly when choosing and weighing the criteria. Therefore, selecting the best-fitting criteria for MCDA and the weighted overlay approach requires extra consideration. The application of multicriteria analysis is significant in land suitability analysis for afforestation in Gran Canaria, allowing the integration of several environmental, socio-economic, and topographic factors. This comprehensive approach ensures more accurate and holistic decision-making, optimizing suitable sites for afforestation selection, enhancing ecological conservation, and contributing to human well-being. Due to time and resource constraints, another limitation of the study is the inability to derive the CO2 sequestration map of Gran Canaria. It could be achieved using advanced remote sensing techniques. Future research could include a more robust methodology of temperature and vegetation mapping using LST and NDVI datasets, considering the unique characteristics of the ecosystem of Gran Canaria.

Further research is required to establish suitable plant species, the necessary techniques to undertake its installation, and the management indications corresponding to the first years of installation and maturation of the new trees. The selection of forest species is the most important technical decision since the success of repopulation will depend on it. The carbon sequestration capacity of the newly selected site will depend mainly on the productivity of the land where forest repopulation is carried out, the set of selected species and the planting density introduced (Government of Las Palmas, 2023). Future research may also aim to understand residents' perceptions of green spaces. It could be more specific, focusing on children, aged adults, or recreational users.

After new areas have been located and identified for reforestation purposes, the next stage will be to design a forest repopulation project, considering the kind of tree species needed, the methods required to implement it, and the management guidelines for the initial years of installation and growth of the new trees. The most crucial technical choice is which forest species to choose, as it will determine whether or not the repopulation effort is successful. The new revegetated space's ability to sequester carbon dioxide will primarily rely on the productivity of the land used for forest repopulation, the species chosen, and the introduced planting density.

5.0 Conclusion

The result of the GHG emission shows that the majority of the emissions of the Canary Islands are from energy processes and transportation sectors, accounting for approximately 92% of GHG emissions. Conversely, waste emissions, agriculture, and industrial processes account for lower emissions. There is a strong inverse correlation between the LST and NDVI values. The LST and NDVI results revealed that areas with higher temperatures are usually associated with places devoid of vegetation, such as Maspalomas dunes, suburbs, and built-up regions. In contrast, the NDVI peaks are found in urban green spaces, except for a few parks with high NDVI values. With the exception of a few parks with high NDVI values, the built-up or core urban areas of Gran Canaria have generally low NDVI values and minimal vegetation. It is possible to conclude that the seven pilot regions with a high human effect are urban, with comparatively higher LST and lower NDVI. Land suitability mapping is relevant to policymaking, environmental sustainability, land use planning, risk management, public awareness, and climate resilience. In this study, we analyzed the GHG emissions of CO_2 in Gran Canaria. In response to the increasing CO_2 gases, we evaluated the relationship between temperature and vegetation cover, and we developed a land suitability model for land suitability analysis for the afforestation project in Gran Canaria, highlighting the urgency to sustainable restoration and conservation practices. The study also contributes to the corresponding goal of mitigating climate change by increasing the carbon sequestration capacity of the identified areas through strategic afforestation and reforestation efforts. Additionally, this study recognizes the potential of forests not only as carbon sinks but also as sources of green infrastructure that can further reduce greenhouse gas emissions when utilized as alternatives to emission sinks.

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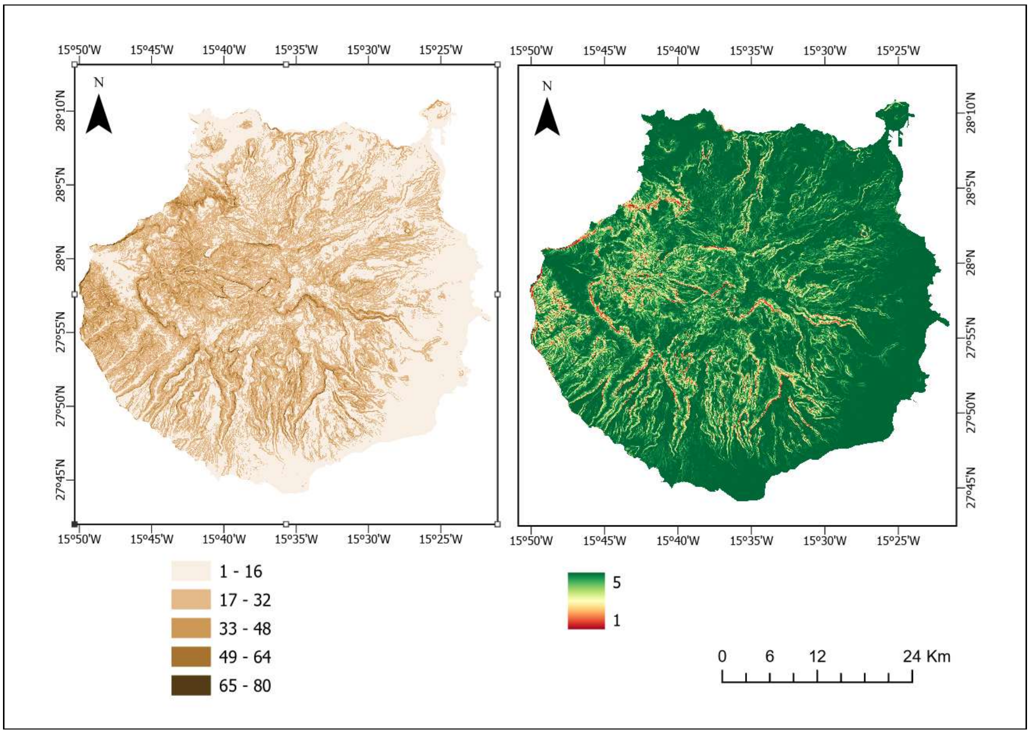
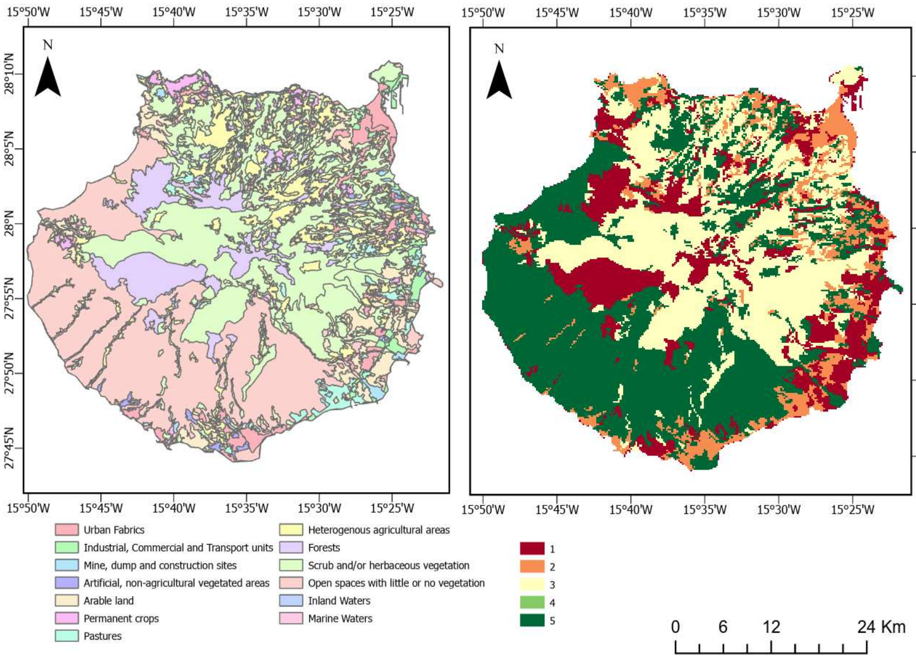
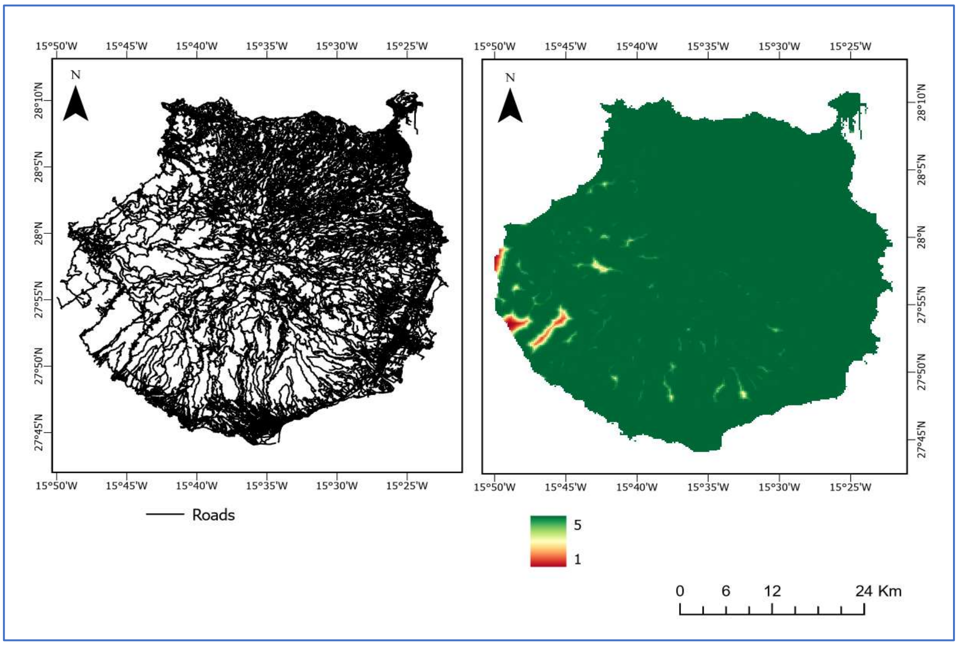
Appendix



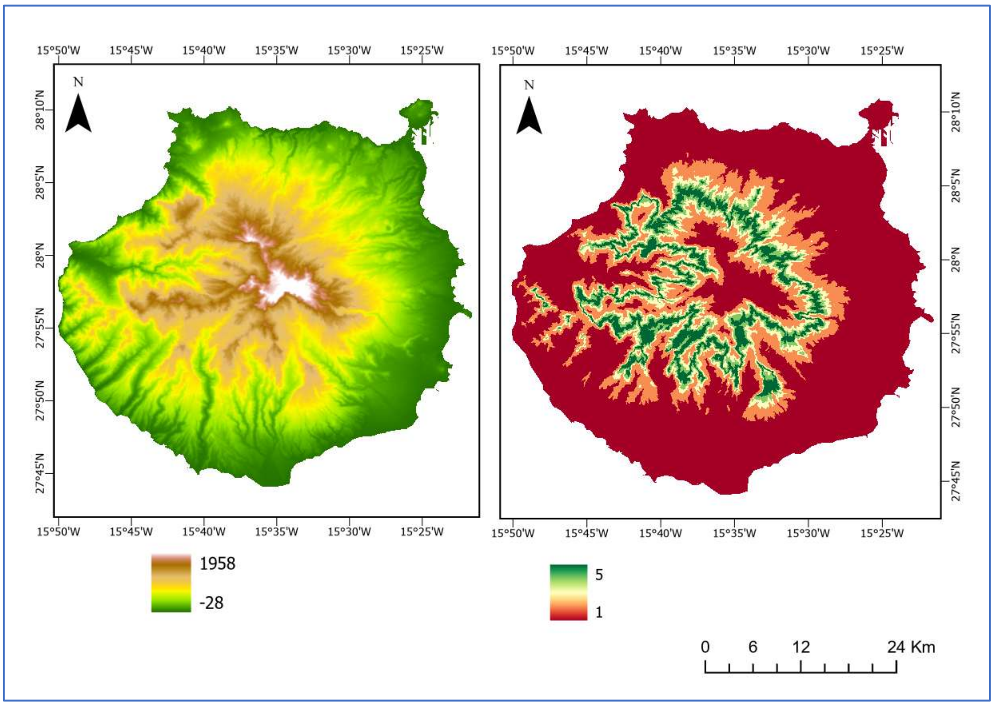
i. a. Slope b. Transformed slope.



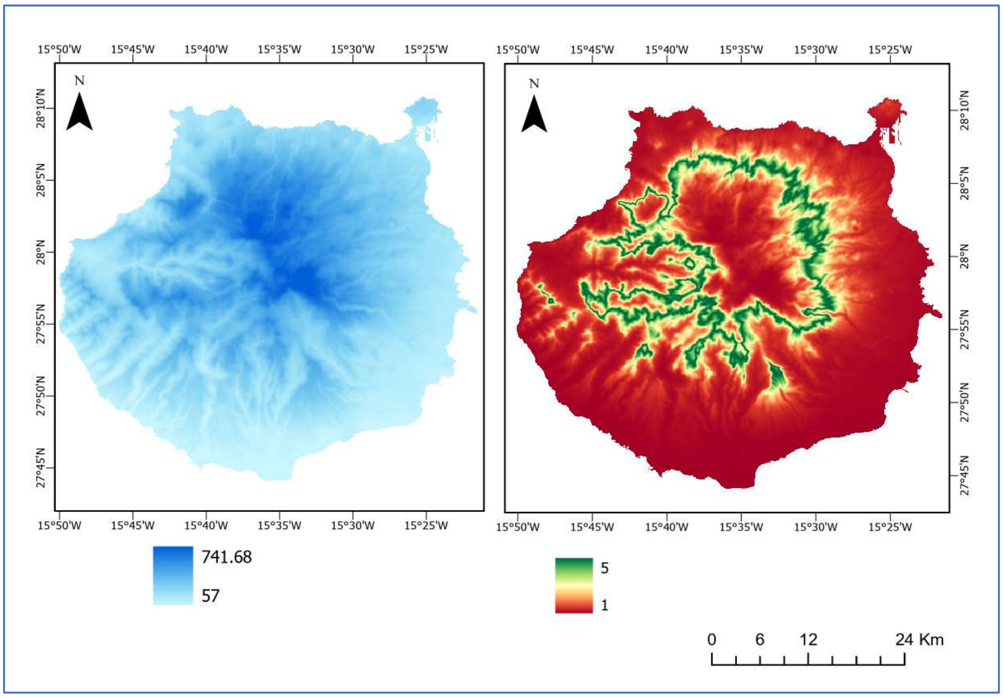
ii. a. LULC b. Transformed LULC



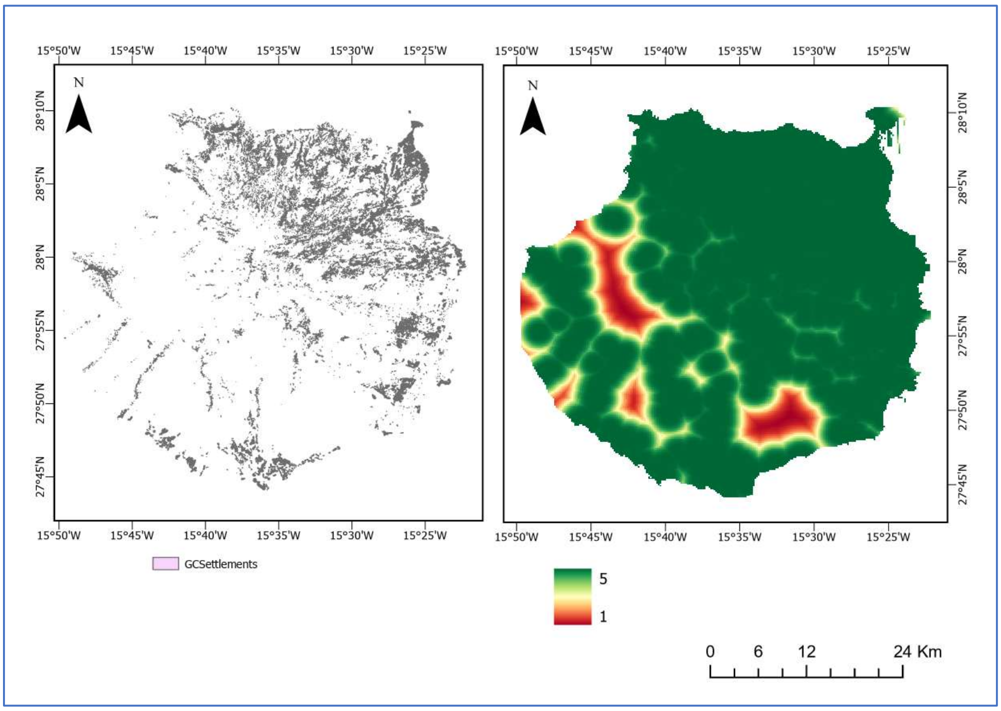
iii. a. Roads b. Transformed roads.



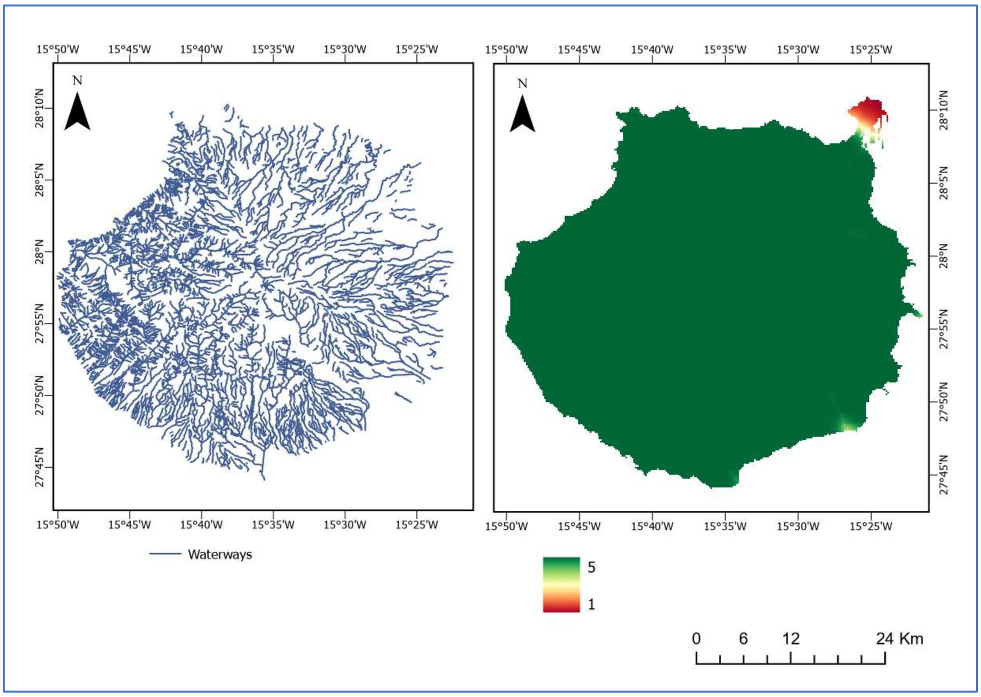
iv. a. Elevation b. Transformed elevation.



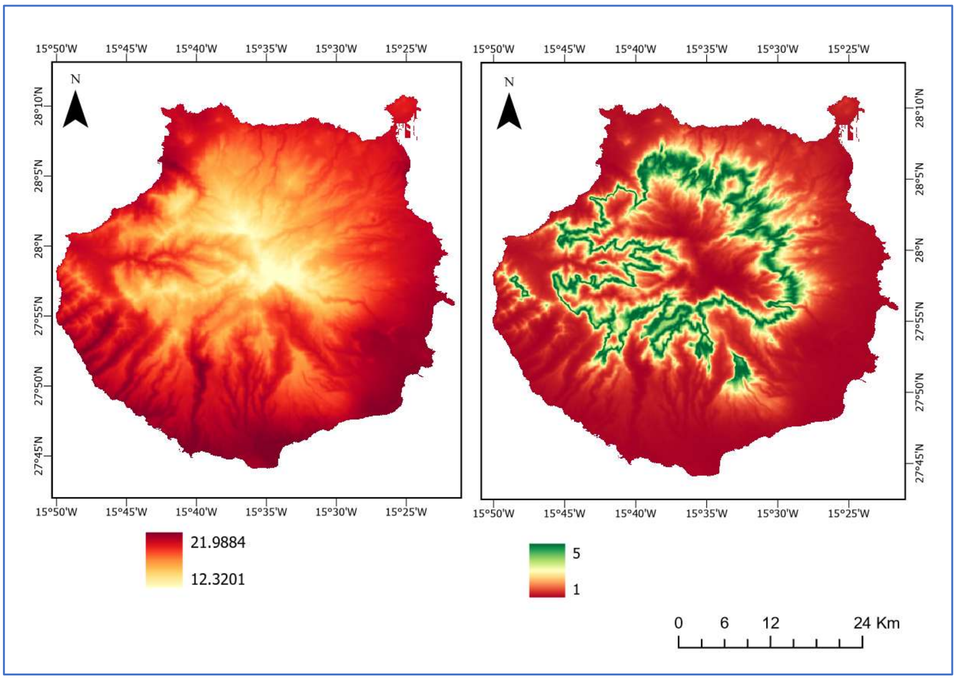
v. a. Precipitation b. Transformed precipitation.



vi. a. Settlements b. Transformed settlements.



vii. a. Waterways b. Transformed waterways.



viii. a. Temperature b. Transformed temperature.