Employing spatial queries in Qgis: Identifying and evaluating potential sites for forest nurseries installation in the Limassol district.

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Abstract: Geographic Information Systems (GIS) are a modern tool for managing, analyzing, and processing spatial and temporal data. This technology ensures secure and reliable data while maintaining a steady and valid flow of information. The proficiency in utilizing GIS has enabled modern societies to draw precise and rational conclusions, particularly when various decision-making centres are called upon to engage with phenomena, processes, and activities intricately connected to the broader economic and social dimensions of human activity.

Integrating GIS into the comprehension, prediction, analysis, and surveillance of forest fires in science has for many years, fostered collaboration among diverse socioeconomic stakeholders, including governmental bodies, academic institutions, and various organizations, to address this devastating issue. As a cause-causation of climate change, forest fires are the dominant threat to Cypriot forests. Given the sluggish natural regeneration of the island's forests, primarily caused by climatic constraints, steep terrain, and inadequate moisture and precipitation, there is an urgent need to implement artificial reforestation strategies.

This study seeks to identify and define suitable locations for establishing and managing nurseries in the Limassol district, which local forestry services and various public or private entities can leverage. The optimal selection of nurseries guarantees a reliable supply of plant resources to entities participating in activities and initiatives aimed at the artificial regeneration of Cypriot forests. Such nurseries are envisioned to facilitate future reforestation projects while fostering economic growth and activity among the mountain and peri-urban populations. The study's workflow is within the Qgis free software environment, leveraging satellite imagery from the Limassol provincial unit, the latest Land Use Cover maps, Digital Elevation Model (DEM) maps, and maps of ecologically vulnerable areas and regions under conservation protection. Data regarding the hydrographic and road networks of the examined area are also employed. The conclusive selection of viable locations involves environmental criteria related to the cultivation of native forest species, such as *Pinus nigra var. pallasiana* and *Pinus brutia (Calabrian pine)*, as well as factors that facilitate the seamless and continuous operation of the nurseries.

Findings from the study demonstrate that the ideal areas for establishing and managing nurseries in the wider Limassol district are confined to the northern mountainous massif. These areas are scattered and vary in size, situated within zones of existing forest ecosystems and accessible through the current road network alongside the existing hydrographic network. This study aspires to be an integral part of the framework for forthcoming assessments and evaluations, focusing on identifying suitable areas for

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rational grazing, pasture farming, sustainable hunting, and agrotourism, as well as selecting prime locations for establishing tourist units.

Keywords: Qgis, Optimal land use selection, Spatial Planning, Remote Sensing, Forest artificial regeneration, Limassol, Cyprus.

Introduction

A GIS is a holistic framework for systematically acquiring, storing, modifying, analyzing, and presenting geographical data, ensuring efficiency and clarity throughout the process [1]. The development of GIS has transcended its essential function of cartographic representation; thus, given the current sophistication of GIS tools, users can now create dynamic and interactive maps, accessing spatial databases through online platforms while monitoring and assessing natural phenomena in real time. The relationship between GIS and technologies such as the Internet of Things (IoT), Big Data, and drones has been thoroughly examined in the literature [2], [3]. Notably, ESRI delineates eight essential technologies crucial for the advancement of GIS and the collection of various spatial data types[1]. These include Artificial Intelligence (AI), Augmented Reality (AR), Blockchain technology, Drones (UAV), IoT, Robotics, Virtual Reality (VR), and 3d printing. Incorporating those technologies elevates the informational depth of the maps and modelling procedures developed, aiding in various information types and facilitating decision-making activities, thereby ensuring effective management [4]. For instance, GIS facilitates the mapping and assessing burned areas, which is crucial in predicting the spread and damage inflicted by wildfires at various intervals and scales.

The island of Cyprus, positioned in the southeastern Mediterranean region, is profoundly impacted by the occurrence of fires [5]. Data extracted from the Forest Department in Cyprus, covering the period from 2000 to 2021, reveals 1,327 recorded forest fires. A predominant share of these fires, totalling 85%, are ascribed to human intervention, in contrast to the 15% of fire incidents attributed to natural phenomena. Historical data regarding fire incidents on the island reveals a declining trend in the number of occurrences over the past several decades. Nevertheless, this decline does not correspond with the overall area that has been burned. Notable examples include the years 2013 (2,835ha burned), 2016 (3,205ha burned), and 2021 (6,612ha burned), which demonstrate that recent fires have been characterized by increased severity and a more extensive wildfire extent.

The legislation governing forests in Cyprus, specifically the Forest Law of 1967, does not stipulate reforestation initiatives. The management of state forests utilizes a selective silvicultural system that fosters natural regeneration. In the aftermath of forest fires, the authorities generally refrain from immediate intervention, allowing several years for natural regeneration before resorting to artificial reforestation techniques. Such artificial methods are employed solely when natural regeneration fails [6]. An analysis derived from a 2020 Food and Agriculture Organization (FAO) report concerning Cyprus's national reforestation initiatives reveals that approximately 350 ha were reforested from 2011 to 2015. The subsequent years, 2016 and 2017, marked a reforested area of 1,410 ha. However, the most recent national statistics for 2018 reflect a downturn in these efforts, with only 52.5 ha reforested [7].

The Cypriot Forest Department oversees four nurseries in *Athalassa, Fasouri, Platania*, and *Stavros tis Psokas*, which serve the dual purpose of supplying the public and supporting reforestation initiatives by providing plant materials and stock. The Fasouri nursery is the only one located in the

[1] https://www.arcanagis.pl/osiem-przelomowych-technologii-i-ich-znaczenie-dla-geoinformacji/

Limassol district. The nurseries at Athalassa, Platania, and Stavros tis Psokas began their operations around 1926, in contrast to the Fasouri nursery, which was inaugurated in 1977[2]. These four facilities are dedicated to the production and conservation of plant species. They produce approximately 130 plant varieties, with a focus on forest-endemic and native types.

As the current research delves to derive in-depth results based on two distinct forest species, namely *Pinus nigra var. pallasiana* and *Pinus brutia*, in the ensuing section, a detailed examination considering their unique features, their ecological status and significance is provided. *Pinus nigra*, commonly known as the black pine, is a prominent evergreen coniferous tree that generally grows to a height of 30m, and in ideal circumstances, it can reach heights of up to 40m [8]. Black pine is found across more than 3,5 million ha[3], making it one of the most widely distributed conifer species in the Balkans and Asia Minor. Black pine stands dominantly at the optimum altitudes of 800 and 1,500m [9]. The subspecies classification of *Pinus nigra* falls under the purview of the European Council Directive 1999/105/CE[4]. Similarly, the Joint Research Centre [10] acknowledges only two morphologically differentiated categories: the eastern subspecies, which possess thick and rigid needles, and the western subspecies, characterized by slender and elastic needles. *Pinus nigra* is known to establish itself in either monospecific stands or in mixtures with a variety of deciduous and coniferous species, especially *Scots pine*. Furthermore, it is commonly associated with other pine species, including *Pinus cembra L*., *Pinus brutia Ten*., *Pinus halepensis Mill., Pinus pinea L*., and *Pinus heldreichii Christ* [11].

Pinus nigra have relatively good frost tolerance and can survive up to -20 °C [12]. It is highly tolerant to drought and wind [13]. Its drought resilience is further augmented by the increased potassium concentration in its needles, which offers a distinct competitive advantage amid the challenges posed by climate change. The ecological versatility of *Pinus nigra* renders it one of the predominant tree species employed in reforestation initiatives throughout Europe [14]. Its relative robustness against biotic influences, in contrast to other species, suggests its potential as a viable pine species amid climate change challenges, yet the importance of utilizing a suitable ecotype cannot be overstated [15]. Ultimately, *Pinus nigra* proves to be highly effective in the rehabilitation of degraded soils, as its tap root system plays a crucial role in bolstering soil stability [16]. As a result, it is utilized to fix dunes and develop protective shelter belts [17].

Pinus brutia serves as the predominant tree species in Cyprus, accounting for 65% of the island's forested areas, as reported by the FAO (2020) [7]. The adaptability of *Pinus brutia* forests enables them to thrive on a wide range of substrates and in nearly all bioclimatic settings throughout the Mediterranean region. These forests are found at altitudes ranging from 0 to 600 m in the northern Mediterranean and from 0 to 1,400m in the southern Mediterranean. The *Pinus brutia* forests are prevalent across vast landscapes in the Eastern Mediterranean, notably in Greece, Turkey, Cyprus, Syria, and Lebanon. The successful development of *Pinus brutia* forests is contingent upon higher rainfall levels. Yet, these forests can tolerate various temperatures, with absolute mean minimum temperatures between –5 and +10°C, found in both sub-humid and humid bioclimatic conditions [18]. *Pinus brutia* is recognized as the primary or only source of wood and forest resources in many Mediterranean regions.

This research aims to identify the best-suited locations within the Limassol district that may

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[2] https://www.moa.gov.cy/moa/fd/fd.nsf/fd77_gr/fd77_gr?OpenDocument
[3] https://forest.jrc.ec.europa.eu/media/atlas/Pinus_nigra.pdf
[4] https://eur-lex.europa.eu/eli/dir/1999/105/oj/eng

be leveraged by the Forestry Services and/or interested stakeholders to develop and operate nurseries. These nurseries will provide essential plant materials for future forest restoration projects across the island. Such nurseries are envisioned to facilitate future reforestation initiatives and enhance the economic activity and development of the mountain and peri-urban population.

Methodology

The Limassol district entity has been identified as a case study for this research due to its status as one of Cyprus's most ecologically compelling districts. This area features various natural components, including wetlands and aesthetically pleasing forests, which are preserved by international conventions such as the Natura 2000 network. Significant examples of these protected sites are the Salt Lakes and the Troodos Mountain National Park, located north of the city. Within the Limassol district, there are six principal municipalities and 104 communities, each managed by a community council and primarily located in rural areas. The district's population is 262.157 (2021 census), constituting 28,4% of the total Cyprus population. Regarding citizenship, 8,6% of the individuals are EU citizens, while 13,1% are non-EU citizens[5]. From a climatic aspect, there is low annual precipitation in the Limassol district, averaging 300-400mm [19]. The Köppen-Geiger climate classification designates the district as Csa, corresponding to a hot summer Mediterranean climate. The average annual temperature for 2023 in Limassol, the district's capital, was 18.79°C [20].

The study's objectives will be realized using the Qgis software environment (version 3.3)[6]. The analysis and processing of data, encompassing both vector and raster formats, incorporates satellite maps of the Limassol district, Land Cover maps from 2021[7] at a spatial resolution of 10m, Shuttle Radar Topography Mission (SRTM) Elevation Data at a 30m resolution, Slope maps, and additional mapping data related to hydrographic systems, the broader road network, and urban residential areas.

In the process of determining the ideal locations for the establishment and functioning of the nurseries focused on the forest species *Pinus nigra var. pallasiana* and *Pinus brutia,* environmental data about their cultivation will be considered alongside factors that facilitate the seamless and continuous operation of the nurseries. Therefore, ensuring a functional and operational road network in the vicinity of the nurseries, along with a comprehensive hydrographic network, is crucial. This necessity arises from the substantial water requirements of the examined forest species and other potential varieties, especially during their early stages of development. These considerations are fundamental in determining the quality and characteristics of the eventual outcomes.

The research delineates the distance coefficients, with X representing the hydrographic network at 150m and Y corresponding to the road network at 100m. In addition, the environmental variable of altitude will be evaluated, with the coefficient Z defined between 350m and 1,200m, reflecting the ideal values of the plant communities found in the natural habitats and phytosociology of the two forest species. Furthermore, soil slopes of less than 10% will be recognized as suitable for identifying preferred locations.

Results

The land cover inventory for the reference year 2021, which presents a thorough and spatially coherent dataset across Europe, was obtained from the Copernicus Land Monitoring Service database. It

[5] https://www.cystat.gov.cy/en/PressRelease?id=71235
[6] https://qgis.org/project/overview/
[7] https://land.copernicus.eu/en/products/clc-backbone/clc-backbone-2021

identifies the primary land cover for each pixel, classified into 11 basic land cover classes. The final raster data product clipped to present the regional entity to be studied is illustrated below (Fig 1).

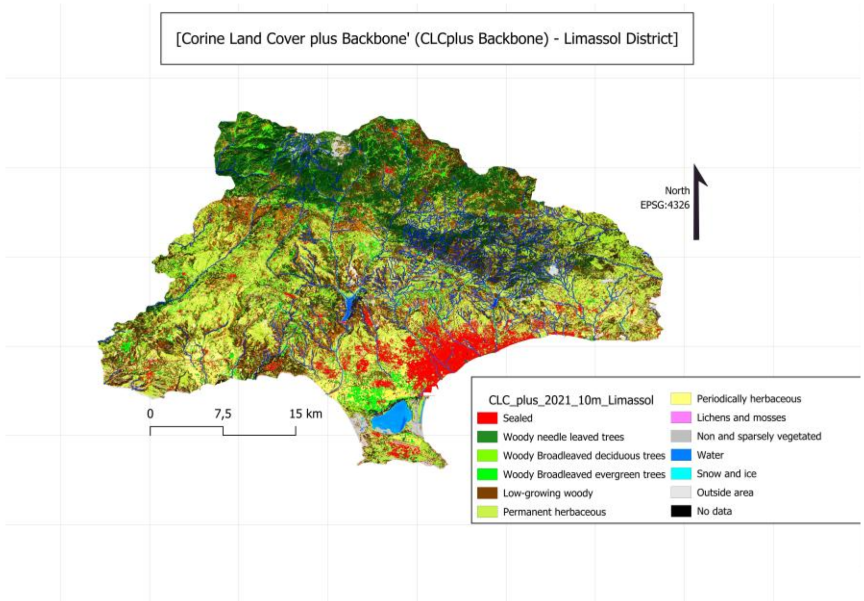

Fig 1. Land Cover Map – Limassol District.

A DEM digitally depicts certain terrestrial features across a two-dimensional surface. The NASA SRTM utilized interferometric synthetic aperture radar (InSAR) to collect elevation data, achieving a spatial resolution of 30m [21]. The DEM gives crucial information about topographical features, including slope, aspect, perspective, three-dimensional view, and hill shading. Fig 2 depicts the district's SRTM Elevation map, featuring 40 defined altitude classes. The maximum value recorded in the district is 1.870m.

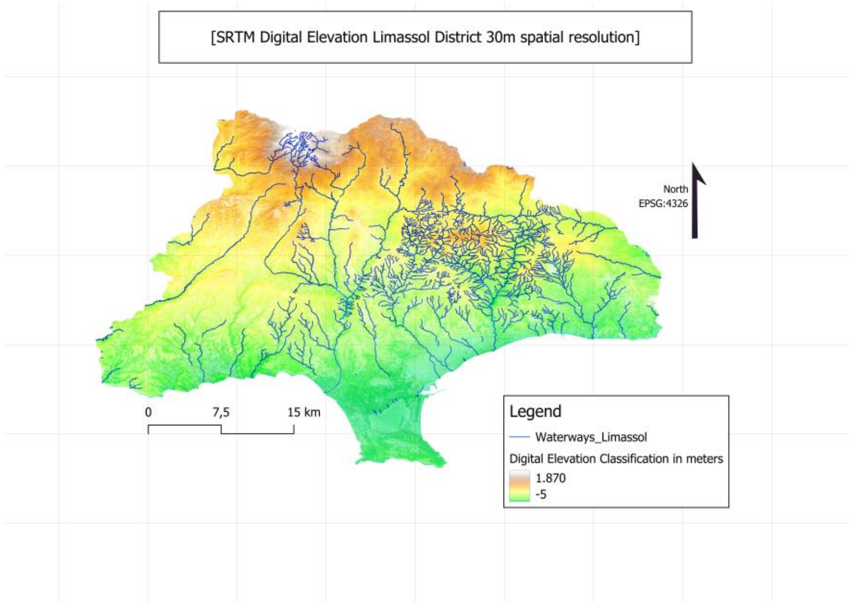

Fig 2. SRTM Elevation – Limassol District.

Fig 3 presents the terrain analysis data associated with the hillshade map for the Limassol district. This data was derived from the preceding SRTM elevation map using the Qgis application through the specified command path: *Raster >Analysis > Hillshade.*

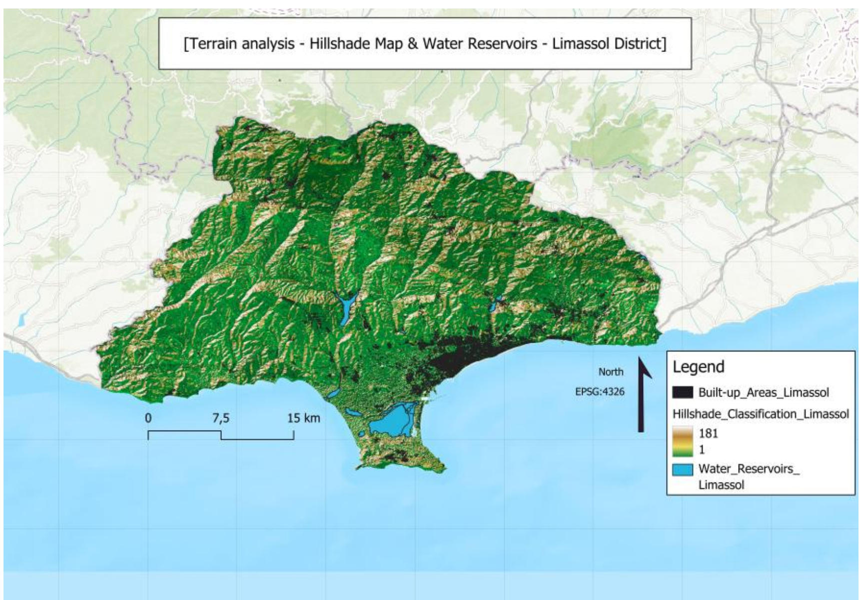

Fig 3. Terrain Analysis: Hillshade and Water Reservoirs in Limassol District.

Setting the slope variable is crucial when selecting suitable sites for establishing the nurseries. The slopes generated in the study area were systematically arranged into distinct degree classes, as represented in Fig 4, which provides further insights into the terrain analysis, explicitly presenting the contour map of the region, which were extracted using the command paths *Raster >Analysis >Slope* and the *Raster >Extraction >Contours* paths, respectively.

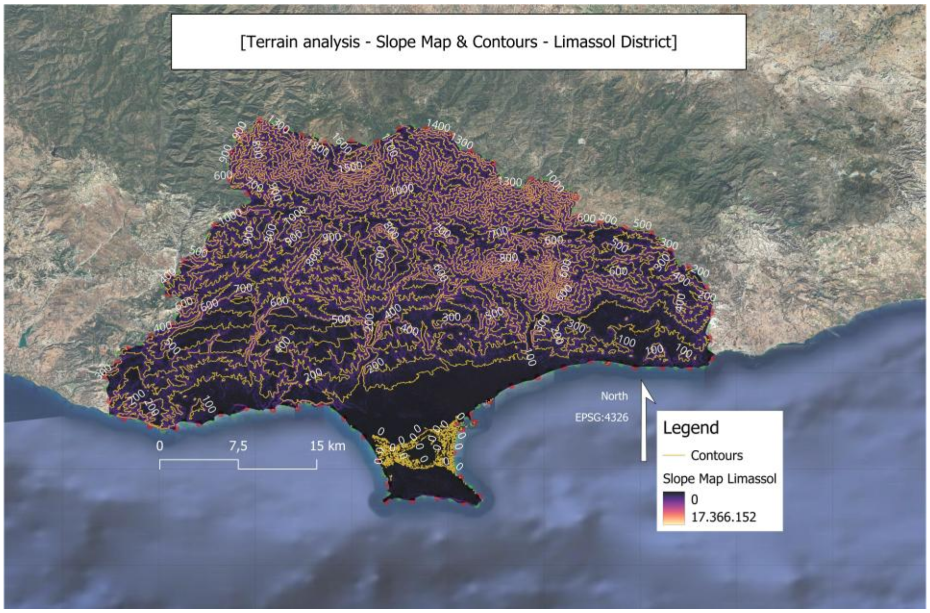

Fig 4. Terrain Analysis: Slope and Contours in the Limassol District.

The polygon data pertaining to the international Natura 2000 network were sourced from the Ministry of Environment of Cyprus. This dataset was subsequently clipped to illustrate solely the protected areas of the network within the district under examination, as depicted in Fig 5.

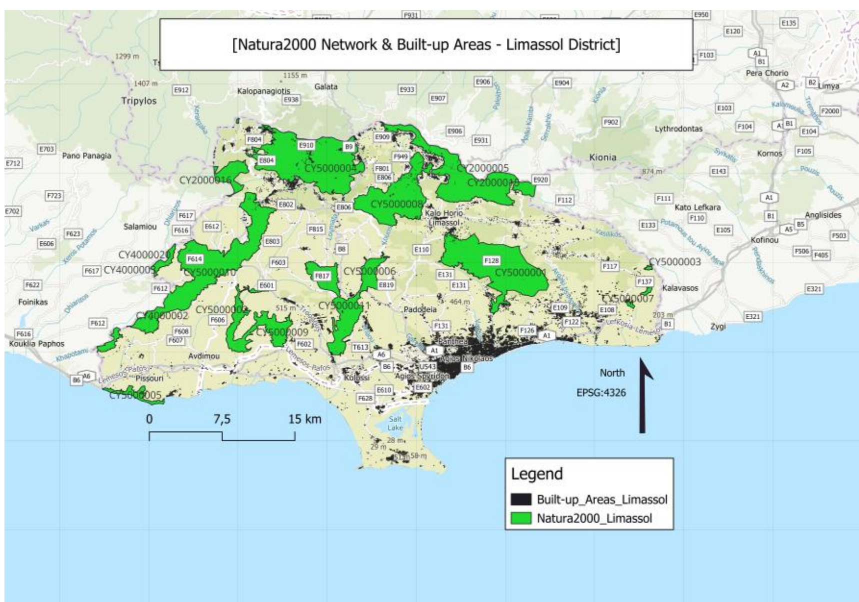

Fig 5. Natura2000 Network – Limassol District[8]

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[8] https://www.moa.gov.cy/moa/environment/environmentnew.nsf/index_en/index_en?OpenDocument

Based on open data from the Copernicus Earth Observation Program, a forest classification has been established at a pan-European level, characterized by a spatial resolution of 10m. This classification encompasses three thematic classes: non-forest areas, broadleaved forests, and coniferous forests, corresponding to the reference year 2018. The entire database was streamlined to display only the data relevant to the case study. Limassol district is distinguished primarily by forest cover in its northern aspect, with most of it consisting of coniferous tree species (Fig 6).

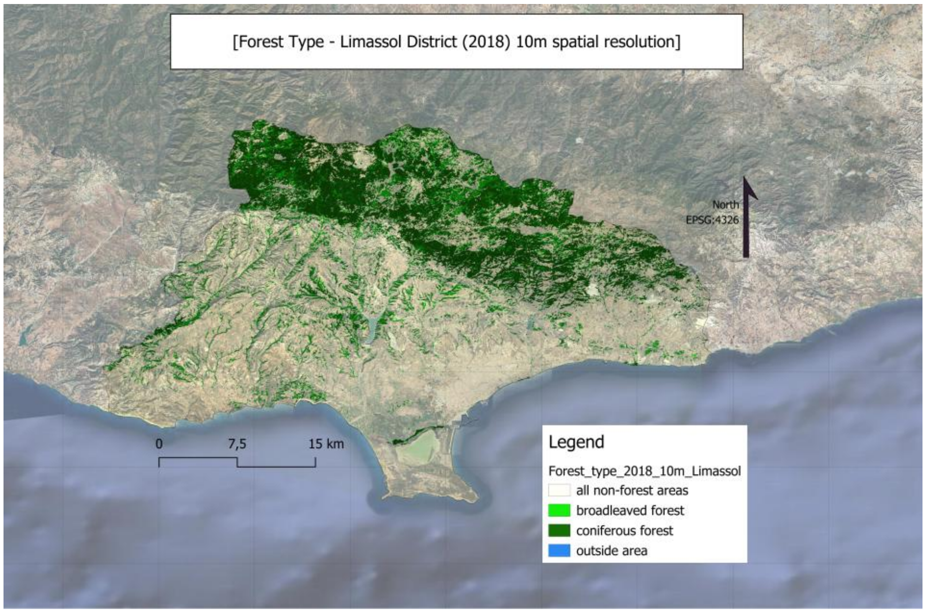

Fig 6. Forest Type[9].

The habitat distribution of *Pinus brutia* is represented in Fig 7 for the year 2018. The vector data employed in this representation were derived from Caudullo et al.'s data article [22], which is also available in the EU JRC publications repository[10]. Findings suggest that the species is expanding nearly throughout the entire district, extending its range to include the coastal areas. Regarding *Pinus nigra var. pallasiana* species, its distribution is observed in isolated locations and scattered clusters within the Troodos Mountain in regions that extend beyond Limassol district.

[9] https://sdi.eea.europa.eu/catalogue/copernicus/api/records/59b0620c-7bb4-4c82-b3ce-f16715573137?language=all
[10] https://publications.jrc.ec.europa.eu/repository/

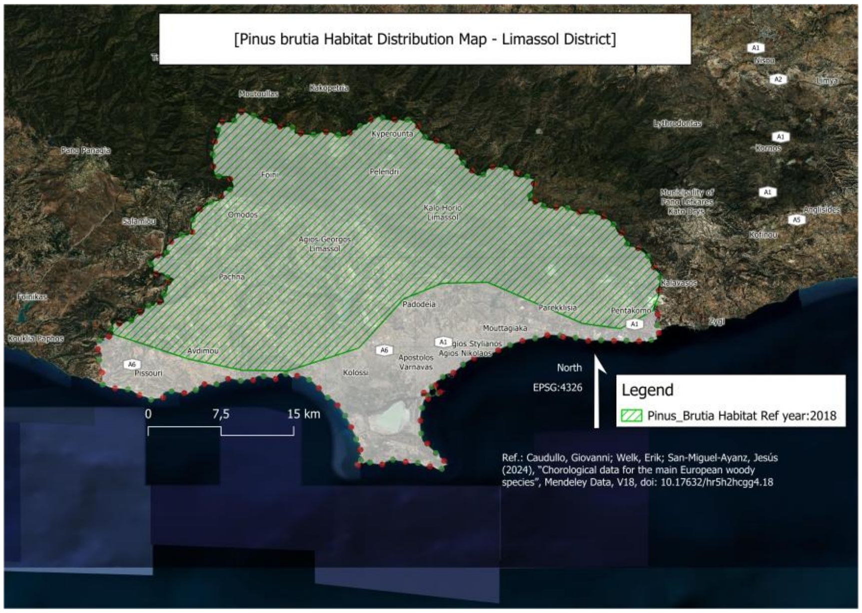

Fig 7. *Pinus brutia* Habitat Distribution (2018).

In conjunction with the established hydrographic network, Fig 8 illustrates the altitude verification, as a fundamental environmental variable to be considered, achieved within the permissible range of 350m < Z < 1,200m. This verification process was conducted using the SRTM Elevation file alongside the raster calculator command, where the formula was inserted as follows: ("SRTM30m_Limassol" >= 350) * ("SRTM30m_Limassol" <= 1200) * ("SRTM30m_Limassol").

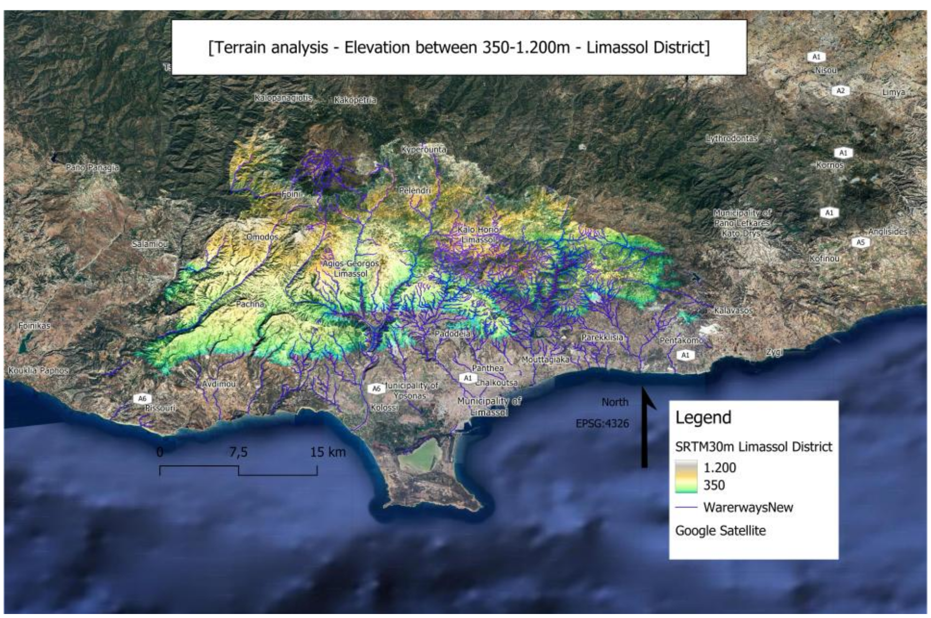

Fig 8. Terrain Analysis: Permissible Elevation Range.

Drawing conclusions about the permissible elevation range specified by the study from an environmental dimension is particularly compelling. As demonstrated in Fig 9 and corroborated by a statistical analysis of the altitude values, the district exhibits a relatively low to moderate elevation profile, with most of its elevation falling within the 400-800m range.

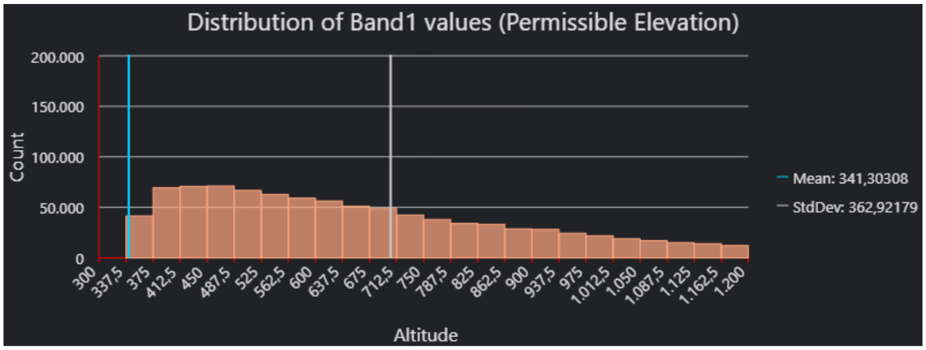

Fig 9. Permissible Elevation Distribution Range.

The subsequent stage of the methodology involved reassessing the slope map, with its representation now expressed in percentage (%) units (Fig 10).

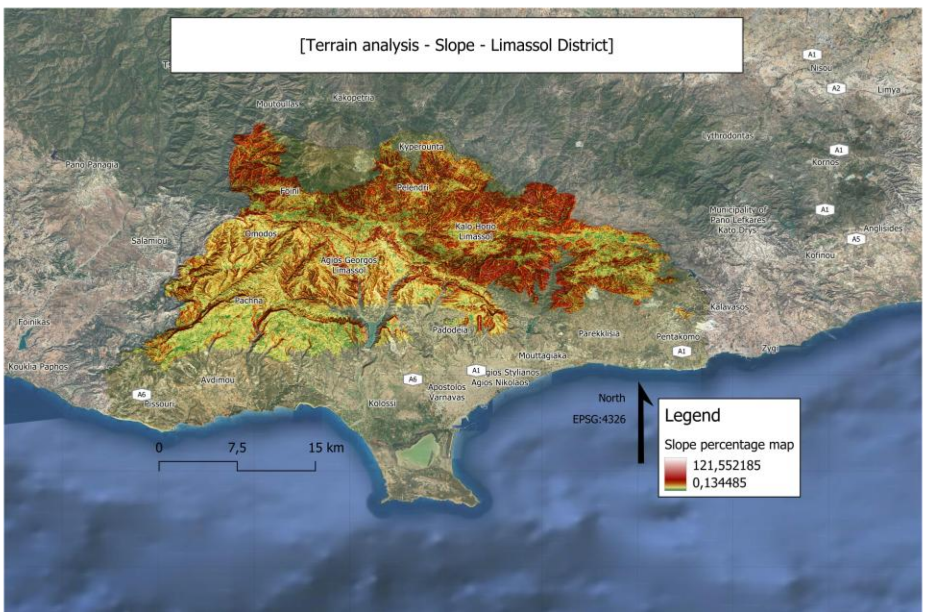

Fig 10. Terrain Analysis: The Slopes of less than 10% in the Limassol District.

Based on the assumption that the ideal slopes for future nursery installations should remain gentle to facilitate their easy access and establishment, Fig 11 highlights regions with slopes of less than 10% inclination values.

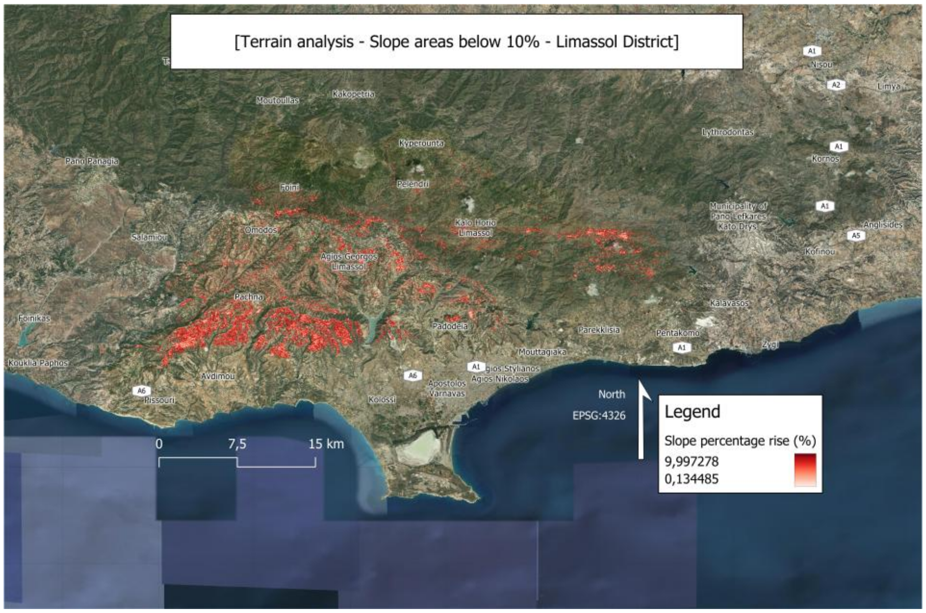

Fig 11. Terrain Analysis: Permissible Slope Areas.

The segment of regions designated as sealed areas was removed from the previous terrain analysis map product, which provided permissible slopes below 10%. In a similar vein, the rationale applied led to the exclusion of all Natura 2000 protected sites. The map in Fig 12 presents the final terrain analysis areas that fulfil this study's previous requirements and criteria.

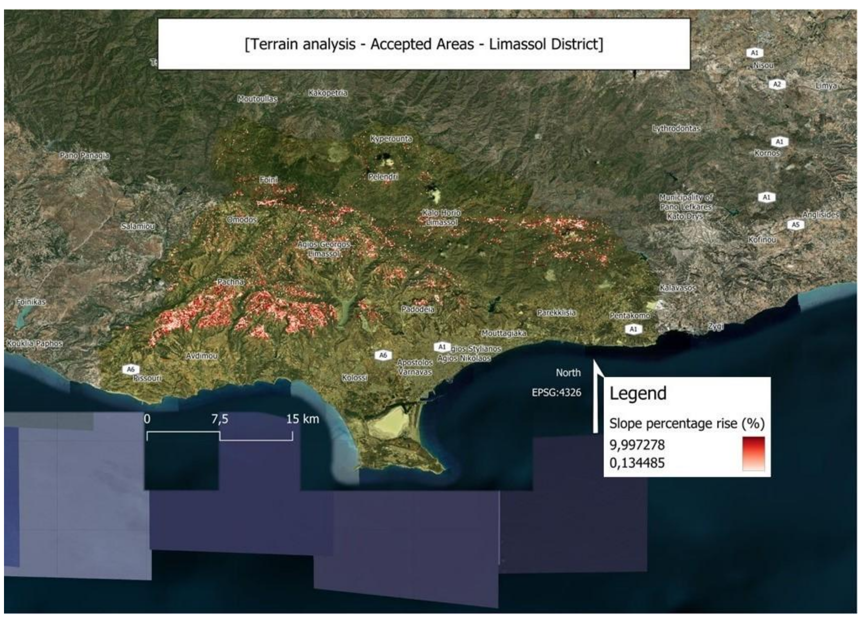

Fig 12. Terrain Analysis: Final Accepted Areas.

Conducting a detailed statistical evaluation of the above results highlights that the mean average slope value is calculated at 6.73%, while the highest slopes documented are between 8.5% and 10%, as presented in Fig 13.

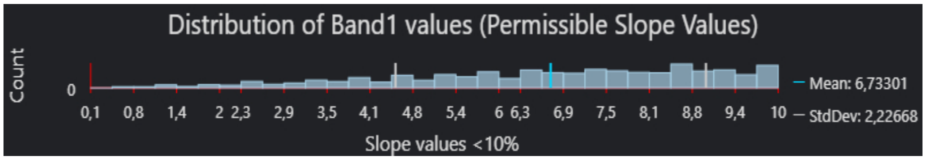

Fig 13. Permissible Slopes Distribution Range.

The spatial data buffering technique was employed to evaluate socioeconomic criteria, including distance to the existing road network. Although socioeconomic status is not directly related to proximity to roads, developments tend to occur near road networks. The environmental criteria of the proximity to the existing hydrographic network were also considered. The buffer command was applied to the hydrographic and road networks, utilizing acceptable distances of 150 and 100m, respectively. These results are illustrated in Fig 14.

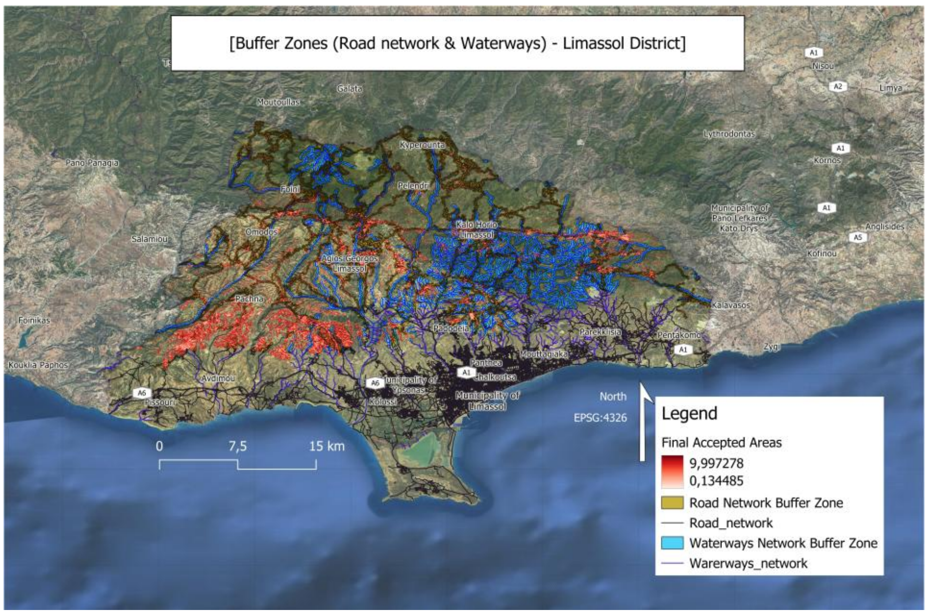

Fig 14. Road Network - Waterways Buffering Zones.

The conclusive results, illustrated in Fig. 15, were generated by applying the intersection command to the two polygon buffer layers in conjunction with the final accepted areas layer. These findings correspond to the predetermined acceptable zones outlined as goals in this study, effectively addressing the four spatial queries formulated in the Qgis application.

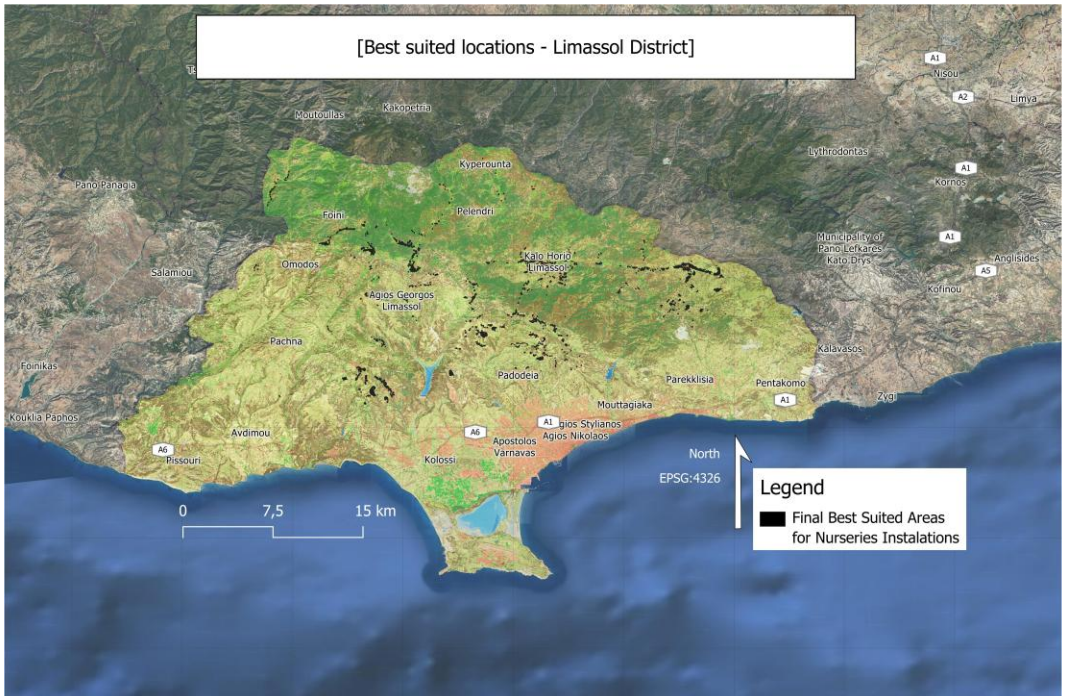

Fig 15. Best Suited Locations.

The findings of the study demonstrate that the identical sites for the establishment and operation of nurseries dedicated to the artificial regeneration of *Pinus nigra var. pallasiana* and *Pinus brutia* in the Limassol district are majorly situated in dispersed clusters in the Northern–Northern East mountainous mass of the region. These locations exhibit a range of differences in area, density and positioning. These areas are demarcated within existing forest ecosystem zones and connected to a pre-existing road network enriched by a comprehensive hydrographic system. The evidence is further validated in conjunction with the Corine Cover Map, as the identified areas correspond to permanent tree classifications (deciduous and coniferous) and permanent herbaceous zones. Numerous optimal sites are situated in proximity to local villages, namely Apesia, Kalo Chorio, Pera-Pedi, and Agios Georgios. Identifying these optimal sites is crucial for the efficient establishment and management of nurseries, and it also serves as a significant impetus for investment and the economic upliftment of the mountainous communities nearby.

Beyond merely identifying the areas of interest, a more comprehensive application of GIS yields additional data about these suitable locations, including geometrical metrics such as areas. Upon reviewing the attribute table associated with the final layer in Qgis, it has been determined that the overall area of the zones identified as optimal totals 53.9km². The quantitative attributes of primary density found in suitable zones are of great relevance, particularly in terms of their aggregate area and spatial distribution. Notably, approximately 10% of the total area is encompassed within or around the Pera-Pedi village's boundaries, totalling 5.3km². Furthermore, an equivalent area can be identified within or around the settlements of Moniati and Trimiklini villages, covering an area of 2.5km².

Conclusions

The study implemented a data-driven GIS framework to devise an effective methodology for selecting optimal sites for establishing future forest nurseries in the Limassol district. Identifying the optimal locations necessitated a flexible, effective, and all-encompassing data source in conjunction with an appropriate software tool. The Qgis software served as a valuable tool in this study, facilitating the amalgamation of data from diverse thematic layers to pinpoint the optimal locations. The analysis evaluated multiple factors, including slope, elevation, land use and cover types, proximity to roadways, and the hydrographic network.

According to the findings, the optimal sites for establishing and operating prospective forest nurseries are predominantly situated in areas with a north-northeast orientation, in proximity to several dispersed villages within the district, such as Pera-Pedi, Kalo-Chorio and Moniatis. The cumulative area of the preferred sites is approximately 54 km^2, with most locations predominantly located within or adjacent to established forested zones.

By employing analogous methodological approaches that potentially integrate a more diverse set of factors, such as indicators of soil health, air quality, and other climate-related metrics, GIS can be leveraged to identify areas appropriate for rational grazing, pasture farming, sustainable hunting, and the promotion of agrotourism. This would enable the identification of ideal sites for establishing tourism-related facilities and contribute as a valuable tool for sustainable spatial planning as part of a holistic approach.

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