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Research Paper

Scale issues for geoheritage 3D mapping: The case of Lesvos Geopark, Greece

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ABSTRACT

A geopark can be composed of many individual geosites of various geographical scales, thus, categorization according to cartographic scale is crucial for their 3D mapping. The UNESCO Global Geopark of the island of Lesvos in the north-east Aegean, Greece, is a distinctive example of this type of geopark as it contains many unique geosites that vary in geographical scale. The geographical scale is interconnected with the cartographic scale in which the geosite is visualized. The desired cartographic scale is an essential user requirement within an unmanned aerial vehicle's (UAVs) 3D mapping project as the basis for the data acquisition strategy. This research investigates the scale issues in 3D mapping of geosites. Furthermore, it contributes to the incorporation of the geographic and cartographical scales in association with UAV flight parameters such as Ground Sample Distance (GSD), altitude, gimbal pitch, orientation, and front and side overlapping. A total of 132 geosites located in Lesvos Geopark are being studied to determine the flight parameters of three different UAVs and their camera characteristics. The methodology followed to collect very high-resolution images suitable for 3D mapping consists of five main stages: i) determining the geographical scale of each geosite, ii) defining the cartographic scale of all geosites, iii) calculation of the GSD based on cartographic scale, iv) calculation of UAV flight altitude and flight characteristics, and v) classification of geosites based on the flight characteristics for their 3D mapping. Five geographic (G1: < 0.1 ha, G2: 0.1–1 ha, G3: 1–10 ha, G4: 10–100 ha, G5: >100 ha) and five cartographic (C1: > 1:50, C2: 1:50–1:100, C3: 1:100–1:250, C4: 1:250–1:500, C5: < 1:500) categories were defined based on the geosites' size and extent. The combination of the two scales determines the most efficient flight characteristics and optimally acquires very high-resolution images required for the 3D mapping of the selected geosites. Finally, the categorization and characteristics of flights for data collection for high-resolution 3D mapping are collected and presented in a web application. The web application is addressed to the management board of Lesvos Geopark and supports the decision-making processes on mapping geosites using UAVs.

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1. Introduction

Geoparks are geologically significant areas. They contain a variety of geological entities of great scientific value, rarity, and beauty, as well as several globally important geological heritage sites on any scale (Zouros, 2004). These characteristics reflect the geological history and the events and activities that shaped the area (Zouros, 2017). The boundaries of a geopark are clearly defined and include large areas of geoheritage monuments of international significance. Geological heritage or geoheritage includes geological features at a global, national, regional, and local scale and is important as it provides information about geological history. Geoheritage feature the variety of our planet to represent the importance of the biotic and abiotic factors that report the Earth's evolution (Gordon, 2018; Zafeiropoulos, Drinia, Antonarakou, & Zouros, 2021). Besides, geoheritage sites host significant geographical components, like rocks, minerals, and fossils that decipher the effects of the timeless activities which shaped the earth's surface (Joyce, 2010).

Due to the high importance of geoheritage throughout many different fields, it is necessary to protect and preserve these geological and geomorphological sites geoparks focus on the conservation of geosites and geomorphosites, which is associated with the protection of elements of the earth sciences (Brocx & Semeniuk, 2007). Geoconservation acknowledges that the abiotic parts of the natural environment are as important to nature conservation and in need of proper management as the living parts (Sharples, 2002). Geoconservation is also essential for bioconservation as the earth's diversity provides a wide array of directly impacted environments and environmental pressures on biodiversity (Sharples, 2002). It also focuses on the management of the geological elements that offer great scientific, educational, cultural, and touristic value (Henriques, dos Reis, Brilha, & Mota, 2011).

In recent years, there has been intense interest in visiting areas of great natural beauty, both in the biotic and abiotic environments (Williams, McHenry, & Boothroyd, 2020). Geotourism has thus become a rapidly developed branch of sustainable tourism, which seeks to preserve all natural and human attributes rendering a given location distinct from others instead of focusing on minimizing the impact on the ecological environment (Ólafsdóttir & Tverijonaite, 2018). The promotion of geoheritage is an important factor for geotourism (Brilha, 2016). New technological tools such as Geographic Information Systems (GIS) and two-dimensional and three-dimensional cartographic products offer new possibilities for promoting and managing geoheritage.

Geoheritage mapping is a process necessary for the effective management and documenting of geodiversity towards the development and implementation of geoconservation strategies (Bouzekraoui et al., 2018; Comănescu, Nedelea, & Dobre, 2012; Coratza et al., 2021; Fuertes-Gutiérrez & Fernández-Martínez, 2010; Gordon, 2019; Pál & Albert, 2019). With their rapid development in recent years, geographic information systems and geographical, geological, and geomorphological databases create the right conditions for various cartographic applications in geoheritage (Cayla, Hobléa, & Reynard, 2014). They contribute to the identification, evaluation, monitoring, and dissemination of spatial information that help in the understanding, conservation, and promotion of geoheritage (Cayla et al., 2014).

Thematic maps are effective information tools for geological and geomorphological landscapes (Faccini et al., 2018; Sacchini et al., 2018). Geoheritage maps offer new possibilities for managing, preserving, and enhancing landscape values (Coratza, Reynard, & Zwoliński, 2018; Ghiraldi et al., 2009) even if there is a lack of a common methodological approach to map implementation (Coratza et al., 2021). Apart from the management of the geo-heritage, maps can also be used in its promotion. The Administration board of geological heritage/geosites uses printed or digital material to promote geosites / geoheritage to the general public (Martin, Reynard, Pellitero Ondicol, & Ghiraldi, 2014). Another area in which printed and digital maps make an important contribution is educating and raising public awareness on the issue of geological heritage. In modern literature, there are reports where printed maps, digital geo-visualizations, and 3D models are utilized to inform and sensitize people of all ages. Accurate and precise geomorphological mapping is a complex process and requires specialized knowledge (Coratza et al., 2018; Martin et al., 2014).

The geographical area covered by the geosites can vary, as it can be a volcano's caldera (Antoniou, Nomikou, Panousis, & Zafeirakopoulou, 2021) or even a single finding (Zouros, Velitzelos, Valiakos, & Ververis, 2004). The variation in the geographical area occupied by a geosite significantly affects how it is mapped as it determines the geographic scale. The areal coverage directly affects its spatial analysis and the level of detail of the geovisualization. The cartographic scale is also an important parameter in both two-dimensional impressions of geological forms and 3D imprints (Martin et al., 2014). The scale issues in the 3D mapping of geosites and the wider geological heritage are currently under investigation (Chiabrando, Lingua, Maschio, & Teppati Losè, 2017; Papadopoulou, Vasilakos, Zouros, & Soulakellis, 2021).

The appearance of unmanned aerial vehicle's (UAVs) played a catalytic role in the 3D mapping of geosites (Cook, 2017; D'Oleire-Oltmanns, Marzolff, Peter, & Ries, 2012; Fernández-Lozano et al., 2018; Papadopoulou et al., 2020; Santos, Henriques, Mariano, & Pereira, 2018). UAVs have been characterized as an alternative, low-cost, remote sensing approach to collect and generate high-resolution 2D and 3D data (Balla et al., 2020; Colomina & Molina, 2014; Whitehead & Hugenholtz, 2015; Whitehead, Moorman, & Hugenholtz, 2013). UAVs, in combination with the science of photogrammetry (Image-Based 3D Modeling) and the development of computational vision and image processing algorithms such as the Structure from Motion algorithm (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012) and Multi-View Stereo, made the creation of three-dimensional information accessible (Pavlis & Mason, 2017). The 3D data generated by the above algorithms, i.e., the dense point cloud, the texture 3D mesh, the high-resolution Digital Surface Model (DSM), and the orthomosaics, contain important information such as altitude, elevation, slope, and orientation and provide valuable data on the management of a geopark (Nesbit, Boulding, Hugenholtz, Durkin, & Hubbard, 2020; Nesbit, Durkin, Hugenholtz, Hubbard, & Kucharczyk, 2018; Papadopoulou, Papakonstantinou, Zouros, & Soulakellis, 2021).

Another modern tool for geovisualization and management of geographical data on geoheritage is online maps (Antoniou et al., 2021). "Web Mapping" is the process by which the internet is used to present, share, and analyze a visual representation of geospatial data as a dynamic map composition. An "Internet Map" or "Web Map" is an interactive display of geographic information (Dorman, 2020). "Web Maps" provide the utilization of multimedia such as geodata of different levels of detail, images, videos, and audio, beyond their interactive nature (Roth, 2011). Furthermore, their use and application, in addition to geographical navigation, can contribute to various fields such as education (Coltelli et al., 2017; Mango, Çolak, & Li, 2021; Mouafo & Müller, 2002; Pál & Albert, 2019; Pasquaré Mariotto et al., 2021), presenting a story or an event, as well as in research institutes (Balla et al., 2020; Williams & McHenry, 2020).

Based on all the above, it appears that the rapid development of tools for the collection, creation, analysis, and geovisualization of geospatial data has a lot to offer to the management of a geopark, not only in terms of detailed and accurate geoheritage mapping but also in decision-making for its maintenance, protection, and promotion. Despite the various applications listed in the literature, there is no specific application that investigates the scale issues and, in particular, the combination of the cartographic scale of the geopark's geoheritage elements with the appropriate flight altitude of different UAVs for their more efficient 2D and 3D mapping. This paper aims to investigate scale issues for 2D and 3D mapping of the geological heritage, in particular, the geosites of the Lesvos Geopark. The relationship between the cartographic scale and the spatial analysis of images collected by a UAV is studied since it is affected by the flight altitude according to the properties of the optical sensor used. The goal is to create a web application that considers the geographic features (geographical scale) of the area or geosite being mapped and provides the optimal values for the cartographic scale, flight altitude and spatial analysis required for aerial (UAV) data acquisition, depending on the sensor specifications. This web application should be easy to use, with easy-to-follow methodological steps, and aimed at non-experts needing 3D mapping. In addition, it must contain qualitative and quantitative data on the geosites of the Lesvos Geopark and also should be dynamic, interactive, and updatable at any time. The present work contributes to the management of a geopark by clarifying the scale issues for geosite 3D mapping using UAV data and creating a web application oriented towards geosite management that is easily operated by non-experts in 3D mapping.

2. Materials and methods

2.1. Case study area

The study area used to demonstrate the proposed workflow is the geosite of the Lesvos Geopark in Greece. Lesvos is the third largest Greek island, located in the northeastern part of the Aegean Sea, with a total area of 1632 km^2 having a maximum length of 67 km and a width of 45 km. The island is divided into three sections by two gulfs, the larger gulf of Kalloni in the west and the smaller gulf of Gera in the east, with both having narrow openings to the Aegean Sea. The geological identity of the island is the result of Alpidic and pre-Alpidic rocks later covered by post-Alpine formations, mainly Miocene volcanic rocks and Neogene marine and lacustrine deposits (Novak & Soulakellis, 2000; Soulakellis, Novak, Zouros, Lowman, & Yates, 2006).

Lesvos Island consists of a significant number of geological heritage sites, areas of natural beauty, rich biotic and abiotic heritage and a large number of cultural monuments (Zouros, 2005, 2007). UNESCO acknowledges the variety of all these elements and recognizes it as a UNESCO Global Geopark (Global Geopark Network, 2008). The elements which exist all over Lesvos Island are geological structures such as volcanoes, fossil sites, active faults, waterfalls and hot springs (Wang & Zouros, 2021). These geological and geomorphological monuments are important witnesses to the Aegean basin's geological history. The most well-known is the Petrified Forest of Lesvos, located on the western peninsula of Lesvos. The Greek state declared the geopark a preserved natural monument (Presidential Decree 443/85) (Natural History Museum of Lesvos Petrified Forest, 2020).

2.2. Methods

The data used in the present study were a database of Lesvos Geopark's geosites and the sensors characteristics of the five most common consumer or enterprise grade UAVs. The list of geosites includes their name, type, and geographical coordinates. The list was distributed by the Museum of Natural History of Lesvos Petrified Forest and was edited and digitized with geoinformatics methods to create the web map.

The UAVs used in this application were the i) Phantom 4 Pro, ii) Mavic 2 Hasselblad, iii) Inspire 2, and iv) Matrice 300. These UAVs have sensors in the visible spectrum with different lens characteristics. More specifically, the optical sensors of the UAVs mentioned above have lenses with the following focal length: i) 9 mm (fl), ii) 10.5 mm, iii) 15 mm and 25 mm (Olympus), and iv) 35 mm (P1), respectively. All the above information was combined to create a web application (Fig. 2). Following these easy-to-follow methodological steps created from this research, scientists will receive information on the scale and flight mission parameters to achieve the most effective 3D mapping of a geosite using UAVs (See Fig. 1).

The methodology presented in this study consists of five methodological steps: i) the determination of the geographic scale of each geosite, ii) the selection of the cartographic scale for the geographical areas selected, iii) the definition and selection of the most appropriate spatial scale and Ground Sample Distance (GSD), iv) the calculation of all UAV mission parameters (e.g., flight altitude, flight characteristics) and finally, v) the development of a web app dashboard for the illustration of 2D and 3D maps of geosites. For the above process, the Lesvos Geopark geosites were classified according to five geographical and five cartographic scales, and five spatial analysis resolutions (GSDs) were defined as the most appropriate to be used.

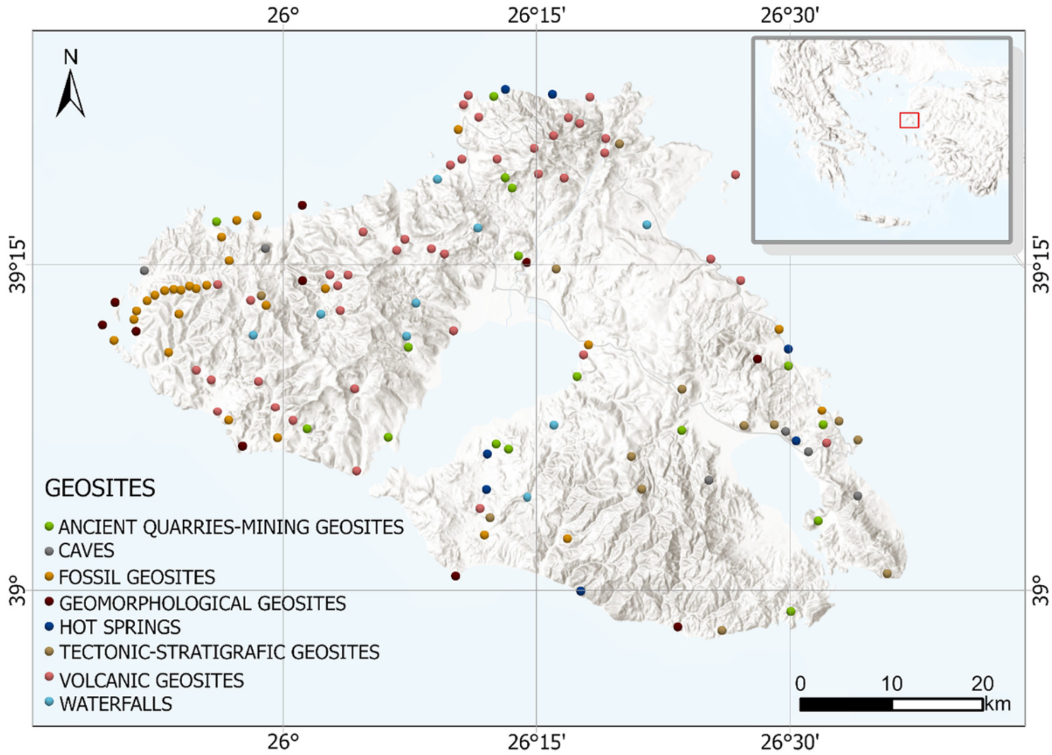

Fig. 1. Map of Lesvos Geosites, North Aegean Sea, Greece.

2.2.1. Categorization of geosites based on their cartographic scale

The categories for the geographic scales were created based on the area of the geosites (Table 1). In Lesvos, sites of high geological importance can consist of a single fossil or extend over many hectares, such as a caldera. For this reason, the first category of geographical scale (G1) created is the very small geographic scale, of <0.1 ha, for the depiction to the level of a fossil. The second category (G2) is a small geographic scale with an area of 0.1 to 1 ha that may contain a fossil-bearing site. The third category (G3) is of medium geographic scale with an area of 1 to 10 ha, and the fourth category is of large geographic scale (G4) with an area of 10 to 50 ha. Finally, the fifth category (G5) is of very large geographic scale, with an area of over 50 ha. All last three scales are used to depict larger geoheritage important regions. On Lesvos island exist typical examples of all the above categories.

The next step was to define the five categories concerning the geosites' cartographic scale. The cartographic scale mainly depends on the geographic scale of the geosite (area) and the area of the mean to be depicted and secondarily on the user's needs. For example, a petrified tree trunk is mapped at a cartographic scale of <1:50 because its mapping must capture its current state in detail. Accurate mapping of its geometry and texture is essential as theinformation depicted can be utilized in preserving, protecting, and highlighting the finding. Therefore, mapping on a large cartographic scale is required, where the necessary details can be observed.

Similarly, a large geographical scale geosite such as a volcano's caldera is important to be mapped in 3D but not on a large cartographic scale. In addition, if significant parts of a large geographical scale geosite need to be recorded at a higher resolution, they can be mapped independently at a larger cartographic scale, according to the observation needs. Secondly, data collection, information volume, and visualization must be manageable and targeted to be efficient.

Table 1
The five categories of geographical scales of Lesvos geosites.

Geographic scales			
	Category	Area description	Area
G1	1st category	Very small	<0.1 ha
G2	2nd category	Small	0.1–1 ha
G3	3rd category	Medium	1–10 ha
G4	4th category	Large	10–50 ha
G5	5th category	Very large	>50 ha

Table 2
The five categories of the cartographic scale of Lesvos Geosites.

Cartographic scales				
	Category	Scale description	Scale	Mean
C1	1st category	Very large	>1:50	Terrestrial & laser
C2	2nd category	Large	1:50–1:100	UAV
C3	3rd category	Medium	1:100–1:250	UAV
C4	4th category	Small	1:250–1:500	UAV
C5	5th category	Very small	<1:500	Generalization and satellite

The resulting cartographic scales served the above needs and were formed based on the geographical scale and the desired spatial analysis to map geosites (Table 2). In more detail:

- the first category (C1) is the very large cartographic scale of >1:50, and the suggested data collection for accurate mapping is by ground means, such as handheld cameras, laser scanners or low UAV flights;
- the second category (C2) concerns the large cartographic scale of 1:51 to 1:100;
- the third category (C3) includes the cartographic scales of 1:101 to 1:250;
- the fourth category (C4) includes the cartographic scales of 1:251 to 1:500;
- the last and smallest cartographic scale is <1:501 and concerns geosites of a large geographical area that can be mapped using satellite data or by generalizing data of higher spatial resolution.

It is important to note that a geosite may fall into several categories of cartographic scale depending on the observation need but falls only in a single geographical scale category. The geosite of a large geographical area may include subsections that require mapping on a larger cartographic scale. For example, a fossil-bearing site belongs to the G2 geographic and C2 cartographic categories, but some revealed tree trunks need to be mapped again on a larger cartographic scale (C1).

2.2.2. Calculation of GSD and height of flight

The calculation of the flight altitude (h) and the GSD was based on the theory that requires the spatial analysis of cartographic products to be 1/3 of the acceptable error considering the cartographic scale and the resolution of the human eye (1/4 mm) (Abdullah, 2016). Thus, the appropriate spatial analysis of the data for the five cartographic categories was calculated and are:

- for C1 $<$ 0.33 cm;
- for C2 from 0.33 to 0.65 cm;
- for C3 from 0.66 to 1.63 cm;
- for C4 from 1.64 to 3.22 cm;
- for C5 $>$ 3.22 cm.

After calculating the GSD, the UAV's flight altitude is based on the characteristics of the sensor and the recording camera each UAV carries. Table 3 lists the characteristics of the recording sensors tested in this study. These characteristics are the focal length (fl), i.e., the distance of the lens from the recording sensor, the width of the image in pixels (iw), i.e., the number of pixels in the width of an image, and the width of the recording sensor (sw), which is the actual size of the sensor width.

The minimum flight altitude was calculated for each UAV to collect data having the appropriate spatial resolution required for each cartographic scale. Fig. 2 shows the relationship between the flight altitude of the four different UAVs (5 different recording sensors) and the cartographical scale. Eq. (1) was used for calculating the values shown in Fig. 3. The corresponding flight altitude was calculated based on the appropriate (minimum) GSD corresponding to each cartographical scale category. From the calculation of the flight altitude, it is observed that the Inspire 2 with the Olympus 25 mm camera can fly at a higher altitude than the other comparable UAVs on any cartographic scale, while the Phantom 4 Pro and the Mavic 2 need to fly at a much lower altitude to collect images suitable for the respective cartographical scales.

$$GSD = \frac{sw*h}{fl*iw} \tag{1}$$

Table 3
UAVs sensor characteristics: UAV type, focal length (fl), image width (iw) and sensor width (sw).

	fl (cm)	iw (pixel)	sw (mm)
Phantom 4 Pro/Advance	0.09	5472	13.2
Mavic Pro Hasebland	0.1	5472	13.2
Inspire Olympus	0.25	5280	17.3
Inspire Zenmuse X5S	0.15	5280	17.3
Matrice 300 P1	0.24	8192	35.9

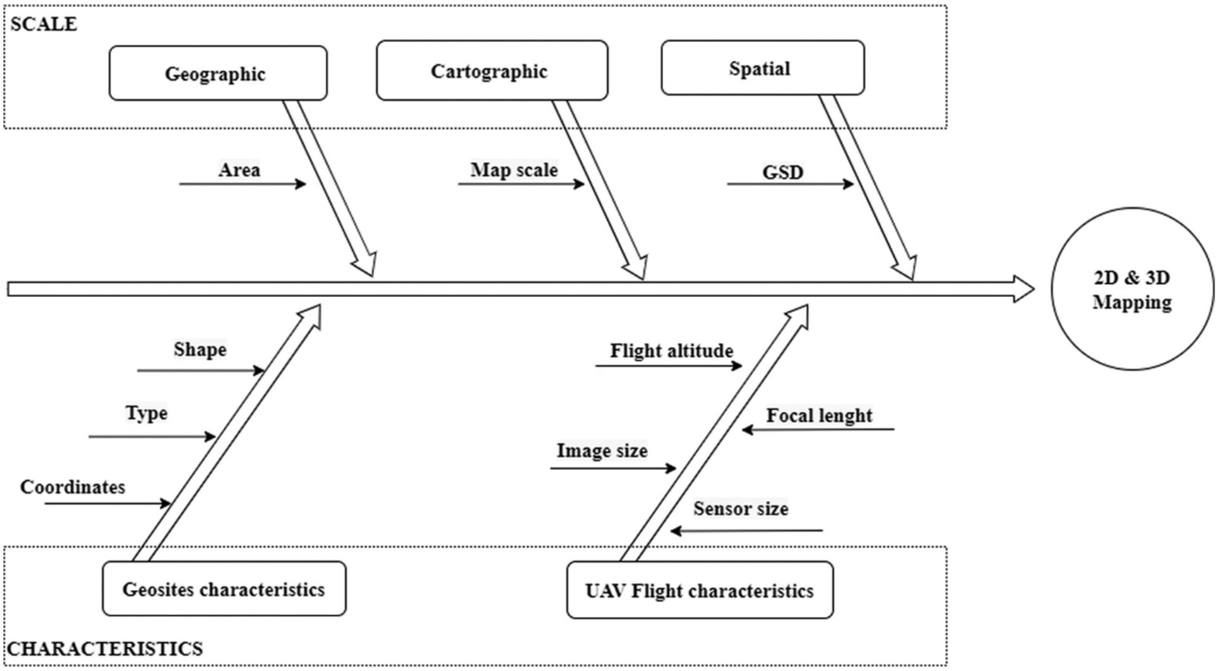

Fig. 2. Methodology workflow.

In addition, the specific operations were standardized and are embedded in a dynamic web environment where the user can choose the UAV used, enter the desired cartographic scale and the desired overlap and receive the appropriate flight altitude and other flight characteristics such as the speed of the aircraft, the distance between the overlapping images and the acceptable errors. These calculations define the appropriate flight altitude for each available UAV in each cartographic scale category. The 150 geosites were categorized according to their geographical area, and their respective cartographic scales were defined, while the flight altitude of all available UAVs for data collection was calculated with the appropriate spatial resolution for each geosite.

2.3. Development of Web Map and WebApp Dashboard

Initially, each geosite was defined as a point determining the latitude, longitude, and altitude at which it is located. In cases where a geosite extends over a large geographical area, the point that identifies it is placed in a position from which the

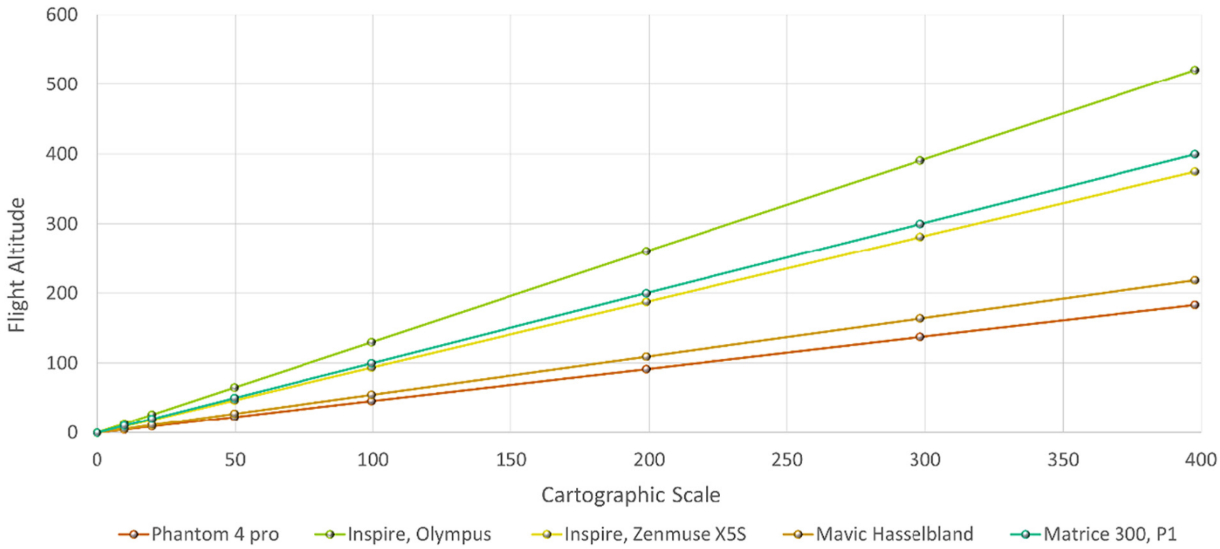

Fig. 3. Correlation of flight altitude and cartographic scale according to UAVs recording sensors.

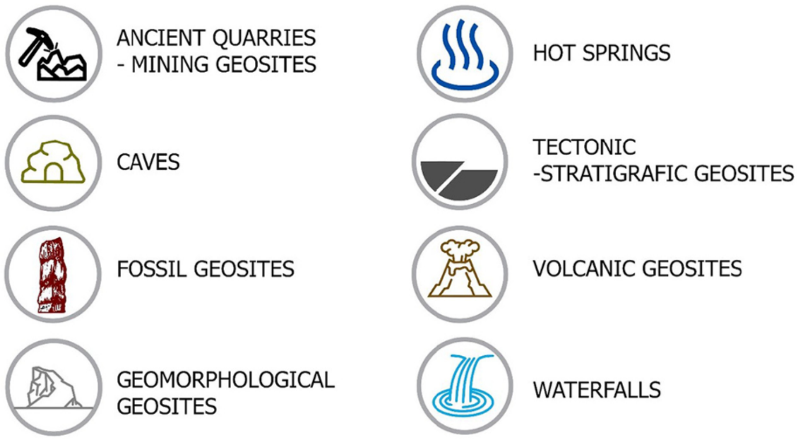

Fig. 4. Eight cartographic symbols for each geosites type.

respective geosite is visible or can be observed. The list of the points' characteristics was then updated by adding information on the geographical and cartographic category to which each geosite belongs, as well as data on spatial analysis, flight altitude, and type. Geosite type depends on their geological and geomorphological structure as eight different types appear. These types are: 1) ancient quarries-mining geosites, 2) caves, 3) fossil geosites, 4) geomorphological geosites, 5) hot springs, 6) tectonic-stratigraphic geosites, 7) volcanic geosites and 8) waterfalls. Scientists from the end-user, i.e., the Museum of Natural History of the Petrified Forest of Lesvos, assigned the type to each geosite. Therefore, a point shapefile was created, in which geosites of the Lesvos Geopark are described in digital form and can be updated at any time if required.

The next step in creating the interactive Web Map was the geosites' revisualization based on their type. Once the nominal scale has been selected for the visualization of the points, each cartographic symbol should refer to the type of each geosite. For this reason, eight cartographic symbols were created, one for each geological-geomorphological type (Fig. 4). The symbols had a common shape and size but different content (See Fig. 5).

This was followed by sharing digital cartographic information on the internet through ArcGis Pro software. This Web Map consisted of two thematic levels: a) the point archive of the Lesvos geosites and b) a topographic background. The Web Map display scale is initially set when the user first activates the application. The scale is 1:300.000 as it allows the presentation of the entire island. Larger cartographic scales were chosen, as the aim is to present the geopark and not the rest of Greece. Nevertheless, a location map was included in the Web Map, which depicts the island's position in relation to the rest of the mainland and helps the user orient himself regarding the location of the Lesvos Geopark in Greece. Additional features in this Web Map offer the user the choice for the background, i.e., the application of satellite or other image base maps as a background. The user can also navigate through the study area, zoom in and out of places of interest, and select any point on the map. Selecting the point displays a pop-up window that lists information about the specific geosite. This information can be qualitative and quantitative. In the present application, the information shown is relevant to the 3D mapping of each geosite. More specifically:

- the geographical coordinates of the geosite;
- the category of its geographical scale;
- the cartographic scale category;
- the spatial analysis of the data required for 3D mapping; and
- the flight altitude for each available UAV type.

Additionally, the user can edit the geodatabase by adding new geosite locations or configuring existing records. Editing is not accessible by all application users but only by the accounts of geopark's management board.

The digital map created in the previous step is the basis for developing a WebApp Dashboard application. WebApp Dashboard is a tool that allows detailed presentation of information based on a specific geographical area / location using an intelligent and interactive display of data on one screen. The data is legibly presented in the form of interconnected dynamic graphs, lists, and maps.

The need for collection, organization, and homogenization of the visualization of the produced information led to the creation of a WebApp Dashboard on the issues of scale and the 3D mapping of the Lesvos Geopark geosites.

This web application, "Scale Issues for Lesvos Geosites" [WebApp Dashboard], was created in ArcGIS Enterprise. First, the Web feature layer created for geosites in the North Lesvos was entered. While entering the data in the application, certain features such as the display of information in pop-up windows, the scale setting on the map, a memo display, the thematic levels selection, and the ability to change the base map were selected. This was followed by the general configuration of the application environment, such as the selection of the appropriate nested windows utilized for the visualization of the information and the identification of additional thematic settings regarding the information displayed.

In this application, the available tools were utilized for presenting the information, as they are listed below:

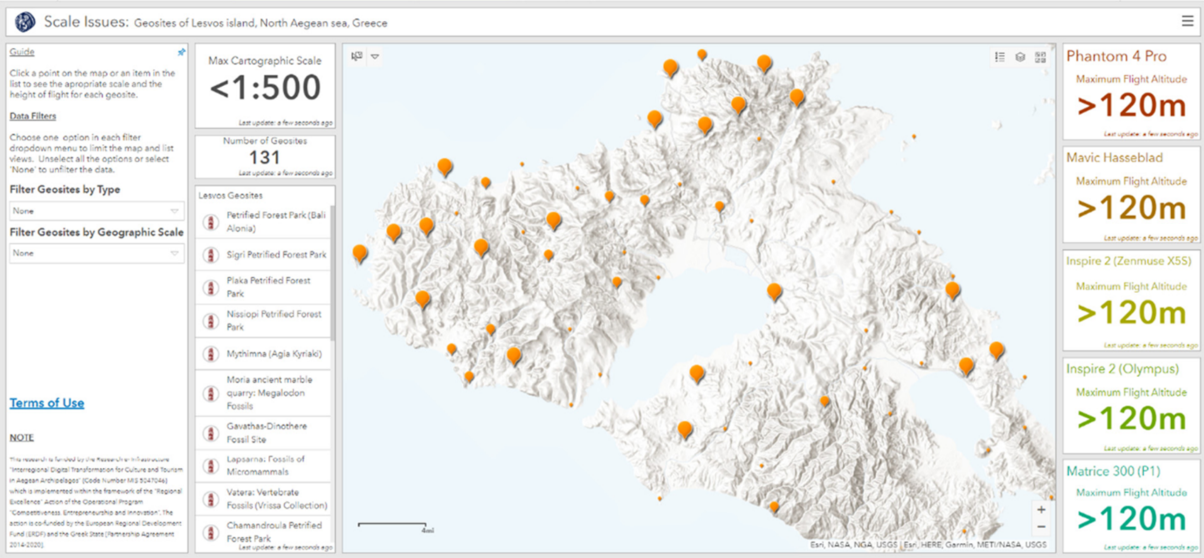

Fig. 5. Interface of WebApp Dashboard "Scale Issues: Geosites of Lesvos Island, North Aegean Sea, Greece" (https://bit.ly/Scale_Issues_Geosites_of_Lesvos).

① indicators (maximum cartographic scale, number of geosites, flight altitude of the available UAVs);
② side Panel (geosite filters);
③ list (geosite names).

Due to the interactive nature of this application, the information in the above windows has been set to be automatically configured according to the scale change in the Web Layer.

More specifically, the first window titled "Maximum Cartographic Scale" is an "Indicator", i.e., an indicator that provides the ability to display numerical data, individual characteristics, or summary statistics. Where the maximum cartographic scale recommended for visualizing the area is presented. The value displayed in the window is derived from the data contained in the Web Feature Layer information table and is configured in combination with the scale change. Also, another "Indicator" was created that displays the number of geosites available to users, depending on the map's extent. Five additional indicators that display the UAV recommended flight altitudes configured according to the map's scale. In addition, a new "List" window was added, in which the names of the available geosites are displayed, as indicated in the information panel shown on the map.

3. Results and discussion

The result of this work was the development of a WebApp Dashboard named "Scale Issues: Geosites of Lesvos Island, North Aegean Sea, Greece". The Webapp Dashboard collects and visualizes all the above information and calculations. A window is displayed on the left part of the application, including the instructions for use and the operation of the dynamic tools. The user guide helps unfamiliar web application users navigate and use the available tools. The same tab displays two filters linked to the map levels and the list of geosites. In more detail, the first filter allows the classification of the Lesvos Geopark's geosites based on their type and the second filter allows their classification based on geographical scale. This window was chosen to be pop-up as it covers a significant part of the screen when it is fixed as an always-on display. Therefore, if it remains fixed, the part of the web map displayed in the application would be reduced. The window containing the filters and usage instructions is a key element of the application, but can be omitted. This window does not appear on the home screen when opening the Web App Dashboard.

Another window on the top left of the WebApp Dashboard is the maximum cartographic scale indicator. This indicator is linked to the list of geosites and the interactive web map. Selecting a point from the list of geosites will update the maximum cartographic scale display field with the corresponding value. The same will happen if the user selects a point from the interactive web map. This dynamic field when the map's extent shows the entire Lesvos Island or a large geographic area with many geosite locations, cannot simultaneously display the maximum cartographic scale for each geosite appearing in the extent. This limitation led to the definition of the minimum cartographic scale as a value that appears in the "Max Cartographic Scale" field when the geographic area displayed in the Web Map is large and covers more than one geosite. This value was determined based on the above methodology and the fact that a large geographic area is mapped at a smaller cartographic scale than individual geosites covering smaller geographic areas.

There is a window that lists the number of geosites that appear on the Web Map. The number is updated depending on the web map's extent, i.e., when the cartographic scale increases and ends at the position level. If a pop-up window covers an area of the map that includes geosite locations, these points are subtracted from the field, and the value reflects only the total number of geosites visible.

In the WebApp Dashboard named "Scale Issues: Geosites of Lesvos Island, North Aegean Sea, Greece," there is a list that contains all the Lesvos Geopark geosites sorted by name. This list is also dynamic and is linked to the filters mentioned earlier and to the web Map. More specifically, when filters are selected, all geosites resulting from applied criteria are listed. In case one criterion is applied, the list displays the results of the respective criterion, while if both criteria are applied, the list includes them and shows the geosites that meet both conditions.

The list is linked to the interactive map. So, when a geosite is selected from the list, the map will focus on the geosite's location by changing the scale and the point flashes. In addition, the number of geosites that appear in the list corresponds to the number of geosites the web map contains. When the map's extent or geographic area changes, the list shows the geosites that exist in the specific area. The web map is placed in the central part of the application and depicts a point thematic level of the Lesvos Geopark's geosites. The interactive map has an option to change the base map used, navigate in all directions, and zoom in and out. Any change of scale in the interactive map affects all application areas and updates the values depending on the extent. The web map is linked to all the elements (lists and indicators) of the web App Dashboard. The thematic levels that appear on the map are also dynamic and when selected by the user a pop-up window (Fig. 6.a) is activated in which information about the geosite corresponding to the specific point is listed. The information shown in the pop-up window derive from the table of the geosites' characteristics and refers to the geographical coordinates where the geosite is located, its geological structure type, the geographical category in which it belongs, the maximum cartographic scale to which they can be mapped based on the present research and the maximum spatial resolution that the data collected with the UAV must have in order to meet the conditions for further 3D data processing. Pop-up windows can be enriched with any information or text related to the geosite, with attached representative photos and a built-in URL.The window displayed at the right part of the application indicates the UAV's maximum flight altitude for the most appropriate 3D mapping of geosites based on the scale. More specifically, the maximum flight altitude of the Phantom 4 Pro is listed in the first window, the Mavic 2 with a Hasselblad camera in the second, the Inspire 2 with the X5S 15 mm in the third, the Inspire 2 with the 25 mm Olympus lens in the fourth and the Matrice 300 with P1 camera with 35 mm lens in the fifth. These windows are dynamic and depict calculation results that take place over each selection at the same time. In addition, they are linked with the map and lists and are updated after each geosite's selection. The of these indicators is that they can provide the flight altitude information of selected UAVs, not for multiple geosites simultaneously. Fig. 6 illustrates three

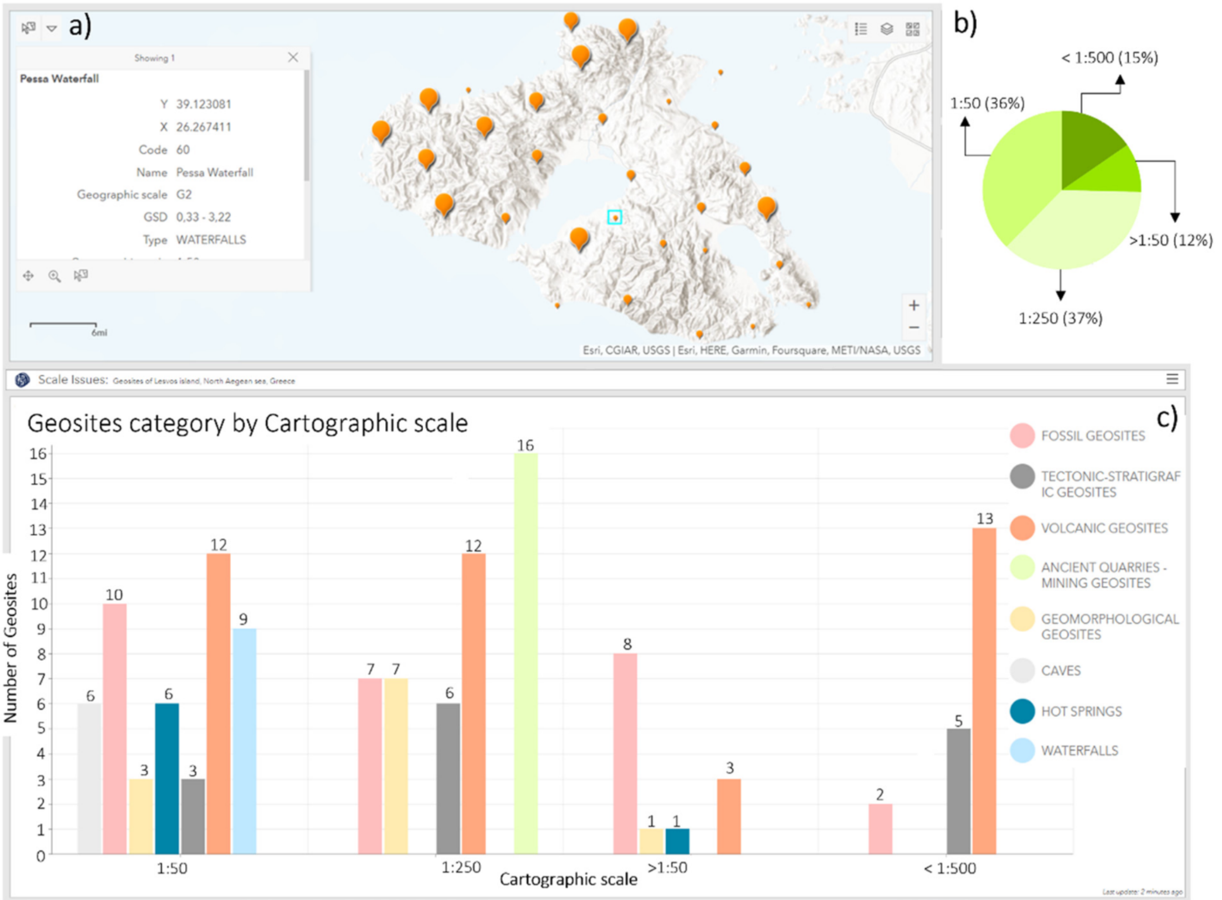

Fig. 6. (a) The pop-up window on the web map when a geosite is selected. (b) Pie chart with the percentage of geosites per maximum cartographic scale. (c) Histogram with the distribution of geosites.

graphs presenting data available in the dashboard. In more detail, Fig. 6.b is a pie chart that depicts the distribution percentage of the geosites per cartographic scale. In this pie chart, the largest percentage (36%) of the geosites of the Lesvos Geopark can be mapped on a scale ranging from 1:100 to 1:500. On the other hand, the smallest percentage (1%) corresponds to the geosites that can only be mapped on a scale of <1:250. Fig. 6.c shows the categorization and numbers per category of geosites based on the type and cartographic scale. Both the pie chart and the graph are connected to the Web Map and are updated based on the adjustments to the map's extent.

4. Conclusions

The geosites that consist of a geopark vary significantly in size. This differentiates the cartographic scale at which they should be captured and discriminates the UAV type and the recording sensor that needs to be used. More specifically, the investigation of scale issues of Lesvos Geopark's geosites led to the conclusion that they can be classified into five geographic categories. These categories are i) G1: <0.1 ha, ii) G2: 0.1–1 ha, iii) G3: 1–10 ha, iv) G4: 10–100 ha and v) G5: >100 ha. Consequently, five categories of cartographic scales have been proposed ranging from i) C1: >1:50, ii) C2: 1:50–1:100, iii) C3: 1:100–1:250, iv) C4: 1:250–1:500, and v) C5: <1:500. Of the five categories of cartographic scales created, it appears that only 4 of them can be used for UAV data acquisition to depict 3D geovisualizations of geosites. The flight altitude of all UAVs exceeds 120 m to collect data to the smallest cartographic scale; therefore, the flight cannot be executed above the maximum allowed flight altitude as set by Greek legislation (120 m). Based on the morphologic and topographic characteristics of the geological monument, a decision must be made on which UAV should fly and with which sensor the data should be acquired. The above process led to the development of a web application that facilitates non-experts in 3D mapping to decide on the cartographic scale, the equipment (UAV and sensors) and the data acquisition plan that must be followed for 3D mapping a geosite. This web application collects, analyses, and presents information about the mapping scale of all the geosites of the Lesvos Geopark in a dynamic and user-friendly environment. This specific application calculates the flight altitude for the appropriate cartographic scale of the Lesvos Geopark geosites for four specific UAVs and five different optical sensors (cameras). Thus these calculations do not apply to other aircraft and cameras. The proposed methodology does not apply to all types of geosites as the 3D visualization is not in need for all as, in some cases may not show surface formations such as the intersection of a fault or might exist below the ground surface (e.g., caves).

Web mapping and UAV-based 3D Geovisualizations have evolved rapidly over the last years and refer to various capabilities enabling users to interact with geospatial data in various scales in 2D or 3D. In geoparks management, all the above can provide important information regarding the topography and geometric characteristics of individual geosites. The proposed web app improves the quality of the acquired data, saves time on the survey plan, and includes all scale variant necessary calculations for effective data acquisition and 3D mapping of geological monuments. Additionally, our web app is an easy-to-use and user-friendly tool that can improve the management process of a geopark.

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CRediT authorship contribution statement

Papadopoulou Ermioni-Eirini: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. **Papakonstantinou Apostolos:** Conceptualization, Writing – original draft, Writing – review & editing. **Vasilakos Christos:** Conceptualization, Writing – original draft, Writing – review & editing. **Zouros Nikolaos:** Conceptualization, Writing – original draft, Writing – review & editing. **Tataris Georgios:** Writing – original draft, Writing – review & editing. **Proestakis Stavros:** Writing – original draft, Writing – review & editing. **Soulakellis Nikolaos:** Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare no conflict of interest.

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