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Inventory and Quantitative Assessment of Geosites in the Southern Sector of the Island of Malta

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Abstract: The island of Malta, despite its small size, boasts a great variety of landscapes and landforms, offering a wide range of geological and geomorphological features of great interest. The identification and assessment of geosites can contribute to the preservation, protection, and promotion of this rich geodiversity. In addition, geosites have a high potential of attracting geotourists, thus also contributing to the development of the local economy. Tourism plays a key role for the Maltese Islands, with Malta's tourism direct contribution to GDP being among the highest in Europe. Thus, geotourism could represent a significant resource for Malta, though it has yet to receive the attention and recognition it deserves. Within this framework, this work aims to highlight the role of geoheritage and geotourism as potential resources for the enhancement of sustainable tourism and geoconservation in the southern sector of Malta. This region of Malta receives less visitors compared with the northern sector of the island, which is popular for its sandy beaches. To this end, potential geosites were inventoried and quantitatively assessed using a commonly applied methodology tailored to the local setting. The results of this evaluation let to identify 18 potential geosites that can be recognized as both parts of the Maltese natural heritage and tourist resources. Among these 18 sites, we identified four priority geosites which could be incorporated into a potential geotourism route to also highlight the valuable elements of the cultural heritage located in the vicinity. Moreover, the assessment methodology, applied for the first time in the investigated area, has proven to be a valuable support for geosite identification and can be extended to other Maltese regions.

Keywords: geoheritage; geotourism; coastal geomorphology; Blue Grotto; Il-Maqluba sinkhole

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1. Introduction

In the last decade, there has been a growing interest in geoconservation (sensu [1]), including the protection and sustainable management of geoheritage and geosites. This growing interest is leading to a significant increase in the scientific literature on this topic [1–6]. These works are aimed at promoting the protection, conservation, and enhancement of geoheritage, with particular attention paid to geosites. The identification of geosites for geoconservation purposes is usually carried out through a quantitative or qualitative assessment, which serves as a valuable tool to prioritize management actions and plans. Several assessment methodologies have been developed for the selection and classification of geosites based on specific criteria [7–14]. However, a universal method has not yet been established, as the diversity of geoheritage makes a one-size-fits approach challenging. Typically, methodologies are customized according to the characteristics of each study site by taking into consideration its site-specific geological, geomorphological, aesthetic, and cultural features. This customization approach ensures that the evaluation is relevant to and accurate for the specific context of the geosite being assessed. Recently, over the last decade, different research groups have analyzed or reviewed quantitative methods for assessing geosites [15–17]. The use of these methods is useful for reducing subjectivity in the evaluation and selection of geosites and geomorphosites (a type of geosite), but it should be emphasized that some degree of subjectivity is inevitable. Considering and analyzing all proposals in the literature, Bollati et al. [18] developed a specific method for identifying geosites. This methodology has undergone several improvements and refinements over the years [10,19–21], enhancing its applicability across different contexts such as glaciers [10], fluvial areas [18], and for various purposes [19,20,22]. The latest methodology developed by Bollati et al. [21] was chosen for this study because it is both robust and comprehensive. We applied this method to the southern sector of the island of Malta.

The Maltese archipelago is of significant geomorphological interest, cf. [23], and possesses remarkable geoheritage features [24–27]. However, the literature on the geoheritage features of Malta is primarily focused on the northernmost areas of the island [24]. Nevertheless, Selmi et al. [26] partially investigated the southern sector, which is covered by this study, and defined its degradation risk. The northern area of the island of Malta is undeniably very attractive. It features pristine and spectacular landscapes due to the presence of a variety of landforms such as extensive coastal landslides [28–30], sinkholes [30], and shore platforms [30–32]. This part of Malta also benefits from a well-developed public transport network, the Majjistral Nature and History Park, the Popeye Village amusement park, and recreational areas equipped with suitable facilities, services, and recreational accommodations. This attractiveness is further enhanced by the presence of the island's only sandy beaches (Ghajn Tuffieha Bay, Golden Bay, Mellieha Bay, Paradise Bay, etc.) and a more pristine territory, with urban areas concentrated in the northeastern part. Conversely, the southern area of the island of Malta has been more affected by residential and industrial development. However, areas such as the Delimara peninsula, located at the southernmost part of Malta, lack integral public transport connections and are poor in tourist facilities. Nevertheless, the southern sector of Malta encompasses several unique and distinctive landscapes and landforms, both aesthetically and scientifically significant. These areas possess the potential to attract tourists, representing a valuable resource for the development of geotourism.

In this context, this study inventories and evaluates sites of geological and geomorphological interest in southern Malta, becoming one of the most detailed investigations about the geoheritage of this area. A widely applied methodology for geosite assessment was used to identify the most valuable geoheritage features. This research study aims to enhance the understanding of southern Malta's geoheritage and provide a robust framework for future studies and conservation efforts in the investigated area, contributing to both academic knowledge and the development of management initiatives focused on geoheritage.

2. The Study Area

The Maltese Islands are located in the middle of the Mediterranean Sea and cover an area of 316 km^2 [33,34], making Malta the EU country with the highest population density, at 1650 people/km^2 [35]. In the last decade, Malta often welcomed over 2 million tourists annually, with the majority coming from the UK, Italy, and Germany [35]. This upward trend has significantly boosted the local economy. The archipelago comprises three main islands—Malta, Gozo, and Comino—along with a group of uninhabited islets (Figure 1). Malta is the largest and primary island, covering an area of 245.8 km^2, followed by Gozo (67.1 km^2), located further north, and Comino (3.5 km^2) in between the two main islands [33,36].

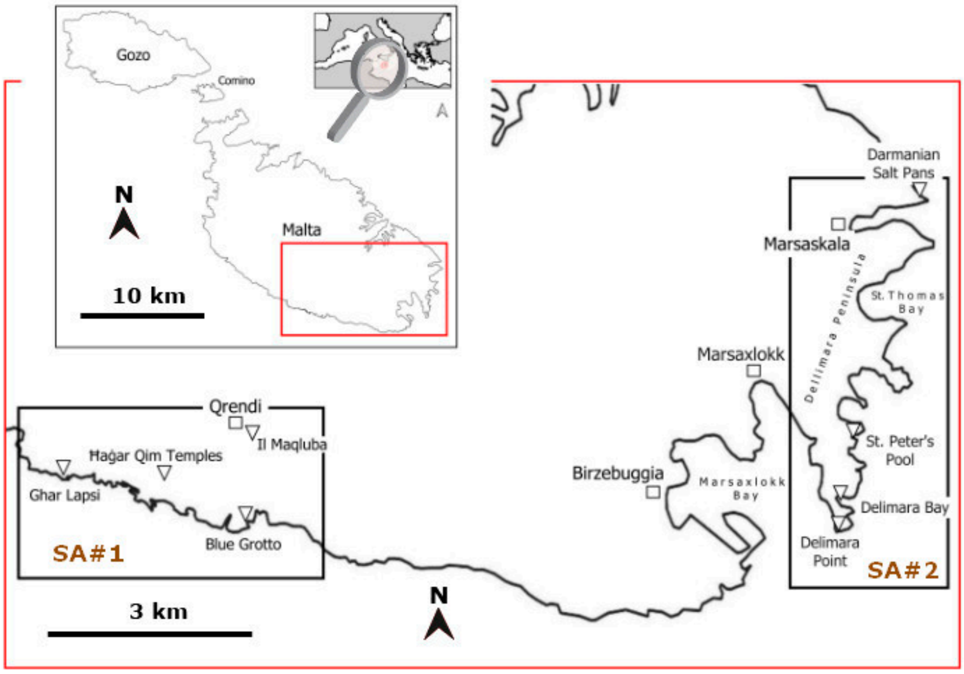

Figure 1. Location map of Maltese Islands. The black rectangles indicate the two study areas.

Malta is characterized by a Mediterranean climate with mild winters and hot, sunny summers. The average annual temperature is about 18.6 °C and the average annual precipitation is around 578 mm [34,37]. This mild climate, combined with the diverse valuable landscape features, including scenic pocket beaches, cliffs, and viewpoints, attracts tourists during all months of the year. According to the Malta Travel and Tourism Economic Impact Report [38], the total contribution of the travel and tourism industry to Malta's GDP was approximately 13.6% in 2023, +4.5% compared to the European average (9.1%). In view of the expected increase in the number of tourists, geotourism emerges as a sustainable form of tourism, representing the optimal solution to sustain and enhance the identity of the territory, especially in rural areas.

From a geological viewpoint, the Maltese Islands are composed of sedimentary rocks, around 250 m thick, dating from the Upper Oligocene to the Miocene [39–42]. These rocks consist of limestones, marlstones, and clays [39,41]. The four main rock units within a stratigraphic oldest-to-youngest sequence are as follows: (i) Lower Coralline Limestone (LCL), (ii) Globigerina Limestone (GL), (iii) Blue Clay (BC), and (iv) Upper Coralline Limestone (UCL). Figure 2 shows a simplified geological map of the island of Malta.

Two structural regions influence the occurrence of geological formation, topography, and landforms of Malta [39–42]. The ENE-WSW fault-oriented system, primarily represented by the Great Fault (Figure 2), influenced the northern part of Malta, producing an alternation of horst and graben structures [30]. In this sector, resistant UCL rocks and underlain BC terrains are dominant, leading to the presence of lateral spreads that evolve into large block slides [28–30,43–46]. Additionally, intersecting faults from the NW-SE Pantelleria Rift, developed during the late Miocene and early Pliocene, are evident south of the Great Fault, notably the Magħlaq Fault [39–42].

This paper focuses on two study areas (Figure 1), differing in lithological and structural characteristics. The southwestern study area includes both LCL and GL formations, whereas the eastern study area is characterized totally by GL rocks. These differences have resulted in varying landforms and different geomorphological processes between the two areas. GL rocks form wide shore platforms and very erodible cliffs that are subject to rapid retreat caused by rockfalls and collapses. In contrast, LCL rocks are susceptible to karstic processes, producing peculiar landforms such as gorges, caves, and sinkholes [47].

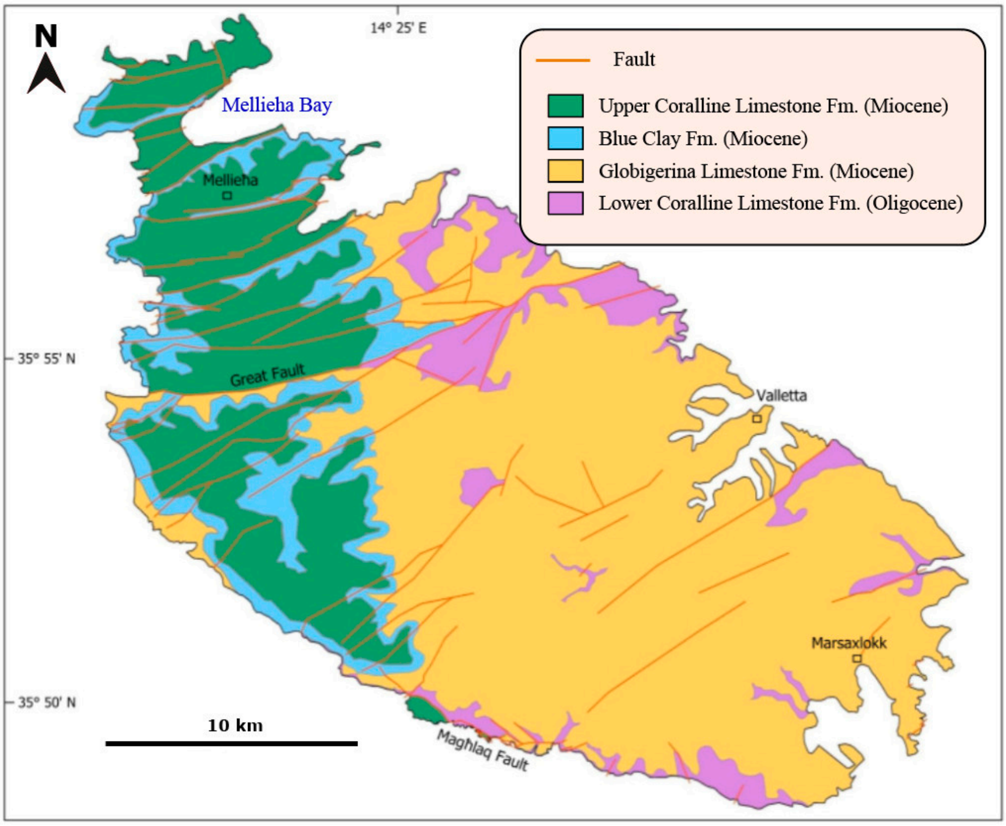

Figure 2. Simplified geological map of the island of Malta.

Study area #1 (SA#1), located in the southwest, encompasses the coastal stretch from the Għar Lapsi to Blue Grotto karstic system (cf. Figure 1). This area includes some of the most spectacular landforms of the Maltese Islands: Għar Lapsi Bay, the Ras il-Ħamrija peninsula, the Blue Grotto karstic system [47], and the Il-Maqluba sinkhole (Figure 1). The area is significantly influenced by the Magħlaq Fault, which displaces the younger members beneath the older ones. The Magħlaq Fault is also responsible for the presence of the small islet of Filfla [48], the visibility of which is an attraction in its own right along this stretch of the coast. The footwall (inland) consists of the LCL formation, exposed to a height of over 100 m, while the hanging wall sees the entire sedimentary sequence displaced to sea level and subsequently eroded, leaving fragments of UCL near the coast [49]. The result is a clearly visible and sharp fault plane that can be observed for kilometers [50]. This karstic area has several caves and sea arches, with the most famous being the Blue Grotto karstic system [48]. The inland area includes the Il-Maqluba sinkhole [51], which is historically attributed to have formed on 24 November 1343 following the storm-induced collapse of a limestone floor above a cavity. It is a subcircular sinkhole with a major diameter of 104 m, representing the most exemplary and spectacular sinkhole of the Maltese archipelago [51].

The second study area (SA#2) is situated further southeast than the first and focuses on the coastal stretch of the Delimara peninsula, between Marsaskala and the Delimara Point (Figure 1). This study area is completely composed of GL rocks. The majority of the inland section of the peninsula is primarily composed of Upper Globigerina Limestone (UGL) member, while most of the western coastal fringes feature cliff outcrops of Middle Globigerina Limestone Member (MGLM) [52]. This Maltese coast alternates MGLM steep cliffs, subcircular coves, marine arches, and a well-developed area of shore platforms [32,36]. Most of these shore platforms are cliff-backed by retreating cliffs in MGLM and develop as a result of differential erosion at the contact between different members of GL rocks [32]. The cliffs along the Delimara peninsula offer a unique landscape for the island, as they are the longest stretch of cliffed coasts in MGLM in the archipelago [34]. Despite this, they are not as frequently visited as the Dingli cliffs. Unfortunately, the steep cliffs are subject to retreat caused by rockfalls and collapses, which pose a threat to the safety of tourists and local hikers that use the trails along the edge of cliffs. The study areas were selected based on two key criteria. The first criterion considers the fact that the intense urbanization in southern Malta, combined with the high presence of private properties, significantly reduces the accessibility of certain areas. This limited accessibility poses challenges for geotourism development. The second criterion concerns the presence of sites of high cultural or tourist significance, such as Mnajdra and Ħaġar Qim temples and the Blue Grotto karstic system. The presence of these two sites may further flow visitors to the nearby geological sites of interest.

3. Materials and Methods

The methodological approach adopted for the identification of geosites in southern Malta comprises four operational phases (Figure 3).

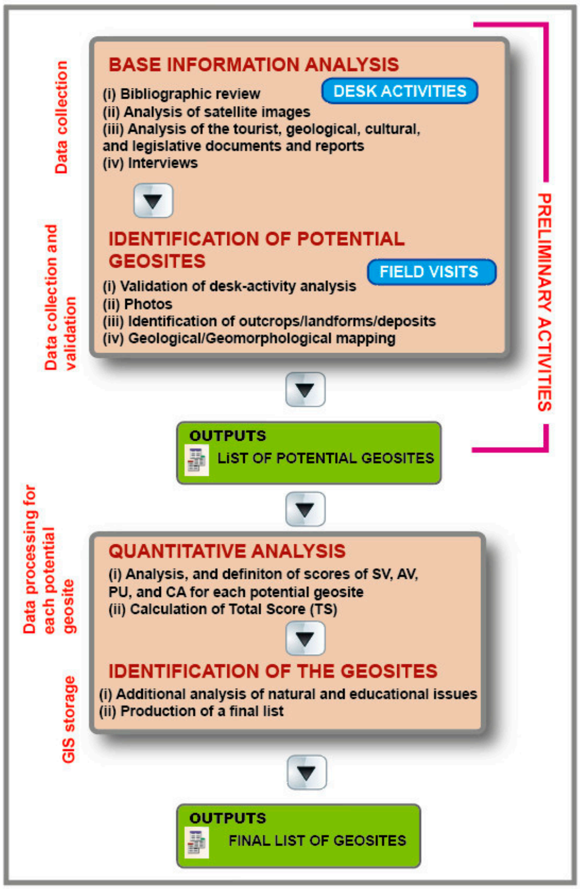

Figure 3. Workflow used for this study.

The first phase includes the collection of preliminary data and a preliminary qualitative analysis of possible areas where sites of geological interest occur. The output of these preliminary activities is a list of potential geosites. The second phase was carried out using a quantitative analysis for the evaluation of geosites using scores of the methodology developed by Bollati et al. [21]. The application of the above-cited method allowed us to produce an inventory of possible geosites, and to populate the datasets in GIS. The sites with the higher scores were selected as exemplary sites of geological assets.

3.1. Base Information Analysis and Identification of Potential Geosites (Phase 1)

The initial activities consist of a literature and cartographic source analysis of the two test sites and identification of potential geosites using descriptive cards. A comprehensive compilation of data allowed us to collect all information about the tourist, geological, cultural, and legislative aspects of the sites.

This bibliographic collection, joined by an analysis of satellite images, interviews with experts, and outcomes of field surveys, allowed us to recognize and select an initial list of sites of geosites in the study areas.

All the data collected using the outcomes of desk activities and field surveys were used for the production of descriptive cards. These cards include a series of parameters characterizing each potential geosite (an example is visible in Figure 4). Each descriptive card collects the following headings, modified from Selmi et al. [26]:

1. ID: identification code.
2. Name of the potential geosite: if the site has a local name, this was used; in other cases, a personalized name which could describe the site was chosen.
3. Geometry: type of landform distinguished by its shape as (i) punctiform (a single isolated form with a limited size, such as a cave), (ii) linear (forms with development oriented in a single direction, such as rivers, faults, or cliffs), or (iii) areal (a form with a considerable size or an area with more than one type of landform related to just one type of genetic process, such as a shore platform or a bay) [53,54].
4. Type of geosite: this describes what kind of geosite it is (e.g., sinkhole, shore platform, fault, or geological contact).
5. Municipality: this refers to the local council where the site is located. The two study areas involve four local councils: Qrendi, Siġġiewi, Marsaskala, and Marsaxlokk.
6. Location: this refers to the nearest built-up area or the specific area in which the site is located.
7. Main lithology: for better statistical analysis, we chose to identify the main outcropping lithology in every site.
8. Genesis: this describes the main processes involved in the formation of the potential geosite (marine, karstic, gravitational, or tectonic process). We used the term "complex" where there are multiple processes.
9. Main interest: this was based on the most representative geological field that the site can be attributed to (e.g., geological, geomorphological, etc.). The main interest is categorized as "cultural significance" when the site illustrates the relationship between the territory and humans (who have exploited the geological context) or when it holds cultural and the historical significance for the island of Malta.
10. Brief description: a short summary of the site.
11. Pictorial representation (e.g., photographs, UAV-DP 3D models, or sketches).

3.2. Quantitative Analysis for the Identification of the Geosites (Phase 2)

This phase foresees the evaluation of potential geosites using the methodology developed by Bollati et al. [21], partially modified and adapted to the study area. The approach involves scoring several attributes that characterize the geosites to minimize the selection subjectivity [18]. The geosites with the highest scores are the most representative geosites of the respective study areas. The attributes of the methodology are divided into three main categories: (i) scientific value (SV), (ii) additional value (AV), and (iii) potential for use (PU). The quantitative methods are more than 30, but the attributes of the different methods are frequently similar [55]. The categories used in the method used for this paper recall ones proposed by many authors [7,15,17,56,57] and are still being debated within the scientific community [13,17,53,55,56,58]. The attributes are listed in Table 1.

Table 1. Attributes of geosite assessment methodology developed by Bollati et al. [21]. The ranges of the scores for each attribute are listed in Appendix A (Table A1).

Attributes				
Scientific value (SV)	RGmP	Representativeness of the (paleo) geomorphological process	GI	Geohistorical importance
	RGP	Representativeness of the geological process	ESR	Ecologic support role
	EE	Educational exemplarity	In	Integrity
	Gd	Intrinsic site geodiversity	ra	Rareness
Additional value (AV)	Cu	Cultural value		
	Ae	Aesthetic value		
	Sec	Socio-economic value		
Potential for use (PU)	TA	Temporal accessibility	SAs	Sport activities
	SAc	Spatial accessibility	LCs	Legal constraints
	Vi	Visibility	UGI	Use as geoheritage-related interest
	Ses	Services	UAI	Use of additional interests
	NT	Number of tourists	SGs	Geo(morpho)sites in the surroundings
Calculated accessibility (CA)	Ti	Typology	GM	Ground material
	SL	Sloping	SM	Slope material
	SI	Slope inclination	St	Steepness
	TI	Tourist information	WSP	Water/snow on the path
	Wi	Width	DC	Degree of path conservation
	HIs	Human interventions		

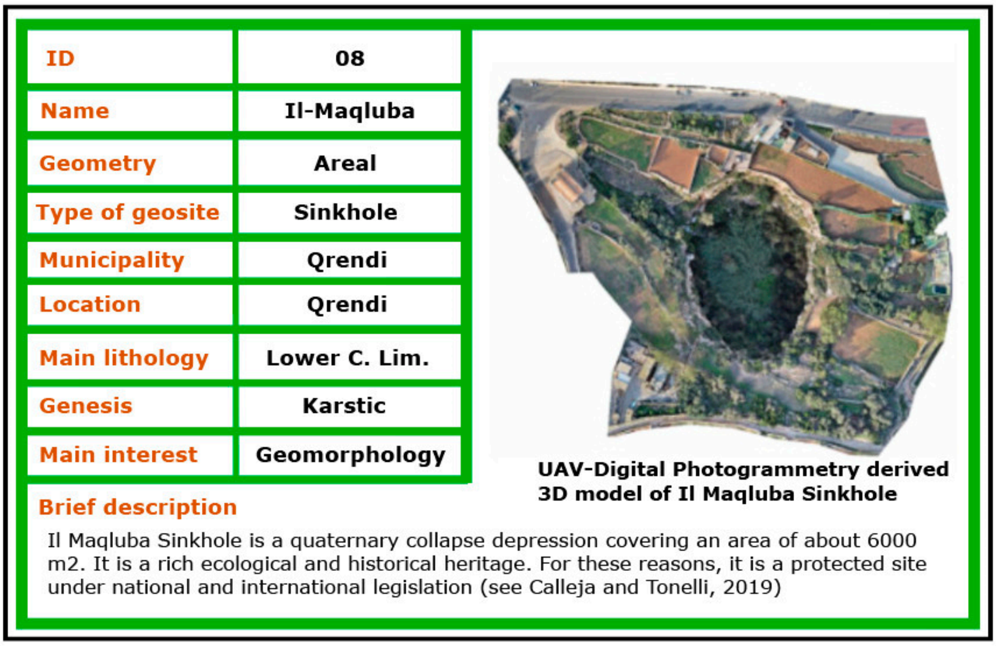

Figure 4. The descriptive card of Il-Maqluba sinkhole [57].

The methodology also considers the degree of accessibility of the site by providing a fourth category (CA), which contributes to the definition of the potential for use (see the relative equation in Table 2). The attribute scores were assigned directly during field visits using specific forms for each potential geosite. These scores were stored in a GIS database for the application of specific equations (cf. Table 2) to calculate the total score (TS) for each site.

Table 2. Equations used to calculate the main macrocriteria and the geosite total score [21].

Macrocriteria		Equations	Range of Values
SV	Scientific value	SV = (GM + RGmP + EE + Gd + GI + ESR + In + Ra)	0–8
AV	Additional value	AV = (Cu + Ae + SEc)	0–3
GV	Global value	GV = (SV + AV)	0–11
IU	Index of use	IU = EE+ Ae	0–2
PUss	Potential for use	PUss = (TA + Vi + Se + NT + SA + LC + UGI + UAI + SGs)	0.25–9
PPU	Partial potential for use	PPU = (PUss + IU)	0.25–11
CA	Calculated accessibility	CA = (Ti + St + Sl + Wi + GM + WSP + SI + SM + DC + HI + TI)	0–11
AFc	Accessibility factor (on foot)	if SAc $\leq$ 0.4; AFc = (CA/11) $\times$ 0.5	0–0.5
AFs	Accessibility factor (other)	if SAc $\geq$ 0.6; AFs = SAc	0.6–1
SIn	Scientific Index	SIn = (RGmP + GI + GM)/3	0–1
EIn	Educational Index	EIn = [EE + Ae + (AFc/s)]/3	0–1
PUc	Potential for use (on foot)	PUc = PPU + AFc	0.25–12
PUs	Potential for use (other)	PUs = PPU + AFs	0.25–12
TS	Total Score	TS = GV + PUc/s	0.25–23

Once the scores for each attribute were assigned, the main category values (SV, AV, PU, and CA) were calculated by using specific equations (Table 2). Finally, the TS of a site was obtained by determining various macrocriteria. These macrocriteria were defined by specific equations (listed in Table 2). Through an iteration of sums among these macrocriteria, the TS for each geosite was determined.

All the attributes and their corresponding scores are compiled in dedicated tables, which can be found in Appendix A (Tables A1–A4).

A geosite, to be defined as such, must possess a high scientific value [7,15,24,53,56]. For this study, we set a threshold value requiring the SV to be greater than 4, as this represents the average between the lowest possible score (0) and the maximum possible score (8). However, given the purpose of the investigation (identification of geological sites potentially exploitable for geotourism), it was also essential to consider high scores in other attributes included in the AV, PU, and CA macrocriteria.

4. Results and Discussion

4.1. First Qualitative Analysis: Identification of Potential Geosites

The preliminary activities focused on analyzing the literature review [32,36,47,50,51,59] and interpreting the satellite images. Additionally, we gathered and analyzed tourist, cultural, and legislative documents, as well as geological maps and relevant reports. This phase was particularly important due to the limited availability of scientific papers on the two study areas.

The literature review conducted alongside several field surveys played a crucial role in identifying 18 potential geosites (Figures 5 and 6). These field surveys were particularly important for merging the list of previously identified sites with new ones that were not documented in the existing literature. Moreover, the field surveys played a fundamental role in gathering site-specific updated information necessary for completing descriptive cards and conducting the quantitative assessment of potential geosites.

The sites that have been selected represent significant evidence of the primary geological and geomorphological processes that have been active over time in the study area.

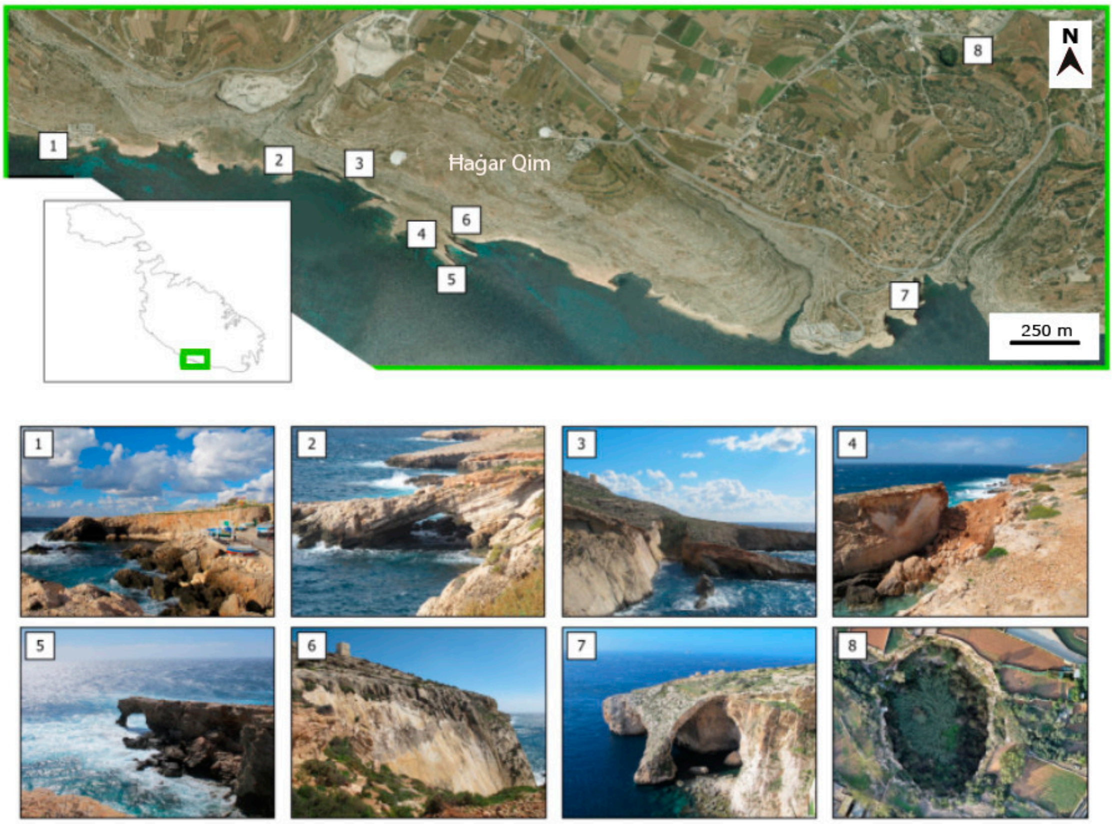

Figure 5. Location of the potential geosites selected within SA#1, located between Għar Lapsi and the Blue Grotto karstic system. The numbers indicate the ID of the sites.

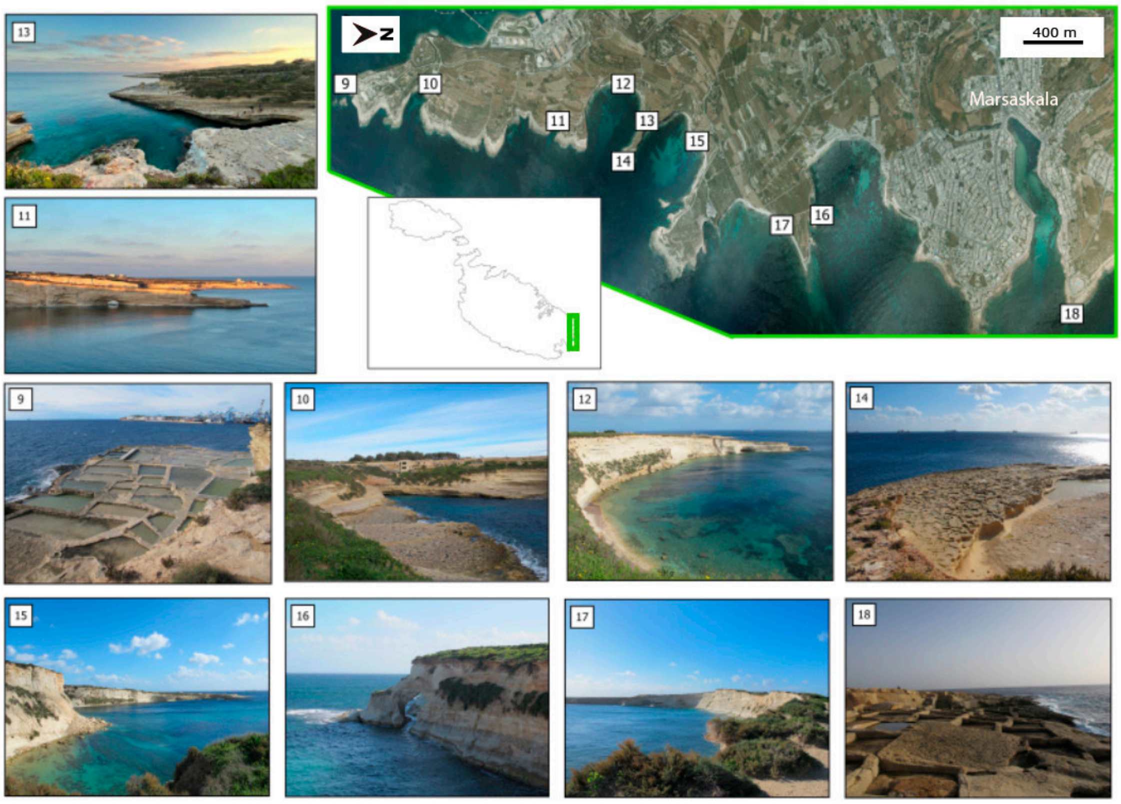

Figure 6. Location of potential geosites selected within SA#2. The numbers correspond to the ID of the sites.

4.2. Characterization and Statistical Overview of the 18 Potential Geosites

The 18 potential geosites were analyzed using descriptive cards, as illustrated in Section 3.1 (see also Figure 4).

As shown in the map and in the pie chart included in Figure 7, marine geosites dominate (55%), followed by complex geosites. A complex genesis was attributed to those geosites whose genesis is assumed to be due to the combined action of two or more processes that have determined the geomorphology of the geosite. Il-Ħofra ż-Żgħira [#12], Il-Ħofra I-Kbira [#15], and the Blue Grotto karstic system [#7] are perfect examples of this.

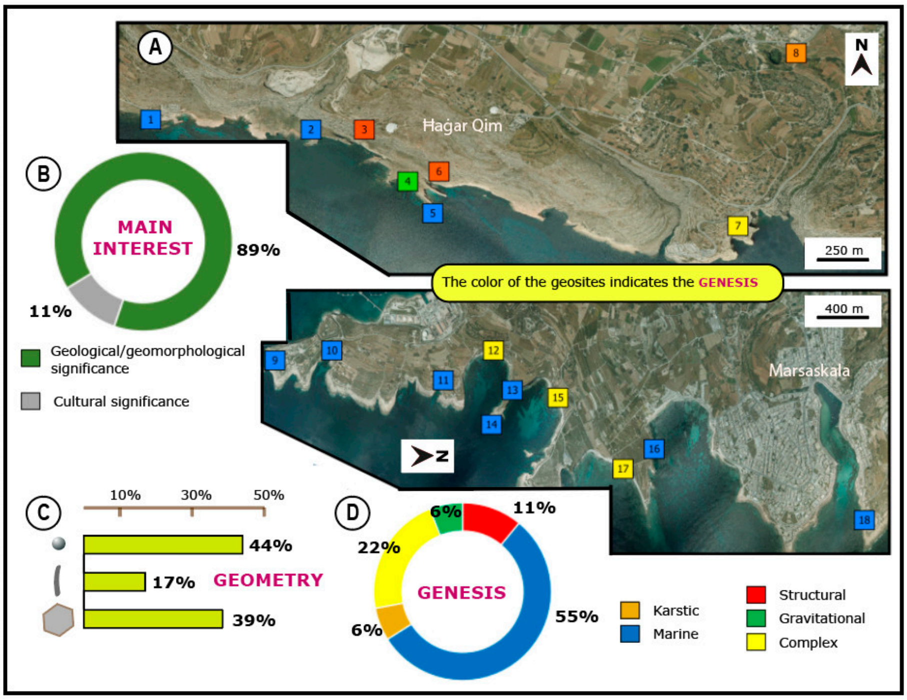

Figure 7. (**A**) Spatial distribution of potential geosites in the two sites; (**B**) main interest of the geosites, with 89% having geological and geomorphological interest; (**C**) geosites' geometry, with 44% in punctiform shape; and (**D**) genesis of geosites, with 55% accounting for marine-related genesis.

In addition to purely natural sites, areas of geological and geomorphological significance closely tied to human activity were chosen. This selection acknowledges how geology has profoundly shaped settlement locations and the activities of human civilization in southern Malta. In fact, 11% of the selected sites are closely related to cultural, socio-economic, and historical Maltese heritage (Figure 7B). The salt marshes developed in the shore platforms are part of this category of interest. In addition to this, the geosites analyzed concern various aspects of geological disciplines (geomorphology and structural geology).

The interest that geosites can attract is linked to the main characteristics of which a given geosite is most representative (or exemplary) (Figure 7): most of the sites are of marine genesis. Complex sites are common (22%), as is the case of the Blue Grotto, where karstic-origin cavities are shaped by marine erosion. Fourteen sites (78%) have a main geomorphological interest; these sites could be further divided based on the type of genesis (karstic, gravitational, marine, etc.). Two sites (11%) were of primarily tectonic–structural interest. The perfectly visible fault planes of the Magħlaq Fault offer an educational gymnasium for students of geological sciences, testifying the dynamism of tectonic activity (clearly visible presence of kinematic indicators).

Moreover, an initial analysis emphasized the distinction of geosites on their geometric character (Figure 7C):

- Eight sites were classified as punctiform (44%) because they consisted of a single isolated form, such as a sea arch;

- Three sites were classified as linear (17%) because of their preferential development in space in a single direction, which is the case of fault planes;
- Seven sites were classified as areal (39%) due to their extension and/or the presence of a set of smaller forms linked to the same type of genetic processes, such as salt marshes and bays.

4.3. Results of the Quantitative Analysis

The 18 potential geosites were evaluated using the methodology outlined in Section 3.2 to identify the most representative geosites in their respective areas.

The results are listed in Table 3, illustrating the attributes scores of each geosite. Table 4 lists the TS values of the eighteen geosites.

Table 3. Scores assigned to the potential geosites for each attribute according to Bollati et al. [21].

		Ghar Lapsi	**Ghar Neffied**	**Maghlaq Fault 1**	**Hamrija Landslide**	**Hamrija Marine Arch**	**Maghlaq Fault 2**	**Blue Grotto Karstic System**	**Il-Maqluba Sinkhole**	**Delimara Point Salinas**	**Delimara Bay**	**St Peter's Pool**	**Il-Hofra Z-Zghira**	**Hofriet Window**	**Ras Il-Fenek**	**Il-Hofra I-Kbira**	**Munxar Window**	**Munxar Cliffs**	**Darmanin Salt Pans**
	ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Scientific value (SV)	**Attributes**																		
	RGmP	0.33	0.67	1	0	0.67	1	1	1	0.67	0.67	0.67	1	0.67	0.67	0.67	0.67	0.67	0.67
	RGP	0.33	0.33	1	0.33	0.33	1	1	1	0.33	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	1
	EE	0.33	0.33	1	0.33	0.33	1	1	1	1	0.33	1	0.67	0.33	1	0.67	0.33	0	1
	Gd	0.5	0	0	0	0	0	0.5	0.5	0	1	1	0	1	0.5	0.5	0	0	1
	GI	0.33	0	0.67	0	0	0.67	0.67	0.67	0.67	0	0.33	0.33	0	0.33	0.33	0	0	0.67
	ESR	0.67	0	0	0	0	0	0.67	1	0	0	0	0	0	0	0.33	0	0	0
	IN	1	1	1	0.5	1	1	1	1	0.5	1	1	0.5	1	1	0.5	1	1	1
	Ra	0	0	0	0.5	0	0	1	1	0	0	0	0	0	0	1	0	1	0
Additional value (AV)	Cu	1	0	1	0.5	0.5	1	0.5	1	1	0.5	0.5	0	0	0	0	0.5	0.5	1
	Ae	0.5	0	1	0	0.5	1	1	1	0	0.5	0.5	1	0.5	0.5	0.5	0.5	1	1
	Sec	1	0	0	0	0	0	1	0.33	0.33	0	1	0	0	0	0	0	0	0.67
Potential for use (PU)	TA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Sac	1	0.4	0.4	0.4	0.4	0.4	1	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.8
	Vi	0.6	0.8	1	0.8	0.8	1	0.8	0.4	0.6	1	1	0.8	0.6	1	0.6	0.8	0.8	0.6
	Se	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	NT	0.5	0	0	0	0	0	1	0.5	0	0	1	0	0	0	0	0.5	0.5	0.5
	SA	1	0	1	0.5	0	1	1	0	0	1	1	0	1	0	0	0.5	0.5	0.5
	LC	0.33	0.67	0.67	0.67	0.67	0.67	0.67	0	1	1	1	1	1	1	1	1	1	0.67
	UGI	0.5	0	0.5	0	0	0.5	0.5	1	0.5	0	0	0.5	0	0	0	0	0.5	0.5
	UAI	0.5	0	0.5	0	0	0.5	0.5	0.5	0.5	0	0.5	0	0	0	0	0	0	0.5
	SGs	1	1	1	0.5	1	1	0.5	0.5	1	1	1	1	0.5	1	1	1	0.5	1
Calculated accessibility (CA)	Ti	1	0.4	0.4	0.4	0.4	0.4	1	1	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	SL	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0
	SI	0.25	0.25	0	0	0	0	0.75	0	0.25	0.25	0.25	0.5	0.5	0.25	0	0.5	0.5	0.75
	TI	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	Wi	1	0.5	0.5	0.5	0.5	0.5	1	1	0.5	0.5	0.5	0.25	0.5	0.5	0.25	1	0.5	0.5
	HI	1	0.33	0.33	0.33	0.33	0.33	1	1	0.67	0.67	1	0.33	0.33	0.33	0.67	0.33	0.67	0.67
	GM	1	1	1	1	1	1	1	1	1	1	0.8	0.8	1	1	1	1	1	1
	SM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	St	0.5	0.5	0	0	0	0	1	0	0.5	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	1
	WSP	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	DC	0.67	0.33	0.33	0	0.33	0.33	1	0.67	0.33	0.33	0.33	0.33	0.33	0.33	0	0.67	0.67	0.33

Table 4. Final quantitative evaluation of potential geosites (sites with the highest scores compared with each study area are highlighted in blue).

	Ghar Lapsi	**Ghar Neffied**	**Maghlaq Fault 1**	**Hamrija Landslide**	**Hamrija Marine Arch**	**Maghlaq Fault 2**	**Blue Grotto Karstic System**	**Il-Maqluba Sinkhole**	**Delimara Point Salinas**	**Delimara Bay**	**St Peter's Pool**	**Il-Hofra Z-Zghira**	**Hofriet Window**	**Ras Il-Fenek**	**Il-Hofra I-Kbira**	**Munxar Window**	**Munxar Cliffs**	**Darmanin Salt Pans**
ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Macrocriteria																		
SV	4.16	3.00	4.67	2.33	3.00	4.67	6.84	7.17	3.84	4.00	4.80	3.30	4.00	4.50	5.00	3.00	3.67	5.34
AV	2.50	0.00	2.00	0.50	1.00	2.00	2.50	2.33	1.33	1.00	2.00	1.00	0.50	0.50	0.50	1.00	1.50	2.67
GV	6.66	3.00	6.67	2.83	4.00	6.67	9.34	9.50	5.17	5.00	6.80	4.30	4.50	5.00	5.50	4.00	5.17	8.01
0IU	0.83	0.33	2.00	0.33	0.83	2.00	2.00	2.00	1.00	0.83	1.50	1.67	0.83	1.50	1.17	0.83	1.00	2.00
Puss	6.43	4.47	6.67	4.47	4.47	6.67	6.97	4.90	5.60	6.00	7.50	5.30	5.10	5.00	4.60	5.80	5.80	6.27
PPU	7.26	4.80	8.67	4.80	5.30	8.67	8.97	6.90	6.60	6.83	9.00	6.97	5.93	6.50	5.77	6.63	6.80	8.27
CA	7.42	5.31	4.56	4.23	4.56	4.56	8.75	7.67	6.05	6.65	5.78	6.11	5.56	6.33	4.32	6.40	7.24	7.65
AFc	-	0.2	0.2	0.2	0.2	0.2	-	0.3	-	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	-
AFs	1	-	-	-	-	-	1	-	0.6	-	-	-	-	-	-	-	-	0.8
PUc	-	5.0	8.9	5.0	5.5	8.9	-	7.2	-	7.1	9.3	7.2	6.2	6.8	6.0	6.9	7.1	-
PUs	8.3	-	-	-	-	-	10.0	-	7.2	-	-	-	-	-	-	-	-	9.1
SIn	0.6	0.6	0.9	0.3	0.6	0.9	0.9	0.9	0.8	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.6	0.8
EIn	0.6	0.2	0.7	0.2	0.3	0.7	1.0	0.8	0.5	0.4	0.6	0.6	0.4	0.6	0.5	0.4	0.4	0.9
TS	15	8	15.6	7.8	9.5	15.6	19.3	16.7	12.4	12.1	16.1	11.5	10.7	11.8	11.5	10.9	12.27	17.1

The selection process did not solely focus on sites with high SV but also considered their potential as tourist attractions and suitability for educational purposes, aligning with the research aim.

4.4. Identification of the Geosites

Out of the eighteen potential geosites, the two geosites with the highest TS values were identified for each study area. Having SV scores greater than 4, these sites of geological interest can be categorized as geosites. The high scores of these four geosites in the four main categories (SV, AV, PU, and CA) highlight their potential for tourism exploitation (Table 4).

The four most representative geosites (Figure 8) in the two study areas are (i) the Blue Grotto karstic system, (ii) the Darmanin Salt Pans, (iii) the Il-Maqluba sinkhole, and (iv) St. Peter's Pool.

The designated geosites exemplify the rich geological variety and the diverse geomorphology of southern Malta, offering the potential for exploitation as geotourism assets. Additionally, each geosite showcases a considerable overall aesthetic value, rendering them appealing to a wider audience beyond geoscientists.

A brief description of the four geosites is provided below.

Figure 8. Oblique views of (**A**) Il-Maqluba sinkhole; (**B**) Blue Grotto karstic system; (**C**) St. Peter's Pool; and (**D**) Darmanin Salt Pans.

4.4.1. Blue Grotto Karstic System [#7]

The Blue Grotto (TS = 19.3) is a structurally controlled karstic system. Marine processes have contributed to shaping its great variety of landforms [47]. It features partially submerged chambers and an impressive sea arch (Figure 8B). Its main advantage, compared to other potential geosites, lies in its easy accessibility to a panoramic viewpoint, as well as its proximity to touristic amenities (PUs = 10).

4.4.2. Darmanin Salt Pans [#18]

The Darmanin Salt Pans (TS = 17.1) embody a significant intersection of island traditions and territory [32]. The salt pans, located on the shore platforms, are among the few salt pans still in operation on the Maltese Islands. The Darmanin family organizes tours and workshops open to the public, aimed at promoting the geoheritage of the salt pans, which are formed on the limestone of the shore platforms [32].

4.4.3. Il-Maqluba Sinkhole [#8]

The Il-Maqluba sinkhole is the second most relevant site in SA#1 (TS = 16.7, GV = 9.5). According to the most used sinkhole classification [60], Il-Maqluba is a large karst depression that can be categorized as a bedrock collapse sinkhole [51,61]. Its steep walls create a natural sanctuary, providing protection for local flora and supporting bird nesting. The Il-Maqluba sinkhole's high scores across all three fields (SV, AV, PU) highlight its broad importance. This site is already part of the national tourism network, as well as part of the Natura 2000 sites, making it protected by national legislation [62]. The site's origin is shrouded in several legends, and the presence of a nearby place of worship has further established its high cultural value.

4.4.4. St. Peter's Pool [#11]

St. Peter's Pool Bay (TS = 16.1) is an inlet located on the Delimara Peninsula, renowned for its azure waters and a suspended shore platform in GL, attracting locals and tourists throughout the year and swimmers during the summer. It stands as one of the island's busiest seaside destinations, despite its challenging accessibility. However, this affluence is exposed to the risk of cliff collapse events [63]. Unfortunately, the entire Delimara Peninsula is highly susceptible to rapid erosion, driven by the combination of the erodible quality of GL rocks and the erosive action of marine processes eroding the coastal cliffs surrounding the bay [61]. Media reports feature numerous incidents involving casualties and fatalities, including hikers and individuals on boats near the coast [64].

5. Conclusions

Tourism in Malta is mainly concentrated in the northern part of the island, overlooking much of the southern areas. This work aimed to draw the attention to rich geoheritage assets in the southern part of the Island of Malta, so they can be used to promote and incentivize tourism in this area, which is lesser known to tourists.

An inventory of 18 potential geosites was produced following the methodology developed by Bollati et al. [21] that combines scientific value parameters, aesthetic parameters, and accessibility in a final total score (TS). We identified and selected four geosites with the highest TS values that exemplify the rich geological and geomorphological diversity of southern Malta. These geosites also possess considerableaesthetic value, rendering them suitable for a geotourism development.

In particular, the Blue Grotto karstic system (TS = 19.3) and the Il-Maqluba sinkhole (TS = 16.7) are exemplary cases of karstic landforms. These two sites are also important for the protection of flora and bird nesting due to the presence of inaccessible walls and cavities. Additionally, they are located near many tourist amenities (restaurants, parking areas, etc.) and are well connected to main roads. These sites are also very close to the Ħaġar Qim site [65], a well-preserved megalithic temple site between Għar Lapsi and the Blue Grotto (Figure 1). This proximity makes them suitable to being a part of an itinerary for tourists interested in exploring the geological, biological, and cultural heritage of southern Malta.

An exemplary site important for cultural heritage is the third selected geosite, constituting a remarkable resource for education for kids and teenagers. The Darmanin salt pans (TS = 17.1) represent a significant educational asset, as the owners organize workshops to raise awareness among the population about the heritage that the shore platform and the salt pans represent for Malta.

St. Peter's Pool Bay (TS = 16.1) is an inlet located on the Delimara Peninsula, renowned for its azure waters and a suspended shore platform in GL. This geosite attracts locals and tourists throughout the year and it is particularly visited by swimmers during the summer months.

The methodology used proved to be suitable for the study area, even though it was mainly applied to mountainous rather than coastal areas in previous studies. It is evident that such methodologies still involve a subjective aspect in scoring allocation. Although this issue is not completely resolved, their usage remains a valuable tool for geosite evaluation.

The results revealed that the four identified geosites represent a valuable resource for geotourism, primarily due to their good accessibility. Geotourism is expected to facilitate a deeper understanding of the identity and character of southern Malta, promoting a sustainable type of tourism. Nevertheless, the challenge will lie in developing tourism capacity and quality without negatively impacting the environment and landscape. The increasing pressure on geosites linked to the rising number of visitors must be considered, analyzed, and incorporated into research programs.

The high scientific value and exemplary nature of the four geosites make them a significant educational resource in geosciences for studying structural geology and geomorphology. In fact, within a confined area, these sites provide an exceptional opportunity for students in geology to recognize, classify, and map a diverse range of geological features and landforms. These features highlight the urgent need for the protection and conservation of the four geosites. Specifically, the aspect of the conservation and protection of coastal geosites should be prioritized due to the increased frequency of extreme weather events associated with ongoing climate change. In fact, extreme weather events are expected to impact geosites situated in exposed and vulnerable environments [66,67]. This is particularly true for the Maltese coasts, with their rich geological heritage and susceptibility to be affected by climate-related impacts [61,68–72]. Therefore, it is imperative for local legislation and scientific research to address the challenges posed by climate change in the field of geoconservation.

In this context, this study has enhanced the understanding of southern Malta's geoheritage by providing a more objective assessment of 18 selected sites. By promoting these sites through geotourism, this approach may encourage a greater appreciation of the geological heritage of the region among visitors, which in turn could inspire local authorities to place an increased emphasis on geoconservation efforts, supporting the long-term management of southern Malta's unique geoheritage.

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Appendix A

Table A1. Scientific value (SV) attributes and related scores according to Bollati et al. [21].

Scientific Value (SV)			
Attributes		Score	Description
RGmP	Representativeness of (paleo) geomorphological process	0 0.33 0.67 1	Poor/no representativeness of a morphogenetic system Discrete representativeness of a morphogenetic system Good representativeness of a morphogenetic system Exemplar representativeness of a morphogenetic system
RGP	Representativeness of geological process	0 0.33 0.67 1	Poor/no representativeness of a geological system Discrete representativeness of a geological system Good representativeness of a geological system Exemplar representativeness of a geological system
EE	Educational exemplarity	0 0.33 0.67 1	Representativeness without any educational value Representativeness with poor educational value Representativeness difficult for non-experts Representativeness with excellent educational value
Gd	Intrinsic site geodiversity	0 0.5 1	1 lithology, 1 main landform 1 lithology, n-landforms n-lithologies, n-landforms
GI	Geohistorical importance	0 0.33 0.67 1	Without production or scientific divulgation Low-frequency topic for scientific research Relevant topic for scientific research Fundamental for development of Earth Sciences in general
ESR	Ecologic support role	0 0.33 0.67 1	Without any connection with the biological element Presence of interesting flora and fauna Geo(morpho)logical features condition the ecosystems Geo(morpho)logical features determine the ecosystems

Table A1. *Cont.*

Scientific Value (SV)			
Attributes		Score	Description
In	Integrity	0 0.5 1	Essential geo(morphological) elements are not preserved Essential geo(morpho)logical elements are just preserved Essential geo(morpho)logical elements are intact
Ra	Rareness	0 0.5 1	Frequent also at the level of the study area Rare at the level of the study area, abundant at the national level Rare at the national level

Table A2. Additional value (AV) attributes and related scores according to Bollati et al. [21].

Additional Value (AV)			
Attributes		Score	Description
Cu	Cultural values	0 0.5 1	Any cultural feature in the surroundings Presence of cultural features not correlated with geo(morpho)logical features Presence of cultural features correlated with geo(morpho)logical features
Ae	Aesthetic value	0 0.5 1	Not relevant Strong contrasts in landforms, lithologies, and colors, spatially limited Strong contrasts in landforms, lithologies, and colors
SEc	Socio-economic value	0 0.33 0.67 1	Element without exploitation or insertion in an economic area (not touristic) Element with exploitation or insertion in an economic area (NT) Element inserted in an economic–touristic area Element inserted in an economic–touristic circuit

Table A3. Potential for use (PU) attributes and related scores according to Bollati et al. [21].

Potential for Use (PU)			
Attributes		Score	Description
TA	Temporal accessibility	0.25 0.5 0.75 1	Only in summer Except in winter Except on rainy days All through the year
SAc	Spatial accessibility	0.2 0.4 0.6 0.8 1	On foot, expert excursionists On foot, touristic/excursionist On foot for numerous groups, difficult access for bus Allows means of transportation Allows means of transportation, access also to disabled visitors
Vi	Visibility	0 0.2 0.4 0.6 0.8 1	Not observable or great difficulties in observing it Just visible or with special tools (artificial lights, ropes) Reasonable visibility but limited by vegetation Good visibility but with the need of moving to improve it Good visibility for all geo(morpho)logical elements Excellent visibility for all geo(morpho)logical elements
Se	Services	0 0.33 0.67 1	Hotels and services 25 km or more away Hotels and services 10–25 km away Hotels and services 5–10 km away Hotels and services 5 km or less away
NT	Number of Tourists	0 0.5 1	Few Medium Abundant

Table A3. *Cont.*

Potential for Use (PU)			
Attributes		Score	Description
SAs	Sport activities	0 0.5 1	None Yes, not correlated with geo(morpho)logical features Yes, correlated with geo(morpho)logical features
LCs	Legal Constraints	0 0.33 0.67 1	Total protection, prevents use Protection, limited use Under protection but with little or no prevention from use No protection or limitation to use
UGI	Use of Geo(morpho)logical-related interest	0 0.5 1	No divulgation or use Use in the academic sphere With divulgation and use as a geo(morpho)site
UAI	Use of additional interests	0 0.5 1	Any divulgation or use Use of additional interests Naturalistic or cultural paths already started
SGs	Geo(morpho)sites in the surroundings	0 0.5 1	Any sites in the study area Sites in the neighborhood but not genetically correlated Sites in the neighborhood and genetically correlated

Table A4. Calculated accessibility (CA) attributes and related scores according to Bollati et al. [21].

Calculated Accessibility (CA)							
Ti	Typology	0	Any traces	GM	Ground material	0	Ice
		0.2	Traces			0.2	Snow
		0.4	Path			0.4	Coarse debris coverage
		0.6	Mule tracks			0.6	Medium debris coverage
		0.8	Dirt road			0.8	Fine or soil debris coverage
		1	Paved road			1	Bedrock or dirt/paved road
SL	Sloping	0	Yes	SM	Slope material	0	Fractured rock, soil, snow, and ice
		1	No			1	Rocks and coherent deposits
SI	Slope inclination	0	>61°	ST	Steepness	0	High
		0.25	51°–60°			0.33	Medium
		0.5	41°–50°			0.67	Low–null
		0.75	31°–40°				
		1	<30°				
				WSP	Water/snow on the path	0	Yes
TI	Tourist information	0	No			1	No
		1	Yes				
				DC	Degree of path conservation	0	Very bad
Wi	Width	0	<30 cm			0.33	Fairly good
		0.25	30–50 cm			0.67	Good
		0.5	50–100 cm			1	Excellent
		0.75	100 cm				

Table A4. *Cont.*

Calculated Accessibility (CA)			
	Human	0	Present
Hi	intervention	0.33	Absent
		0.67	Present, no influence
		1	Present and reduces vulnerability

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