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Research Article

Development of a database structure for the first Geomorphological map of Greece at 1:1,000,000 scale

Alexandra Zervakou [1], Alexandros Petropoulos [1], Niki Evelpidou [2]✉, Eirini Zananiri [1], Giannis Saitis [2], Evangelos Spyrou [2], Dionysis Goutis [1] & Hampik Maroukian [2]

[1] Institute of Geology and Mineral Exploration, Greece
[2] Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, Greece

✉ Correspondence:mailto: evelpidou@geol.uoa.gr

Abstract: Geomorphological maps offer researchers multiple advantages when studying an area, as they can provide insights into the formation processes of the observed landforms, as well as their possible evolution in the future. The geodatabase seems to be of primary importance, as it determines the way in which the data will be organized and presented on a map, and thus the map's functionality. There are not specific guidelines for a database for geomorphological maps, as this would be dependent, inter alia, on the scale of the maps. However, up to this day, there is not a single data base template to be used for geomorphological mapping. In each case, the cartographer/geomorphologist determines the number of fields their layers will have and their type, as well as what information they will contain, depending on the scale they are working on, the variety of landforms of their area, the time and resources available (correspondingly, the accuracy their map will have) and the purpose of its creation. Also, while several countries - not only large ones, but smaller ones as well - do have a geomorphological map at national scale, many countries, Greece among them, do not. On the contrary, only parts of them have been mapped by various researchers, who did not share any common database, which renders the combination of the individual maps difficult. But even in countries with existent national geomorphological maps, a specific and common geodatabase structure was not followed. In this way, there is no uniformity in the data and comparisons between maps, as well as combinations of data are very difficult and require a lot of work. Therefore, as we have initiated a project to create the geomorphological map of the Greek territory at 1:1,000,000 scale, we found that, prior to the beginning of the mapping, it was imperative to create a geodatabase template which we intend to follow, and which can be used as a template for geomorphological mapping at national scale by other countries (researchers and/or authorities). Thus, in this paper, we propose a database template to be used in geomorphological mapping at global scale globally, so that the data and structure of maps share common properties, thus allowing for comparisons and combinations of data where necessary.

Keywords: geomorphological cartography; symbolization; geodatabase; national scale

Highlights:

- Proposed database structure for geomorphological mapping at national scale
- Guidelines for geomorphological mapping
- Basis for the geomorphological mapping of Greece at 1:1,000,000-scale

1.Introduction

One of the best tools for comprehending the Earth's surface and its physical components is the geomorphological map. Geomorphological maps provide an objective depiction of landforms, their shape and morphology, by identifying natural features with specific colors and symbols (Dramis et al., 2011; Reddy, 2018). Geomorphological maps have been widely and successfully used in the visualization and analysis of the Earth's surface (Dykes, 2008).

One of the principles of geomorphological mapping is that the maps need to depict the appearance of landforms, their genesis and age (Radoane et al., 2011). The origin and evolution of past or present endogenic and exogenic processes is depicted by providing information on the spatial properties (dimensions, slope, curvature, relief) that produce the shape of the topographic relief (Dramis et al., 2011). Geomorphological maps depict several structures and landforms, including submarine landforms, highlighting morphographic and morphometric characters and lithographic details (Pavlopoulos et al., 2009).

According to Dramis et al. (2011), geomorphological maps can be categorized into basic maps and derived maps. Basic maps are maps of general interest, depicting several landforms and structures and at different scales. They can depict either the overall landscape or selected landform types/scales etc. (Verstappen, 2011). Derived maps, on the other hand, are maps whose purpose is more specific, such as natural hazard susceptibility maps (Dramis et al., 2011).

Generally speaking, there is hardly an international symbology for geomorphological mapping, except for some good works, e.g. by the Commission on Geomorphological Survey and Mapping (e.g. Embleton, 1981), contrary to most other types of geoscientific maps. In most cases, the symbols used in geomorphological cartography are selected based on the purposes of the maps, as well as the potential readers they are addressed to (Otto & Smith, 2013). There have been, however, several case studies and/or guidelines regarding symbols and legends in geomorphological cartography (Barsch & Liedtke, 1980; Brunsden et al., 1975; Demek, 1972; Embleton & Verstappen, 1988; Evans, 1990; Gustavsson et al., 2006; Klimaszewski, 1982; Leser & Stäblein, 1975; Otto & Smith, 2013; Pellegrini et al., 1993; Rączkowska & Zwoliński, 2015; Schoeneich, 1993; Schoeneich et al., 1998; Tricart, 1965; Van Dorsser & Salomé, 1973). Also significant are the guidelines on geomorphological mapping, provided by the Commission on Geomorphological Survey and Mapping (e.g. Embleton, 1981) and Demek & Embleton (1978).

Geomorphological mapping is usually carried out on a topographic map with a scale depending on the objective of the study. Geomorphological maps are divided into large-scale (e.g., scale > 1:100,000), medium-scale (e.g. scale 1:100,000 to 1:1,000,000) and small-scale maps (e.g. scale < 1: 1,000,000) (Smith et al., 2011). The landforms are depicted with specific symbols, based on an international symbol system. The basic geomorphological maps require a graphic transfer of data, which can be collected from field survey, aerial photograph interpretation and other maps, e.g. geological ones, while the derivative geomorphological maps are obtained through selection, generalization and reuse of data, with the purpose of zoning the significant geomorphological processes according to each research scope (Dramis et al., 2011).

Landform Surveys and Special Feature Investigations are the two basic categories of geomorphological maps (Pavlopoulos et al., 2009). Geomorphological maps can be distinguished into general and specific ones, depending on the selection of features of the relief. A specific category of geomorphological maps are the thematic ones, such as, for example, maps of morphological gradients, or density and frequency of the hydrographic network. In order to adapt this kind of data into a digital file, the original map must be converted into vector format (points, lines, polygons) using GIS software (Gustavsson, 2006).

A major problem with geomorphological information is that it is extremely complex to represent due to the sheer amount of data, thus analogue geomorphological maps may not be easily readable in some cases. Remotely sensed data contribute to landscape comprehension for both specialized and non-specialized audiences. Standard image enhancement techniques such as false color composites, band ratios, convolution filtering and contrast stretches can be applied and improve the mapping result (Otto & Smith, 2013). The color arrangements of RGB (Red, Green, Blue) can highlight different natural aspects of the ground, the morphological characteristics and processes that can facilitate the recognition of landforms (Pavlopoulos et al., 2009; Melelli et al., 2012). All these elements are crucial to be included in the final database.

Field work is always a necessary component of geomorphological mapping. Despite its requirements, it can provide the geoscientist with the necessary experience in order for them to be able to observe the landscape and draw conclusions that cannot be extracted in another way (Cooke & Doornkamp, 1990). And in any case, it must be accompanied by pre-field mapping and literature review, as well as post-field work in order to evaluate the observations and measurements taken in the field (Otto & Smith, 2013). Digital analysis is, however, necessary for areas/sites where field work is unachievable (Oguchi et al., 2011; Smith, 2011).

In this research, we created a data base for geomorphological mapping of Greece at 1:1,000,000 scale (which consists in the creation of various geomorphological sheets at 1:50,000 scale). It was created using a number of geomorphological map and database construction systems from the literature. We used this data base to digitize the sites, structures and landforms of high geomorphological value and at the desired scale.

The database that was created during this survey aims to be a point of reference at national and regional level for public bodies regarding the civil protection of the natural environment, the implementation of technical projects, the management of natural resources and the study of natural disasters. These topics will facilitate the visualization, analysis, interpretation, and application of geomorphological data in medium-scale geomorphological maps. Designing national databases is an extended research attempt, which fills only one little piece of understanding and communicating Environmental spatial information on global scale. Through the implementable database of attributes, qualitative and quantitative data and information that cannot be replicated on a map are allowed to be collected. The geomorphological database aids to the creation of thematic maps, geomorphological analyses and exchange with other external databases. As the geomorphological mapping of Greece at 1:1,000,000-scale has already been initiated by the Hellenic Survey of Geology & Mineral Exploration (H.S.G.M.E.), which is the official public body of Greece focusing on geological issues, the development of this geodatabase template was deemed important as a first step.

1.1. Geomorphological maps at national level

There is a high need for the creation of geomorphological maps, both at local and at national level, since it is a preliminary tool for land management, but also for the management of geomorphological-geological risks (erosion risk, flood risk, landslides, volcanic eruptions etc.). It provides basic data for the scientific fields of environmental research, such as ecology, forestry, land-use planning and soil science. Their use is also significant in urban development, archaeological prospecting, climate adaptation and cultural resources management (Lashlee et al., 2002; Marijn van der Meij et al., 2022).

The first geomorphological map was probably made by Genhe (1912). Another attempt was made by Passarge (1914), in Morphological Atlas, The Stadtremba 1:25,000, including information on slopes, valleys shapes, petrography and relief types (Radoane et al., 2011; Verstappen, 2011). The first bedrock maps of British Columbia were made in the late nineteenth and early twentieth centuries by geologists like G. M. Dawson and R. Daly (Resources Inventory Committee British Columbia, 1996).

In Italy, a GIS-based, full-coverage geomorphological mapping system was created, applied in several national and regional projects on engineering geomorphology, landscape ecology and hydrology. This geomorphologic information system is a key tool for the Department of Civil Engineering and Great Risks Interuniversity Consortium, in the Salerno University (Italy) (Dramis et al., 2011).

The digital geomorphological map of Poland is another database, composed of layers and sheets with information on the relief of the country at the scales of 1:100,000 and 1:500,000. Its creation started in 2013, after the Regulation of the Council of Ministers of the October 3rd, 2011 (Rączkowska & Zwoliński, 2015). The geomorphological map of the Netherlands is part of a central database that contains all public data and models of the Dutch subsurface, called the Dutch National Key Registry of the Subsurface (Basisregistratie Ondergrond, BRO in Dutch) (Marijn van der Meij et al., 2022).

The Geological Survey of Finland (GTK) Map Data Architecture, as part of the broader National Geological Framework of Finland, supports the ongoing transition of geology features from 2D to 3D modelling (Ahtonen et al., 2021). A momentous advancement has occurred concerning GIS databases across European nations. The European Union spatial data infrastructure, INSPIRE project (Infrastructure for Spatial Information in Europe) was designed to facilitate access to environmental spatial information among public sector organizations and citizens across Europe. Data sharing tools are crucial for setting common environmental policies, cross-border collaboration strategies and transnational policymaking. The infrastructures for geographical information built and run by the European Union's Member States serve as the foundation for INSPIRE.34 geographic data themes that are required for environmental applications are covered by the Directive. The Directive was enacted on May 15, 2007, and it will be implemented gradually until it is fully implemented by 2021 (Kotsev et al., 2020).

In the Greek territory there have been numerous local scale GIS studies, including investigations in the geomorphology domain. In their book, Pavlopoulos et al. (2009) present detailed guidelines on the geomorphological mapping of different geomorphic environments, also presenting case studies, where they conducted detailed geomorphological mapping. These case studies include three sites in Attica (Southern Attica, Attica basin and Oinois river) and Paros island. Vassilopoulos (2001) and Evelpidou (2001) conducted an analytical geomorphological study, and constructed the corresponding geomorphological map, for the islands of Naxos and Kefalonia respectively.

At larger scales, various works have been conducted on detailed geomorphological cartography in the 20th century. For example, Dufaure (1978) published a geomorphological map of the Peloponnese. Bonnefont (1977) constructed the geomorphological map of Crete, Bousquet(1976) constructed the geomorphological map of NW Greece (Epirus and Macedonia) and Faugères (1978) constructed the geomorphological map of Central and Eastern Macedonia. There is not, however, a geomorphological map of Greece as a whole.

The geodiversity map of Crete was produced by analysis of the geoinformatic data sets, in order to quantify the geodiversity, by calculating landscape diversity and other spatial pattern indices (Argyriou et al., 2016). The Digital Geomorphological Map of Northeastern Messinia was created to identify archaeological sites of great importance (Vandarakis et al., 2022). Local-scale geomorphological maps indicate landscape formation and evolution in various Greek locations, thus they concern a tool for research methods (Tsanakas et al., 2019). The H.S.G.M.E. has made the digital Geological and the Hydrological Map of Greece available to the public. There are also the private sector and individual attempts to create online digital GIS platforms for geoparks, georoutes and monuments of natural beauty in Greece. An integrated data base for the national geomorphological map has not been created yet for the whole Greek region.

2. Materials and Methods

International scientific documents and classification standards were collected to compare already existing databases. The geomorphological GIS database was built using Microsoft Access and ESRI ArcGIS® Pro. Their geomorphological information was transferred into the GIS database, based on qualitative and quantitative geomorphological characteristics. Information for each object was inserted in the corresponding fields of its attribute table.

The data related to the above were recorded from available databases and literature, referring to the most important[1] geomorphological features of the Greek area, according to international standards (INSPIRE) (Table 1). The coordinate system used was the Hellenic Geodetic System of Reference (HGSR/ΕΓΣΑ 1987). It is similar to the WGS84 system, but adjusted to the Greek area. In this way, the ellipsoid is best suitable for Greece (Delikaroglou, 2008). It uses a transverse Mercator cartographic projection, projecting the whole Greek territory within one single zone. The axes are in meters; the northing is the true distance from the equator, while the easting is the distance from the Central Meridian increased by 50,000, so that easting does not take negative values (Fotiou & Livieratos, 2000).

Concerning the size of the depicted landforms, considering the scale of 1:1,000,000, we considered as mappable all landforms (regardless of environments) whose size is greater than, or equal to, 0,5 cm in the map, that is 5 km. Landforms and geomorphic characteristics that have at least one dimension of 5 km or more could be abrupt changes in inclination, V-shaped valleys, canyons, U-shaped glacial) valleys, hanging valleys, poljes, continuous beachrock slabs, as well as fields of karren, monadnocks, inselbergs etc.

The final step was the updating of the metadata and a final organization of the existing data (Gustavsson et al., 2008). The National Cadastre and the H.S.G.M.E. geological maps have been used as basic geospatial reference (background maps). The rich symbology available in the ArcGIS Pro software have been used, either taken from the symbol library or generated during the creation phase of the digital geomorphological map improving graphical performance.

Table 1. Part of the database of the geomorphological map of Greece at 1:1,000,000 scale (Note: For practical reasons, the fields are shown as columns and the features as rows)

Landform_No	576	2083	484
Landform_Code	Phthiotida_GMPH_PL_0516	Evrytania_GMPH_L_0554	Arta_GMPH_PL_0426
Geometry	Polygon	Polyline	Polygon
NAME	Spercheios delta	Mpouzonikou Gorge	Logarou Lagoon
Country	Greece	Greece	Greece
Region	Phthiotis	Evrytania	Arta
Environment	fluvial	fluvial	coastal
Descr_En	deltaic fan	canyon	lagoon
Descr_El	δελταϊκό ριπίδιο	φαράγγι	λιμνοθάλασσα
Info	-	-	-
Longitude	373663.755079	279122.345000	232207.115686

1. It is to be mentioned that in the geomorphological map of Greece at 1:1,000,000 scale, only macro- and meso-scale features are mappable; therefore, small-scale landforms are not included in the database.

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Latitude	4301600.47025	4324977.495000	4326005.25012
NaGeoFT_Label_Inspire	marine, littoral and coastal wetlands features	alluvial and fluvial features	marine, littoral and coastal wetlands features
NaGeoFT_ID_Inspire_link	http://inspire.ec.europa.eu/codelist/NaturalGeomorphologicFeatureTypeValue/marineLittoralCoastalWetland	http://inspire.ec.europa.eu/codelist/NaturalGeomorphologicFeatureTypeValue/alluvialFluvial	http://inspire.ec.europa.eu/codelist/NaturalGeomorphologicFeatureTypeValue/marineLittoralCoastalWetland
EventEnv_Label_Inspire	deltaic system setting	river channel setting	lagoonal setting
EventEnv_ID_Inspire_link	http://inspire.ec.europa.eu/codelist/EventEnvironmentValue/deltaicSystemSetting	http://inspire.ec.europa.eu/codelist/EventEnvironmentValue/riverChannelSetting	http://inspire.ec.europa.eu/codelist/EventEnvironmentValue/lagoonalSetting
AnthroGeoFT_Label_Inspire	-	-	-
AnthroGeoFT_ID_Inspire_link	-	-	-
Lithology	alluvial deposits	limestones	Quaternary deposits
Photo	no	no	no
Polygon	yes	yes	yes
Source	-	-	-
Hyperlink	https://www.geofabrik.de/	https://www.geofabrik.de/	https://www.geofabrik.de/

The open structure and data separation of the mapping system create an environment where the geomorphological features can be investigated separately. The database shown in this paper can be simply transformed into a server geodatabase with structured raw data on comprehensive scientific aspects of the landscape, which can contain a wide variety of data and be used and edited by a whole workgroup and a variety of applications (Longley et al., 2005).

In this project, a number of geomorphological database construction systems were studied in order to evaluate and combine the most effective methods and apply them to the present project. These are the ITC Geomorphological System (Enschede, The Netherlands), the German GMK Mapping Systems (Barsch et al., 1985; Barsch & Liedtke, 1980), British Geomorphological Maps, the AGRG Geomorphological Mapping System (Amsterdam, The Netherlands) (de Graff et al., 1987), the IGUL Mapping System (Lausanne, Switzerland) (Schoeneich, 1993), the mapping system by Gustavsson et al. (2006, 2008), the Swiss BUWAL Mapping System (Kienholz, 1978; Kienholz & Krummenacher, 1995) and some examples of databases proposed by various authors (Clark et al., 2004; Gaspar et al., 2004).

3. Results

Each landform has been categorized based on a classification scheme combining geomorphological characteristics, adopting all the required landform units. Morphography describes an external form, morphogenesis refers to the geomorphological processes that predominate under a particular climatic regime, and produce a characteristic topographic expression, while morpho-structure describes the geological feature of a landscape typically caused by tectonic activity and climate. The hierarchical classification system is a modification of the purely genetic classification system of the INSPIRE code list register on geology and geomorphology. Table 1 shows a part of the geomorphological database designed for a map of national scale.

3.1. Classification of genetic type

The landforms' classification was based on existing geomorphological maps from national authorities and scientific literature (involving geomorphological handbooks). Major genetic categories of geomorphologic classification systems can be divided into natural geomorphological features and anthropogenic geomorphological features. We then categorized them according to the primary geomorphic process of their formation (e.g. fluvial, coastal, karstic etc.). The resulting genetic classification method presents a total of 9 major genetic categories (aeolian, coastal, fluvial, karstic, lacustrine, glacial, man-made, tectonic and volcanic).

3.2. Description of the proposed database

The database we propose is shown in Table 2 for all three types of layers (points, polylines and polygons). Most fields are common for all three types of layers. More specifically, we propose the following fields, in the quoted order:

1. **Landform_No:** this is a field accepting integer characters and concerns the landform's serial number (from 1 to maximum number). Numbering is suggested to be done in a "logical" order, i.e. from north to south and from east to west rather than randomly.
2. **Landform_Code:** Text variable. We propose that the code have the following form: Area_GMPH_LT_SN. "Area" refers to the region (e.g. prefecture, province, department, island etc.) where the landform is located. We propose that this be written with the first letter in capitals and the rest of the word in small letters. "LT" is the layer type; we propose the following abbreviations (in capital letters): P (point), L (polyline) and PL (polygon). "SN" is the serial number; for uniformity reasons, we propose that this be written in four digits (e.g. 0015 instead of 15).
3. **Geometry:** Text variable; layer type that each landform corresponds to.

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4. **Name:** Text variable; the name of each landform; in the case where a landform does have a given name (for instance, "Meteora"), we suggest that this name be preserved as is. If, on the other hand, no given name has been found, we propose that a descriptive name be given, including the broader area or a local settlement's name and the depicted landform (e.g., Pyrgaki sand dunes; Paliopyrgos alluvial fan etc.).
5. **Country:** a text field containing the name of the country.
6. **Region:** a text field containing the administrative division (province, prefecture, district, department, arrondissement, municipality, parish, united state etc.) in which the landform is located.
7. **Environment:** a text field indicating the formation environment of the landform (e.g. fluvial, coastal, glacial, karstic, aeolian, hillslope, deltaic, submarine etc.). In case a landform corresponds to multiple environments, we suggest that the most significant one be cited (for instance, if a landform is owed to karstic processes, but has also been shaped due to hillslope or fluvial erosion, we suggest that the environment be named as "karstic", rather than having characterizations such as "fluvio-karstic", "fluvio-glacial", "tecto-karstic" and so on, as this would make the database rather complicated (when we are talking about the national rather than local scale).
8. **Descr_En:** a field text including a brief description or comments for the depicted landform (when necessary) in English.
9. **Descr_Nl:** the same as Descr_En, only in the national language (Nl); for example, Gr (Greek), It (Italian), Ru (Russian) etc.
10. **Info:** a field text containing supplementary information (e.g. lithology, datings etc.), in case the description in Descr_En does not suffice.
11. **Longitude:** a text containing numerical characters (double). It contains the longitude of the landform. It is applicable only to points.
12. **Longitude_midpoint:** a text containing numerical characters (double). It contains the longitude of the landform's midpoint. It is applicable only to polylines and polygons, corresponding to Longitude for points.
13. **Latitude:** a text containing numerical characters (double). It contains the latitude of the landform. It is applicable only to points.
14. **Latitude_midpoint:** a text field containing numerical characters (double). It contains the latitude of the landform's midpoint. It is applicable only to polylines and polygons, corresponding to Longitude for points.
15. **NaGeoFT_Label_Inspire:** a text field containing the Natural geomorphological feature type (standard Inspire characterization) (for the case where Inspire has been utilized).
16. **NaGeoFT_ID_Inspire_link:** a link referring to this characterization.
17. **EventEnv_Label_Inspire:** a text field containing the Event environment (standard Inspire characterization) (for the case where Inspire has been utilized)
18. **EventEnv_ID_Inspire_link:** a link referring to this characterization.
19. **AnthroGeoFT_Label_Inspire:** a text field containing the Anthropogenic geomorphologic feature type (standard Inspire characterization) (for the case where Inspire has been utilized)
20. **AnthroGeoFT_ID_Inspire_link:** a link referring to this characterization.
21. **Lithology:** a text field containing the lithological formation that surrounds the landform; we propose that only type of rock and a supplementary characterization be added, such as "karstified limestones", "unconsolidated sands" etc. In the case of polylines and polygons, all lithological formations are suggested to be included.
22. **Photo:** one image (or sketch) of the landform, when existent and when applicable and necessary.
23. **Hyperlink:** a hyperlink connecting to a platform where one can gain more information about this landform (when applicable).
24. **Point:** a field which is only applicable to point layers. It indicates whether the respective landform can or cannot be depicted in the map at the desired scale. It can either be a text (e.g. yes or no) or a number (e.g. 0 and 1).
25. **Line:** a field which is only applicable to polyline layers. It indicates whether the respective landform can or cannot be depicted in the map at the desired scale. It can either be a text (e.g. yes or no) or a number (e.g. 0 and 1).
26. **Polygon:** a field which is only applicable to polygonal layers. It indicates whether the respective landform can or cannot be depicted in the map at the desired scale. It can either be a text (e.g. yes or no) or a number (e.g. 0 and 1). By using the fields 24-26, all landforms can be included in the database, which can then be used for all maps, regardless of scale and purpose.
27. **Source:** a text field containing the source from which information on this landform was extracted. We propose that reliable sources be used (e.g. scientific papers) or own fieldwork and observations), in case they have been conducted. Also, when more than one source has been used, all should be contained.

Table 2. The database for the geomorphological mapping database.

Field	Type	Applicable layer type	Description/Comments
Landform_No	integer	all	Serial number
Landform_Code	text	all	Includes area, layer type and serial number
Geometry	text	all	Layer geometry (point, polyline, polygon)
Name	text	all	Name of feature
Country	text	all	Country

Field	Type	Applicable layer type	Description/Comments
Region	text	all	Adm. region (e.g. province, prefecture, district, department, arrondissement etc.)
Environment	text	all	Geomorphic environment of formation
Descr_En	text	all	Description in English
Descr_Gr	text	all	Description in local language (Greek)
Info	text	all	Supplementary information (e.g. lithology, elevation range)
Longitude	text	points	Longitude
Latitude	text	points	Latitude
Longitude_midpoint	double	polylines, polygons	Longitude of the midpoint
Latitude_midpoint	double	polylines, polygons	Latitude of the midpoint
NaGeoFT_Label_Inspire	text	all	Natural geomorphological feature type (standard Inspire characterization)
NaGeoFT_ID_Inspire	link	all	Natural geomorphological feature type (link to the Inspire characterization)
EventEnv_Label_Inspire	text	all	Event environment (standard Inspire characterization)
EventEnv_ID_Inspire	link	all	Event environment (link to the Inspire characterization)
AnthroGeoFT_Label_Inspire	text	all	Anthropogenic geomorphologic feature type (standard Inspire characterization)
AnthroGeoFT_ID_Inspire	link	all	Anthropogenic geomorphologic feature type (link to the Inspire characterization)
Lithology	text	all	Lithological formation
Photo	image	all	Photograph or picture (if applicable)
Hyperlink	link	all	External link (if applicable)
Point	text/ integer	points	Indicates whether the feature is drawable as line at given scale
Line	text/ integer	polyline	Indicates whether the feature is drawable as line at given scale
Polygon	text/ integer	polygon	Indicates whether the feature is drawable as polygon at given scale
Source	text	all	Literature, link, map etc.

4. Discussion

Geomorphological mapping can prove a very valuable tool when assessing the suitability of the land for various purposes (Coratza et al., 2021; Lee, 2001), as well as land planning (Cappadonia et al., 2018), ecological studies, tourism (Quesada-Román et al., 2023) public works and infrastructure (Barbosa & Furrier, 2023) and watershed management (Thakuriah, 2023). It can also be very useful in natural hazard assessment, mapping, mitigation and management (Chelli et al., 2021; García-Soriano et al., 2020), such as floods (Quesada-Román, 2021), erosion (Martín-Velázquez et al., 2022), landslides (Dykes, 2008; Quesada-Román, 2021), wildfires (Quesada-Román & Vargas-Sanabria, 2022), liquefaction (Valkaniotis et al., 2024) and volcanic eruptions (Carrión-Mero et al., 2020).

One major problem concerning geomorphological mapping, regardless of scale, is that there are not specific guidelines to be followed. This issue is also extended in the geodatabases used for their creation. While several geomorphological maps at national or regional scale have been conducted, they do not follow a specific database. Simultaneously, there are but a few studies that have published the structure of their database. For example, while there are geomorphological maps at national scale, these studies have not published their databases e.g. Poland, Rączkowska & Zwoliński, 2015; Sweden, Gustavsson, 2006; Grenada, van Westen, 2016 etc., or have published them partly and in a non-organized form, e.g. Spain; Instituto Geologico Y Minero De España, 2005. In other cases, they only made a part of their database structure public (e.g. China, Cheng et al., 2011; Cyprus, Metakron Consortium, 2010). And some of them also do not explain the methodology behind which they created them. Besides the fact that data obtained through such studies cannot easily be subject to comparisons due to the differences in the databases, another issue is that, since the method of landform classification is not known, potential errors in the classification cannot be identified and corrected, which may potentially lead to misinterpretations of several geomorphic features.

Several databases have been created by various researchers (e.g. Barsch & Liedtke, 1980; Gaspar et al., 2004; Kienholz, 1978; Rączkowska & Zwoliński, 2015; Schoeneich et al., 1998). They do have, however, certain problems and can thus not be used in geomorphological mapping at regional or national scales. For example, some of them are case-based (e.g. focusing on specific geomorphic environments and/or processes) or can only be applied at local scales and local geomorphic regimes. Other databases are appropriate for specific applications of geomorphology (e.g. specific natural hazards; e.g. Bălteanu et al., 2020; van Westen, 2016).

Thus, a globally accepted database, suitable for geomorphological mapping at larger scales is not yet available (Gustavsson et al., 2008). Yet, the development of an organized geodatabase prior to the geomorphological mapping seems to be necessary for more accurate geomorphological mapping (Bufalini et al., 2021). And arguably, there are several other geomorphological maps around the world at national scale, but are only available in the local countries and are not public. We thus believe that a sharing between potential structures of a geomorphological mapping database, and experiences and issues faced during the mapping procedure, can help researchers create more uniform and homogenous maps and address potential problems they previously did not realize. In that way, different data from different areas may be combined if this is necessary.

Additionally, different maps can be compared more easily. This has already been conducted for geological mapping (cf. Commission for the Geological Map of the World; https://ccgm.org/en/, accessed August 26, 2024), which allows for comparisons between completely different geological settings, or the study of two adjacent areas belonging to different nations, or even continents.

In this work, we have described in detail the geodatabase we intend to use for the first geomorphological map of Greece and we have explained what each field's importance is, and how it should be used in geomorphological maps at national scale. Therefore, our study aims to publish a proposed database structure, which we believe is suitable for general geomorphological mapping at national scale, regardless of geomorphic environment and processes.

While many countries do have a geomorphological map at national level, including larger ones (e.g. Russia, U.S.A. etc.), as well as smaller ones (Turkey, Armenia, Cyprus etc.), Greece is one of the many countries that do not. There are some works on geomorphological mapping at large scales in various Greek regions (Bousquet, 1976; Bonnefont, 1977; Dufaure, 1978; Faugères, 1978). These works do have three major disadvantages, however. First, they are only available in French, which limits their usefulness. Second, they are too old, and have not incorporated the results of newer studies. And third, while all of them are preeminent, they were generally conducted by students-researchers in the framework of a master of Ph.D. thesis and not through an official body, such as the H.S.G.M.E. Also, they do not cover all of Greece, nor could they be combined easily, due to lack of a common database. Therefore, it was imperative to initiate the geomorphological mapping of Greece, at national scale, and to create a database template to be used as a reference point. On the other hand, there are several stidies on geomorphological mapping of Greece at smaller scales, such as Pieria (Tsanakas et al., 2019), Naxos (Evelpidou, 2001), Messinia (Vandarakis et al., 2022) etc., but still they only cover a small part of Greece.

Geomorphological mapping, together with the advances in technology, has enabled collaborations between different nations and/or scientists from different disciplines, thus providing additional opportunities to address global challenges, including environmental issues and the climate change (Giaccone et al., 2022; Griffiths & Lee, 2022). Thus, it is very important to continue this research on geomorphological mapping and contribute to the advancement of the scientific knowledge and experience, as well as education and technology (Deng et al., 2018; Quesada-Román, 2022). In this way, our understanding of the Earth's processes can be highly improved, and so can the strategies for sustainable resource management, land planning and environmental protection (Giaccone et al., 2022; Griffiths & Lee, 2022).

However, geomorphological mapping has not shown a significant advance in all countries, and there is a need for this discipline to be developed at a global scale (Verstappen, 2011; Oguchi, 2020; Quesada-Román & Peralta-Reyes, 2023). By using a common database for geomorphological mapping, maps of different areas, possibly belonging to different nations, may easily be combined into one map. For example, this could be the case of the Great Lakes between U.S.A. and Canada, Prespes Lakes, which are shared by three countries, or the Alps, which occupy even more countries. This is particularly useful, given that, practically, the geomorphology does not change at regional or larger scales over the human time (Slaymaker et al., 2021), which ensures the diachronic usefulness of a geomorphological map at national or even global scale.

Also, the usage of a database from different countries may ultimately contribute to the development of a global geomorphological map, showing full uniformity in its structure and symbology, as is the case of geological mapping (e.g. Geological Map of the World Commission - https://ccgm.org/en/, accessed August 19, 2024). Additionally, a uniformity in geomorphological maps at national scale may also contribute to the development of educational activities and cooperations between different countries (cf. through a mobility program, similar to Erasmus+) (e.g. Quesada-Román and Peralta-Reyes 2023), in that it could facilitate the comparisons between different sites of interest and, thus, the development of both educational (or research) activities and field trip guides (or reports, respectively). Moreover, a uniform system of landform categorization and characterization, which is exactly the aim of the database we propose, can facilitate the development of geoheritage towards sites of geomorphological interest (the so-called "geomorphosites" – Panizza, 2001), from geomorphosite identification and selection to mapping, or even the creation of georoutes concentrating on geomorphological heritage.

5. Conclusions

Geomorphological mapping flourished to the benefit of society by depicting the natural formations and possible hazard and risks that enable updating the National prevention mechanisms. Environmental spatial data provide synchronous educational opportunities for a better understanding of 3D objects and dimensions of natural landscapes. Databases are fundamental techniques that provide a generic framework, which can be used by a wide variety of different users and purposes. Unfortunately, a significant problem concerning these databases is that most works either do not publish their structure and/or how they used it to generate their map, or they only publish a part of it. The result of this is that data from different geomorphological maps (e.g. of different countries) cannot be compared, or combined into a uniform format and a common map, if needed.

In this work, we created the database for the first geomorphological map of Greece conducted by the official sector (H.S.G.M.E.), based on an extended review of the international scientific literature, in which Greek landforms were classified in nine general categories, determined by existing geomorphological maps and the literature. This database could be used for multiple environmental investigation case studies and for creating the National Integrated Geomorphological Map of Greece. Digital mapping is undergoing renaissance, following new technologies and tools, thus an opportunity for great graphical inventories of landscapes and landforms is well developed. According to our literature review, there are no globally accepted guidelines for geomorphological mapping at a national scale. Several maps and databases were studied, but a detailed and organized (and also public) database was not found. Therefore, our study aims to provide a generalized database that can be used in all cases, regardless of prevailing geomorphic processes.

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