

Geological studies for regional and urban planning in Greece

Nikolaos Depountis^{1,*}

<https://doi.org/10.5281/zenodo.10463556>

This article presents the importance of geological studies for identifying the most suitable areas for regional and urban planning in Greece. Termed as geological suitability studies, these studies aim to determine the geological suitability of land to protect the built environment from natural hazards and hazards associated with human interventions and activities. Key areas of focus include the exploitation of geological resources and the protection of the geological environment. In addition, the application of Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE) for assessing geological parameters, which are crucial for the delimitation of geologically suitable zones, are discussed. Furthermore, the article explores how GIS and MCE can be applied in the development of geological suitability models.

Cet article présente l'importance des études géologiques pour identifier les zones les plus adaptées à l'aménagement régional et urbain en Grèce. Appelées études d'aptitude géologique, ces études visent à déterminer l'aptitude géologique des terres à protéger l'environnement bâti des risques naturels et des risques associés aux interventions et activités humaines. Les principaux domaines d'intervention comprennent l'exploitation des ressources géologiques et la protection de l'environnement géologique. En outre, l'application des systèmes d'information géographique (SIG) et de l'évaluation multicritère (MCE) pour évaluer les paramètres géologiques, qui sont cruciaux pour la délimitation des zones géologiquement appropriées, est discutée. En outre, l'article explore la manière dont les SIG et les MCE peuvent être appliqués au développement de modèles géologiques d'acceptabilité.

Este artículo presenta la importancia de los estudios geológicos para identificar las áreas más adecuadas para la planificación regional y urbana en Grecia. Denominados estudios de idoneidad geológica, estos buscan determinar la aptitud geológica del terreno para proteger el entorno construido de los riesgos naturales y los peligros asociados con intervenciones y actividades humanas. Las áreas clave de enfoque incluyen la explotación de recursos geológicos y la protección del entorno geológico. Además, se aborda la aplicación de Sistemas de Información Geográfica (SIG) y Evaluación Multi-Criterio (EMC) para evaluar parámetros geológicos, cruciales para la delimitación de zonas geológicamente aptas. Además, el artículo explora cómo SIG y EMC pueden aplicarse en el desarrollo de modelos de idoneidad geológica.

1. Introduction

In general, spatial planning includes all levels of land use planning ranging from urban, regional, and national spatial plans, to plans in the European Union and at international levels. In Greece, the geological studies elaborated for regional and urban planning are called geological suitability studies. These are mandated for the design of regional and urban plans at scales of 1:25,000 and 1:2,000 (or larger), respectively. Their primary focus lies on the protection of the built environment against geologically active phenomena that could trigger natural disasters, such as earthquakes, landslides, liquefaction, floods, ground subsidence, etc. These studies

also address the exploitation of geological resources and the protection of the geological environment.

The preparation of geological suitability studies in Greece became more effective after the implementation of the Law N.2508/1997 [1] on sustainable residential development, which has been reformed several times in recent years. Its latest updated version is presented in Law N.4759/2020 [2] entitled "Modernisation of the regional and urban planning legislation". Furthermore, several Ministerial Decisions (MD) based on these laws have been published in Government Gazettes (GG), providing specifications and guidelines for the preparation of geological suitability studies [3,4] and other related studies [5,6,7,8].

The rapid development of Geographic Information Systems (GIS) has made the use of technological tools used in

geological studies and site suitability more effective. Moreover, one scientific approach that can be further developed in the geological suitability studies is the Multi-Criteria Evaluation (MCE) methodology. The application of the MCE methodology proves efficient in the grading and delimitation of several geologically suitable zones. Various layers can be generated and graded in a GIS environment in order to produce a general geological suitability map for regional and urban planning.

2. General schedule of geological investigations for regional and urban planning in Greece

The process of examining geological conditions used in the context of regional and urban planning studies in Greece follows the following stages:

¹ University of Patras, Department of Geology, Greece

* ndepountis@upatras.gr

Stage A: During the initial planning of land use and development programs, a preliminary geological assessment is carried out, which mainly addresses geomorphological, tectonic, hydrological, hydrogeological, seismological, engineering geological and geological threat issues related to the areas under investigation. It describes and specifies the prevailing geological resources and submits proposals for the protection and enhancement of the geological environment. The geological survey at this stage excludes areas that generally are geologically unsuitable and divide the remaining areas into several zones of suitability. These zones are related to the prevailing geological conditions combined with the different land uses, such as residential, industrial and tourism. This assessment results in the formulation of proposals which are included in the approval decisions of the country's regional land-use plans or General Urban Plans (GUP).

Stage B: Subsequently, in the areas that have not been excluded from the previous stage, a more detailed engineering geological survey is carried out. Here, the physical and mechanical characteristics of the geological formations as well as the geological hazards threatening the potential residential areas and the natural environment are identified, mapped, and described in detail. This stage also includes an assessment of the problems that may arise during the foundation of the buildings. At this stage, the conclusions and recommendations of stage A are thoroughly reviewed, and, among other things, a final map is presented showing the geological suitability zones in the study area, described by one of the following proposals:

- i. Suitable for residential development. In these areas, buildings of ordinary importance may be constructed. The building conditions may only mention observations that should be considered for optimal planning.
- ii. Suitable for residential development under certain conditions. Specific conditions and restrictions are imposed on building in these areas.
- iii. Unsuitable for residential development. There are serious reasons for excluding these areas from building.
- iv. Doubtful for residential development. Further investigation is required either because there is

insufficient data or because the existing legal framework requires it.

This work leads to the formulation of proposals which are included in the approval decisions of the country's local urban plans related to the geological suitability for residential development on the area under consideration.

Stage C: For areas where the stage B survey raises doubts as to their suitability due to lack of data, or indicates problems for which further investigation is required, additional specialised geological investigations shall be carried out. These investigations typically include geophysical surveys, micro-zone studies in areas of active faults, as well as geotechnical surveys and studies.

At each planning stage, the analyses and recommendations of geological investigations are communicated to the public planners, inhabitants, and private stakeholders so that they can participate in the decision-making process. Based on the conclusions of the geological investigations, the relevant administrative body issues a specific decision on the suitability for residential or other building development to accompany the planned regional and urban plan that is finally published in a Government Gazette (GG).

3. Geological Suitability Studies

3.1. Geological Suitability Studies for regional planning

These studies are compulsory for all Greek Municipalities, numbering 332, and they essentially represent the first step (Stage A) for the later urban planning (Stage B). These geological studies are governed by specifications which stipulate that the scale of the produced maps is 1:25,000 and that an initial overview of the existing geological condition is provided.

The area under investigation usually includes a few tens to several hundred squared kilometres and it includes all land-uses (residential or other urban uses, inland waters, infrastructures, forest, agricultural or environmentally sensitive areas).

The geological investigation carried out as part of these studies usually identifies three different areas related with the regional development:

- i. Areas from a geological point of view for residential or other devel-

opment (e.g., landfilling, cemeteries, wastewater treatment plans, and other infrastructures) related to building, to safeguard the built environment from natural hazards or risks from human intervention and activities;

- ii. Areas for the protection of potential exploitable geological resources;
- iii. Areas requiring conservation and enhancement of the geological environment.

Therefore, the information provided by the geological survey at this early stage of planning can be used in multiple ways: (i) as an initial approach of the general development of the municipality, (ii) in the planning of residential areas, showing the expected problems and restrictions that need to be imposed on building, (iii) in the exploitation of natural geological resources and (iv) in the assessment of certain initial geological parameters in infrastructure.

At this stage, as it has been mentioned in the introduction section, the MCE methodology may be used to produce geologically suitable zones of different grading and/or define zones of protection. For this purpose, three different categories of land-uses are examined (i) residential development and other uses related to building, (ii) geological resources, and (iii) the geological environment. Each of these categories is examined using different geological parameters and variables that are scored so that a graded scale of suitability or protection for each sub-area (or zone) is obtained. An example of this methodology is presented in Table 1.

The spatial determination of the relative geological suitability in each sub-area is carried out by the method of superposition of the corresponding thematic levels and their summation to define zones of different graded geological suitability by using the MCE methodology (Table 1) and the ArcGIS software [9]. Thus, the relative geological suitability is obtained as an algebraic sum of the grading determined for each class of each variable, according to the formula:

$$\sum_{j=1}^n B_{ij} \quad (1)$$

where, n is the number of variables and B is the grade of each class i of each variable j.

According to Table 1, the geological suitability for residential or other

Table 1: Application of MCE methodology related to different land-uses.

Categories of land-uses for residential Suitability	Parameters	Variables	Grading class			
			3	2	1	0
(i) residential or other related uses	Geomorphology	Slope inclination (%)	0-10	10-20	20-35	>35
		Distance from coastlines	>100 m	50-100 m	10-50 m	<10 m
		Presence of unstable Geomorphological or Anthropogenic structures	No		Yes	
	Geology-Tectonics	Presence of highly weathered or fractured Geological formations	No		Yes	
		Distance from active/ Probably active faults	>100 m	75-100 m	50-75 m	<50 m
	Hydrology-Hydrogeology	Distance from river Embankments	>100 m	50-100 m	10-50 m	<10 m
		High water table (0-3m depth)	No		Yes	
	Geological Hazards	Presence of landslide Phenomena	No		Yes	
		Delimited century flood hazard areas	No		Yes	
	Seismicity	Ground seismicity hazard category (according to the hellenic regulations)	A (very low)	B (low)	C (medium)	D, X (high to very high)
		Seismicity hazard zone (according to the hellenic regulations)	Zone i (<0.12g)	Zone ii (0.12-0.24g)	Zone iii (0.24-0.36g)	Zone iv (>0.36g)
	Engineering Geology	Soils prone to liquefaction or settlements	No		Yes	
Ground subsidence		No		Yes		
(ii) geological Resources	Existence of exploitable aquifers	Yes		No		
	Existence of natural Surface water reservoirs	Yes		No		
	Existence of springs	Yes		No		
	Presence of industrial Minerals and ores	Yes		No		
	Existence of construction materials and aggregates	Yes		No		
	Existence of energy raw materials	Yes		No		
(iii) geological Environment	Geo-environmentally Sensitive/protected areas	Yes		No		
	Areas of degraded Geological environment	Yes		No		
	Geosites and monuments of nature	Yes		No		

related uses may be calculated by using six parameters, i.e., geomorphology, geology-tectonics, hydrology-hydrogeology, geological hazards, and engineering geology. Each one of these parameters is graded with the use of several graded geological variables and thematic maps and relative geological suitability zones are generated with the use of the raster calculator in the ArcGIS software.

All areas surveyed are graded according to their relative geological suitability in relation to the intended use, and the conclusions are considered in the land-use planning and the later urban planning.

3.2. Geological Suitability Studies for urban planning

These studies are compulsory in every case of urban planning or demarcation of a settlement. They are usually drawn up at a scale of 1:1,000 or 1:2,000 and aim to safeguard the built environment from natural hazards or hazards resulting from human intervention and activities.

The subject of these studies is:

- i. The identification and separation of the areas to be built on as geologically suitable, unsuitable, and suitable under specific conditions;
- ii. The description of the ground conditions and/or necessary ground improvement or other protective measures required for permitting construction in the designated suitable areas under specific conditions;
- iii. The submission of proposals for the types of further studies and investigations required to clarify the geological suitability of the areas to be developed, to the extent that the data of the geological suitability study are insufficient or where more specific investigations are required.

In detail, the contents of such a study may investigate the following sections.

Geomorphology: A general and specific description of the geomorphology of the study area is given along with its relationship with geomorphological struc-

tures of the wider area. An assessment is also made of whether the geomorphology of the area is subject to changes due to geodynamic processes and human intervention. This includes factors like slope stability, soil creep, landslides, erosion and karstification phenomena. Human activities such as soil and rock exploitation, quarrying, landfilling, and soil embanking are also considered in this evaluation.

Geology: The geological data of the broader and study areas are systematically studied and mapped. The lithological composition down to a depth of 20 meters is also evaluated, based on field observations and other existing data. The most crucial tectonic features of the area are identified, and an assessment is made regarding their potential impact on buildings. In a broader context, the physical condition of surface rock and soil formations, along with their anticipated behaviour relevant to the study, is also thoroughly assessed.

Hydrology-Hydrogeology: All data and information relating to the hydrology and hydrogeology of the study area are examined, always in relation to the subject of the study.

Seismicity and Ground Hazard: The seismicity data for the wider area are provided and, an evaluation of the ground hazard within the study area is also conducted.

Engineering Geological Behaviour: The engineering geological behaviour of the predominant geological formations is assessed, and the geological conditions are identified and delimited on the geological map of the study area, particularly in places where geological disasters exist or there is a potential risk of occurrence. In general, all factors that may impact future foundations and structures are examined and mapped in detail.

Geological Suitability - Proposals: A fully justified classification of the area of interest is provided, categorising it into four suitability categories:

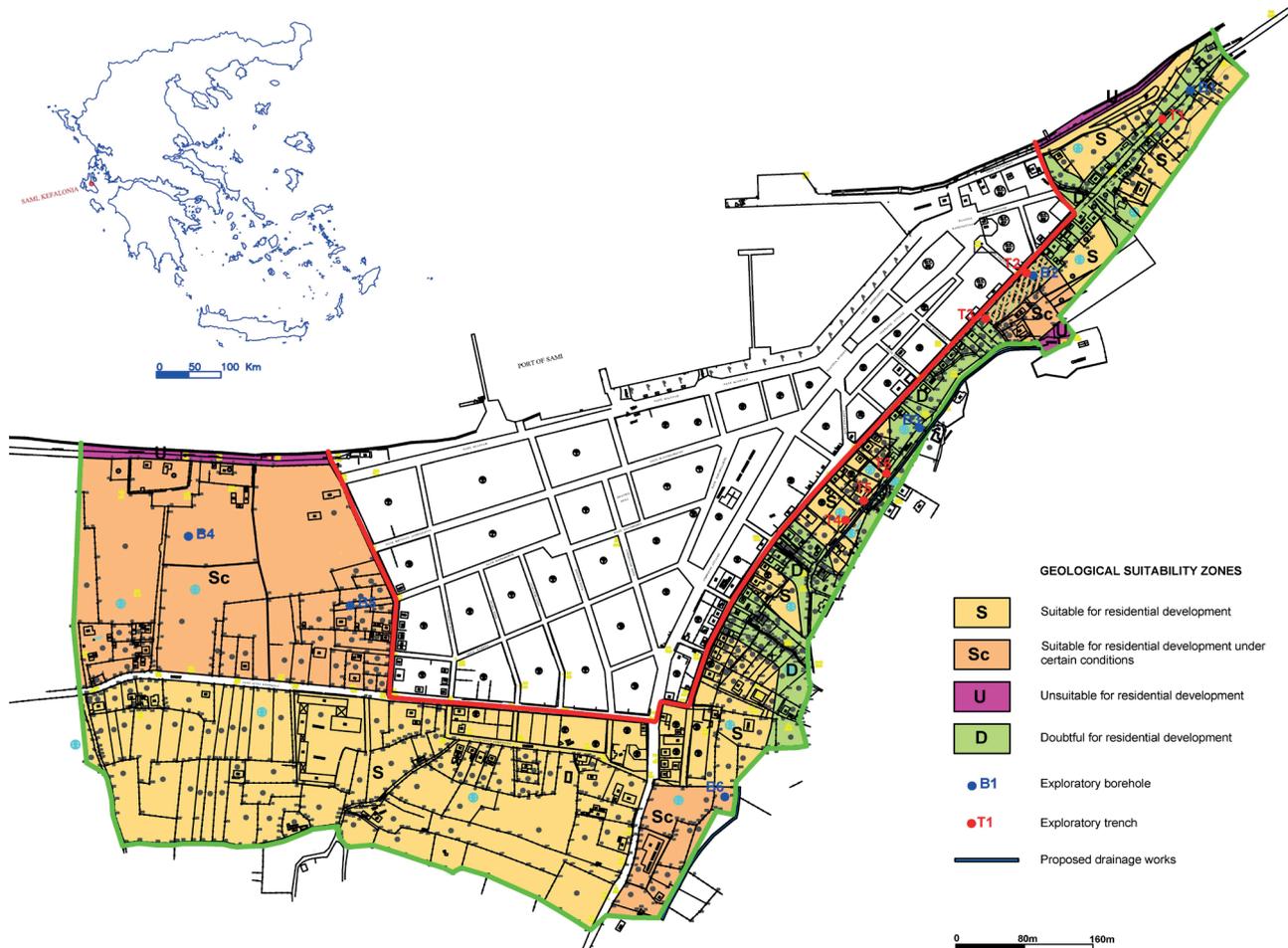


Figure 1: Geological Suitability Map of the town of Sami on the island of Kefalonia in Greece.

- i. Suitable for building;
- ii. Suitable for building subject to conditions (e.g., construction of protective works or other protective measures are mandatory);
- iii. Unsuitable for building;
- iv. Doubtful suitability for building where basic data is missing and further studies are required.

An example of a suitability map is given in Figure 1, where the geological suitability of the town of Sami, in the Kefalonia island is presented.

4. Cooperation of Geoscientists and Legislators

The cooperation between geoscientists and legislators in spatial planning is crucial for informed decision-making, sustainable development, and the well-being of communities. The following outlines how geoscientists and legislators can work together in the context of land-use planning:

- i. Data Sharing and Collaboration: Geoscientists can provide legislators with valuable data on geological features, natural resources, land use patterns, and environmental conditions. Collaboration between geoscientists and legislative bodies ensures that policymakers have access to accurate and up-to-date information for effective spatial planning;
- ii. Evidence-Based Decision Making: Geological research and data analysis can inform legislators about the geological suitability of different areas for specific types of development. Legislators can use this evidence to make informed decisions regarding land use zoning, infrastructure development, and environmental protection measures;
- iii. Policy Formulation: Geoscientists can assist legislators in formulating policies that take geological factors into account. For example, regulations related to building codes, land use planning, and environmental protection can be crafted based on geological assessments and recommendations;
- iv. Natural Hazard Mitigation: Geoscientists can identify areas prone to natural hazards such as landslides, earthquakes, and floods. Legislators can use this information to implement policies that restrict development in high-risk zones and enforce construction standards that enhance resilience against these hazards;
- v. Infrastructure Planning: Geoscience expertise is crucial in planning infrastructure projects. Geologists can help legislators identify suitable sites for infrastructure development, ensuring that projects are built on stable ground and are less vulnerable to geological risks;
- vi. Environmental Conservation: Geoscientists can assess the environmental impact of various spatial planning decisions. Legislators can use this information to create policies that promote sustainable development, protect natural habitats, and conserve biodiversity;
- vii. Public Awareness and Education: Geoscientists and legislators can collaborate on public awareness campaigns to educate communities about geological risks and the importance of considering geological factors in spatial planning. Informed citizens can advocate for policies that prioritise geoscience-based decision-making;
- viii. Legal Framework Development: Legislators can work with geoscientists to develop legal frameworks that support geoscience research, data collection, and dissemination. This can include funding for geological surveys, establishing standards for geological data, and promoting interdisciplinary collaboration between geoscientists and policymakers;
- ix. Adaptive Planning: Geological data can inform adaptive planning strategies. Legislators can create policies that allow for flexibility in spatial planning, enabling adjustments in response to change geological conditions, climate change impacts, and emerging geological research findings;
- x. International Collaboration: Geoscience and legislation are not confined by national borders. International collaboration between geoscientists and legislators can facilitate the sharing of best practices, data, and expertise, especially in regions prone to transboundary geological risks.

5. Discussion and Conclusions

Geological suitability studies for regional and urban development are essential for ensuring that regional and urban planning and infrastructure development consider geological parameters to minimise risks and maximise sustainability.

Current practices in geological suitability studies emphasise comprehensive assessments of several geological parameters, hazard mitigation, sustainability, and community engagement. These practices may include (i) Site Characterisation and Geological Mapping, (ii) Geotechnical Investigations, (iii) Geological Hazard Assessment, (iv) Hydrological and Hydrogeological assessment, (v) Sustainable Resource Management, and several others that depend on each country's regulations and needs.

In Greece, the corresponding geological suitability studies mainly focus on the protection of the built environment against geologically active phenomena (geological hazards), the exploitation of geological resources and the protection of the geological environment by using many of the above-mentioned practices during the different stages of planning. The main objective is to provide a geological suitability map with several zones and guidelines, on which zoning regulations are established. This ensures that high-risk areas are not developed for residential or critical infrastructure purposes. This is then followed by a specific geological suitability decision that accompanies the regional and/or urban plan published in a Government Gazette (GG).

Geographic Information Systems (GIS) play a crucial role in integrating geological data with other spatial data, allowing for comprehensive analyses and visualisation of geological suitability parameters and variables. With the use of the discussed MCE methodology a more comprehensive mapping is generated that is very useful in the establishment of more detailed spatial and urban plans.

The geological suitability studies that are carried out to define areas suitable for building in Greece contribute to the urban and spatial planning and the development of the country. These studies are crucial for creating resilient and safe urban environments that can withstand geological challenges and contribute to the overall well-being of their residents.

However, climate change consider-

ations, such as assessing the impact of rising sea levels on coastal urban areas, the impact of forest fires, or the impact of flooding in lowland areas are in their early stages and have not yet been mandatory in land-use planning. This is because both the political parties and the local population in Greece have not yet been convinced that climate change will shortly and severely affect large arable and habitable areas. Recently, the region of Thessaly, Greece, experienced a natural disaster named Storm Daniel. The resulting floods in the lowland areas of Thessaly impacted more than 720 km² of arable and habitable areas. Consequently, new land-use plans must now be formulated to guide development in the affected areas over the next decades.

Given the evolving nature of geological conditions and climate change impacts, it is important to adopt adaptive planning

strategies that allow for adjustments and updates to existing and new land use plans as new climatic data and information become available. Communicating this new information with local communities and stakeholders is essential. It ensures the incorporation of their concerns and perspectives into the planning process, aligning geological suitability studies with community needs, expectations, and climatic changes.

Furthermore, by fostering cooperation between geoscientists and legislators, land-use planning can be more resilient, sustainable, and responsive to the geological complexities of the environment. This collaboration ensures that policies and regulations are grounded in scientific understanding, leading to more effective spatial planning outcomes. In the author's opinion, the flood hazard management plans that have been published

in the Government Gazette (FEK) for the 13 regions of Greece should become mandatory in spatial planning, especially after the natural disaster that occurred in the region of Thessaly. The rapid adaptation of these plans to land-use planning, and the corresponding geological suitability studies can be achieved by the cooperation of geoscientists and legislators to produce more effective and publicly acceptable land-use plans.

Author Contributions: Author has read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Conflicts of Interest: The author declares no conflict of interest.

References

- [1] N.2508/1997 (GG 124/A/1997). Sustainable residential development of cities and settlements of the country and other provisions.
- [2] N.4759/2020 (GG 245/A/2020). Modernization of the regional and urban legislations and other provisions.
- [3] MD (GG 723/B/1998). Approval of specifications for the preparation of geological suitability studies in the areas to be developed.
- [4] MD (GG 1902/B/2007). Approval of specifications for the preparation of geological suitability studies elaborated in the framework of General Urban Plans (GUP) and Spatial and Housing Organisation Plans for Open Cities (SHOPOC).
- [5] MD (GG 35/B/1999). Approval of specifications for the preparation of hydrogeological studies for the protection of thermal springs in the areas to be developed.
- [6] MD (GG 838/D/1998). Determination of the supporting documents and procedure for reducing the distances of cemeteries to be established or extended.
- [7] Government Gazette (2184/B/20-12-99). Approval of the Greek Seismic Regulation (EAK - 2000).
- [8] Government Gazette (781/B/18-6-2003). Amendment and completion of the decision of approval of the "Greek Seismic Regulation (EAK - 2000).
- [9] ArcGIS Pro [GIS software]. Version 3.0. Redlands, CA: Environmental Systems Research Institute, Inc., 2010.