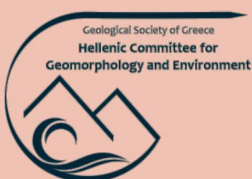# Book of Proceedings

online one day
Conference

"The Role of Geomorphology in Modern Society"

Wednesday December 16, 2020

Hellenic Committee for
Geomorphology
and Environment
of the Geological Society of Greece

Under the auspices of the
International Association of Geomorphologists

Geological Society of Greece
**Hellenic Committee for
Geomorphology and Environment**

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**GEOMORPHOLOGY
GEOMORPHOLOGIE**
AIG

Edited by:

**Efthimios Karymbalis
Niki Evelpidou
Konstantinos Tsanakas
Eleana Karkani**

BOOK OF PROCEEDINGS

of the Online Conference
"The Role of Geomorphology in Modern Society"
Wednesday December 16th 2020

organized by
the Hellenic Committee for Geomorphology & Environment
of the Geological Society of Greece

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Editors:

Efthimios Karymbalis
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Organizer: **Hellenic Committee for Geomorphology & Environment of the Geological Society of Greece,**
(IAG National Scientific Member for Greece)
under the auspices of the
International Association of Geomorphologists (IAG)

Harokopio University, Department of Geography

Co-Organizers: **National & Kapodistrian University of Athens, Department of Geology & Geoenvironment**

University of Patras, Department of Geology

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		Prof. Assimina Antonarakou (Vice President of the Geological Society of Greece, National and Kapodistrian University of Athens)
		Prof. Efthimios Karymbalis (President of the Hellenic Committee for Geomorphology and Environment of the Geological Society of Greece - Harokopio University of Athens)

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Earthquake Research Cell, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, India
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Department of Geography, University of the Aegean, Global Geoparks Network President
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National Technical University of Athens, Athens, Greece
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University of Zadar, Department of Geography, Croatia
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	Department of Geography, Harokopio University of Athens, Greece
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Ioannis Papadopoulos, Andreas Karavias, Issaak Parcharidis, Efthimios Karymbalis

Department of Geography, Harokopio University

The Role of Geomorphology in Building a Landslide Risk Culture: Romania, between Achievements and Perspectives

M. Micu [1]

(1) Institute of Geography, Romanian Academy, Dimitrie Racovita 12, Bucharest, Romania, mikkutu@yahoo.com

Throughout a vast literature enriched consistently during the last 10 years, landslides are acknowledged worldwide as being among the most significant natural risks, expressed in terms of economic, human and environmental damages or losses. Moreover, landslides not only act independently, but very often interact (directly or indirectly) with highly dangerous phenomena like earthquakes (as both co- and post-seismic processes) of floods (especially during flash floods) in a framework known as multi-hazard, increasingly approached during the last decade. The potential impact of multi-hazard risk may increase exponentially the economical damages as well as the potential death toll, thus new approaches of risk management in this new framework being constantly requested by local, national and even continental policy makers.

The development of a consistent risk culture might be considered as the key issue in building the most efficient strategies of risk management and governance. Although a very strict, case-specific definition doesn't exist, landslide risk culture may be defined as the complexity of common values, beliefs, knowledge, attitudes and understanding about landslide risk which is shared by a group of actors/stakeholders (public or governmental bodies, private companies, non-profit/NGOs, academics and general public) (after Institute of Risk Management, 2012). This culture of risk implies all the proactive and reactive measures which, commonly-agreed upon, should be evaluated, developed, implemented and constantly revised by the wide range of above-mentioned actors. This approach is extremely complicated and highly complex; it is also time consuming, since it requires a long-lasting common perception (expressed in attitude and behavior) of risk levels, a good communication and a constantly-improved education.

Geomorphology plays a crucial role in developing a strong landslide risk culture. Not only that the landslides are representing one of the most important processes studied by geomorphologists (in terms of morphogenesis, morphodynamics, modeling of future distribution and quantification of hazard and risk), but the systemic perception of the environment by the geomorphologists turns them into key stakeholders. Such an example is represented by Romania, a country severely affected by landslides (as recently described by Bălteanu *et al.*, 2020; Micu *et al.*, 2017). Their wide spectrum of processes and resulted forms, as well as the large areas across which their effects are complexly-linked with fluvial (flash floods) or seismic (earthquakes) ones, raised during the last decade the importance of performing state-of-the-art hazard studies at regional and national scales for developing reliable risk estimations, evaluations or management strategies, in support for a proper risk governance. This process was harnessed by the recent progresses achieved at the level of the European Union; following the process of EU joining (2007), Romania started a long and complex process of enhancing its capacities for disaster risk reduction, and landslides were considered among the key risks at a national scale, as outlined by the Romanian National Reports

delivered in the framework of HFA and SFDRR. Throughout a long, complicated and complex stakeholder dialogues, the need for an intra-to-multi – disciplinarity breakdown was acknowledged, and the need to promote transdisciplinarity (by allowing the actors the opportunities to engage together from the beginning and develop common perspectives) was foreseen. The implication of Romanian geomorphologists into this process was constant, and it consisted out of: fostering a common language (acknowledging the existence of high uncertainties, but reducing the focus on complex terminology like aleatory, epistemic, single, accumulated uncertainties when explaining the robustness/prediction capacity of different hazard models; encouraging transdisciplinary discussions with policy makers); tailoring the message (emphasize on communicating only clear scientific aspects, confidently known); drawing a less theoretical, more applied framework of evaluation (developing explanations which have a strong social and political relevance during the scientific work and throughout the know-how development); adapting the scientific content (outlining the relevance of the work for both locals as well as policy-makers).

As a conclusion, the implication of geomorphologists proved to be a key component in the initiation of developing of a landslide risk culture in Romania. Not only by drawing the attention through numerous analytic and synthetic studies on the importance of landslide hazard in the framework of disaster risk reduction, but moreover providing a local to regional and national methodology for evaluating the past, present and future behavior of such processes, the geomorphologists fostered numerous stakeholders to develop a constructive dialogue aiming at developing the optimal proactive measures for risk prevention and preparedness and the most suitable reactive actions for response and recovery. It is the purpose of this presentation to provide an overview on how, where and when geomorphic experience and expertise may influence the development of such a specific risk culture.

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Quantification of Mass Movements with Structure-from-Motion Techniques: The Case of Myrtos beach in Cephalonia, after Ianos Medicane (September 2020)

Emm. Vassilakis [1], A. Konsolaki [1], S.Petrakis [1], E.Kotsi [1], C. Fillis [1], S.Lozios [1], E.Lekkas [1]

*(1) National and Kapodistrian University of Athens, Panepistimiopolis Zographou, Greece,
evasilak@geol.uoa.gr*

Introduction

The area of Myrtos beach is an 800 m long popular Natura protected coastal area at the Northern part of Cephalonia Island. The beach has relatively small width (average width 50 m) and it is located under a rather steep slope, consisting of loose highly tectonised material, consisted of cobbles and boulders. The area has suffered extended landslides, rockfalls and mudflows in the past and specific marking has been placed along the beach for the protection of the visitors. It also suffered severe damages during the Medicane "Ianos" which affected the Greek territory on September 2020. The area mostly affected by Ianos was the Ionian complex and more specifically the island of Cephalonia. According to the nearest meteo-station, located on Ithaki island, the total rainfall during the two-day event of 17-18/09/2020 reached 227.4 mm, whilst the average wind speed for the same period was 21 km/h, with wind gusts of the order of 90 km/h (~10 Beauforts).

Methods

The use of Unmanned Aerial Systems (UASs) is a practical way of mappingrelatively small areas and it has been proved to be optimal for landslides that often cover areas that range from less than one square kilometer up to few square kilometers (Figure 1). High-resolution images acquired by UASs may support the definition of not only the identification of the actual margins of the studied landslide phenomenon but also the identification and mapping of the main geomorphological features (Fiorucci *et al.*, 2018; Karantanellis *et al.*, 2019), either based on the classic methodologies or by using more sophisticated and automated state-of-the-art techniques (Karantanellis *et al.*, 2020).

A sequence of a relatively low-cost UAS time series dataset can provide useful support for the delineation of the earth's surface structures and specifically for the study of gravitational processes evolution (Niethammer *et al.,* 2012; Liu *et al.*, 2015). Furthermore, it is generally accepted that landslide monitoring within the framework of multi-temporal UAS data acquisition is a method that could produce accurate results after careful data collection and photogrammetric processing (Turner *et al.*, 2015).

An important barrier that needs to be overcome for creating a successive multi-temporal image processing is to co-register the Structure-from-Motion (SfM) products very accurately, by using several tactics such as establishing symmetrically distributed Ground Control Points (GCPs), preferably at various elevations around the mass movement area (Vassilakis *et al.*, 2020) or using aerial Network Real Time Kinematics (NRTK) rover antenna, or even rely on Post Processing

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Kinematics procedures. These techniques, each one with its pros and cons, lead to the determination of surface deformation features as well as the calculation of changes within the prone area covered by a debris flow accompanied by several volumetric differences from the multi-temporal Digital Surface Models (DSMs) (Rossi *et al.*, 2018). In cases of active movements, the latter allows the surface geomorphological elements related to a landslide to be tracked and calculate the velocity of the displacement, not only on the horizontal but also on the vertical plane (Niethammer *et al.*, 2011).

By overlapping a DSM of the study area acquired after a specific event that has significantly altered the surface morphology (e.g. flood, earthquake, mass movement) on top of a previously acquired DSM, a new "DSM of Difference" is created, depicting the spatial alterations due to the effects of the event on the study area's morphology (Williams, 2012). Volumes of moved material can be calculated, providing useful information for the researchers on the damage control and the protection measures that should be obtained for further fortification of the affected area, in order to prevent similar disaster in the future.

UAS Data Collection and Processing

The described work was performed by using exclusively the novel DJI Phantom 4 RTK, which, with the onboard multi-frequency multi-constellation GNSS receiver, allowed the adoption of both NRTK and PPK approaches for the data acquisition and processing. The area covered was about 1.2 km^2.

The aim of multi-temporal UAS data collection and analysis is to create a series of DSMs along with ortho-photo-mosaics, based on the SfM photogrammetric techniques (Westoby *et al.,* 2012; Granshaw, 2018), in order to quantify the surface topographic changes. Many aerial images (nearly 600 scenes) have been acquired during several flights within the framework of two campaigns, which were held before (July 18th, 2020) and shortly after (October 6th, 2020) the disastrous Ianos Medicane. The earlier survey was planned during a research project, whereas the second survey was intentionally scheduled for acquiring comparable data, aiming to produce micro-topography, through the above-mentioned photogrammetric approach at both time periods, along with high-resolution orthorectified imagery.

The initial processing involves the alignment of the aerial images and creation of a sparse 3D point cloud, followed by a regular mesh generation. We chose the NRTK approach for the first survey as this is a quite accurate and less time-consuming data acquisition technique (Panagiotopoulou *et al., 2020)*. During this technique we managed to succeed the high precision Direct Georeferencing (DG), of the imagery captured by the UASs, which does not necessarily require GCPs, even though we established 7 points for using them as check points after the photogrammetric procedure. The on-board Global Navigation Satellite System (GNSS) receiver, antenna and an inertial measurement unit (IMU) calculate the absolute camera positions and altitudes directly with high accuracy measurements (Klingbeil *et al.,* 2017; Grayson *et al., 2018).* The NRTK data acquisition approach was also chosen for the post Medicane survey, even though connectivity problems led to adopt the PPK approach during the processing, which was rather complicated in terms of collecting and including GNSS permanent stations' data within the procedure. The succeeded

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accuracy on both datasets was more than satisfactory, reaching horizontal and vertical errors less than 0.08 meters, making the comparison very reliable.

Figure 1. The main geomorphic changes at the famous Myrtos beach, can be clearly seen by comparing the orthoimages before (left) and after (right) the Medicanelanos disaster.

For both surveys, high quality dense point clouds, consisting of about 80,000,000 points each, were generated through the processing of UAS imagery data. The information for each point of the cloud includes values of reflectance at the visible (RGB) spectra along with X, Y, Z coordinates, calculated after taking into account the high accuracy positions of the camera when shooting at each point from different angles (Westoby *et al.*, 2012). The procedure continued with meshing the original images and generating a dense point cloud, therefore creating much finer topographic details. Texturing was also applied to the resulted mesh in a later step, before generating the final ortho-image as well as the DSM (Mancini *et al.*, 2013).

Change Detection and Quantification

The comparison of the photogrammetry products showed that between July and October, significant surface alteration has been taken place. According to the data from the aforementioned meteo-station, no significant other weather phenomena took place during this 3-month period, so we can certainly assume that the entire deformation observed is due to the studied Medicane. Most of the prone area, which hosts the road that leads to the waterfront and the beach area itself were covered by debris from upstream, revealing large mudflows and debris

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cones caused by the intense rainfall during the Ianos weather event. The mass movement is obvious at the ortho-photographs and in terms of quantification it can be delineated quite effortless leading to a precise calculation of the area that has been covered with debris. The approximation is of the order of few centimeters and it is rather accurate that a total area of 59,418.60 square meters has been altered after the storm and 40,678.20 square meters have been covered with mud, at the central section of the area (Figure 1). Additionally, an area of 6,618.25 square meters located at the parking lot was covered with debris material, which is the estuary of a relatively small river with SE-NW direction.

The comparison between the DSMs showed significant elevation changes and a total volume of difference was calculated at 45,575.05 (± 8,247.79) cubic meters, mainly at the central part of the area of interest, where the elevation values at the point clouds were found rather altered either positively (deposition) or negatively (erosion) (Figure 2). It was calculated that a volume of 15,318.73 (± 3,158.05) cubic meters were deposited at new locations within Myrtos beach and 30,256.33 (±5,089.74) cubic meters were removed from their original location before the Ianos storm.
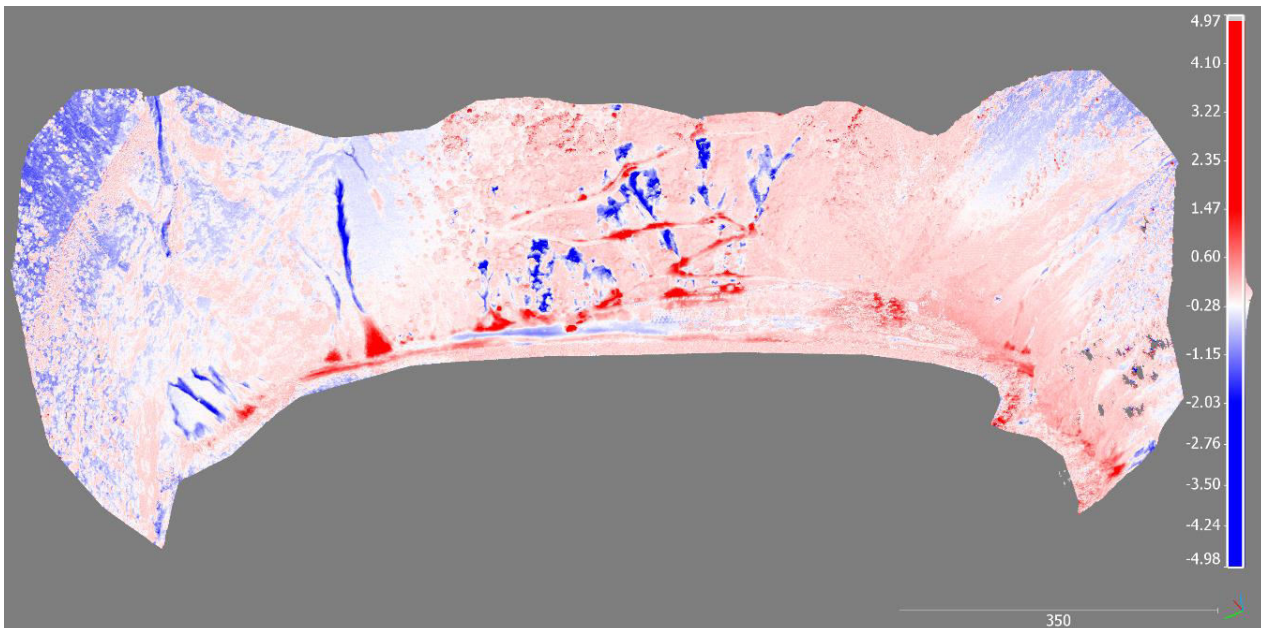
Figure 2. A perspective pseudo-3D aspect view of the affected prone over the Myrtos beach. The color scale shows the vertical changes as calculated with DoD techniques. Blue areas show elevation loss (erosion) and Red areas show elevation gain (deposition), which in many locations reached the order of 5 meters.

Conclusions

We have scheduled an acquisition and processing sequence for generating DSMs with decimeter resolution. The described UAS-based methodology introduces a quite simple but very convenient way of combining datasets containing elevation information throughout a given time period, in order to quantify the volume of mass movement through mudflows and consequently, the surface alteration. Even though the UAS data collection proved to be quite challenging, in terms of both

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weather conditions and coverage of a quite large area, high quality results were obtained. Additional difficulty comes from handling of large datasets and the requirements in terms of computational resources to reduce processing time.

Finally, the accuracy in photogrammetric products extraction including the co-registration between multi-temporal datasets proved to be very crucial in terms of accurate results in calculating volume changes after the mudflows occurred during the three months interval between the two campaigns.

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Soil Geomorphology Links between Geomorphology and Sustainability: Study on Garpanchakot Hill Area, India

A. Sarkar [1]

(1) Department of Geography, Purash Kanpur Haridas Nandi College, arindam.srkr1@gmail.com

Introduction

Pathway between geomorphology and sustainable development is soil geomorphological understanding. Soil geomorphology) stands as the study of the genetic relationship of soil and landforms (Gerrard 1992). Potentiality of land can be evaluated through soil geomorphological study. Scientific evolution of land is very important issue. Unprecedented growth of population has created tremendous pressure on land alarming; the existing available lands are being intensively utilized (Chatterjee and De, 2009). Soil geomorphology is a pioneer methodological approach to soil inventory and it can give us geomorphic analysis of soil distribution pattern (Zinck, 2016). Change of elevation and slope factors has great significance in soil character and topo-sequence. Unit wise soil geomorphological characterization of an area has great importance in land use (LU) and land cover (LC) pattern. Here catena is very important because catena is sequence of soil from top of hill to foot hill. Soil down a hill slope is rarely uniform. The factors of forming the soil will differ from top to bottom and different soils will develop (Malloy, 1998). Soil geomorphological model was first introduced by Darymple *et al*. in the year of 1968.
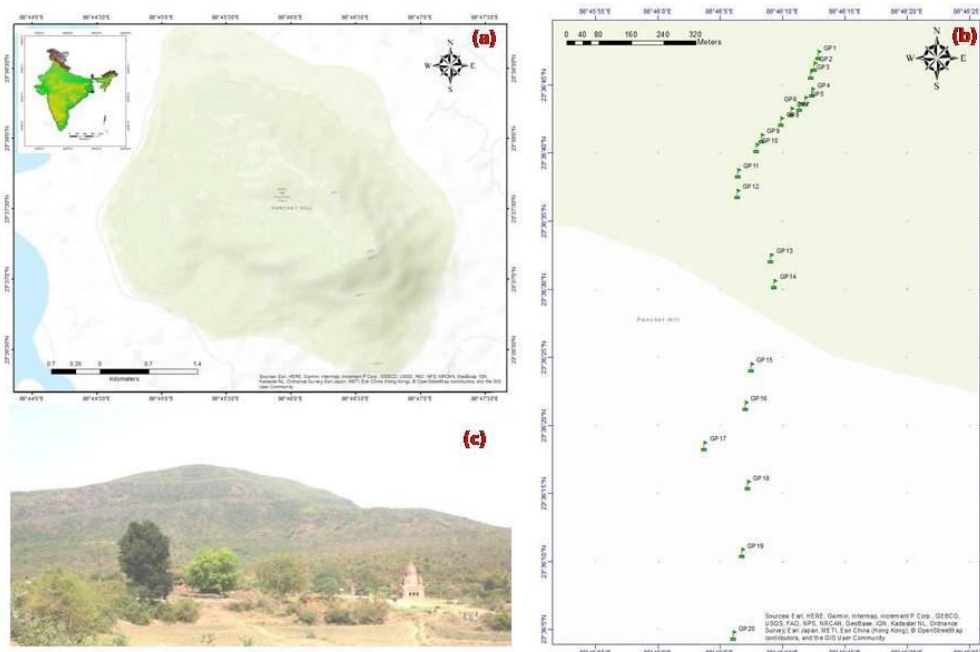
Figure 1. Location of Garpanchakot hill, (a) Sample locations in the Garpanchakot hill, (b) Photograph of Garpanchakot hill, (c) Southeastern face.

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Study is concentrated to identify soil geomorphological unit, unit wise land use land cover evaluation and find out the potentiality of land towards sustainable development. Area of present study Garpanchakot hill, located at North-Western boundary of Purulia district (Figure 1).

Data and Methodology

Pre-filed associated with preparation of research. 20 soil samples have been collected during field survey. In post-field phase laboratory analysis, data evaluation and preparation of report are done. Objective of laboratory analysis of sample was to find out pedagogical character. Geomorphological parameter (elevation, slope) has been analyzed by the application of geo-informatics techniques with the help of SRTM DEM. Samples have been collected by random sampling method according to change of elevation measured by altimeter and GPS receiver. Two geomorphological parameters (elevation and slope) and five soil parameters (Soil texture, hygroscopic moisture, organic matter, pH, and salinity) are selected for the present study. Land use and land cover map is prepared from Land sat 8 OLI_TIRS (date of acquisition: 04/04/2014, 29/04/2014, Path/Row: 140/44, 139/44) with the help of geo-informatics software. Present study is conducted on unit wise describe geomorphology, soil, LULC and assess their sustainability towards the local resource management.

Result and Discussion

Regional Geology and Soil Geomorphology

Garpanchakot hill is situated at eastern extending part of the Chhotanagpur plateau about four to five thousand million old considered as. This formation is Panchet group of hills (Garpanchakot, Gardhrubeswar, Jaychandi, Chandi etc.) are associated with denudation protecting hard sandstone and conglomerate (Gondwana sedimentary rock). It is influenced by Damodar river system (Sarkar, 2019). This area has significant evidences of active to mature peneplanation process. Here weathering works go on parallel to the surface (GSI, 2013; Dasgupta, 2015; Dolui *et al.*, 2016). Weathered blocks of granite and gneiss remains as balanced rock at the top of hill. Dense vegetation at high elevated area leads of high rate of overland flow. Garpanchakot hill is formed by continental upliftment due to the effect of endogenetic forces. Surface expression of this hill area is produced by climo-genetic deep weathering process. This area is influenced by deep chemical weathering and mechanical removal of the weathered materials. Overland flow, rain splash erosion, rolling is the main erosional processes of this area which operating throughout the year.

Maximum elevation (643.5 m) of Garpanchakot hill is located at South-Western top of the hill. From peak area elevation decreases gently towards the West and South –West, but opposite of the peak and in the right side of the peak (North-East to North-West) steep escarpment with variant slope is located. This is formed due to suddenly decrease of elevation. Foothill area is almost flat. Maximum rugged topography is formed in the Northern side of the hill area. Slope of foothill pediment area varies between 16° to 41° in the escarpment side of the hill. Sandy loam is dominating soil texture of this area. Foothill area is associated with clay dominated soil texture. Clay is produced from weathering process, disintegration of rock and alteration minerals in the higher elevated area and goes downward by overland flow and finally gets accumulated in the less

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sloped foothill pediment area. Soil of this area is dry in character. Soil organic matter (SOM) ranges between 1 to 5 percent. Maximum percent of SOM is found in the scattered dry grass land and forest because grass land and forest litter produces much biomass to the surface soil. Soil pH is neutral in character but some time it ranges between slightly acidic to slightly alkaline. Concentration of nitrate nitrogen is high, ammonical nitrogen is medium, phosphorus (P) and potassium (K) is low.

Soil Geomorphological Units

Scientific explanation of soil geomorphology follows unit wise description of soil and geomorphological parameters and their sustaining land use. Identification of soil geomorphic unit is a cumulative interactive result of land, soil formation, geomorphic configuration and operation of geomorphic processes over an area with long term sequence. Elevation and slope are genetic factor of soil formation that is why soil character is dependent on elevation and slope. Water action on surface soil with variation in slope plays dominating role in characterization of soil geomorphic units. Soil character depends on the architecture of landform. Land use depends on slope and soil character. Soil geomorphic unit is associated with complex and coherent relationship between soil character and landscape system. In the present study three soil geomorphic units has been identified based on unique segment of slope (Soil geomorphic Unit-I-Free face slope, Soil geomorphic Unit-II-Rectilinear slope, Soil geomorphic Unit-III-Concave slope) (Table 1).

Table 1. Nature and character of soil geomorphic unit.

Character	Soil geomorphic Unit-I	Soil geomorphic Unit-II	Soil geomorphic Unit-III
Topography	Escarpment	Medium	Gentle
Slope segment	Free face	Rectilinear	Concave
Texture	Sandy loam, Sandy clay loam	Sandy loam	Loamy Fine Sand Sandy clay loam
Hygroscopic moisture (%)	Maximum	Low	Medium
Organic matter (%)	High	Medium	High
pH	Neutral	Slightly alkaline	Neutral
Salinity	Low	Medium	Medium-High
Nitrate Nitrogen	High	High	High
Ammonical Nitrogen	Medium-Low	Medium-Low	Medium-Low
Phosphorous	Low	Low	Medium
Potassium	Low	Low	Low
LULC	Moderate forest, Scattered vegetation	Dense forest	Agricultural land,Fallow land, Water bodies

Nature and characteristics of soil geomorphic units is controlled by slope geometry, weathering process, denudation chronology, weathering residuals, micro relief, water action, soil character and vegetation. Land use and land cover pattern of this area is associated with character of soil geomorphic units.

Soil Geomorphic Unit-I: Moderate forest is located between 200-250 m elevations. When slope ranges between 10° and 15°. Moderate forest grows on sandy loam and sandy clay loam soil texture. SOM ranges between 0.69 and2.99 percent. Soil pH varies in slightly acidic to neutral in moderate forest area. Soil pH is neutral in character but soil salinity ranges between 53.5 and 138.6 μm/cm. scattered vegetation is located in elevation between 200-250m and below 200m, when slope remains less than 15°.Scattered vegetation develops on sandy loam soil texture. Here SOM ranges between 1.39% and 1.8%. Percentage of HM in the soil is found maximum (0.84-3.42%) in scattered vegetation area. Soil pH is neutral in character. Escarpment area is associated with intensive surface erosion accelerated by gravity enhanced well drainage activity. Actually weathering sequence and denudation chronology plays primary function for development of soil catena. Soil can provide such information concerning evolution of landscape, soil development takes time therefore a soil represents a standstill in geomorphological history (Gerrard, 1995). Geological formation and rock composition of the Garpanchakot hill produces siliceous type of parent material. Temperature-moisture (TM) ratio is also very important for land use planning.TM ratio depends on slope and soil texture. Depth of soil in an escarpment area is less and immature in nature. Soil catena of Garpanchakot hill area is developed from uniform parent material

Soil Geomorphic Unit-II: Dense forest is located at elevation between 150-200m. Sandy loam is the soil texture of dense forest area. In this region SOM ranges between 1.39 and 1.81% and HM ranges between .84 and 3.42 percent. Soil HM of dense forest area ranges between 0.84 and 1.31percent. Soil salinity varies between 27.6-87.6 μm/cm. Soil catena takes place in the hill slope with sequential changes in elevation. Topography has great influence on chronological development of surface soil. Surface run off can be controlled by differential slope segments. That can affect percent of moisture content in surface and sub-surface soil. Soil of top of the hill differs from escarpment area as well as foothill pediment area.

Soil Geomorphic Unit-III: Agricultural land, fallow land, water bodies are located in the foothill pediment area. Elevation of foothill pediment area is less than 200m. Gorund slope remains less than 5° in foothill pediment area. Sandy loam and loamy fine sand are two major soil texture of this region, when SOM ranges between 0.52 and 2.12%. HM of this area range between 0.62 and 2.11 %. Soil pH remains in range between ultra-acidic to neutral, when soil salinity remains maximum (51.2-174.1 μm/cm.). Foothill is considered as zone of accumulation of weathering material. Depth of soil depends on amount and length of slope, that is why depth of the soil in escarpment area is very thin and foothill pediment area is associated with thick soil profile. Balance situation between erosion and weathering is present in foothill pediment area. Foothill area of Garpanchakot is associated with thick alluvial deposition with rich of mineral. History of topographic development of the area has great influence on soil catena and its character. Foothill pediment area is associated with thick soil layer with rich of minerals. Foothill area is covered by fertile alluvial deposition.

Conclusion: Goal of Sustainability in Soil Geomorphology Perspectives and Action to Resilience

Sustainable use of land resource is prime concern because use of land is limited in the foothill area. Scientific utilization of resource is essential for sustainable development of this area. Introduction of appropriate land use planning, monitoring as well as weather forecasting is very

important for development of this area. Conservation of resource depending on slope and soil character of foothill pediment area. It can be suggested that terrace cultivation method is most suitable. Step cultivation method is also applicable in this area. It can check soil erosion and increase agricultural productivity in this area. Temperature-Moisture ratio depends on intensity and duration of rainfall. Rainfall is also the main source of water for agriculture and natural vegetation. So rain fall prediction is very important for this area. Conservation and monitoring of water resource through rainwater harvesting needs proper implementation with scientific manner with active participation of local people. Water treatment to protect water and enhance soil quality, increase of soil moisture and valuable nutrients for plant growth into the soil of foothill pediment area. Leguminous crops can be introduced for long-term solution. Stabilization of slope by plantation is required. It can resist soil erosion, degradation of land and vegetation growth. Depth and quality of soil can be ensured in this way. Some actions are required to resilience; enhance land carbon sink by stopping deforestation and promote plantation in the forest area and rotation of crop in the foothill area. Less tillage of agricultural land in the foothill area can store more carbon into the surface soil. Another way to treatment soil for better sustainable use is converting biomass to charcoal. It is better to left agricultural waste to the field for natural decomposition process.

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Long-term Detection of Soil Erosion Induced Spatio-temporal Changes Using the Photogrammetric Processing of Historical Aerial Photographs

F. Domazetović [1], A. Šiljeg [1], I. Marić [1]

(1) University of Zadar, Department of Geography, Trg kneza Višeslava 9, 23000 Zadar, Croatia, fdomazeto@unizd.hr, asiljeg@unizd.hr, imaric1@unizd.hr

Introduction

Due to specific climatic conditions and distinctive soil properties many parts of Mediterranean are subject to intensive soil erosion (García-Ruiz *et al.,* 2013; Castillo and Gómez, 2016; Stark *et al.,* 2020), which causes gradual degradation of soil sediments and long-term geomorphological landscape evolution (Conforti and Buttafuoco, 2017). Soil erosion is a dynamic process whose intensity depends on a number of different predisposing factors (Dube *et al.,* 2020) and varies significantly both seasonally and annually (Vanmaercke *et al.,* 2016). Long-term observations are reducing the influence of such variations, thus allowing the more reliable and accurate insight into soil erosion dynamics (Aucelli *et al.,* 2016).

Main aim of this paper was long-term determination of soil erosion induced spatio-temporal changes (STC), focused on monitoring of intensity and spatial coverage of soil erosion process within a multi-year period. Consequently, second aim of this study was assessment of applicability of existing historical aerial photographs (HAP) for detection of soil erosion induced STC. Detection and quantification of STC was based on photogrammetric processing of available HAP and creation of very-high resolution (VHR) digital surface models (DSMs) of chosen study area.
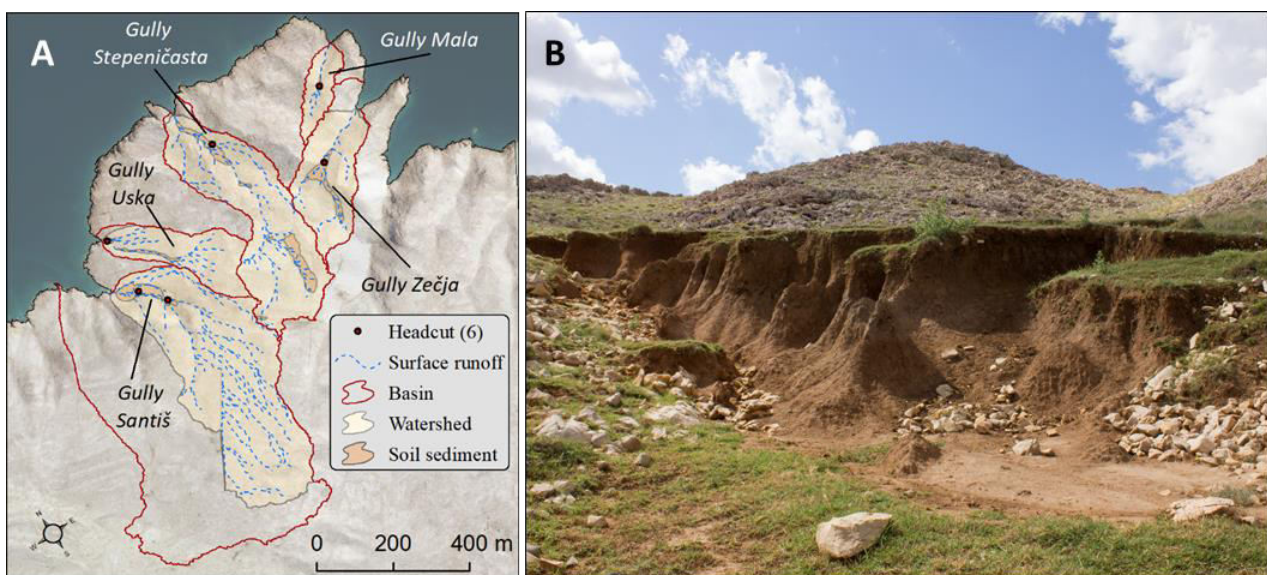
Figure 1.Gullies within study area covering Santiš peninsula (A) and recent traces of soil erosion documented within study area (B).

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Historical aerial data was available for period of almost 60 years (1959 – 2018), thus serving as perfect basis for long-term monitoring of STC. However, due to the complex and time-consuming processing this study presents only preliminary results of STC detection and quantification, where only changes in the period from 2014 to 2018 were analyzed.

Study area covers Santiš peninsula (2.14 km^2), located on the southeastern part of Pag Island (Croatia) (Figure 1.A). Santiš peninsula was chosen due to the pronounced presence of various erosion forms, especially distinctive gullies and gully headcuts. During the conducted fieldworks recent traces of soil erosion (Figure 1.B) have been documented within all five gullies, located within Santiš peninsula.

Methods

Multi-temporal DSMs of Santiš peninsula were created from available HAP collected within the systematic aerophotogrammetric surveys, conducted by the State Geodetic Administration of the Republic of Croatia periodically every few years (SGA, 2018). Photogrammetric processing of available HAP and creation of multi-temporal VHR DSMs was carried for two image datasets (2014 & 2018), using the Agisoft Metashape 1.5.1 software. Image processing was adjusted to the characteristics of acquired HAP (e.g. camera type; pixel size; focal length; etc.), as well as to the guidelines given in similar published papers (James *et al.,* 2019; Stark *et al.,* 2020). Highest possible spatial resolution of created DSMs was achieved as all processing steps were performed at maximal settings (e.g. Align – Highest accuracy; Build Dense Cloud – Ultra High Quality; etc.). In order to improve absolute positioning of created DSMs 13 ground control points (GCPs) were added, from which eight were used as control points, and five as check points. Identical GCPs were used for processing of both created DSMs (DSM_2014; DSM_2018). Additional 22 points collected during the field work with Stonex S10 RTK-GPS were used for assessment of accuracy of created multi-temporal DSMs. While accuracy of DSM_2014 was 0.36 m (Standard deviation (SD)), accuracy of DSM_2018 was slightly better (SD = 0.31 m).

Detection and quantification of STC was based on differencing of created multi-temporal DSMs and creation of digital elevation model of difference (DOD), which was performed by the Geomorphic Change Detection 7 software add-on, within the ArcGIS 10.1 software. DOD was created through differencing of DSM that represents initial surface (DSM_2014), from the DSM that represents final surface (DSM_2018). Minimal level of detection threshold was determined based on calculated accuracy (SD) of created multi-temporal DSMs. Detected STC covers both erosion and accumulation, which has occurred within the studied period.

Results

Photogrammetric processing resulted with creation of two DSMs (DSM_2014 and DSM_2018) with spatial resolution of 0.3 m, thus allowing creation of VHR DOD. According to created DOD in period between 2014 and 2018. Soil erosion has mostly occurred within three larger gullies (gully Santiš, gully Stepeničasta and gully Zečja), with strong predominance of erosion over accumulation (Figure 2.A & B). In two smaller gullies (gully Uska and gully Mala) no STC were detected within studied period, as soil erosion intensity was probably below the fixed threshold for minimal level of detection.

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In total erosion was detected at significantly larger area (164.34 m^2 – 97.28 % of all detected STC), while accumulation was present within only one isolated and smaller area (4.59 m^2 – 2.72 % of all detected STC) within gully Santiš. This is further confirmed with detected volumetric STC, where in total 201.28 m^3 of material was eroded, while only 5.01 m^3 was accumulated.

Spatial distribution of detected soil erosion is not uniform across whole study area, as most of the erosion is concentrated within four gully headcuts (Figure 2.C). Gradual uphill regressionof gully headcut is one of the most distinctive characteristics of all active gullies (Vanmaercke *et al.,* 2016; Hosseinalizadeh *et al.,* 2019), which is why detected STC are confirming that at least three gullies were active within studied period. However, spatial distribution and intensity of erosion within largest gully (gully Santiš) significantly overcomes theerosion rates that were detected within other two active gullies. Volumetric STC detected within two headcuts of gully Santiš (GH-1 (76.03% - 153.03 m^3) and GH-2 (9.86% - 19.84 m^3)) are accounting for 85.89% of total detected volumetric STC, while headcuts of other two gullies (GH-3 and GH4) together account for only 14.11% (28.4 m^3). This possibly can be accounted to several important factors, such as: size of gully Santiš and characteristics of its two gully headcuts (GH-1 and GH-2); size and shape of its watershed; higher density of hydrological network; etc.

Detected STC values are confirming that available HAP has great potential for long-term monitoring of soil erosion induced STC. Thus within future research all available HAP should be processed following the same methodology.
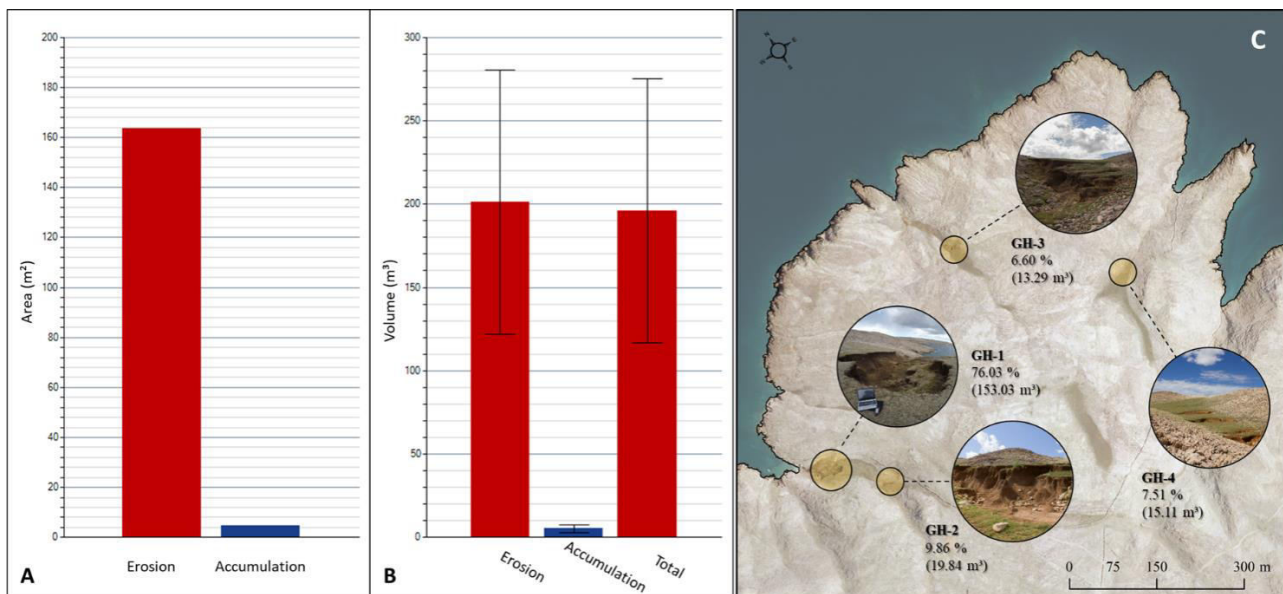
Figure 2. Surface (A) and volumetric (B) indicators of total STC within Santiš peninsula; distribution of detected soil erosion within individual gully headcuts of Santiš peninsula (C).

Conclusion

In conclusion, this study demonstrated how available HAP can be successfully applied for creation of VHR DSMs and long-term detection of soil erosion induced STC. Spatial resolution and accuracy of such multi-temporal DSMs are allowing detection of areas affected by soil erosion, as well as detailed quantification of aerial and volumetric STC. Within the analyzed period between 2014 and 2018 strong predominance of erosion over accumulation was recorded, where 201.28 m^3 of material was eroded in total, while only 5.01 m^3 was accumulated. Most of the erosion occurred within gully headcuts, thus confirming the gradual uphill regression of three active gullies. Within two gullies (Mala and Uska) no STC haven't been detected, as soil erosion intensity was probably under the set detection threshold.

Beside long-term detection of soil erosion induced STC, available HAP has great potential for various other geomorphological applications (e.g. river dynamics; volcanism; ice dynamics, etc.), where temporal evolution of relief is subject of research.

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Geomoprhometric Anomaly and Active Tectonics Vulnerability towards Existing Settlements & Infrastructures in Sub-Himalayan Tributary Basins of Tista River, India

S. Ghosh [1], R. Sivakumar [1,2]

(1) Earthquake Research Cell, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, 603203 Kanchipuram, Chennai, TN, India, snehasis@srmist.edu.in

(2) Department of Civil Engineering, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, 603203 Kanchipuram, Chennai, TN, India, sivakumr@srmist.edu.in

Introduction

Morphometric characteristics of drainage basin changes due to the influence of structural strains, lithological differences, asymmetric gradient etc. which interrupts the geomorphic evolution process is referred as geomorphometric anomaly (Keller and Pinter, 2002). The sub-Himalayan tributary basins of Tistariver (Figure 1) are associated with active thrust zone where the rivers are dynamics in nature.

Figure 1. Location map of study area.

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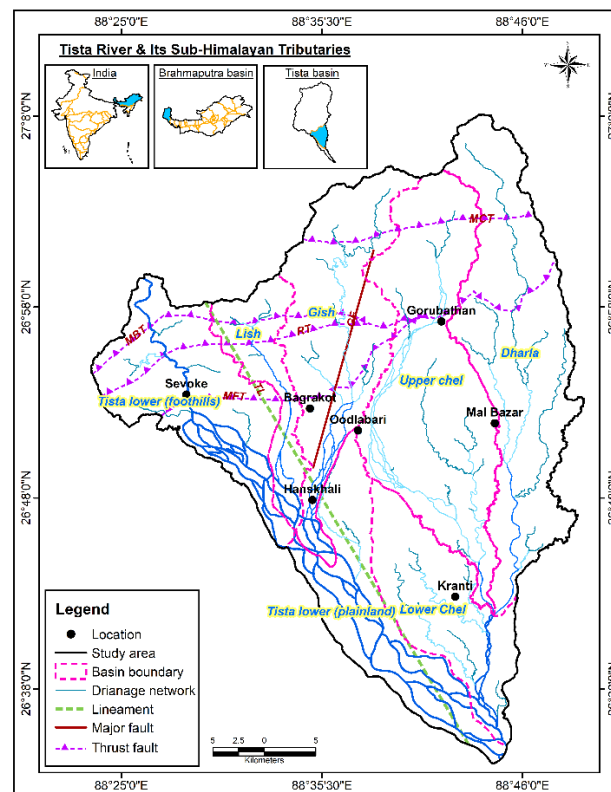
This region have not produced any significant earthquake in the past but noted as significant active tectonic zone (Ghosh and Sivakumar, 2018). The settlements are built and infrastructures are developed in this active tectonic belt which needs to be protected from future earthquakes. The main objective is to identify the geomorphometric anomaly and active tectonics vulnerability towards existing settlements and associated infrastructures.

Methods

In the present study, the long and cross profiles of selected basins have been analyzed to identify the disequilibrium and non-uniformity of the topography. Stream length gradient index (SLGI) curve is prepared and integrated with geological formation for the identification of lithological resistance anomaly. Further, Active tectonics evidences are recognized from satellite images and field observation data. Finally, settlements and infrastructures are observed from satellite image and field datawhich is associated with geomorphometric anomaly and active tectonics.

Results

The long profile of all the tributaries (Figure 2) shows breaks their slope along frontal surface and it produces gentle concave gradient in lower reach of the stream at foothill region indicating base level changes near mountain front (Altin, 2012). The frontal surface is associated with rejuvenated topography where gradient is changed at knick point and deviation is observed along the longitudinal profile of the river at all foothills basins. The presence of knick point in lower altitude is the result of increasing in stream power due to the effect of structural geological features (Figueroa and Knott, 2010). The changes in position of knick point indicates important geomorphometric anomaly. The cross profile of Dharala, Lish and Gish River depicts alluvial terraces indicating the presence of fractures and lineaments. The different level of terraces in quaternary surface implies terrain uplift and rock deformation which suggests a significant geomorphometric anomaly (Pathak *et al.,* 2015).
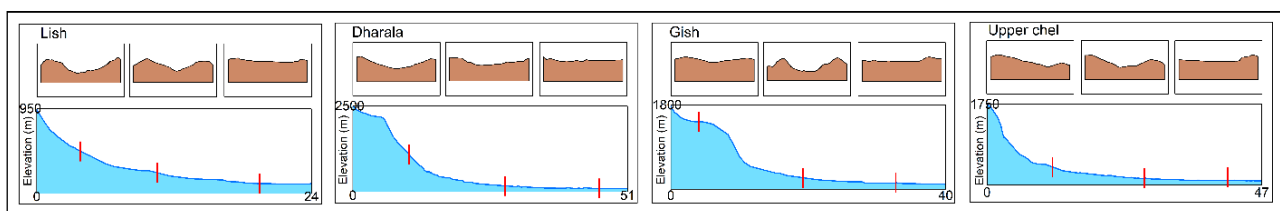
Figure 2. Long and cross profile analyses for the identification of geomorphometric anomaly.

The significant peak in SLGI curve is observed in between Gorubathan and Matiali formation in Upper chel basin. Also, the peak of SLGI curve is observed in between Phuentsholing and Matiali formation in Dharala micro basin. In Gish river basin, higher SLGI peak is observed in between Siwalik and Gorubathan formation while in Lishriver, it is observed in between Siwalik and Chalsha (Figure 3). The significant peak in SLGI curve in alluvial soft sedimentary formation suggests resistance anomaly due to lithological differences along the structural geological features (Keller and Pinter, 2002).

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The different active tectonics evidences have been identified from satellite image such as compressed meander in sub-Himalayan terrain, tilted surface in foothills zone, alluvial fan in Quaternary piedmont zone and narrow linear valley in sub-Himalayan terrain followed by wider channel in alluvial surface (Figure 4).
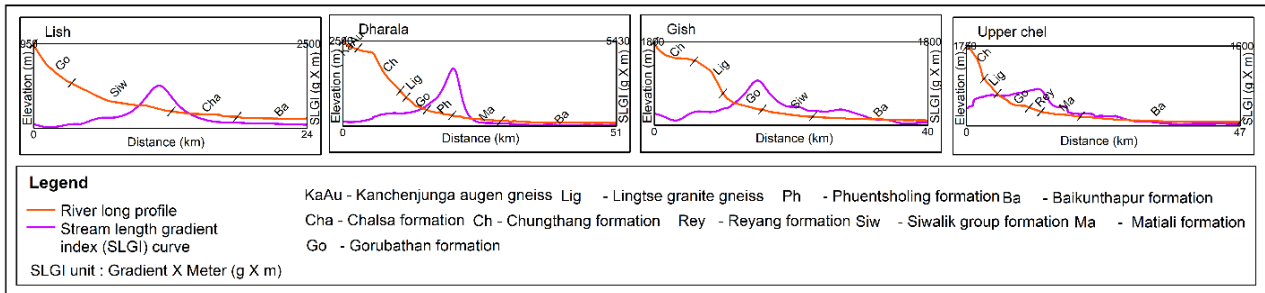
Figure 3. Analysis of SLGI curve along the long profile for the identification of geomorphometric anomaly.
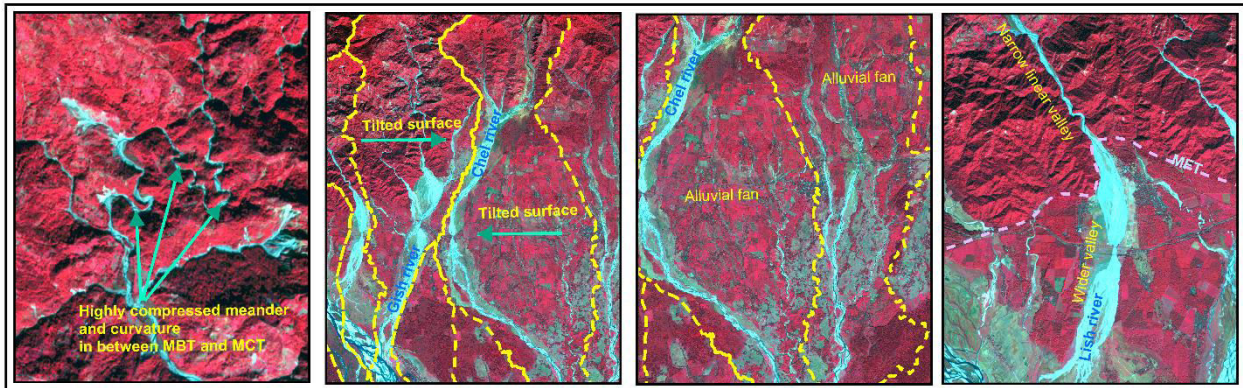
Figure 4. Active tectonics evidences identified from Sentinel-2 satellite image.

The dense settlements in the study area are Oodlabari, Sevoke, Bagrakote, Malbazar etc. which are located in the sub-Himalayan foothills region. These settlements are well connected with transportation as well as railway network which are constructed along the main frontal thrust zone. The associated infrastructures of these settlements are public and private buildings, administrative office, hotels and lodges etc. which are most vulnerable during an earthquake because it is not strong enough to resist high magnitude seismic activity.

It is recognized that the Sevoke and Oodlabari settlements are located at active fault zone and associated with uplifted topography, alluvial terraces, tectonic tilt surface which are important geomorphometric anomaly in the study area (Figure 5).
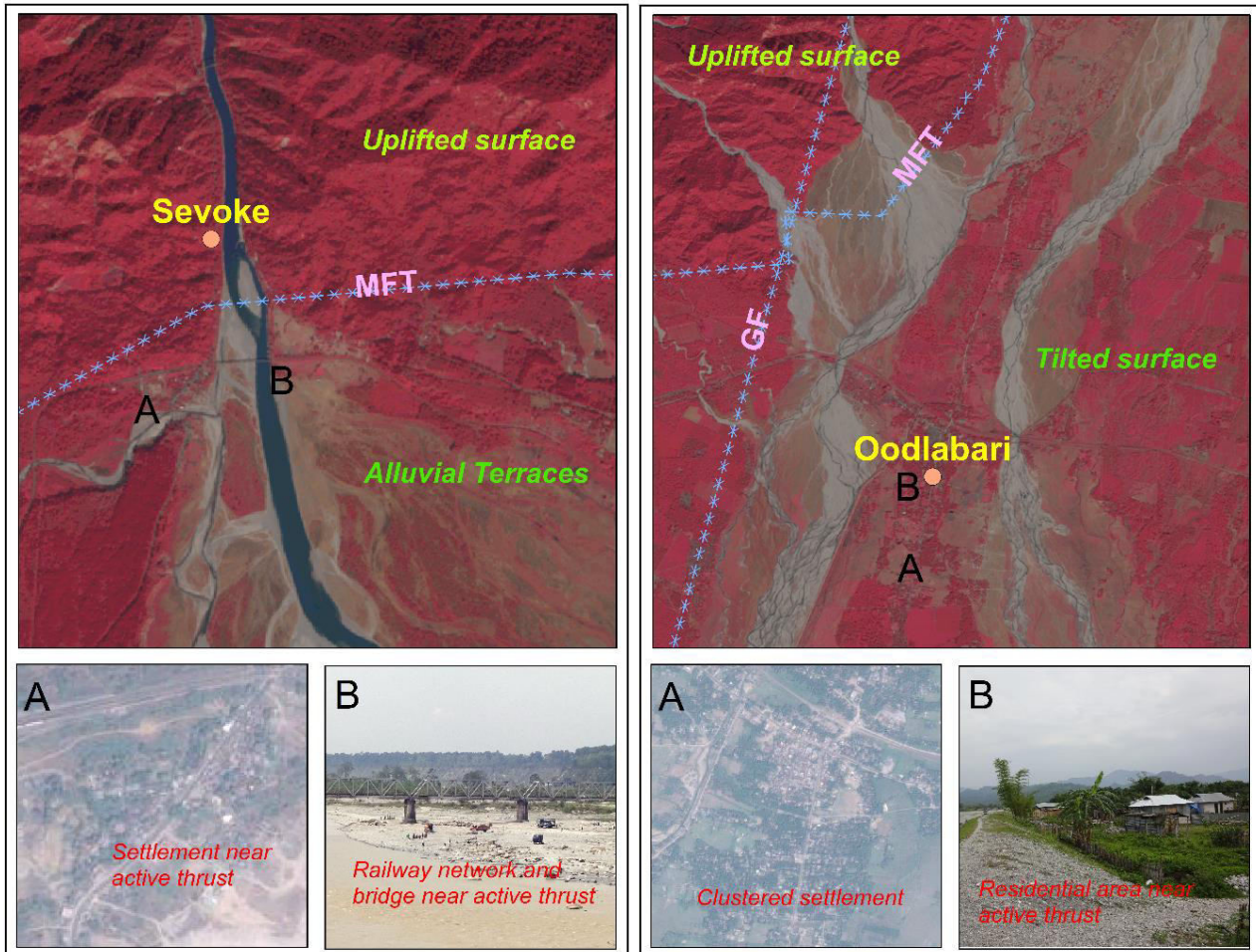
Figure 5. Geomorphometric anomaly and active tectonics evidences associated with existing settlements and infrastructures.

Conclusions

The present study analyzed various geomorphic profiles which depicts significant geomorphometric anomaly and also identified active tectonics evidences in sub-Himalayan tributary basin atLish, Gish, Dharala and upper chel region. The study infers that the settlements and its associated infrastructures are located in sub-Himalayans foothills zonewhich are most vulnerable for future earthquake as it is associated with active thrust, faults, tectonic features and geomorphometric amolmaly. It is required to protect such settlements and infrastructures by implementing seismic resistance structure for the future construction and re-modification of existing structures by retrofitting techniques.

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Active Tectonics Evaluationby Analyzing Morphometric Correlation and Drainage Pattern in South Andaman Region, India

R. Sivakumar [1,2], *S. Ghosh* [1]

(1) Earthquake Research Cell, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, 603203 Kanchipuram, Chennai, TN, India, snehasis@srmist.edu.in

(2) Department of Civil Engineering, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, 603203 Kanchipuram, Chennai, TN, India, sivakumr@srmist.edu.in

Introduction

The movement of the rock masses along the active fault indicates Neotectonics (Kuk, 2000) which is recognized by the morphometric correlation and drainage pattern analysis. The analysis helps to identify the lithological characteristics of the sub-surface, structural behavior and landform evolution stages which represent the active tectonics process (Sarma *et al.*, 2015).
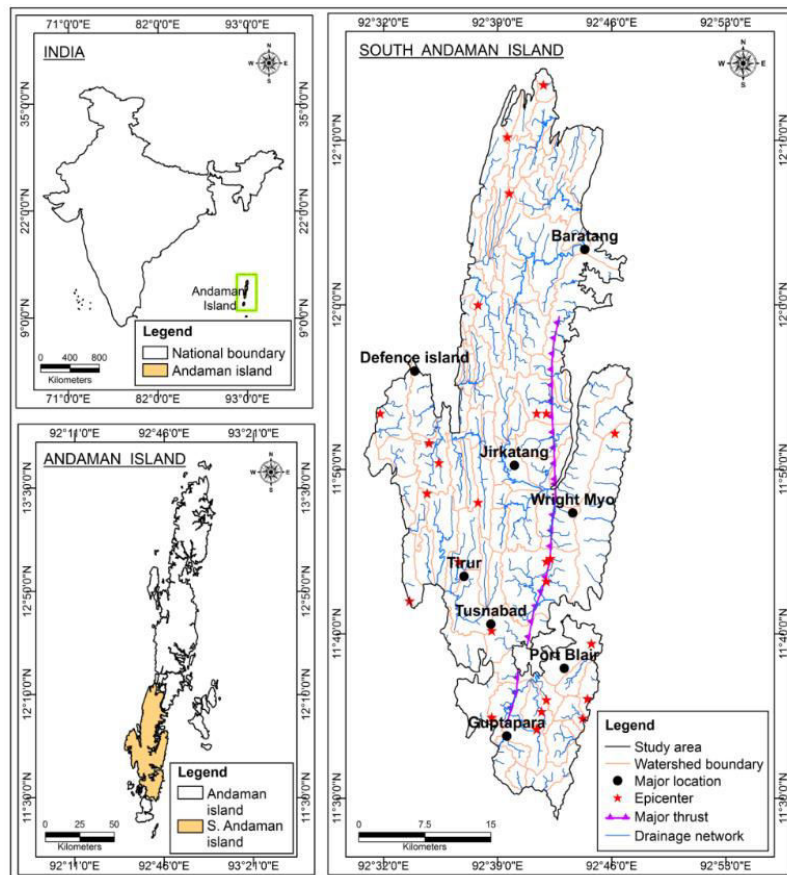
Figure 1. Location map of study area.

The Andaman region is seismically active and researchers have analyzed seismological characteristics of this region in broad way by analyzing geophysical and seismotectonic analysis. In the present study it has been attempted to study the active tectonics by morphometric parameters at watershed level.

Methods

Initially, Topographical map, remote sensing data, earthquake epicenter data andseismotectonic atlas have been acquired from different sources. Watersheds and streamlines have been extracted using ASTER GDEM and rectified using satellite image and topographical map to delineate the study area. Various morphometric parameters are analyzed and thematic databases have been generated. The correlation has been made among the morphometric parameters to understand the level of significance with reference to tectonic activity. The drainage pattern is also analyzed to identify the structural disturbance in the study area due to seismotectonic activity. The integration of this analysis depicts the active tectonic characteristics in the study area.

Results

The morphometric parameters such as Ruggedness index, Landscape roughness index, Hypsometric integral and Local relief have been computed and thematic parameters have been generated (Figure 2). The result shows that the central part around Jirkatang and Eastern coast of Andaman island surrounding WrightMyo shows dissected topography with high and steep slopes in youthful stage which indicates the region is mostly erosion potential and tectonically asymmetric (Altin, 2012; Keller and Pinter, 2002; Mahmood and Gloaguen, 2012). Also analysis suggests that the region is uplifted along the coastal side due to recent tectonic activity (Vijith and Satheesh, 2006).
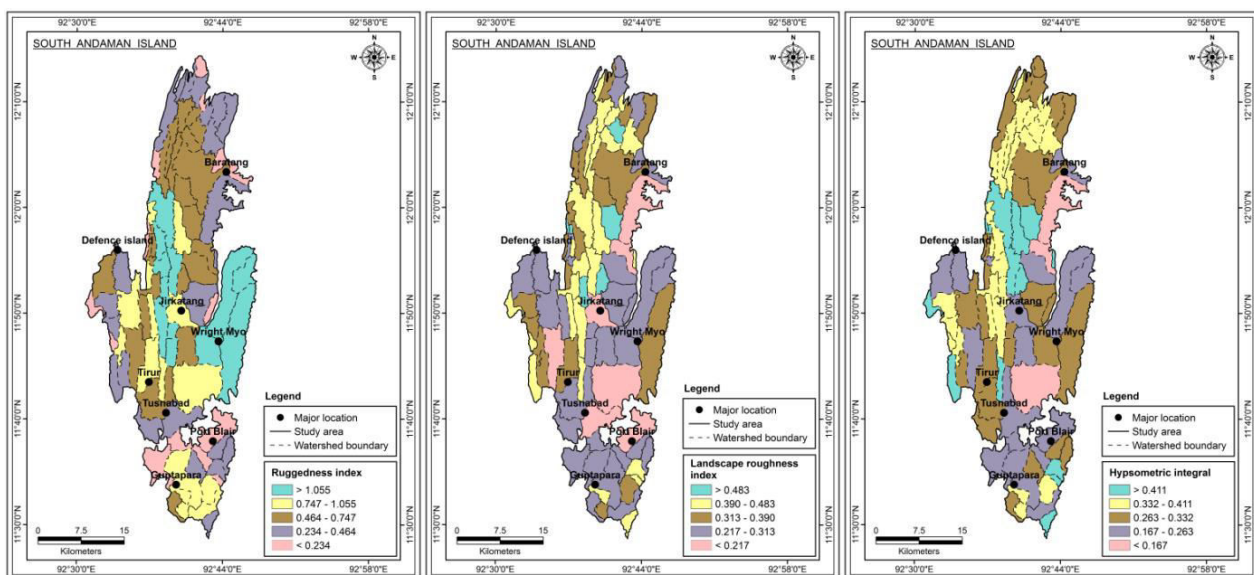
Figure 2. Thematic database of morphometric parameters.

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The correlation analysis has been carried out between the morphotectonic parameters which show good correlation between the parameters indicating significant neotectonic activity in the region (Table 1; Figure 4). The significant relations are observed between Local relief with ruggedness index 0.897 and landscape roughness index with hypsometric integral of 0.966. The study represents that the region is dissected by numerous streams/drainages and created rugged topographic surface which have been evaluated by neotectonic deformation in various geological period.

Table 1. Correlation matrix of morphometric parameters.

Parameters	Local Relief	Ruggedness Index	Landscape Roughness Index	Hypsometric Integral
Local Relief	1.000			
Ruggedness Index	0.897	1.000		
Landscape Roughness Index	-0.169	0.120	1.000	
Hypsometric Integral	-0.153	0.109	0.966	1.000
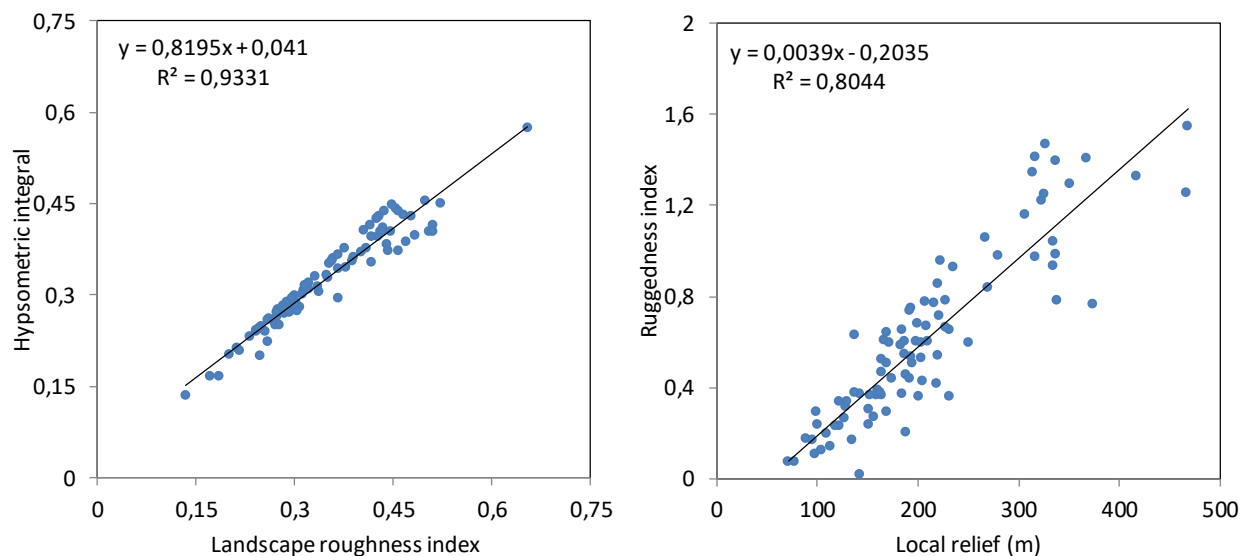
Figure 3. Correlation between morphometric parameters.

The drainage patterns have been analyzed to identify the structural evidences of neotectonic activity (Figure 4). Trellis pattern is recognized in central part along the elongated basin region in between parallel anticlinal ridge and parallel synclinal valley which is associated with 7 earthquake epicenter where the magnitude varies between 3.9 5.0. The presence of this drainage pattern indicates weak underlying structure, influence of folded sedimentary beds on drainage development and compression due to thrustal movement (Agarwal and Garg, 2000; Singh, 2005). Rectangular drainage pattern indicates the line of weakness along the faulted rock structures (Agarwal and Garg, 2000) which includes in 4.8 – 5.0 magnitude earthquakes. Parallel drainage pattern is observed in eastern part which is a newly emerged coastal plaincoinciding with 4 recent

epicenter of the range between 4.2-4.4 along the Jarawaactive thrust. The pattern indicates the presence of active tectono-structural features which control the drainage network (Agarwal and Garg, 2000). Radial drainage pattern is recognized in southern part of the study region which is associated with residual hills indicating tectonic upwarps along the active tectonic thrust (Agarwal and Garg, 2000; Singh, 2005).
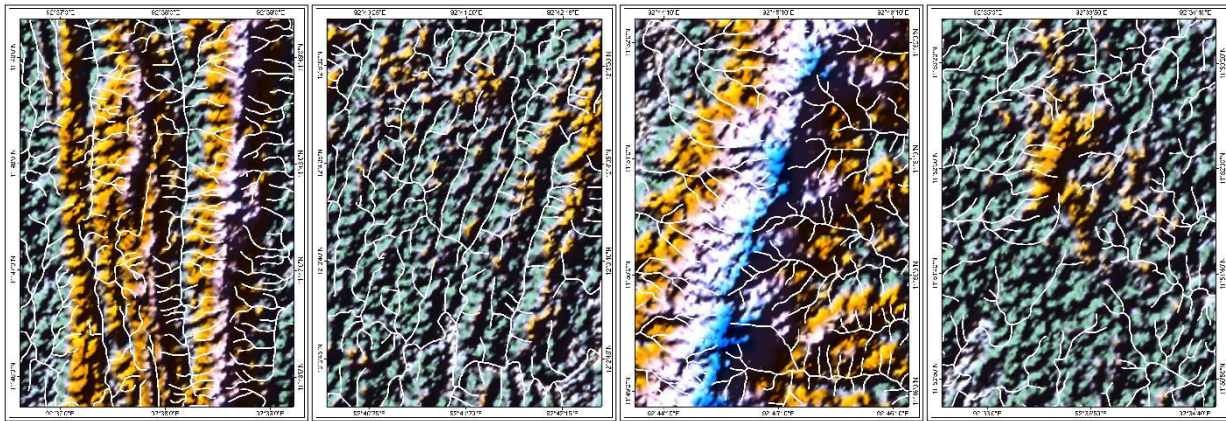
Figure 4. Drainage pattern analysis- Trellis, Rectangular, Parallel and Radial.

Conclusions

The present study analyzed the morphometric parameters to study the active tectonics influences on drainage morphological changes. Further, drainage patterns are analyzed to understand the underlying structural and lithological variation due to active tectonics. The study concludes that the central part along the anticlinal ridge shows undulated dissected topography and eastern coastal belt are uplifted due to recent tectonic activity and produces young geomorphic features. Similarly, the drainage patterns are aligned as per the topographic characteristics and controlled by the active structural features which indicate the region is tectonically active.

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UNESCO Global Geoparks: A New Geographical Concept in Research Education and Sustainable Development

N. Zouros [1]

(1) Aegean University, Department of Geography, Mytilene, Greece, nzour@aegean.gr

Introduction

The Geopark concept established in Europe during the last decade of the 20th Century, aiming to achieve the protection of the geological and geomorphological heritage sites through local community involvement to their management, in the frame of a sustainable development strategy.

Geopark activities have been part of the UNESCO work plan since 2001 and, since 2004; UNESCO has offered ad-hoc support to Global Geoparks upon requests from individual Member States. The Global Geoparks Network (GGN) established in 2004, under the umbrella of UNESCO, as an international network of cooperation among Geoparks. In 2014 after one decade of successful operation as a volunteer network the GGN gained legal personality and became the international non-profit association of the Global Geoparks and the Global Geopark professionals.

In 2015 the 38th UNESCO General Conference ratified the statutes of the new International Geoscience and Geoparks Programme and the UNESCO Global Geoparks Operational Guidelines, introducing the brand UNESCO Global Geopark as a label of excellence for areas that meet specific criteria. The Geoparks quality control mechanism is the UNESCO Global Geoparks Council through the evaluation and revalidation exercise. The GGN became officially the partner of UNESCO for the operation of the UNESCO Global Geoparks programme. Thus the GGN is the operational and coordination mechanism for the Geopark common activities, working to disseminate knowhow, exchange best practice and built capacity to protect and manage geological heritage sites and promote local sustainable development.

UNESCO Global Geoparks should manage their geological heritage, in connection with all other aspects of that area's natural and cultural heritage, to promote awareness of key issues facing society in the context of the dynamic planet we all live on. In doing so, UNESCO Global Geoparks adopt an holistic approach on territorial heritage and resources, becoming a true geographical concept.

Today there are 161 UNESCO Global Geoparks in 44 countries (July 2020). According to the Programme Operation Guidelines all UNESCO Global Geoparks should become members of the Global Geoparks Network (GGN).

The GGN's mission is to influence, encourage and assist local communities all over the world to conserve the integrity and diversity of abiotic and biotic nature, to enhance tangible and intangible cultural heritage, to explore and promote the links between natural and cultural heritage, to ensure that any use of the territorial natural resources is equitable and sustainable, to enhance

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local communities resilience in natural hazards and climate change, to promote environmental education and geo-tourism activities and to support economic and cultural development of local communities through the valorisation of their unique heritage and identity. The GGN develops, advances, and disseminates strategies and methodologies on geodiversity protection and management and other on disciplines related to geo-conservation, geo-tourism, geo-education as well as on UNESCO Global Geoparks communication and promotion.
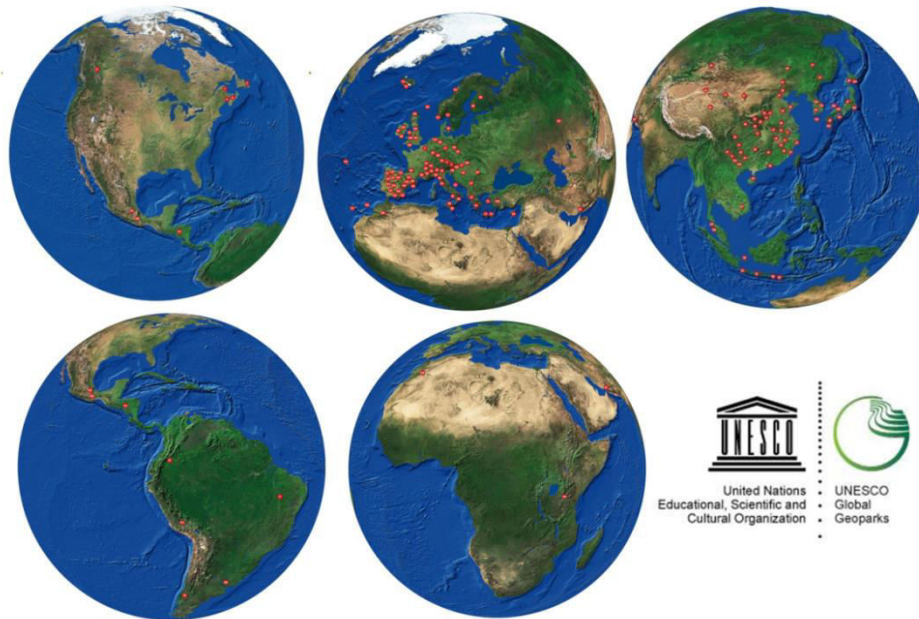
Figure 1. The distribution of the 161 UNESCO Global Geoparks around the globe.

Geopark Networking

Networking played a very strong role in the creation, development and success of the Global Geoparks since the establishment of the Global Geoparks Network in February 2004. Networking among Global Geoparks is taking place at the national, regional and global level and seems to be the main factor of their success worldwide. Networking among Global Geoparks is playing a crucial role in facilitating the sharing of good practices among Geoparks, exchange of experiences on geo-conservation, geotourism and geo-education, exchange of personnel, formation of joint initiatives and projects, creation of common promotional tools, organization of common Geopark activities such as the International Conference on UNESCO Global Geoparks, regional meetings, workshops, capacity building courses, educational and promotional activities.

Regional Geoparks Networks include all the members of the GGN in each region. They promote international co-operation in Geoparks building and management, supporting local communities and fostering local development. The GGN includes the European Geoparks Network (since 2000) the Asian-Psific Geoparks Network (since 2007), the Latin American and Caribbean Geoparks Network (since 2017) and is working for the establishment of similar networks in other regions. In 2019 the African UNESCO Global Geoparks Network was founded in Moroco.

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Figure 2. Common Geopark activities: the 8th International Conference on UNESCO Global Geopark, the 41st European Geoparks Network meeting and the Founding meeting of the African UNESCO Global Geoparks Network in 2019.

The GGN taking into account the need of coordination of Geopark activities at the national level and the increasing number of UNESCO Global Geoparks, encourages the operation of a Geopark's national committee/forum including all the members of the GGN in each country.

Figure 3. The Chinese UNESCO Global Geoparks (41 UGGp), celebrating the Geoparks day in the world EXPO Beijing September 2019. The Spanish national UNESCO Global Geoparks forum (12 UGGp) celebrating the publication of the Spanish Geoparks Geotourism offer.

Working Groups have been authorised by the Executive Board to implement programmes and activities, and to serve as a channel of communication between members of the GGN with similar scientific and professional interests. Currently there are the following GGN Working Groups: on Geo-Hazards, on Geoparks in Volcanic Areas, on Geological heritage assessment, on Tourism, on Education, on Sustainable Development Goals, on Island Geoparks.

Geopark Activities

The GGN encourages the establishment of collaboration and exchange programmes between Geoparks, the development of common research programmes between Geoparks and research institutions and universities as well as the implementation of educational programmes for schools and universities.

The GGN in partnership with UNESCO, organizes capacity building activities and provides assistance to local authorities and communities around the globe to develop and promote the Geopark concept world-wide. Geopark capacity building activities disseminate knowledge on

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UNESCO Global Geoparks building and management focusing on geographical areas with less representation in the Network. Such activities include the annual International Courses on UNESCO Global Geoparks in Lesvos and Beijing, Geopark workshops and seminars as well as advisory missions in aspiring Geoparks. Capacity building activities are implemented in collaboration with UNESCO, national authorities and universities as well as regional and national Geopark networks.

Figure 4. Educational field camp of the China University of Geosciences in Lesvos Geopark (Greece) and Multinational high school students' camp in the transnational Muskau Arch Geopark (Germany & Poland).

Figure 5. International Courses on UNESCO Global Geoparks in Lesvos and Beijing and Geoparks mentorship and knowledge exchange programme of the Great Rift valley aspiring geopark (Kenya) in Lesvos UNESCO Global Geopark.

The GGN promotes the development of geotourism in Geoparks as a form of sustainable tourism. According to the definition agreed with stakeholders at the global level "Geotourism should be defined as tourism which sustains and enhances the identity of a territory, taking into consideration its geology, environment, culture, aesthetics, heritage and the well-being of its residents" (Arouca, 2011). The GGN established a partnership with World Tourism Organization on the International Year of sustainable tourism. The GGN coordinates the Geopark participation and promotion in International Tourism Fairs such as (ITB Berlin, FITUR Madrd, ITB-Hong Kong, etc) to promote Geoparks as sustainable tourism destinations and build new bonds with the international tourism market.

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Figure 6. GGN stand in ITB Berlin in 2019 and in FITUR Madrid in 2020 for the collective promotion of Geoparks as tourism destinations and the logo of the GGN as gold partner of the World Tourism Organization.

Geopark Communication Activities

The GGN is collaborating with specialists and investing towards a global marketing and communication strategy on UNESCO Global Geoparks. The main goal of this strategy is to raise profile and awareness on UNESCO Global Geoparks. Based on the results of this strategy several promotional activities have been held.

The GGN is operating a variety of communication tools to disseminate information among its members and to promote the Geopark concept and activities to the broad public. Communication tools include the GGN websites and social media pages in Facebook and Weido, the GGN Newsletter - published 4 times a year by the Chinese Geoparks Network, the GGN NewsFeed - the internal communication tool among GGN members as well as the GGN map, the GGN Brochure, the GGN leaflets, the GGN posters etc.

The GGN organizes campaigns for the celebration of international days such as Earth's day, Mountains day, Natural Disaster reduction day, Museum's day, World Environmental day etc.

Figure7. Campaigns for the celebration of International days.

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Geoconservation in the Petrified Forest Park Fossil Sites, Lesvos Island UNESCO Global Geopark

N. Zouros [1,2], **I. Valiakos** [1,2], G. Grimpylakos [2], M. Georgitsis [2]

(1) University of the Aegean, Department of Geography, University Hill, Mytilini, Greece, nzour@aegean.gr
(2) Natural history Museum of the Lesvos Petrified Forest, 8th November 17, Mytilini, Greece, lesvospf@otenet.gr

Introduction

The locality of the Petrified Forest Park at "Bali Alonia" at the western peninsula of Lesvos island, Greece, was known as "Kyria Apolithomeni" since the 18th century due to the large number of fossilized tree trunks found in the area. The area was expropriated by the Greek State in 1966 in order to protect and enhance the fossilized trees. The Petrified Forest of Lesvos is protected by the Presidential Decree 443/1985 and the General Forest Legislation, by the 1/1996 Forest Police Order of the Directorate of Forests of Lesvos and is governed by Rules of Operation.

The effective protection of the Lesvos Petrified Forest is priority in the context of compliance with national and European legal commitments of Greece for the protection of the natural heritage (L.1650/1986, L.3937/2011, L.855/1978 - Barcelona Treaty). This work has been assigned to the Natural History Museum of the Lesvos Petrified Forest (Law 2260/1994). The Petrified Forest of Lesvos is a globally recognized natural monument and the main element of geological heritage international significance for the recognition of Lesvos Island as a UNESCO Global Geopark.

Several interventions have been done in the past in the Park for the protection of the fossilised logs. In 1987 the area was fenced and protective measures for the individual fossils have been taken. Since 1997, the Natural History Museum of the Lesvos Petrified Forest has carried out systematic excavations in the area aiming to reveal the richness of the fossil flora. The aim of the research, in addition to the undeniable scientific significance of the new findings that come to light, is to give to the visitor of the Park a sense of the density and variety of trees that made up the forest in the area during Lower Miocene. These fossilized tree trunks needed conservation treatment.

Although at first glance the fossils look hard and resilient, in reality they are very fragile and are endangered by a number of factors (called environmental parameters) that cause significant mechanical and chemical damage. The environmental parameters are responsible for many of the damages observed on fossils. Excess moisture causes the fossils to swell with the highest porosity and the lowest hardness. Excessive drought causes cracking and pulverization (turning surfaces into dust). Excessive heat and extreme cold cause the fossils to expand and contract, leading to cracks. Rainwater enters the cracks and expands after forming ice crystals due to frost in winter, causing additional mechanical damage. Over time, and under the influence of various corrosive factors, is caused the gradual disintegration and loss of fossil material. In some fossil tree trunks, due to moisture, oxides are formed, and pulverization of the surfaces is observed. The soluble salts present in the soil, through the moisture, move inside the fossils. These salts tend to move to

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drier surfaces and form hard crusts, so strong that they can cause cracks or breakage. The fossils in open air parks are - in addition - exposed to a number of biological factors. The plants often grow on the fossils themselves, causing with their roots mechanical damage such as cracks and fractures. Lichens, mosses and fungi attack the surface of fossils in the open, absorbing nutrients from the fossil, causing erosion, destroying fossil surfaces and creating cracks and breaking into small pieces. Unfortunately, the human factor is often a risk factor for fossils too. Unconscious visitors in the past caused significant damage to the fossils, through vandalism by breaking and stealing pieces.

The Park fossil sites protection infrastructures (protective fences, and shelters) after 25 years of operation were aged and obsolete. Thus it was necessary their replacement and reconstruction with a new approach permitting safe approach and better observation of the fossil trees.

The current project aims the conservation of the petrified trees, the enhancement of the fossil sites and the documentation of the fossilized logs at the Petrified Forest Part at "Kyria Apolithomeni". The Park requires combined and at the same time targeted actions for both the conservation of the individual and vulnerable fossilized trees that remain in situ and for the protection and enhancement of the fossil sites.

Methods

The Petrified Forest Park at Kyria Apolithomeni (Bali Alonia) is located on the southern slope of a hill that belongs to the Ordymnos Mountain. It covers a small drainage basin, of one of the branches of the hydrographic network of the river Tsichliontas, which forms one of the most extensive hydrographic networks of Western Lesvos.

Geologically the area of the park consists exclusively of Lower Miocene pyroclastic rocks and includes: a. volcanic ash rich in angular pumice particles of various dimensions, b. mudflows containing lava particles and c. layers of volcanic conglomerate containing large volcanic cobblestones.

The successive horizons of eruptive materials are clearly visible in the area of the park along the walking paths and at the locations of the excavation sections. An overview of the succession of the pyroclastic formations can be observed from the entrance area gazing at the hillside south of the park.

These formations were deposited in the area 20 million years ago due to successive volcanic eruptions created by the main volcanic centers of Lesvos. These, inactive today, volcanoes are located in the central part of the island. During the volcanic eruptions, huge amounts of volcanic ash were released into the atmosphere and were transported away from the volcanic craters and slowly sat on the surface of the earth creating layers of volcanic ash. For each volcanic eruption, a different layer of volcanic ash was deposited in the park area. The layers of the mudflows were created during the quiet periods that interspersed between the volcanic eruptions. The heavy rains that followed the explosive volcanic activity, swept away the volcanic ash that had settled at the highest points of the terrain, creating large mudflows that swept away volcanic rock fragments as well as already fossilized logs that were cut off from their original position and can be seen

laying horizontally inside the mudflow layers. Regarding the topography of the area, there are slopes with a declination ranging from 0 - 30%. The soil layer of the area is thin (depth 0 - 20 cm).

The fossil trunks conservation methodology requires special knowledge, fine handling and patience. Fossils present a range of foreign matter on their surfaces and in their interiors, including dust, earth, pyroclastic material, contemporary vegetation, insects, lichens and other microorganisms, clay deposits, salts and degradation products of the fossils themselves. Mechanical cleaning and wet cleaning are followed by chemical cleaning.

The same fossil presents various areas of different porosity, hardness and chemical composition. Each area is treated separately, based on the outcome of cleaning tests, to avoid dissolving part of the fossil itself, creating cloudy effects on the surface, cracking and dissolving the most porous specimens. Fossils are often found broken in number of pieces due to unstable temperature and RH conditions, different rates of expansion and contraction within a fossil, salt movement towards the warmer surfaces, living plant roots and careless visitors. Various concentrations of acrylic resin are used as adhesives. Solutions are injected in surface cracks to prevent breakages.

Figure 1. Conservation work at two of the emblematic petrified trees of the Petrified Forest Park at "Kyria Apolithomeni".

Figure 2. Conservation team during conservation work at the lying tree trunk at the Petrified Forest Park at Bali Alonia.

Concerning the consolidants and water-repellents, acrylic emulsions, are used for porous and softer fossils. An ethyl silicate combined with a neutral catalyst, was used for pre-consolidation and consolidation. Where degradation is too extensive, or where there are many cracks and holes, a spray was used. They are used full strength, or diluted in white spirits, depending on the fossil porosity.

Figure 3. Enhancement of the fossil site of the tallest standing petrified tree trunk, ancestor of a Sequoia tree.

Results

The Petrified Forest Park at "Bali Alonia" underwent a major renovation through the implementation of the geoconservation project. The majority of the fossils in the Park underwent in situ conservation. In addition, the work concerned the mapping as well as the enhancement of the fossil sites and the reconstruction of the protection measures. Conservation was carried out on fifty (50) fossil sites throughout the Park, including the emblematic fossil tree trunks of sequoias, the most popular exhibits of the Park. The identification and documentation work concerns a total of one hundred and twenty (120) fossil logs. In parallel new fossil sites became accessible to visitors and new fossil tree trunks were reconstructed from pieces found during the works.

All fossil trees were documented, cleaned, and welded. Adhesion and aesthetic restoration was applied were necessary and all fossils had a hydrophobicity treatment. In order to protect fossil sites and to solve the severe problems they were facing, the protective infrastructure of the excavation sites were redesigned in order to comply with the latest standards regarding the exposition of natural sites. Therefore fences, protective walls, paths etc were reconstructed in such a way to provide the in order not to abstract the visitor's eye from the real exhibit which is the fossil.

Conclusions

The fossil trees of the Petrified Forest Park at "Bali Alonia" after 25 years of the park operation needed urgent protection and conservation mesaures; as such scale interventions have never been implemented before. The conservation revealed the uniqueness of the Lesvos Petrified Forest and delivered as result the durability of the fossils and the improved visitors' experience.

The geo-conservation intervention at the Petrified Forest Park at "Bali Alonia" resulted to the preservation and protection of the fossils of the historic location of the Lesvos Petrified Forest, to the improvement of safety and accessibility of all fossil sites and to the encouragement of activities contributing to the development of geotourism.

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Lychnospilia or Cave of Pan: an Archaeological Site with an Interesting Quaternary Evolution

I. Kampolis [1,2], *A. Mari* [3], *A. Kampolis* [4]

(1) National Technical University of Athens, 9 Iroon Polytechniou , Athens, Greece, kampolisigeo@gmail.com, kampolisigeo@central.ntua.gr
(2) National Center for Scientific Research "Demokritos", Patr. Gregoriou E & 27 Neapoleos, Agia Paraskevi, Greece
(3) Ephorate of Paleoanthropology& Speleology,34B Ardittou Str., Athens, Greece, amari@culture.gr
(4) Ierea Dimitriou Liosi 12, Ano Liossia, Greece, alexkambolis@gmail.com

Abstract

Located 5 km NW of the modern town of Phyle,on the southwestern slope of Mount Parnes, on the east bank of the Gkoura Gorge, at an altitude of 663 m, Lychnospilia is mentioned by the Greek dramatist Menander and by the Roman writer Aelianas a sanctuary dedicated to the Nymphs by the inhabitants of the ancient deme of Phyle (Wickens, 1986).

Despite difficulties in accessibility, the cave constituted an attractive monument for travellers of the 19th century who were interested in visiting important archaeological sites. It was excavated in 1900-1901 by A. Skias, archaeologist of the Archaeological Society of Athens. Ceramic fragments found in its deposits indicate use of the caves in prehistoric times.

Inscriptions carved at the entrance of the cave and upon ceramic vessels, representations depicted upon pottery, and the marble votive reliefs revealed during excavation confirm function of the cave as a place of worship of Pan and the Nymphs at least since the 5th century BC. According to the excavator's report, more than two thousand lamps, which gave the cave its modern name Lychnospilia, meaning Cave of Lamps, were found during excavation. Most of them are dated to the 4th century AD, indicating that the specific monument remained a prominent cult site after the Roman period, until zealous supporters of Christianity removed, destroyed, and crushed all traces of its previous use (Platonos-Yiota, 2004; Wickens, 1986).

Besides its archeological significance, the aforementioned cave presents an interesting geomorphological evolution throughout the Quaternary period. It belongs to the solutional type of caves (karst endogenic landform) owing its formation to the chemical dissolution by meteoric water. It develops in the Upper Triassic – Lower Jurassic Limestones-Dolomites of the Pelagonian Unit and hosts a variety of different speleothems such as stalactites, stalagmites, draperies, flowstones and small rimstone pools. The total length of the cave is 96 m and the altitudinal range between the entrance and the back of the cave is 10 m.

The neotectonic structure of Mount Parnes is complex and the area is under uplift since the Pleistocene (Mariolakos and Fountoulis, 2002).It comprises the active margin of the Parnes-Kithaironas morphotectonic multi-block. There are two main groups of fault zones WNW-ESE and NE-SW in the area (Mariolakos *et al.*, 2001; Mariolakos and Fountoulis, 2002), whereas the Athens 1999 earthquake seismic fractures close to the cave had an average trend WNW-ESE with smaller

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ones along NW-SE to NNW-SSE (Mariolakos and Fountoulis, 2002). The fault which produced the respective earthquake was trending WNW-ESE. At the western Parnes, the WNW-ESE tectonic structures control the morphology of the drainage network, the areas of river incision, and the morphology of the main karstic landforms (Mariolakos *et al*., 2001). Moreover, the Giannoula stream and particularly, its main trunk, running past the cave entrance, at a lower level, bears a NE-SW orientation (N029^{o}) whereas all order tributaries forming the Giannoula drainage network develop along NE-SW and secondarily WNW-ESE directions (Mariolakos *et al.,* 2001). This is attributed to the abrupt uplift of Mount Parnes at the NE part of this drainage basin (Mariolakos *et al.,* 2001).

We compared the speleomorphology of the cave with the prevailing tectonic pattern of the wider area in order to shed light on its evolutionary history during the Quaternary. To accomplish this, 3D laser scanning and field work were employed. The 3D laser scanning produced a highly accurate model of the cave throughout a dense point cloud resulting in a virtual visualization of its speleomorphology (Figure 1). This point cloud is fully measurable, allowing measurements of the underground morphotectonic features. The field work yielded the local tectonic pattern. Karstic as well as tectonic features (joints, faults) were recorded, providing the prevailing tectonic directions in the broader area of the Cave of Pan. The 3D model of the monument as well as the structural data were combined in order to reveal the contribution of the tectonic activity to the speleogenesis process. The interpretation was also complemented by observations and measurements from the inner part of the cave, highlighting the different stages of its Quaternary evolution.
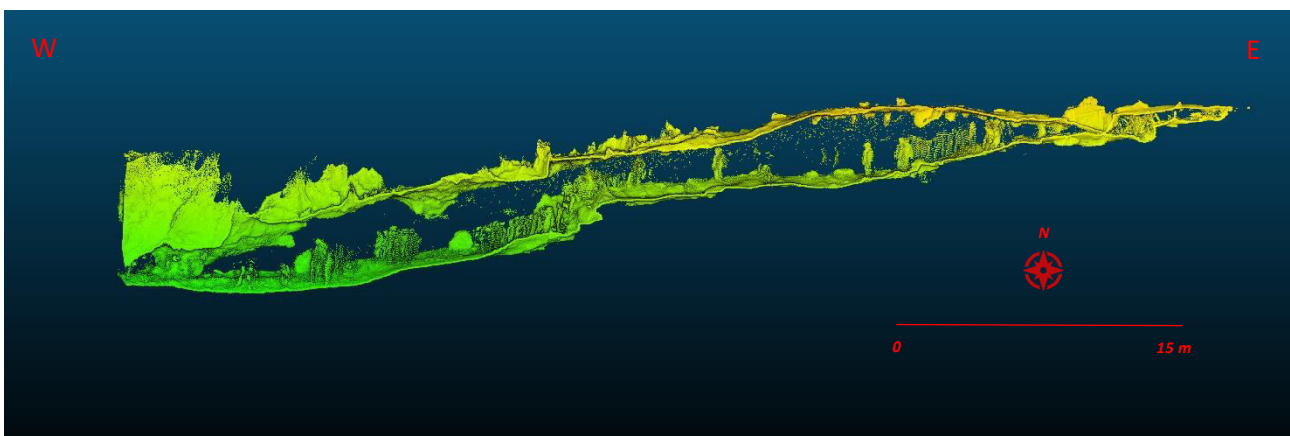
Figure 1. Cross-section of the Cave of Panextracted from the 3D point cloud. The entrance of the cave lies towards the west. The figure of the laser scanner operator can be discerned at the inner part of the cave.

The speleomorphology of the Cave of Pan trends WNW-ESE and coincides with the most recent tectonic direction of the area, implying a structural control of neotectonics on the cave passages. The location of the entrance, 17 m above the river bed, supports the common evolution of the cave with the Giannoula stream. It is generally accepted that large cave passages have a tendency to form at or near the level of the streams where they drain (Palmer, 2007). This is also valid for the Cave of Pan. Its speleomorphology and mainly its development direction as well as its floor, dip towards the stream. When the stream flow was at/close to the level of the cave entrance, the

underground water draining from the eastern sector of the main trunk was dissolving the limestone rock and forming the cave. Also, the paleo-water levels inside the cave suggest the periodic accumulation of large quantities of water in the cave.

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Educational Activities to Enhance Geomorphological Heritage Sites in Lesvos UNESCO Global Geopark

K. Bentana [1,3] _, N. Zouros_ [2,3]

(1) University of the Aegean, Department of Geography, University Hill, Mytilene 81100, Greece, konmpent@yahoo.gr, geod18002@geo.aegean.gr
(2) University of the Aegean, Department of Geography, University Hill, Mytilene 81100, Greece, nzour@aegean.gr
(3) Natural History Museum of the Lesvos Petrified Forest, Sigri Lesvos Island 81103, Greece, lesvospf@otenet.gr

Introduction

Geomorphological heritage sites that have been identified in UNESCO Global Geoparks are the main tools that are used for educational purposes. UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development (UNESCO, 2016). Geoparks host a significant number of sites of geological and geomorphological interest, which coexist with sites of archaeological, ecological, historical or cultural interest (UNESCO, 2016). These characteristics have a special role in the area and Geoparks through a bottom-up approach are conserving and protecting these geoheritage sites, and at the same time are raising awareness and are engaging local communities to adopt a sustainable approach in their area through various educational and informative activities and programmes.

Education is at the core of the interest and operation of UNESCO Global Geoparks which are considered as ideal destinations for educational activities (Zouros, 2004; McKeever and Zouros, 2005). A UNESCO Global Geopark uses its geological heritage, in connection with all other elements of the area's natural and cultural heritage, to enhance awareness and understanding of key issues that modern society is facing, such as the sustainable use of Earth's resources, mitigating the effects of climate change and reducing the impact of natural disasters (UNESCO, 2016). Education in UNESCO Global Geoparks has been recognized as an important pillar for the enhancement of the value of the Earth's heritage and UNESCO Global Geoparks are working for the empowered of local people and mainly young people and children with competences needed to promote sustainable development. Research has highlighted that geosciences education for sustainability is one of the backbones of geoparks' action plans (Catana _et al.,_ 2020). Recently, Geoparks have been asked to participate in the new UNESCO framework for Education for Sustainable Development for 2030 (UNESCO, 2019).

Educating the school children and communities on the conservation challenges enhances their ability to achieve long lasting and effective conservation and sustainability programmes (Norzaini _et al._, 2010). Thus, education is crucial for the enhancement and conservation of geomorphological heritage sites and at the same time empowers children with the necessary skills for sustainable development.

Specific geosites that are characterized as educational are used for educational reasons. Educational are the geosites with characteristics that have a special value for the educational

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community. They have special pedagogical value, as students can be educated there through properly designed activities and can understand the values of the geoenvironment (Theodosiou *et al.*, 2006).

The geosites in Lesvos Island UNESCO Global Geopark have been assessed through various studies and the geosites that can be used for educational reasons have been identified (Velitzelos *et al.*, 2002; Soulakellis *et al.*, 2004; Valiakos and Zouros, 2007; Zouros *et al.*, 2015; Valiakos and Zouros, 2018). Geomorphosites that have been documented in Lesvos are very important tools that are used for educational reasons. Geomporhosites are the part of the Earth that we can directly observed thus allow school students to combine what they can see and research on the landscape with important global and local problems that focus on sustainability issues such as disaster risk reduction, climate change, sustainable use of natural resources, loss of biodiversity etc.

This paper aims to highlight the role of educational programmes and activities implemented by schools for the enhancement of the geomoprhological heritage sites from the sustainable development point of view. For this purpose, the educational programs carried out in Lesvos Island UNESCO Global Geopark and are implemented by the Natural History Museum of the Lesvos Petrified Forest which is the management body of the Geopark are analysed. The educational programmes of the Natural History Museum of the Lesvos Petrified Forest were selected due to its long experience and activity in the field of education the last 20 years as well as its good practices in educational programmes for schools and the design and implementation of educational programmes utilizing the geosites. At this study are documented the geomorphological heritage sites' and the Museum's infrastructures, equipment and tools that are used for educational purposes. Analysed are also the objectives of the educational activities and educational programmes implemented using the geomoprhological heritage sites of Lesvos Island UNESCO Global Geopark.

Methods

The methodology used for this paper consists of fieldwork and content analysis. The fieldwork was carried out aiming to record and analyze the infrastructure, facilities, educational materials and educational activities available for the teaching-learning process at each geomorphosite in the field and at the Natural History Museum of the Lesvos Petrified Forest.

Various educational activities take place in the field at the Natural History Museum of the Lesvos Petrified Forest bringing children in contact with the geomorphological and geological sites.

The second part of the research involved qualitative and interpretative analysis based on the analysis of educational documents, materials and websites connected with educational programmes that are implemented in Lesvos.

The research includes also analysis of the educational programmes utilizing geomorphosites in the scope of promoting the main pillars of sustainable development. The importance and usefulness of sustainable development relies on the increasing interest in three pillars of encompassing economy, society and environment (UNESCO, 2005).

During the research we analysed 28 educational programmes from 3 different categories according to the age of the children: 4-7, 8-12 and 13-18.

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Results

In the first part of the analysis we collected data regarding the number of educational programmes that are utilizing geomorphological sites and are implemented on site in the field and educational activities that are connected with geomorphological sites and are implemented in the Museum (Figure 1).

Then we recorded the main educational activities of each educational programme, as well as the facilities, equipment and materials that are used for educational purposes. Lesvos Island UNESCO Global Geopark has various facilities that are used for the implementation of the educational activities. At every geomorphological site there are information panels and educational routes. Educational field guides, maps, educational books for teachers, activity books for children, digital games, educational cards and games have been produced and are used during the educational programmes and activities.
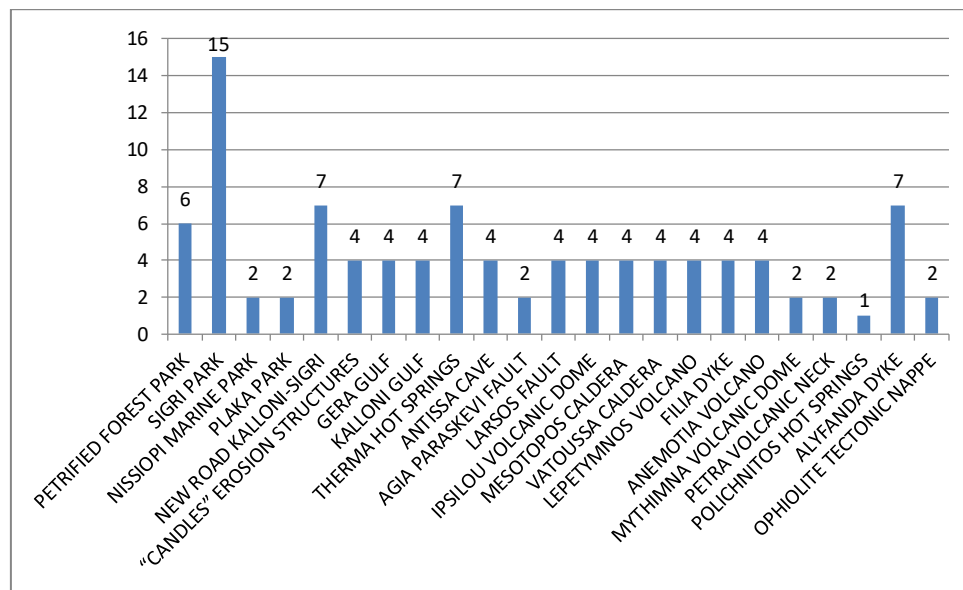
Figure 1. Number of educational programmes that utilize geomorphological heritage sites.

In the Museum, pupils have the opportunity to discover fossils and other exhibits and to use the audio-visual interactive exhibits, the educational seismograph, various models of volcanoes and other geological processes, animals, maps and educational games. In the museum's media room are projected various videos and audio presentations.

The processing of the results showed that the geomoprhosites that are used at most, for educational purposes, are those that are part of specific educational routes, are located in the open air parks (Figure 2), have facilities and educational materials and activities that can be used by the children and teachers.

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Figure 2. School students participate in educational programme in the coastal area of Plaka Park.

The next part of the research involved qualitative and interpretative analysis based on the study of documents, materials and websites connected with the educational programmes that are utilizing geomorphological sites, aiming to find out how many educational programmes are dealing with the main pillars of sustainable development. The three main pillars of sustainable development are the environment, economy and society, while as proposed at the Thessaloniki International Conference in 1997 the basis for all pillars of sustainable development should be education (Skoullos, 2004). The processing of the results shows that educational programs utilizing geomorphological sites in Lesvos fulfill the three main pillars of sustainable development (Figure 3).
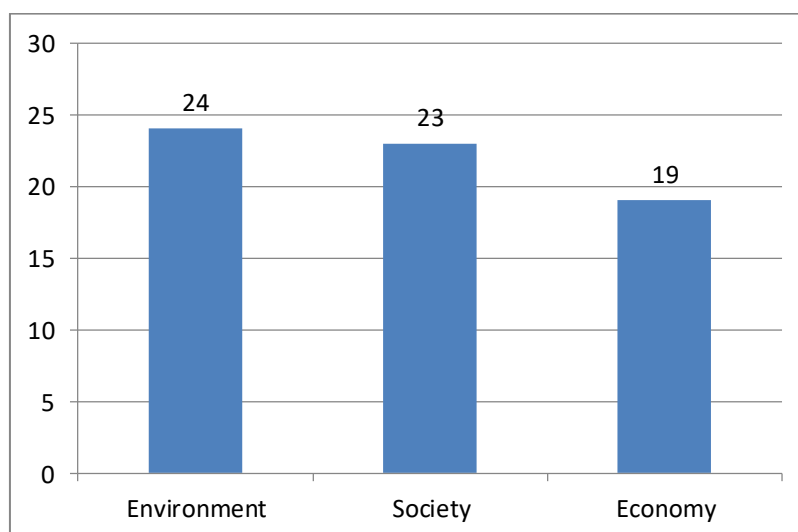
Figure 3. Number of educational programmes related to the sustainable development pillars.

The above results show that the educational programmes of Lesvos Island UNESCO Global Geopark are supporting the main pillars of Sustainable Development and the geomorphological

heritage sites are important tool to achieve this. This is an interesting result and an important indication of the value of geomorphological sites used by educational programmes connected with the dimensions of environment, society and economy.

Conclusions

Education is one of the backbones of Lesvos Island UNESCO Global Geopark. Its educational programmes and activities contribute significantly to the successful enhancement of the geomorphological heritage sites. Main factors in order to achieve this, is to have created educational infrastructure, educational facilities and educational material, to have well organised and planned educational activities and programs providing the necessary interpretation of the geomorphological heritage sites and to have geoscientists to design and implement these.

Lesvos Island UNESCO Global Geopark promotes interdisciplinary educational activities highlighting the relation between geomorphological heritage sites and environmental, social and economical issues. Geomorphological knowledge is also a major tool for geoconservation and empowers children with various skills to find new solutions to important local and global problems.

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Memories of GAIA: UNESCO Global Geoparks in Greece and Cyprus - Eductional Activities

O. Tsalkitzi [1,2], *N. Zouros* [1,2]

(1) Aegean University, Department of Geography, Mytilene, Greece, olgatsalkitzi@yahoo.gr, nzour@aegean.gr
(2) Natural History Museum of Lesvos Petrified Forest, Sigri of Lesvos, Greece, olgatsalkitzi@yahoo.gr, nzour@aegean.gr

Introduction

Geomorphology is the scientific study of the origin and evolution of landforms and landscapes created by physical, chemical or biological processes operating at or near the Earth's surface. Geomorphological heritage includes the elements that provide the evidence to understand why landscapes look the way they do, to understand landform history and dynamics and to predict changes through a combination of field observations, physical experiments and numerical modeling.

UNESCO Global Geoparks, the third site designation of UNESCO after the World Heritage Sites and the Man and Biosphere Reserves, are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. A UNESCO Global Geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness about global problems, while at the same it encourages sustainable development through geotourism and rural activities, as long as the geological resources of the area are protected.

Thus one of the main activities of the UNESCO Global Global Geoparks is to plan, implement and organize educational programs for children of all ages. The educational activities aim to popularize the history and evolution of our planet's surface and they are designed to make the way that geological and geomorphological processes act fully understood by people of all ages and educational levels and abilities.

In Greece there are five areas recognized as UNESCO Global Geoparks: the Lesvos Island, the Psiloritis area in Crete, the Chelmos-Vouraikos National Park in the Peloponnese, the Vikos-Aoos National Park in Epirus and the Sitia Nature Park in Crete. There is also another one in Cyprus, the Troodos. Networking is one of the core principles of Geoparks. The Hellenic UNESCO Global Geoparks in collaboration with the UNESCO Global Geopark in Cyprus, organized a common exhibition to present to the broad public the areas recognized as UNESCO Globals Geoparks in Greece and Cyprus and to promote them as ideal destinations for recreation and environmental education. This exhibition will be travelling in the main cities of Greece and Cyprus and in the UNESCO Global Geoparks Museums and Information Centres giving the opportunity to the areas recognized as UNESCO Global Geoparks to meet new audiences.

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The Exhibition "GAIA Memories"

The exhibition "GAIA Memories" presents the impressive geological and geomorphological monuments of the UNESCO Global Geoparks of Greece and Cyprus in a comprehensive and attractive way for the general public. The different events that sculptured the relief of our planet's surface written on rocks and fossils were presented through representative exhibition displays and audiovisual presentations from each one of the participating Geoparks. The exhibition realizes an exciting journey through time to the geological history of the region from the ocean of Tethys to the Eastern Mediterranean presenting and explaining geological processes, volcanic eruptions, strong earthquakes, fossilization of plants and animals, creation of rocks and mineral deposits, but also the relation and interaction of the abiotic nature with the modern ecosystems and their importance, value and beauty. Thus explaining the value of UNESCO Global Geoparks raised awareness and respect for the protection of our natural heritage!

The exhibition includes nine units. The first one is dedicated to the presentation of the UNESCO Global Geoparks and the wealth of their geological treasures, the Global Geoparks Network and its networking activities. The second one is dedicated to the network of UNESCO Global Geoparks in Greece and Cyprus. Then follow six units with the presentation of each one of the participating UNESCO Global Geoparks.

Figure 1. Panel of the first and second exhibition units, one on the UNESCO Global Geoparks and another on their representatives in Greece and Cyprus.

Lesvos Island UNESCO Global Geopark displays volcanic rocks and geosites related with the famous Petrified Forest of Lesvos, a protected natural monument with impressive fossil trees and mammals like the fossil of the Prodeinotherium of Gavathas, the oldest European mammal. The fossils of the Petrified Forest of Lesvos represent the tropical Miocene forests of Aegis, the land mass that created after the destruction of the ocean of Tethys and was later fragmented by recent tectonism to give birth to the Aegean archipelago. Psiloritis UNESCO Global Geopark geodiversity is represented by rocks and marine fossils of 250 million years. Psiloritis Mountain presents a big

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variety of geosites such as gorges, caves, impressive folds representing the compressional processes that resulted the alpine mountain building, resent fault surfaces, sandy coasts that interchange with cliffs and rock bays characteristic of the physiognomy of the Crete. Chelmos-Vouraikos UNESCO Global Geopark in northwestern Peloponnese includes a variety of popular geosites such as impressive gorge of Vouraikos, the beautiful Cave of Lakes, the springs of Aroanios River, the Tsivlos and Doxa lakes, the mythical waters of Styx, providing links between the geology with the mythology of the area.

Vikos-Aoos UNESCO Global Geopark in Epirus, northwestern Greece includes the wonderful gorges of Vikos and Aoos rock towers, rivers, wonderful alpine lakes as well as stone bridges and traditional villages. The area consists of deep sea sedimentary rocks, deposited in the Tethys Ocean. Sitia UNESCO Global Geopark is located at the easternmost edge of Crete. Its unique landscapes include uplifted paleo-shorelines, gorges, an extensive cave system and impressive rich karst forms. Terrestrial and marine animal's fossils represent the paleo-ecosystems of Eastern Mediterranean. The dry climate of the area, created a mosaic of habitats and ecosystems, such as the unique in the Mediterranean Palm Forest of Vai. Troodos Mountain UNESCO Global Geopark represents the genesis of Cyprus, as a result of a series of complex geological processes, which made the area a key locality for geoscientists around the world and contributed to a better understanding of ocean evolution. Troodos Mountain represents the deepest layer of a piece of oceanic crust, as well as the upper mantle of the earth, an ophiolite complex formed 90 million years ago 8,000 meters below sea level. The final exhibition unit describes the educational, geotourism and other sustainable development activities in UNESCO Global Geoparks in Greece and Cyprus.

Well-designed exhibition panels and floor graphics, photographic and audiovisual displays present the geological evolution of each Geopark and the tectonic and geomorphological processes that created their spectacular landscapes and geosites (Figure 1). The exhibition presents unique fossils of plants and animals, as the 8m long petrified tree trunk and many other tree branches and imprints of leaves from the Miocene Lesvos Petrified Forest, stromatolites 250 million years from the Psiloritis Mountain, Mesozoic fossilized sponges from Sitia Geopark, rocks and minerals from Troodos Mountain in Cyprus, rocks and fossils of Chelmos–Vouraikos Geopark and rock speciments from the Vikos–Aoos Geopark! It also presents volcanic rocks from the Tethyan oceanic floor, calc-alcaline volcanic rocks from Miocene volcanic activity in NA Aegean and also tectonic structures such as folded rocks and fault surface striations.

The exhibition produced by the Natural History Museum of the Lesvos Petrified Forest, the management body of the Lesvos island UNESCO Global Geopark with the contribution of the management bodies of the UNESCO Global Geoparks in Greece – Cyprus, the Institute of Geology and Mining Exploration (IGME), the Geological Survey Department of Cyprus, the Troodos Development Company, the Natural History Museum of Crete, the AKOMM Psiloritis Development Agency S.A., the Municipality of Sitia and the Universities of the Aegean and Patras. The exhibition realized with the support of the cooperation project "Geotourism Development in Insular Geoparks"/GEO-IN which is financed by E.U. INTERREG Greece-Cyprus and national funds from Greece and Cyprus.

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The first presentation of the "GAIA Memories" exhibition was at Eugenides Foundation, in Athens (October 2018 – April 2019). Next station was Nicosia of Cyprus, in the «Peace» Hall of Nicosia Municipality (May – June 2019). It was then moved to Crete and was presented in Sitia, in «Melina Mercouri» Hall of the Multicenter of Sitia Municipality (July 2019), in Rethymno, in «Cultural House» (August – September 2019), in Heraklion, in the Natural History Museum of Crete (October 2019 – January 2020) and last station was Sigri of Lesvos, in the Natural History Museum of the Lesvos Petrified Forest (January – March 2020).

Educational Activities

The educational activities were an integral part of the "GAIA Memories" exhibition and aim to familiarize visitors of all ages with the geological and geomorphological heritage, protected and managed within UNESCO Global Geoparks in Greece and Cyprus (Figure 2). The education visits of school groups were introduced to the geological history and evolution of the Eastern Mediterranean and especially on the processes related to the creation and the destruction of the ocean of Tethys, laying in between Eurasian and African continents, as well as the geodynamic processes and phenomena that followed and resulted to the current topography of the area. The narration uses the highlights of the exhibition which include representative rock specimens and fossils from all Geoparks. Special educational programs have been organized on the importance of the geological heritage and its protection, on the fossil plants and animals, on the climate changes in the geological record, on the geological time and the evolution of life, using a sophisticated exhibit on geological time and life evolution, where figures of animals and plants are associated with the relevant time period giving the opportunity to realize the evolution of life.

Visitors have the opportunity to become familiar with the new program of UNESCO the "UNESCO Global Geoparks" and the areas around the globe included in this third site designation of UNESCO as well as with the importance, the value and the significance of the geological heritage sites in each one of the existing six Geoparks in Greece and Cyprus.

Figure 2. Views of the exhibition "GAIA memories", during educational visits in Eugenides Foundation, Athens.

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Results

During its presentation at the Eugenides Foundation (October 2018 – April 2019), 41.000 visited the exhibition "GAIA Memories". 15,795 were students from 364 school units who participated in educational programs (Table 1). 282 school units were public and 27 were private and also 232 were from Athens and broader area of Attica Prefecture, 111 from the rest of Greece, 8 from Cyprus, 1 from Denmark, 1 from France, 1 from Panamas, 1 from Reunion Islands, and 2 from Turkey.

The majority of the students who visited the exhibition were coming primary schools: 15 kindergartens, 180 primary schools, 104 gymnasium, (12-15 years old), 37 lyceum (15-18 years old), 5 of High Schools were Music, 5 Tutorial, 1 Church School, 2 Second Chance Schools for Adults and 5 Universities. In addition, 3 Laboratories of Special Vocational Education and Training with autistic children (15-18 years old), 8 groups of the International Organization for Migration (IOM) and the NGOs "Elix" and "European Expression" with unaccompanied immigrants (13-17 years old) as well as the Department of Adolescents of the Detoxification Unit "18 Over" (16-18 years old). After the visit in Athens exhibitions many school units arranged and organized a field trip in the area of Geoparks.

Table 1. Total numbers of school units, students and public per month that visited the exhibition "GAIA Memories".

	October	November	December	January	February	March	April	Total
School Units	26	76	63	30	57	54	58	**364**
Students	1,358	2,948	3,159	1,237	2,739	2,155	2,199	**15,795**
General Public	3,055	4,763	6,756	3,930	1,908	3,058	1,207	**24,677**
Total	4,413	7,711	9,915	5,167	4,647	5,213	3,406	**40,472**

Conclusions

Participants rate the exhibition as a useful educational tool to both children and adults on Geoparks and Geoheritage that can be customized and stimulate interest!

- It gave stimuli for reflections and wishes for future collaborations with Geoparks!

- Visitors experience the beauty of the landscapes and the processes that transformed them over time providing the background for the development of a variety of modern ecosystems.

- Its great contribution is the acquisition of knowledge from visitors of all ages, the enthusiasm of young children, the sensitization of people working professionally in various fields

- The exhibition gave birth to new "Geoparkers"! The young children loved the geological heritage of our planet and were educated in a first level contact to understand the geological processes and recognize the role of earth landform to the human communities' development.

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Geological and Geomorphological Heritage Sites in Lemnos Island, Greece and their Geotourism Potential

N. Zouros [1,2], N. Soulakellis [1,2], I. Valiakos [1,2], G. Grimpylakos, [2] V. Rozakis [2], A. Lamprakopoulos [1,2], P. Panidou, [1,2], G. Evangelou [1,2], E. Papadopoulou [1,2], G. Tataris [1,2]

(1) Aegean University, Department of Geography, Mytilene, Greece, nzour@aegean.gr
(2) Natural History Museum of Lesvos Petrified Forest, Sigri of Lesvos, Greece

Introduction

Lemnos Island located in the north eastern Aegean Sea, represents an area rich with numerous geological and geomorphological features, especially fossiliferous sites, volcanic geosites and impressive erosional landforms in sedimentary formations which are excellent representatives of this area's geodiversity. Geosites are protected elements according to Green environmental legislation (Law 1650/1986, Law 3937/2011) as they consist the main witnesses of the history of the earth. However these geosites and their geotourism potential still remains fully unrevealed. In this paper we present the work carried out aiming to identify, map and asses the various geosites of Lemnos Island in order to select the most representative ones based mainly on their aesthetic value as well as their geotourism potential. The research team on geological heritage and geodiversity of the Department of Geography of the Aegean University and the Natural History Museum of the Lesvos Petrified Forest started the a research effort to identify and map the fossiliferous locations of fossil plants on Lemnos island in 2012. As a result the Lemnos Petrified Forest declared a protected natural monument in 2013.

The research effort continued to identify and map the variety of Lemnos geosites. Following an emerging global trend for geotourism our main goal was to link the individual geosites along thematic geotrails with other elements and sites of ecological and cultural value. This strategy has the potential to involve wider community interest, engagement, support and involvement in its management.

This is supported by the North Aegean 2014-2020 Regional Operational Program - Action "Creation-operation of digital applications for the promotion of geo-monuments of Lemnos" implemented by the Museum of Natural History of the Petrified Forest of Lesvos in collaboration with the Municipality of Lemnos, which concerns the promotion of geological monuments, landscapes and places of ecological interest, with the aim of utilizing them for the development of alternative forms of tourism.

The study area

The Island of Lemnos, is the 8th in size Greek island with an extension of 476 km^2 and a shoreline of 310 km. The morphology of the island is smooth with low relief at the eastern side, while the western part is hilly, with the pick Skopia (Vigla) in the north-west reaching 470 m.

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The island of Lemnos lies at the south margin of the North Aegean Trough, which is related with the western extension of the North Anatolian Fault zone. This 1200 km long dextral strike-slip fault and its strands that enter into the Aegean Sea facilitate the westward extrusion of the Anatolia plate. Tectonic structures of Lemnos play a key role to our understanding of the recent geodynamic evolution of the broader area and the active transtensional stress regime (Pavides *et al.,* 1990).

The geological structure of Lemnos Island is rather simple in comparison with the other islands of north eastern Aegean. It consists of two main units; the lower consists of sedimentary deposits with ages ranging from middle Eocene (Lutetian) to Early Oligocene overlain by Lower Miocene volcanic rocks.

The lower sedimentary unit of Lemnos Island (Roussos *et al.,* 1993; Innocenti *et al.,* 1994), consists of conglomerates, sandstones and claystones and has been characterized as deep water in origin.

Sandstone petrography indicates that the detritus is mainly composed by clasts of low-to-medium-grade metamorphic and sedimentary rocks, deriving from Rhodope Massif and Circum-Rhodope belt (Innocenti *et al.,* 1994). Above them, during Early Oligocene, shelf deposits have been conformably accumulated.

Relatively intense magmatism started in early Miocene with pyroclastic flows followed by the emplacement of sills, lava flows and domes; three volcanic units, as well as a quartz-monzonite of limited extent (Fakos intrusion), cover much of the southwestern part of the island. (Davis, 1959; Fytikas *et al.,* 1980; Innocenti *et al.,* 1994). They include andesite, trachyandesite, trachyte, and dacite, with porphyritic plagioclase and alkali feldspar set in a microlitic groundmass of plagioclase, alkali feldspar, biotite, and quartz in variable proportions (Roussos *et al.,* 1993).

Secondary phases include micas, calcite, quartz, and clay minerals. Radiometric dating of these rocks yielded ages ranging from 21 to 18.2 Ma (Fytikas *et al.,* 1984; Innocenti *et al.,* 1994). The Limnos igneous rocks represent the first products in the North Aegean area, where the volcanic activity ceased in the middle Miocene.

The Miocene ends with the deposition of conglomerates, marls and marly sandstones. Localy appear Pleistocene porous calcareous and locally oolitic limestones and Holocene alluvial, coastal deposits and dunes are found.

Geosite Identification and Mapping

Field work carried out from 2013 to 2020 resulted to the identification of 150 geosites located all over the island.

All geosites were classified to the following categories: a. fosiliferous sites, b. volcanic sites, c. stratigraphic – tectonic sites, d. geomorphological (erosional, depositional). e. other sites of interest.

The geosites were mapped using classical methodologies but in parallel the exploitation of Unmanned Aerial Systems (UASs) has been incorporated offering the ability to generate accurate high resolution 3D maps and models at several scales. The purpose of the produced maps was to promote of the rich geological and geomorphological heritage of Lemnos Island and to

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communicate geo-scientific themes. Additionally, 3D geovisualizations has been created by taking advantage of multimedia techniques and methods, such as augmented reality, 360 panorama and ultra high resolution video.

The geological and geomorphological heritage sites were assessed using the methodology proposed for the assessment of geomorphosites (Zouros, 2007; 2009). As a result the selection of the 50 representative geological and geomorphological heritage sites was made. The 50 geosites have been documented for their geoscientific significance. The information for these geosites is taken from field work and literature (Roussos *et al.,* 1993; Innocenti *et al.,* 1994, Maravelis *et al.,* 2007; Chatzipetros *et al.,* 2013). These geological and geomorphological heritage sites as well as sites of ecological and cultural value form the basis for the creation of the interpretative geotouristic map of Lemnos Island, presenting a balanced proportion of scientific and touristic information.

The sites will be linked alond thematic "geo-tails" which will introduce the visitor to the main geological and geomorphological processes that created the landscapes of Lesmnos.

Figure 1. The petrified tree trunk in Baros village.

Fiure 2. The volcanic dome of Evgatis and the Agios Ioanis tafoni structure.

Figure 3. The spheroidal geoforms at Farakla and the dunes at Gomati.
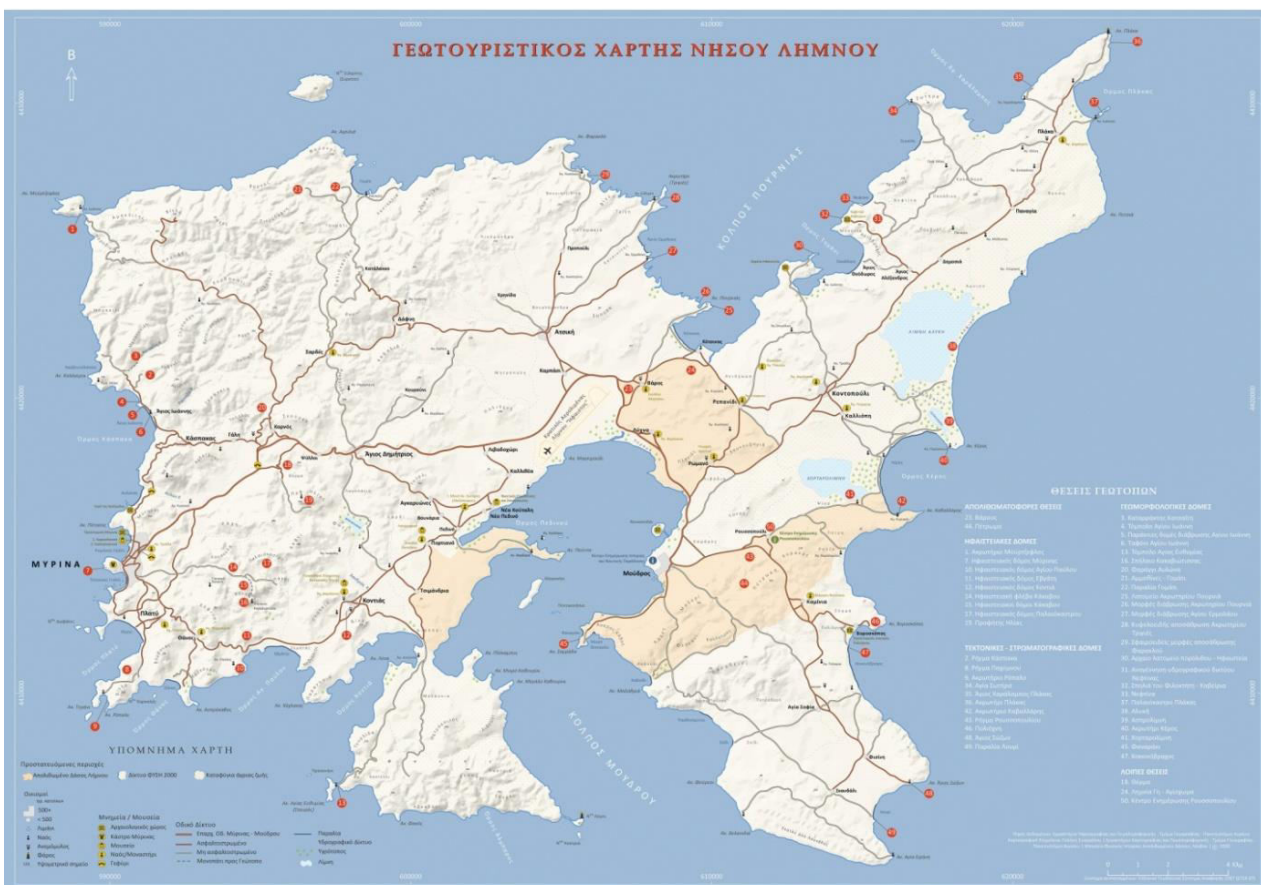
Figure 4. Geotouristic map of Lemnos Island.

Conclusions

The geotouristic map of Lemnos will be used to promote of the rich geological and geomorphological heritage of Lemnos Island and to communicate geo-scientific themes with non-specialist public, providing the opportunity to understand fossils and fossilization processes,

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geomorphological and geological phenomena, formations and rocks as well as recent evolution and current geodynamic processes.

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The Role of Geomorphology in the Education and Knowledge Related to Disaster Risk Reduction (DRR) in Croatia

N. Lončar [1], *Zaviša Šimac* [2], *A. Pejdo* [3], *N. Holcinger* [4]

(1) University of Zadar, Department of Geography, TrgknezaVišeslava 9, 23000 Zadar, Croatia, nloncar@unizd.hr
(2) Ministry of the Interior, Civil Protection Directorate, Risk Assessment Department, Nehajska 5, 10000 Zagreb, Croatia, zsimac@mup.hr
(3) University of Zadar, Department of Geography, FranjeTuđmana 24i, 23000 Zadar, Croatia, apejdo@unizd.hr
(4) Ministry of the Interior, Civil Protection Directorate, Risk Assessment Department, Nehajska 5, 10000 Zagreb, Croatia, enhlocinger@mup.hr

Geomorphology is highly related to education on natural hazards and disasters. The study of earthquakes, landslides, floods etc., is crucial for vulnerability and risk assessments as well as disaster risk reduction (DRR). Thus the incorporation of geomorphologists into the national/regional/local groups of experts to establish adequate strategies of risk assessment and management is highlyrecommended (Alcańtara-Ayala, 2002). But for resilient society, education on natural hazards and disasterson all educational levels is crucial. According to Dunbar (2007) education on geomorphologic phenomena and processes and its outreach are important factors in increasing public awareness on geological hazards and risks. Numerous initiative and campaigns, especially UNISDR campaign "Disaster Risk Reduction Begins at School" 2006-2007, has also shown the importance of DRR integration into formal education and community participation as a way of creating a sustainable community (Shaw *et al.,* 2011).

In Croatia, the education on natural hazards is partially integrated in the Geography curriculum, trough the basic geomorphology related topics (volcanoes, earthquakes, landslides, drought, floods). This study presents the results of the first systematic research on the education and knowledge related to DRR in Croatia. In order to examine current state of knowledge and awareness on natural hazards amongst general population and the contribution of Geography/Geomorphology in the process of gaining basic knowledge on natural hazards, survey was conducted among 1104 randomly selected respondents (general population). Survey questions were focused on level of knowledge on hazards which are most relevant for Croatia; flood and drought as their occurrence is high and damages and losses are major (Ministry of Finance, 2019), and earthquake since Croatia is situated in a seismic active area (Ivančić *et al.,* 2018).

Questionnaire was produced in printed and digital form using the LimeSurvey. There were two-type of questions, closed and open-ended. The latter gave the persons answering the question an opportunity to answer appropriately and the surveyors to understand if the respondents understood the topics truly. Five point Likert type scale (ranging from 1-strongly disagree to 5-strongly agree) was used to examine the public's opinion on individual statements. Data were analysed by descriptive statistics.

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Since the survey was conducted on National level, the representative number of respondents needed to be determined. In order to gain reliable results (population sizes by margin of error at a 95%, Fowler, 1984; Schuman and Kalton, 1985) a standard formula was used considering the valid rule: the larger the number of members of the population, the smaller proportion of that population should be represented in the sample (Fowler, 1984; Cohen *et al.,* 2011). According to Krejcie and Morgan (1970) sample of 384 respondents (0,038%) needs a population sample of a million members to make it representative, i.e., its reliability would be 95%. According to the Census 2011, Croatia had 4 284 889 inhabitants (CBS 2011). Given that 1104 citizens were surveyed, the share of the population participating in the survey was 0.026%. According to the CBS (2011), there is 3 346 514 inhabitants at theage group 18 to 95. Since all the respondents were part of that age group the share of population participating in the survey is 0.033%. Therefore, the sample covered by this survey is considered to be reliable.

When selecting subjects for the representative sample, a modified snowball method (Goodman, 1961; Atkinson and Flint, 2004) was used, based on a targeted selection of the circle of people who then extended the sample. A sample of snow-covered subjects of both sexes, ages from 18 to 95, of varying in degrees of education, was tested.

This paper analyses only a part of the results obtained considering questions based on the premise that people are generally familiar with natural hazards but not the DRR and that Geography as school subject, and consequently Geomorphology, has a significant role in natural hazard and DRR education. In the first question respondents were asked to answer whether they have encountered so far the term natural hazard. Analyses determined 96% of the respondents so far encountered the term. This data is not surprising since recently there were great damage caused by floods (eg. Eastern Croatia in 2014) and droughts (eg. Eastern and Southern Croatia in 2017) (Ministry of Finance, 2019) and Croatian media reported on all the natural hazards. Respondents that are not familiar with the term are mainly senior citizens.

However, when we analysed the role of Geography as a school subject in the process of gaining knowledge on definition of natural hazards, the results are alarming. Namely, 5.3% of respondents stated they gained some knowledge on natural hazards in primary schools and 5.7% chose secondary school. Conversely, analyses of the significance of Geography as a school subject in gaining basic knowledge on particular hazard; flood, earthquake and drought, most respondents consider that the role of Geography is substantial (Table 1) regardless of age groups.

Table 1. The significance of the role of Geography (school subject) in gaining knowledge on flood, earthquake, and drought.

Geomorphologic process	Very Low	Low	Neutral	High	Very High
Flood	82	224	337	264	197
Earthquake	50	122	253	366	313
Drought	93	220	308	279	204

Note: n=1104

The highest significance is related to the earthquakes (62%) while for drought and floods the significance is alike (44% and 42 % respectively). Such result is in good concordance with the

current curriculum (Ministry of Science, 2006; 2011; 2015; 2020) and formal textbox in use, where earthquakes are only topic properly addressed while drought and flood are merely mentioned and heavily depend on the teachers' willingness and ability to involve those topics in his or her teaching.

Based on the respondent's opinion it can be concluded that Geomorphology has substantial role in present Croatian Geography curriculum which provides a fair amount of basic knowledge and information about abovementioned hazards as natural processes but lacks the connection with the aspect of hazards, disasters and preparedness, i.e. is not enough DRR related.

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Reconstructing Lost Coastal Landscapes in the Framework of NEPTUNE – INQUA Project

G. Mattei [1], _C. Caporizzo_ [1], _A. Novak_ [2], _L. Ronchi_ [3], _M. Seeliger_ [4]

(1) Università degli Studi di Napoli Parthenope, Centro Direzionale Is. C4, 80121 Napoli, Italy, gaia.mattei@uniparthenope.it; claudia.caporizzo@uniparthenope.it
(2) Geological Survey of Slovenia, Dimičeva ulica 14, 1000 Ljubljana, Slovenia, ana.novak@geo-zs.si
(3) Università di Padova, Via G. Gradenigo 6, IT-35131 Padova, Italy, livio.ronchi@unipd.it
(4) Goethe University Frankfurt, Altenhöferalle 1, 60438 Frankfurt, Germany, seeliger@em.uni-frankfurt.de

Introduction

Past records of coastal evolution are the key to predict future modifications of littoral areas in the context of global change and sea-level rise. With this scope, several proxies were used in the last decades to reconstruct the evolution of the coastal landscape and its impact on settlements and societies. During the Holocene (i.e. last 11.7 ka BP), major changes in the coastal landscape were triggered by climatic modifications, and notably by the variability of sea-level rising rates. While the late Holocene sea-level rise trends were widely investigated in recent years, far less attention has been dedicated to the mid- to late Holocene paleo-landscape evolution.

In this period, significant changes in the postglacial rates of sea-level rise produced major coastal changes that were only rarely explored with standard methodologies. The landscape modifications and related variations in relative sea-level derive from the sum of global, regional and local processes. All these spatial- and temporal-dependent processes are interweaved into a complex response of sea-level changes. A multidisciplinary approach oriented to paleo-landscape reconstructions at regional and local scale provides the opportunity to understand the role of natural and anthropogenic forcing in the landscape evolution, as well as to discover the past human adaptions to natural modifications of their environment.

The construction of harbours and more generally the coastal urbanization characterized the entire history of humanity and represented key passages in the rising and evolution of many civilizations, especially within the Mediterranean basin. Coastal landscapes were thus gradually transformed under human influence and the study of such changes plays a fundamental role in the comprehension of human occupation. As most of these ancient coastal settlements are today submerged due to the relative sea-level rise occurring over the last millennia, the challenge of coastal geoarchaeological research is to thoroughly study these submerged archaeological structures. This cutting-edge information can shed a light on the impacts of past climate changes on modern populations and the effects of surface processes at the social level. Moreover, as the early Holocene sea-level indicators are widely underrepresented in the available Mediterranean datasets, this project can furthermore contribute to identifying new constraints, which would greatly enhance the modelling of past sea levels and help in the production of reliable future sea-level rise scenarios.

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In the last years, the integration between geo-acoustic and remote sensing methods allowed high-resolution mapping of wide coastal areas, seabed morphologies, and underwater archaeological sites by combining remote and direct data from geological and archaeological samples. These transdisciplinary studies constitute the modern approach to paleo-landscape and paleo sea-level reconstructions, as acquiring a large amount of chronologically constrained data allows us to understand the evolution of a landscape in a four-dimensional way as different 3D surfaces changing with time. In the case of archaeological sites, such investigations also have a documental value of cultural and natural heritage.

While on one hand high-resolution remote sensing and geo-acoustic techniques certainly provide multiscale and multi-temporal datasets regarding landscape evolution over the last millennia, on the other hand, these methods are used to evaluate the local vertical ground movements (VGMs) that are the primary forcing factor in sea-level oscillations at medium-short term. In addition, the recent miniaturization of geophysical instruments resulting from innovative technology enables the use of small crafts carrying out measurements in very shallow water areas, which is a significant development considering that these areas were often neglected due to technical difficulties associated with larger older instruments. These modern marine systems, including Unmanned Surface Vessels (USV), are revolutionizing our ability to map and monitor the shallow marine environment. In the last few years, as reported in the literature, numerous specific crafts were designed for surveying in shallow waters and equipped with several geophysical instruments to reconstruct the seabed and sub-bottom morphology.

Neptune project aims to establish an active discussion on specific surveying protocols by using the above-mentioned techniques for each bathymetric range, starting from the early Holocene deepest environments, arriving up to the shallow water sectors where important testimonies of the Greek-Roman settlements are present along the coasts of the entire Mediterranean basin. The target is to obtain high-resolution data, which will allow the use of underwater landscapes as witnesses of the effects of past natural processes and human impact on the former coastal zones.

Neptune-INQUA Project

Neptune project (http://dist.altervista.org/neptune) started March 30, 2020, in the framework of INQUA CMP commission (https://www.inqua.org/commissions/cmp) activities for the purpose of creating an interdisciplinary working group of young scientists aimed to develop multidisciplinary techniques to analyse and reconstruct past landscapes, presently submerged due to the postglacial sea-level rise. Special attention is paid to the technological content, considering that the recent technological innovation applied to geo-acoustic and remote sensing methods opened numerous new possibilities of high-resolution mapping of wide coastal areas, seabed morphologies and underwater archaeological structures.

Neptune aims to supply a platform for cooperation of experts in coastal geomorphology and geoarchaeology as well as experts in marine surveying in order to provide an optimal integration among geological, archaeological and modelling methods. To counteract the global emergency of COVID-19, the first meeting of this international community was held online and involved more than 60 researchers from all over the world.

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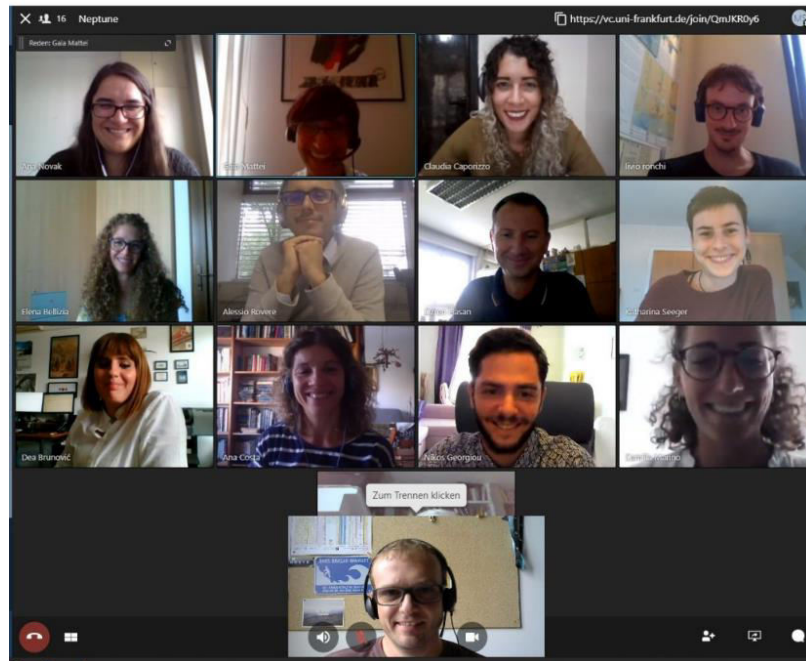
Figure 1. Photo taken during the first Neptune online meeting, September 3, 2020.

The final purpose of this platform will be the establishment of interdisciplinary trans-Mediterranean scientific collaborations, which will provide the foundations needed to reconstruct a bigger and integrated picture on the evolution of submerged landscapes.

The NEPTUNE activities have a twofold purpose:

- A multidisciplinary approach to underwater paleo-landscape reconstruction by means of innovative technologies integrated with well-established methods.

- An active discussion on the methodological protocols for optimal high-resolution surveying suited to different bathymetric ranges, often corresponding to different time scales.

In the scientific framework of INQUA, Neptune points to enlarge the spectrum of their collaborations to other disciplines, which will be able to tackle the main environmental problems of the near future. Collaborations established in our project will result in presentations on important regional and international meetings, as well as publications.

Neptune-Related Research in the Gulf of Naples (Italy)

So far, the geoarchaeological research along the coasts of Naples Gulf has been aimed at reconstituting the Holocene evolution of this peculiar coastal sector and perfectly matches with Neptune philosophy.

The geological and morphological characteristics of the Gulf makes this area one of the most diversified coastal systems in Italy, with alternating high and low coastal sectors of tectonic, volcano-tectonic and volcanic origin whose evolution was controlled by geodynamic, climate and anthropogenic factors. The Gulf represent a unicum along the Mediterranean coasts due to the presence of the two active volcanos of Campi Flegrei and Vesuvius, worldwide known for the

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vertical ground movements accompanying their activity since the Late Pleistocene. The interaction between VGMs of volcano-tectonic origin and glacio-isostatic processes deeply controlled the coastal dynamics and morphology of this sector, causing cliff erosion, barrier beach and lagoon system migration, marine ingression, etc.

In addition, The Gulf of Naples is an example of the continued interaction between anthropogenic and volcanic activities, considering that this area has been strongly inhabited since Greek times. In fact, according to the Greek geographer Strabo, the beauty of the Gulf led the construction of many villas and gardens along the whole coastal area during this period. The archaeological remains of these structures, nowadays submerged or buried by the volcanic products of Vesuvius and Campi Flegrei, were the key-strength of this research, aimed at reconstructing the Roman landscape and studying the phenomena that have influenced its evolution.
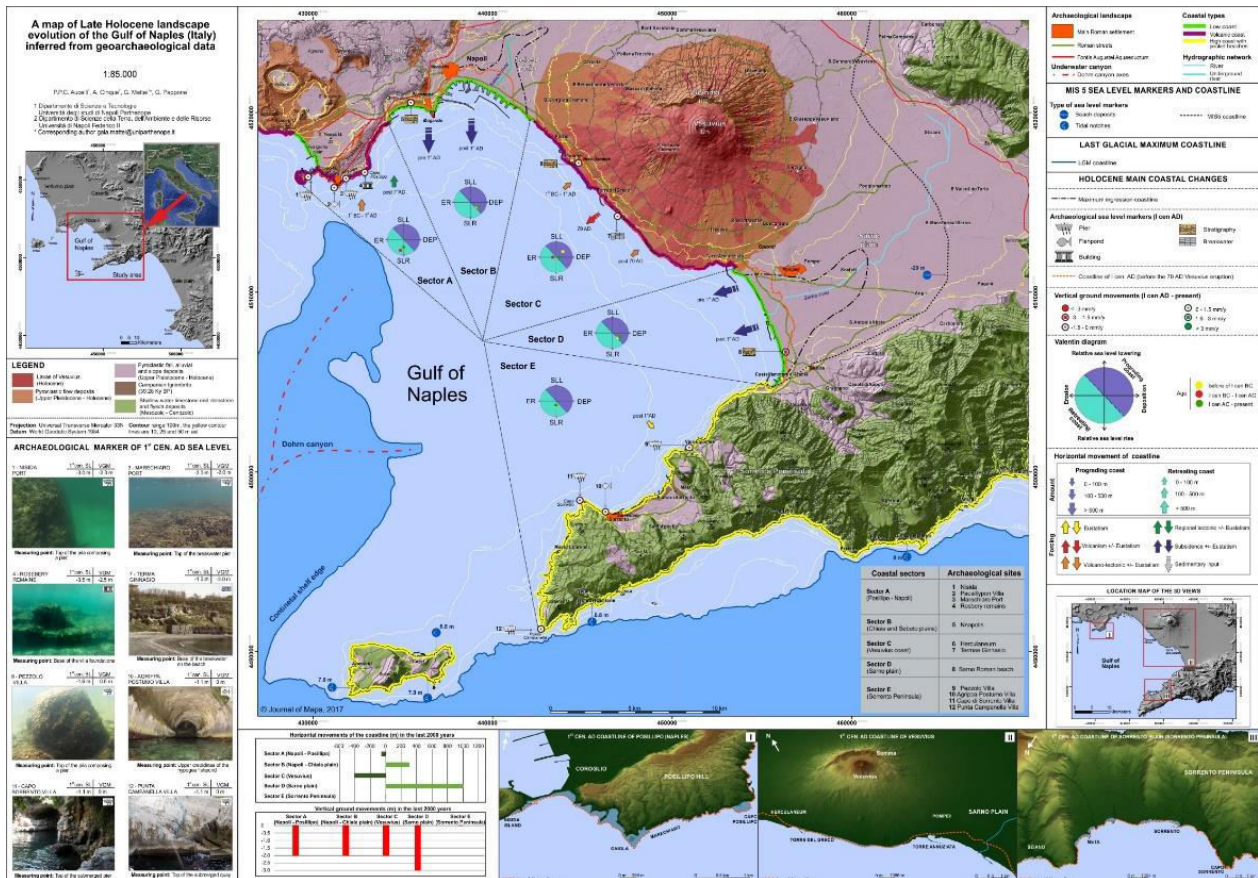
Figure 2. Geoarchaeological map of the Gulf of Naples (Aucelli et al., 2017).

These sites were surveyed using robotic technologies designed and engineered in the Parthenope University laboratories and equipped with geophysical and photogrammetric sensors, according to a multi-modal mapping approach. Consequently, the geoarchaeological researches carried out in very shallow water sectors of this Gulf are a perfect example of activities aimed at reconstructing the natural and anthropogenic underwater landscape by elaborating a multiscale dataset. For this reason, when the COVID-19 emergency will be over, a fest face-to-face meeting will be held in

Naples, during which the results of the field activities will be discussed and a specific surveying protocol will be defined.

Acknowledgements

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Algal Rims and Phreatic Overgrowths on Speleothems (POS) as Indicators of Relative Sea Level Change along the Eastern Adriatic Coast

N. Lončar [1], S. Faivre [2], T. Bakran-Petricioli [3], B. Miklavič [4], B. Onac [5], J. Barešić [6], P. Kovač Konrad [7], D. Horvatić [8]

(1) University of Zadar, Department of Geography, Trg kneza Višeslava 9, 23000 Zadar, Croatia, nloncar@unizd.hr
(2) University of Zagreb, Faculty of Science, Department of Geography, Marulićevtrg 19/II, 10000 Zagreb, Croatia, sfaivre@geog.pmf.hr
(3) University of Zagreb, Faculty of Science, Department of Biology, Rooseveltovtrg 6, 10000 Zagreb, Croatia, tbakran@biol.pmf.hr
(4) University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geology, Aškerčeva 12, 1000 Ljubljana, Slovenia, blaz.miklavic@geo.ntf.uni-lj.si
(5) University of South Florida, School of Geosciences, Stable Isotope Laboratory, 4202 East Fowler Avenue, NES 107, Tampa, Florida 33620,USA, bonac@usf.edu
(6) RuđerBošković Institute, Radiocarbon and Tritium Laboratory, RudjerBoskovic Institute, Bijenička 54, 10000 Zagreb, Croatia, jbaresic@irb.hr
(7) Zagreb Speleological Union, Biankinijeva 3a, 10000 Zagreb, Croatia, petrakovkon1@gmail.com
(8) University of Zagreb, Faculty of Science, Department of Physics, Bijenička c. 32, 10000 Zagreb, Croatia, davorh@phy.hr

We present the research of algal rims and phreatic overgrowths on speleothems (POS) as indicators of relative sea-level change along the Eastern Adriatic coast which will be conducted within the project SEALeveL (HRZZ-IP-2019-04-9445) funded by Croatian Science Foundation.

Lithophyllum byssoides, a fixed biological indicator is a coralline algae belonging to the order Corallinales of the Phylum Rodhophyta, and is characterized by a hard thallus formed by calcareous deposits contained within the cell walls (Rovere et al., 2015). Coralline algae are widespread along the world's rocky shores. Under favourable conditions, *Lithophyllum byssoides* build reef like bioconstructions just above the biological mean sea-level which can be ^{14}C dated. Rims of coralline algae have been largely used in the Mediterranean (Laborel, 1987) and have proven to be a good proxy of past sea levels in microtidal environments (Laborel *et al.,* 1994; Laborel and Laborel – Faivre *et al.,* 2013; Faivre *et al.,* 2019a) because their living range is constrained around sea level. It creates the highest biogenic build-up in the Mediterranean (Rovere *et al*., 2015).

The study of *Lithophyllum* rims as sea-level markers along the eastern Adriatic coast has started ten years ago with the aim of restraining the error bars and obtaining more accurate results. Research conducted on the islands of Vis, Ravnik and Biševo (Central Adriatic) (Faivre *et al*., 2013) as well as along the coast of Istria (Northern Adriatic) (Faivre *et al*., 2019a) revealed algal rims as possible high resolution relative sea-level marker. The accuracy of the marker has been much improved with the knowledge of the *Lithophyllum byssoides* marine radiocarbon reservoir age (MRE) (Faivre *et al*., 2019b). The MRE has been determined on algal samples of known age (ten samples from the Mediterranean and one from the Atlantic) obtained from Museums collections of the Natural History Museum (Museum National d'Histoire Naturelle) in Paris, Naturhistorisches

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Museum in Vienna and Universitat Hamburg, Biozentrum Klein Flottbek und Botanischer Garten in Hamburg. Results of the studies of algal rims (Faivre *et al.,* 2013; 2019a) show that large rims most likely grew during near-stable sea-level conditions that occurred during relatively colder periods over the past 2000 years. They also indicate that best-developed upper levels of the rims formed during ~300 years of stabilization throughout the Little Ice Age period. Those periods of stabilization could be directly related to the morphogenesis of tidal notches on the studied areas, providing thus the possibility of firm relative sea-level reconstructions.

Croatia is abundant with submerged or partially submerged caves with brackish water (Surić *et al*., 2010b). Thus far, detailed reconstructions of the Pleistocene and Holocene relative the sea-level changes along the eastern Adriatic, were done based on data obtained from U-Th dating and stable isotope analyses of the submerged speleothems/biogenic encrustations (Surić, 2002; Surić *et al*. 2004; 2005a; 2005b; 2009; 2010a). These studies encouraged detailed research of cave sediments in order to reconstruct climatic conditions and paleoenvironmental changes during the Quaternary (Lončar, 2012; Lončar *et al*., 2017; 2018; Surić *et al*., 2017a; 2017b; 2018). Research provided insight into environmental change recorded in stalagmites from the late Pleistocene (119 ka) to late Holocene (1.5 ka) (Lončar, 2012). Holocene is characterised by numerous $\delta^{18}O$ and $\delta^{13}C$ fluctuations reflecting sudden changes in the environment (Lončar, 2012; Rudzka *et al*., 2012; Lončar *et al*., 2017; 2018).

Recent diving explorations presumed POS to be deposited in eastern Adriatic coastal caves, offering a new tool for studying relative sea-level changes. POS is a secondary depositional structure (carbonate phreatic encrustation) which precipitates at the water table around pre-existing vadose speleothems if favorable geochemical conditions are acquired. So far, it has been used in sea-level research in only several locations in the world while most of the investigated sites are located in Mallorca (Onac *et al*., 2012; Tuccimei *et al.,* 2006; 2019; 2012; Vesica *et al*., 2000).

Calcite sample collected from Šipun cave (Dubrovnik area) show pre-existing vadose stalactite (a soda straw) around which we assumed POS precipitated, while some inner parts of the speleothem are richer in Mg. Further analyses should confirm the phreatic overgrowth while U-Th dating will give the age of its formation. Since the POS investigation is the first of that kind in the Adriatic, information on their morphology, conditions and time of deposition, will contribute to a better understanding of the POS as sea-level indicator and will allow comparison with results from other parts of the Mediterranean basin.

We expect that new data from both markers will enable the development of longer and more precise curves of relative sea-level change along the eastern Adriatic coast. Moreover, increasing the number of sea-level index points obtained from different markers can contribute to the understanding of the driving mechanisms: climate change, hydro- and glacio-isostatic adjustments, and tectonics.

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The Volcano-Tectonic Influence on Holocene Sea-Level Evolution along the Mid-Tyrrhenian Coasts (Western Mediterranean): A Multiproxy Dataset

*G. Mattei [1], **C. Caporizzo** [1], G. Corrado [2], M. Vacchi [3], P. Stocchi [4], G. Pappone [1], M. Schiattarella [2], P. P. C. Aucelli [1]*

(1) Università degli Studi di Napoli Parthenope, Centro Direzionale Is. C4, 80121 Napoli, Italy, gaia.mattei@uniparthenope.it; claudia.caporizzo@uniparthenope.it; gerardo.pappone@uniparthenope.it; pietro.aucelli@uniparthenope.it
(2) Università della Basilicata, Via Lanera, 20, 75100, Matera, Italy, giuseppe.corrado@unibas.it; marcello.schiattarella@unibas.it
(3) Università di Pisa, Via Santa Maria, 53, 56126, Pisa, Italy, matteo.vacchi@unipi.it
(4) Royal Netherlands Institute for Sea Research - NIOZ, P.O. Box 59, 1790 AB, Den Burg, Texel, The Netherlands, paolo.stocchi@nioz.nl

Introduction

The mid-eastern Tyrrhenian coast (Figure 1) is the most complex volcano-tectonic sector in the Mediterranean basin.
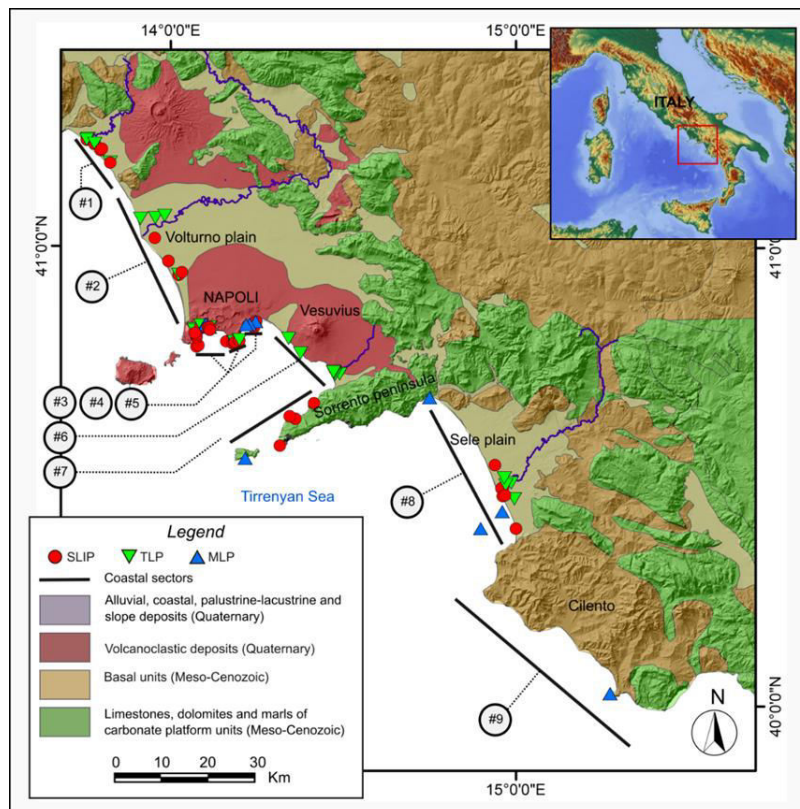
Figure 1. Simplified geological map of the study area and the related investigated sectors: #1, Garigliano Plain; #2, Volturno Plain; #3, CampiFlegrei; #4 and #5, Naples Coast; #6, Vesuvius and Sarno Plain; #7, Sorrento Peninsula and Capri Island; #8, Sele Plain; #9, Cilento Coast.

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Here the vertical ground movements (VGMs) due to the interaction between extensive tectonic processes and volcano-tectonic activities have a significant impact on both past and future sea-level evolution.

The mid-Tyrrhenian coast represents the youngest basin of the Western Mediterranean (Milia *et al*, 2013 and references therein) and, also, its most populated littoral region due to the presence of two major cities (Naples and Salerno) and several touristic localities, as Sorrento and Amalfi peninsula, Capri, Ischia. Here, the coastal density of population often exceeds 1000 /km^2 making this area very vulnerable to the ongoing sea-level rise, because often exacerbated by negative VGMs (Aucelli *et al.,* 2017).

The main aim of this research is to define a high-resolution role of the VGMs on the Late Quaternary (i.e., last 125ka) sea-level evolution along the mid-eastern Tyrrhenian coast, considering that the study area was never included in the recent sea-level database compiled for the Mediterranean area due to its intense volcano-tectonic activity.

Methods

A database of Holocene sea-level data was assembled coupling new data deriving from recent marine surveys to previously available data which were standardized according to the recent international guidelines for RSL studies (e.g. Shennan *et al.,* 2015; Khan *et al.,* 2019). This allowed the production of a multi-proxy dataset composed of depositional, erosional, biological, and archaeological sea-level markers in this very complex Mediterranean area. These data were further compared with a number of geophysical predictions in order to disentangle the different components, which influenced the sea-level evolution. Finally, we used GIS techniques to spatially constrain the coastal sectors, which are more vulnerable to the coupled effects of future sea-level rise and VGMs in the next decades.

The horizontal position of the collected RSLs data was evaluated by using both absolute and relative dating techniques, archaeological dating and tephra interpretations.

Sea-Level Data

We produced a new suite of Sea-Level Index Point (SLIP, i.e., point that constrains the sea-level in space and time, Shennan and Horton, 2002; Shennan *et al.,* 2015, Rovere *et al.,* 2016) using a wide range of proxies and following the most recent scientific protocols (Hijma *et al.,* 2015; Khan *et al.,* 2019). To be classified as SLIP, the following information must be available: (1) the location of the indicator; (2) the age of the indicator; and (3) the elevation of the indicator, corrected for the indicative meaning; (i.e. a known relationship between the indicator and a contemporaneous tidal level, the Mean Sea Level (MSL) in our database, Shennan *et al.,* 2015; Hijma *et al.,* 2015). When the abovementioned information was not completely available, the markers were used as limiting points and divided into terrestrial limiting points (TLPs) and marine limiting points (MLPs) (Rovere *et al.,* 2016).

For the geological samples included in the database, we produced the SLIPs according to the protocols recently developed for the Mediterranean (Vacchi *et al.,* 2016, Rovere *et al.,* 2016).

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For each dated sample, a SLIPn was produced according to the following equation (Shennan and Horton, 2002):

$$SLIPn = An - RWLn$$

where An is the proxy altitude and RWLn is the reference water level of the proxy n (sensu Shennan *et al.,* 2015).
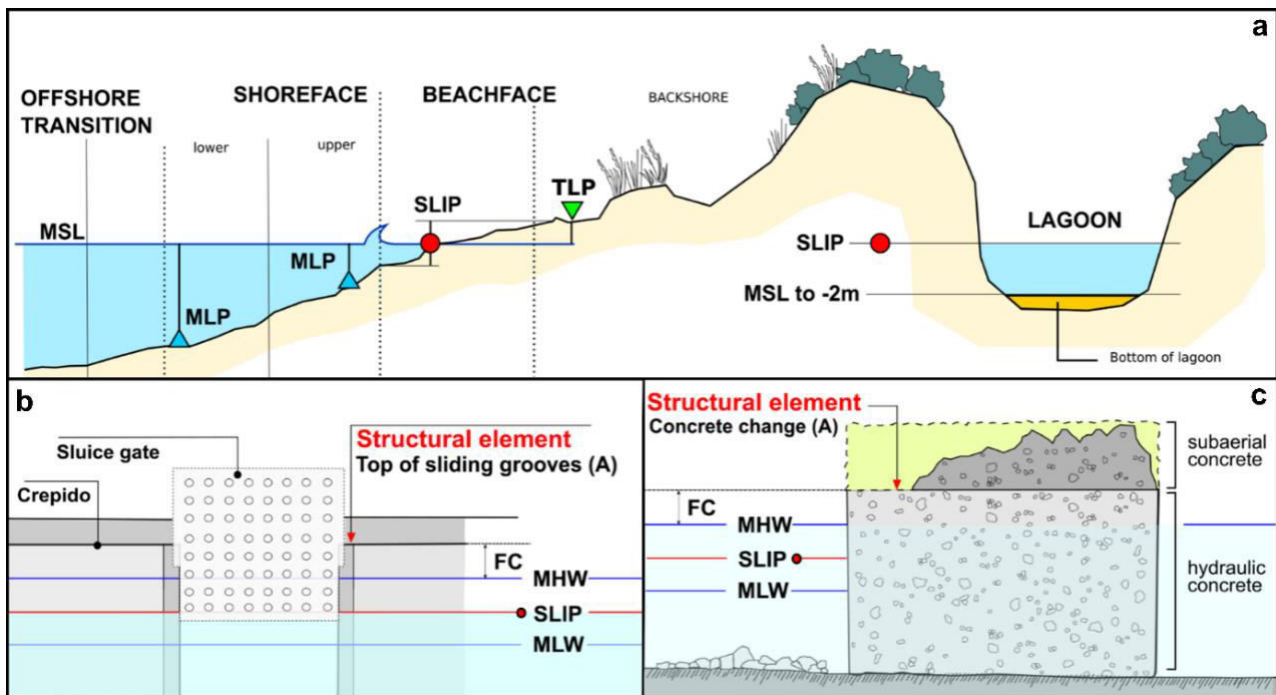
Figure 2. Different typologies of sea-level markers included in the dataset. a: interpretation of the different deposits forming along a beach profile; b: interpretation of the sluice gate of a fish tank in term of SLIP (Fc=0.2 m); c: interpretation of the concrete change of a pila in term of SLIP (Fc=0.5 m).

In the case of archaeological maritime structures related in different ways to the former mean sea-level (Figure 2b and c) their functional clearance (Fc, the minimum elevation of the structure above the MSL at the time of its construction) was taken into account (Figure 2b and c).

GIA Models

In order to determine the GIA-driven RSL changes, a suite of RSL curves was produced by using the sea-level equation solver SELEN coupled to three ice-sheet models: ICE-5G (Peltier, 2004), ICE-6G (Peltier *et al.,* 2015) and ANICE (de Boer *et al.,* 2013; 2014). The sea-level equation has been solved for a total of 54 models, assuming three values of lithosphere thickness (60, 90, and 120 km) and considering 3 ranges of values for the lower and intermediate mantle viscosity (2-10, 0.5-1, and 0.2-0.5 Pas).

The average vertical displacement suffered by each sea-level marker has been calculated through the use of a Bayesian statistical approach by determining the differences between observed and predicted RSL elevations, together with the calculation of the related uplift/subsidence rates.

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Results

The dataset analysed in this study is mainly composed of 63 SLIPs, 23 MLPs, and 38 TLPs, and the area was divided into 9 homogeneous coastal sectors in term of geological behaviour.

Generally, the whole study area was dominated by prevailing subsidence with variable intensity, although a substantial stability can be observed in the main plains of Garigliano and Sele rivers, together with a low rate of subsidence characterizing the mouth of Volturno River, according to recent interferometric data (Figure 3). In particular, in line with the GIA predictions, while the Garigliano and Sele plains showed a continuous rising trend of the RSL, the Volturno coastal plain was affected by a fast RSL rise followed by a period of stabilization in the rate.
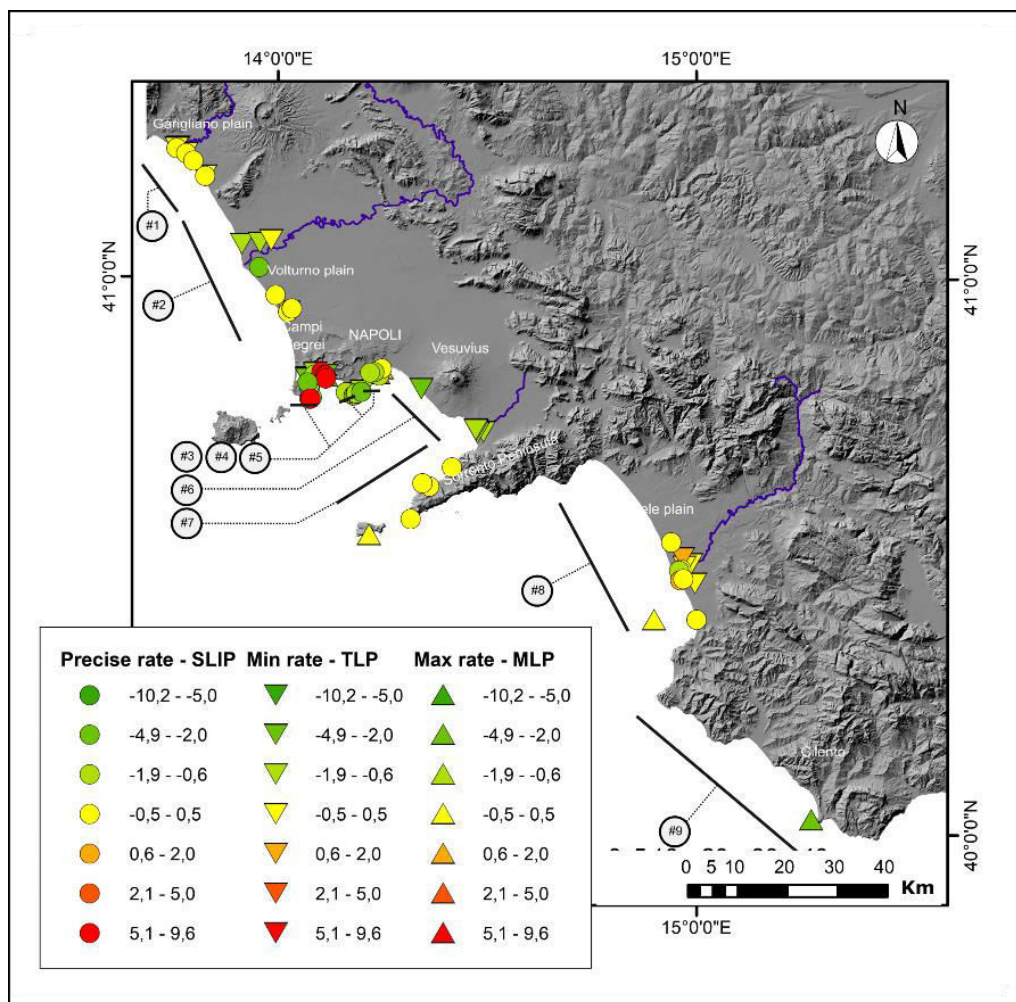
Figure 3. The studied sectors and the results in term of geological behavior (from dark to light green: subsiding rate; yellow: stable area; from orange to dark red: uplifting rate).

On the other hand, the Campi Flegrei and Naples coast sectors were characterized by a Holocene intense volcano-tectonic activity which respectively led to an alternation of subsidence and uplift trends, and to a prevailing subsiding trend (Figure 3).

Moreover, while the Sorrento peninsula is confirmed stable since the Late Pleistocene, the Vesuvius and Sarno Plain sector demonstrate that the area was affected by a subsiding trend (Figure 3), probably suddenly accelerated soon after the eruption in the year 79.

Conclusions

In view of the above, we can affirm that the mid-Tyrrhenian is an area in which is possible to investigate with high-precision the impact of the volcano-tectonic on the of the RSL evolution, due to the presence of both one of the most active Mediterranean volcanic districts and a robust dataset, with a precision that goes far beyond the data accuracy characterizing other parts of the globe.

Moreover, the comparison of the RSL measurements with different models allows us to better evaluate and calculate for the study area the risk of flooding related to the ongoing sea-level rise exacerbated by subsidence rates.

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Holocene Geomorphological Evolution of Volcanic High Coasts: The Case of Procida Island

M. F. Tursi [1], P. P. C. Aucelli [1], M. Pennetta [2], G. Mattei [1], C. Caporizzo [1], G. Pappone [1]

(1) Università degli Studi di Napoli Parthenope, Centro Direzionale - Isola C4 - 80143, Napoli, Italy, francesca.tursi@uniparthenope.it, pietro.aucelli@uniparthenope.it;gaia.mattei@uniparthenope.it, claudia.caporizzo@uniparthenope.it, gerardo.pappone@uniparthenope.it

(2) Università degli Studi di Napoli Federico II, Via Vicinale Cupa Cintia 21, Napoli, Italy, pennetta@unina.it

Introduction

This study aims to reconstruct the coastal response of Procida Island to relative sea-level rise since the mid-Holocene, by analysing the submerged features of the coast. Procida Island belongs to the insular part of the Campi Flegrei (CF) volcanic area and owes its formation to several explosive eruptions related to the CF volcanic activity started more than 60 ky BP (Aucelli *et al.*, 2017). The Campi Flegrei volcanic area represents one of the two main hazardous volcanic areas in the Gulf of Naples (Southern Italy), (Aucelli *et al.*, 2018; 2019; 2020). In detail, the island is characterized by steep cliffed coasts, articulated in a succession of headlands and small embayments (Pennetta *et al.,* 2018) and characterized by small and narrow pocket beaches such as Ciraccio - Ciracciello and Chiaia. The cliffs are generally cut into pyroclastic deposits showing a height of 10 to 40m and an inclination of over 40° and, in some cases; they are connected to narrow shore platforms sloping slightly towards the sea. The presence of different orders of submerged paleo-shore platforms suggests different phases of sea-level stand and related coastal response. Mapping these platforms, together with the interpretation of archaeological and geomorphological markers allowed defining the shoreline evolution of Procida Island during the last 6.5 ky.

Methods

The coastal sector of the study area was investigated by using a multi-techniques approach based on direct and indirect methods. Several on-site investigations were integrated with the geomorphological study of aerial photos. The 3D elaboration of the topo-bathymetric data, concerning Procida coastal area, followed a specific procedure. The first step was the calculation of an onshore-offshore DTM by interpolating the LIDAR (from the Ministry of Environment, 0 – 200 m MSL) and bathymetric data (from the CARG project, 0 – 20 m MSL), with a Topo to Raster interpolator (1 × 1 m grid). The second step was the slope analysis of the abovementioned DTM in order to classify the submerged area in sub-horizontal and steep slope sectors. By integrating the abovementioned GIS analysis with data derived from direct surveys, several sub-horizontal submerged surfaces (0-5% of slopes) were detected and interpreted as ancient shore platforms (Mattei *et al.,* 2018 and references therein). Consequently, the higher sloping sectors (slope > 20%) adjacent to the sub-horizontal surfaces were interpreted as related paleo-cliffs. Finally, the mapped paleo-shore platforms were reclassified depending on their depth in three orders and, subsequently, dated by means of archaeological evidence and our geomorphological

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interpretations. The last step was the morphometric analysis of these landforms to evaluate the retreating rates of the sea cliffs and quantify the vertical displacements (VDs) that have affected Procida costal sector in the last 6.5 ky. In this work, we used paleo-shore platforms as indicators ancient sea-levels (Rovere *et al.,* 2016). According to Kennedy (2015), the outer margin (i.e. the termination point of the platform towards the sea) is the point where active erosion of the bedrock ends. However, the most relevant feature useful for sea-level interpretations certainly is the inner margin of the platform (Figure 1), considering that it is located at the same level of the mean higher high water (MHHW - average of the higher high water height of each tidal day observed over a Tidal Datum Epoch).
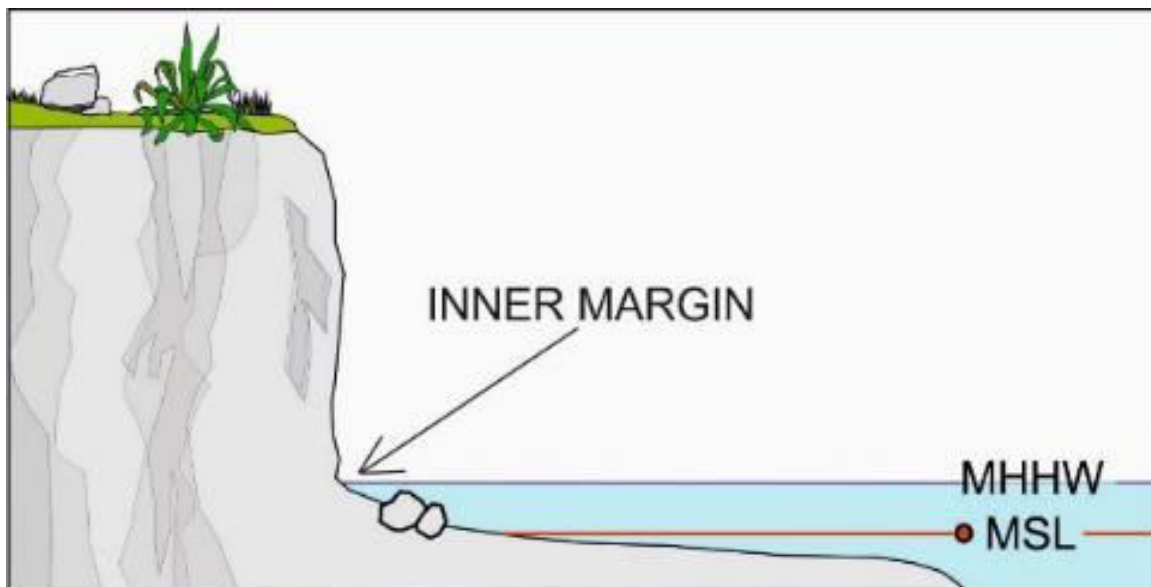
Figure 1. Sketch of a shore platform interpreted as sea-level index point (SLIP).

The Relative Sea Level (RSL) associated with this indicator is equal to:

$$RSL = E - MHHW$$

where E is the present elevation of the platform at issue with respect to the mean sea-level (MSL).

Results

The presence of three orders of submerged paleo-shore platforms highlights as many paleo sea-level stands. The first-order platforms are positioned between -25 and -23 m MSL, cut in the volcanic formation of Tufo di Solchiaro (Putignano and Schiattarella, 2010) emplaced during the last most important eruptive phase of Procida (22 ky BP). Therefore, these platforms were modelled after that date. In fact, by analyzing the eustatic sea-level curve relevant for the last 20 ky (Benjamin *et al.,* 2017), the most favourable morphogenetic conditions for the formation of the above-mentioned morphologies started about 6.5 ky BP when the decrease of the rate of sea-level rise was compatible with platform formation and related sea cliff retreat (Figure 2).

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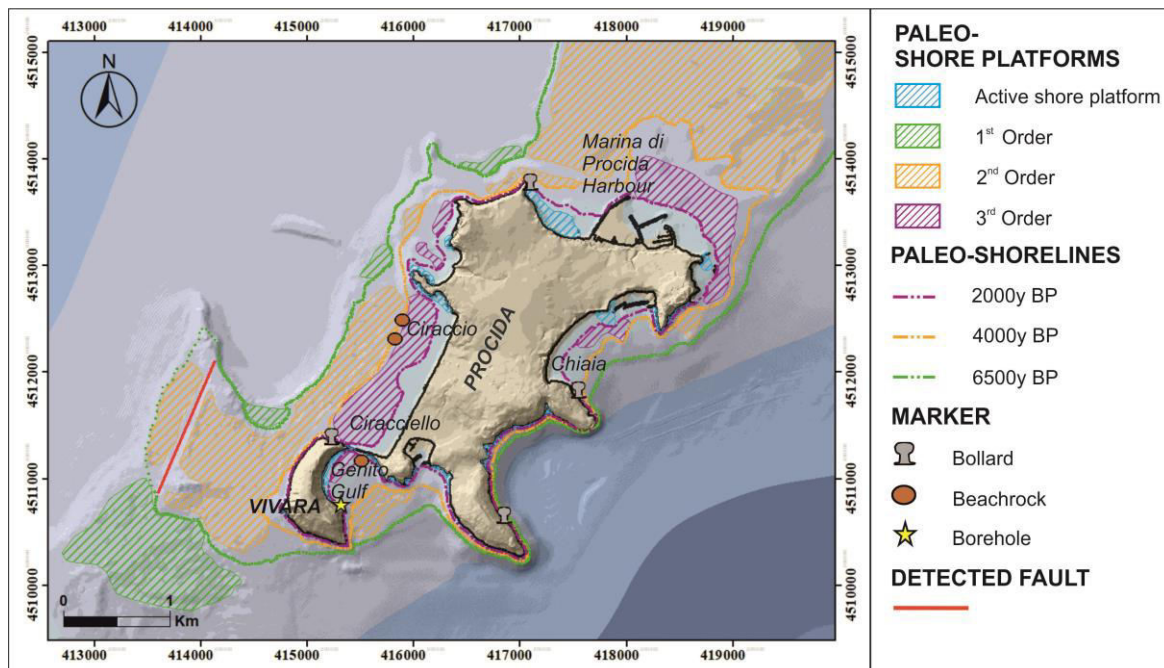
Figure 2. Location of the three orders of paleo-shore platforms.

Accordingly, the age of the first-order of paleo-shore platforms probably ranges between 6.5 ky BP and 4.0 ky BP, when the formation of the second-order began. The RSL here calculated was positioned at -23.2±1 m MSL. The second-order platforms are positioned between -20 and -11 m MSL and dated to 4.0ky BP based on both coring data coming from the Genito Gulf, where abundant fragments of archaeological finds were identified and chronologically constrained by (Putignano *et al.,* 2009), and several beachrocks detected between -13m and -11.8m MSL. The RSL calculated was positioned at -11.2±1 m MSL. The third-order platforms, positioned between -10 and -4 mMSL, were dated by using a ring bollards detected at a depth of -4.5 m MSL and beachrocks detected at a depth of -6,2 m MSL and dating between 2000 and 1000 years ago (Putignano *et al.,* 2014). The RSL calculated was positioned at -4.2±1 m MSL. Finally, through the geomorphological analysis of the present-day submerged morphologies, the active shore platforms dated from 1.0 ky and located along Procida coasts were detected and mapped. Generally, the actual shore platforms are located above -3 m MSL and characterized by narrow shape. In addition, the interpretation of the above-mentioned shore platforms as SLIPs allowed the reconstruction of both the RSL variations and the VDs affecting the area during the last 6.5 ky BP. In this regard, the comparison between the obtained RSLs and the Glacio-Hydro-Isostatic adjustment (GIA) models available for the study area (Vacchi *et al.,* 2019) demonstrates that intermitting subsidence affected the area, leading to the submersion of the three orders paleo-shore platforms here studied (Figure 3). Indeed, different subsidence rates of 0.005 m/yr, 0.005 m/yr, and 0.004 m/yr were calculated for the last 4.0 ky BP, 2.0 ky BP and 1.0 ky BP, respectively.

In order to reconstruct the geomorphological evolution of Procida Island since the Middle Holocene, four morpho-evolutive scenarios were carried out, respectively related to 6.5-4.0 ky BP (Figure 2A), 4.0-2.0 ky BP (Figure 2B) and 2.0-1.0 ky BP (Figure 2C). Moreover, through the reconstruction of the ancient shoreline positions related to the inner margin of the three orders of

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platforms, the retreating rates (RR) of the Procida sea cliffs were evaluated, by using the procedure explained in the Methods section.
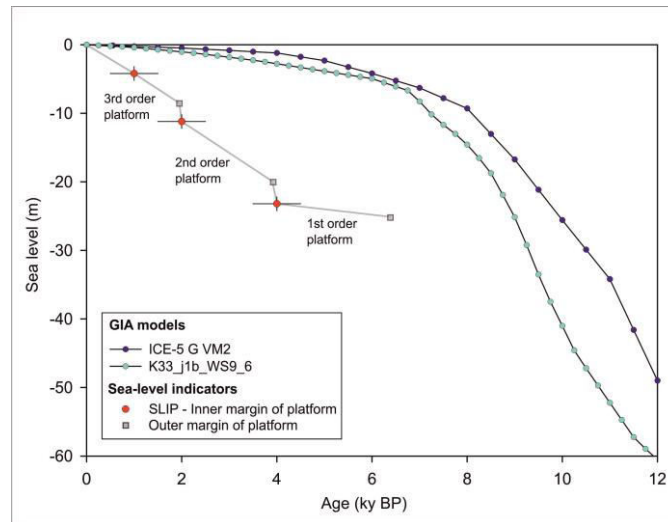
Figure 3. Comparison between the RSL data derived from the three orders of paleo-shore platforms and the GIA prediction for the Gulf of Naples (after Vacchi et al., 2019).

In particular, three retreating rate values of 0.33 m/yr, 0.61 m/yr, and 0.30 m/yr were evaluated for the time intervals ranging between 4.0/6.5 kyBP, 2.0/4.0 ky BP and 1.0/2.0 ky BP, respectively.
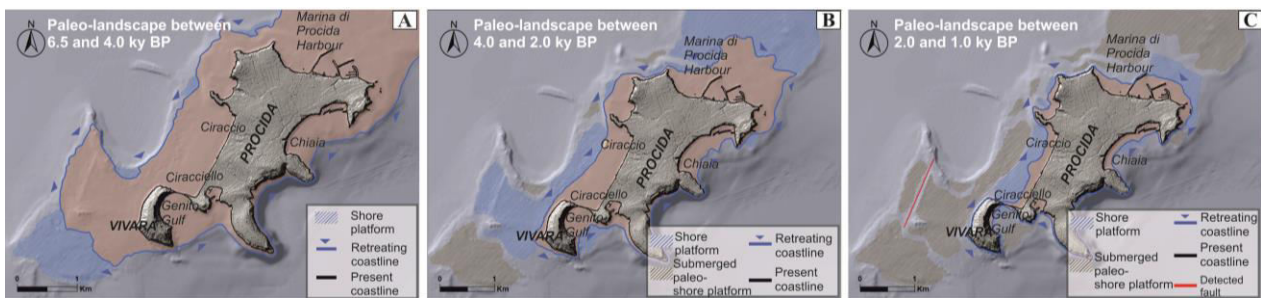
Figure 4. Morpho-evolution of Procida coastal sector since the mid-Holocene.

Conclusions

In this research, the morpho-evolutive trends of the Procida coastal area since the mid-Holocene were evaluated. For this purpose, three orders of submerged paleo-shore platforms were used as morphological markers of ancient sea-level stands. The geomorphological interpretation of these three orders of paleo-shore platforms, formed between 6.5 and 1.0 ky BP, provided the reconstruction of as many ancient shorelines.

In addition, the cliff retreat rates over the last 6500 years along the Cirraccio-Cirracciello and Chiaia sectors were evaluated. The precise mapping of these ancient platforms at various depths allowed establishing that an overall subsidence has certainly contributed to the polyphasic

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Holocene coastal evolution of the island, which was characterized by three main phases of relative sea-level stability (or strong decreasing in the rate of sea-level rise) that occurred during the last 6,5ky.

A volcano-tectonic origin, related to the activity of the Campi Flegrei volcanic area, can be assumed as the main cause of this subsidence, even if the analysis of remote sensing data demonstrates that the island is nowadays stable. The observed subsidence cannot be excluded that was influenced by the eruptions occurred in the CF area in the same span, anyway this issue needs further accurate evaluation.

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Mapping of Uplifted Marine Terraces on the East Coast of Messiniakos Gulf, Southern Peloponnese, Greece

*P. Christodoulou [1], **K. Tsanakas** [1], E. Karymbalis [1], D. V. Batzakis [1], M. Andreou [1], D. Papanastassiou [2], K. Gaki-Papanastassiou [3]*

(1) Department of Geography, Harokopio University, 70 El. Venizelou Str., GR-17671 Kallithea, Athens, Greece, panxr98@gmail.com, ktsanakas@hua.gr, karymbalis@hua.gr, mpatzakis@hua.gr, mandreou@hua.gr
(2) Institute of Geodynamics, National Observatory of Athens, GR-11810 Athens, Greece, d.papan@noa.gr
(3)Department of Geography and Climatology, Faulty of Geology and Geoenvironment, University of Athens, GR-15784 Athens, Greece, gaki@geol.uoa.gr

Introduction

Coastal regions above subduction zones are of great interest for studying the active tectonic processes at convergent plate boundaries, especially if the presence of suitable geomorphic markers allows the quantification of the deformation of the upper plate (e.g. Lajoie, 1986; Marquardt *et al.*, 2004; Pedoja *et al.*, 2011).

Palaeoshoreline indicators such as beachrocks, marine notches, benches, marine terraces and palaeostrandlines, which indicate the former shoreline positions, are among the geomorphic markers commonly used to determine rates and patterns of long-term rock uplift rates and tilting in tectonically active settings (Merritts and Bull, 1989; Mouslopoulou *et al.*, 2015).

Marine terraces are uplifted palaeoplatforms of marine origin that formed in the coast as flat and generally smooth surfaces that dip gently seaward. Their formation occurs in an overall regime of tectonic uplift. A marine terrace typically consists of two distinct surfaces: an abrasion ramp dipping gently seaward and an inland-bounding sea-cliff dipping seaward at the stable angle of repose. The junction between the roughly flat paleoplatform and its internal palaeocliff is called the palaeoshoreline angle (also called the inner edge of the platform) and it is here that a wave-cut notch may be preserved (Burbank and Anderson, 2007). The palaeoshoreline angle represents a marker that closely approximates the elevation of the local sea-level at the time of terrace formation, typically in sea-level highstands (Lajoie, 1986; Scott and Pinter, 2003). Hence this feature is an important palaeo-horizontal indicator that permits us to assess both tilting parallel to the coast and spatial variations in vertical motions of the crust.

In Greece, marine terraces are exposed in the southern coasts of the Gulf of Corinth (the Corinth Rift) as well as in several coastal regions along the emergent forearc of the Hellenic Subduction Zone such as the southwestern Peloponnese and the islands of Cephalonia, Kythera, Crete, Karpathos and Rhodes (Armijo *et al.*, 1996; Gaki-Papanastassiou *et al.*, 2009; 2011; Karymbalis *et al.*, 2013).

The aim of this study is to identify and map the uplifted marine terraces along the east coast of Messiniakos Gulf through Digital Elevation Model (DEM) analysis utilizing GIS techniques and extensive fieldwork.

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Study Area

The study area is located on the western coast of Tenaro Peninsula (Messiniakos Gulf) in south-central Peloponnese. It lies between Kitries, to the NW and cape Tenaro, to the SE Messiniakos Gulf is an asymmetric NW-SE neotectonic structure maintained since late Miocene - early Pliocene times (Papanikolaou *et al.*, 1988). The western slopes of the Gulf dip gently eastwards, while the eastern slopes are very steep, controlled by a NE-SW directed fault (Papoulia and Makris, 2004). It is the direct continuation of the continental slope from the trench to the Hellenic island arc (Peloponnesus, Crete, and Dodekannese). The study area is tectonically very active since it is situated approximately 50 km E-NE of the Hellenic subduction zone where the African tectonic plate is subducting beneath the Eurasian plate at a rate of ~36 mm a^{-1} (Reilinger *et al.*, 2006). The Hellenic subduction zone is the largest, faster and most seismically active subduction zone in the Mediterranean as revealed by earthquakes, seismic tomography and seismic reflection data (e.g. Wortel and Spakman, 2000). Rates of crustal motion offshore the Peloponnese and the Island of Crete, estimated from GPS measurements, are up to ~40 mm a^{-1} Kahle *et al.*, 2000). It is obvious that the geodynamic processes in the study area are related to the active convergent plate boundary hence the study area provides a first-order example of actively deforming continental crust situated in the forearc of a subduction zone.

The Mesozoic basement of the peninsula consists of geological formations of the relative autochthon geotectonic unit of Mani. The study area ismainly composed of crystalline platy limestone of Upper Senonian to Upper Eocene age, while small outcrops of meta-metamorphosed flysch formations occur at the southern part of the peninsula. Uplifted Pliocene marine sediments consisting of loose to semi-loose or cohesive marls, calcareous marls, arenaceous marls, marly clays and conglomerates overlie unconformably their basement at several sites of the area, filling some of the valleys of the streams that flow into the bays of Limeni and Mezapos.

Methodology

The detailed mapping of the distinct marine terrace surfaces and their inner edges has been carried out using both Geographic Information System (GIS) and field techniques (Tsanakas *et al.*, 2019). A GIS spatial geodatabase including various thematic layers (contour lines of 4 m, and 2 m or even 1 m in gently sloping areas, elevation points, drainage network, geological formations and faults) has been organized and implemented utilizing Esri ArcGIS 10. The main sources of these data were detailed analogue topographic diagrams at 1:5,000 scale, obtained from the Hellenic Military Geographical Service, the geological map of the study area, at 1:50,000 scale, published by the Institute of Geology and Mineral Exploration of Greece, a 5m cell size DEM obtained from National Cadastre& Mapping Agency S.A., and extensive fieldwork. The projection system was the Hellenic Geodetic Reference System 1987 (HGRS'87). GIS procedures produced secondary layers which include a hill-shade map, a slope and anaspect map which were necessary in order to delineate morphological discontinuities of slopes and the terrace surfaces. Additionally, the above-mentioned derivatives along with Google Earth and UAV imagery were visually inspected and interpreted in order to produce a preliminary morphographic sketch of the study area depicting marine terraces' surfaces and their inner edges (when possible). Extensive fieldwork was imperative for the validation of the initial output (morphographic sketch) and the production of the final output, the uplifted marine terraces' map.

The field survey focused on the spatial arrangement of the uplifted terraces and the accuracy of the inner edge elevation at specific locations. Field control was necessary to correct and validate marine terraces' maps/sketches drawn from the DEM analysis and Google Earth - UAV imagery interpretation. The entire study area was investigated verifying most of the uplifted marine terraces identified during the previous phase. Furthermore, a handheld Topcon GMS-2 differential global positioning system (DGPS), the accuracy of which is considered to be suitable for 1:5,000 scale field surveys, was used in order to mark waypoints for the precise location of the inner edges that represent former shorelines. During the post-field survey mapping phase, the existing GIS database was integrated with the GPS data and a comparison of field and remote sensing mapping data took place in order to validate the initial map of the marine terraces sequence and proceed to the production of the final maps. The final maps depict a series of relatively well-defined marine terrace surfaces grouped according to the elevation range of their inner edges. The above-described methodology allowed us to map the faults of the study area as well as other landforms such as gorges and deeply incised valleys, alluvial cones etc.

Results and Conclusions

The application of the mapping techniques along with observations in the field led to the identification of a sequence of thirteen uplifted marine terraces along the southeastern coast of the Messiniakos Gulf, between Kitries and cape Tenaro, with the elevation of their inner edge ranging between 3-6±2 m for the lowerand 397-464±2 m for the higher palaeoplatform. A map of the marine terraces, numbered T1-T13 starting from the highest and oldest towards the youngest and lowermost, is presented in Figure 1a. Most of them are characterized by well-preserved wave-cut surfaces mainly carved on crystalline limestone. The lateral morphological continuity of the marine terraces is interrupted due to the fluvial incision caused by the recent tectonic uplift. Stream channel downcutting has led to the formation of deep V-shaped valleys and gorges that dissect the marine terraces' surfaces.

The lowest terrace (T13) is a clearly defined abrasion platform, at the base of a cliff, observed along a significant part of the coastline of the study area. It is indicative of recent coastal uplift. The flight of marine terraces implies tectonic uplift of the western part of the Tenaro Peninsula during the Quaternary due to the proximity of the area to the active margin of the Hellenic subduction zone. An additional cause of the tectonic uplift of the area is the activity of a normal fault located offshore west of the peninsula, towards the subduction zone, having an N.NW-S.SE direction and dipping to the west. The submarine neotectonic map of Messiniakos Gulf (Papanikolaou *et al.*, 1988) shows that this fault is in fact the prolongation of a major N-S oriented fault on land, separating the neotectonic Plio-Quaternary sedimentary basin of Kalamata to the west from the Alpine outcrops of Taygetos Mountain to the east. The submarine fault zone consists of two branches: an upper one, of 12 km length, N-S oriented, and a lower one, running in a NW-SE direction. Both branches strike parallel to the coastline and affect the landscape of the western part of the Tenaro peninsula.
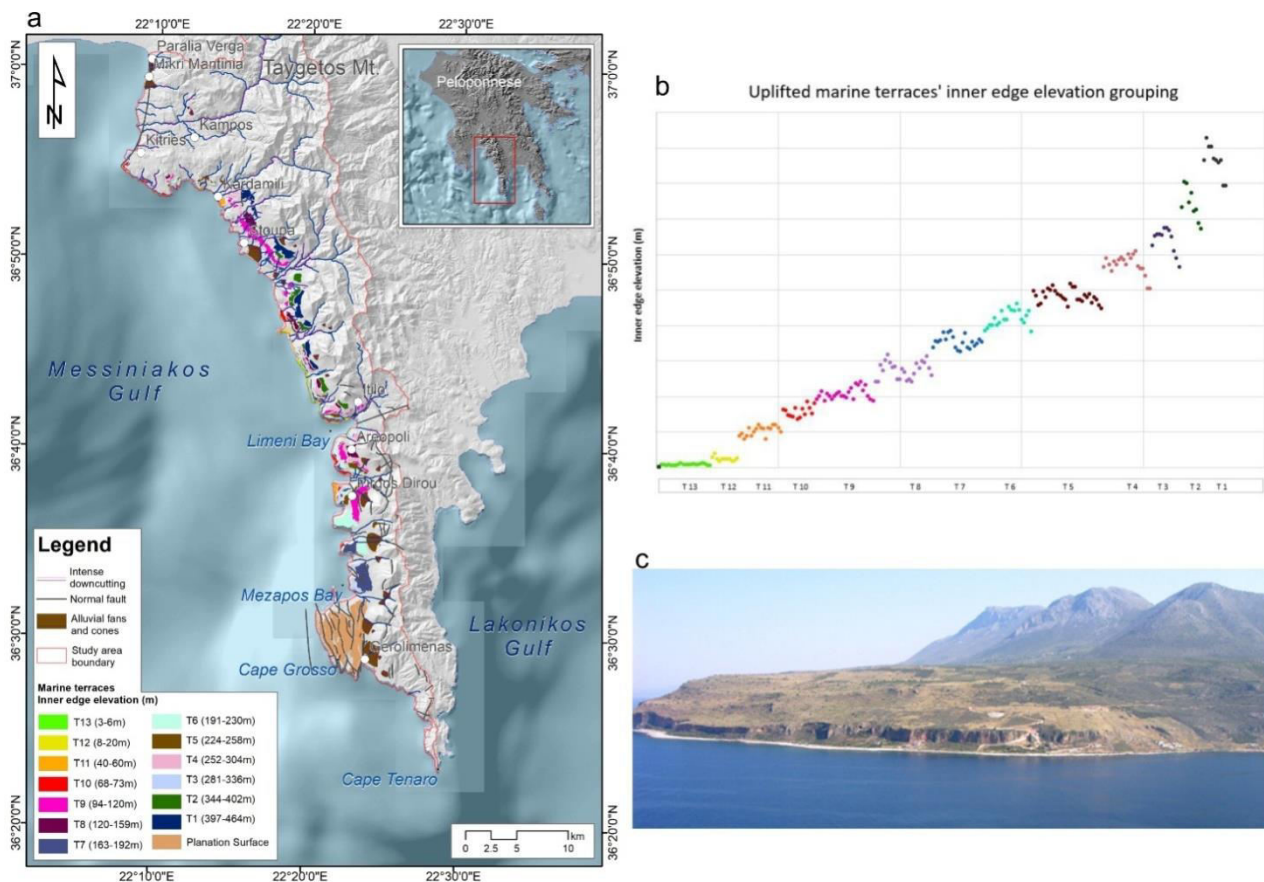
Figure 1. a) Map of the uplifted marine terraces of the study area. b) Scatter plot of the inner edge elevation (in meters) of each marine terrace surface outcrop along the coast of the study area. This diagram was useful in grouping the surfaces according to the elevation ranges of their inner edge. c) Field view of the marine terraces at Limeni Bay, towards the west.

The surfaces of the higher marine terraces (T1, T2, T3 and T5) are wider than those developed at lower elevations, whereas a plot of the elevation of the inner edges of each terrace surface outcrop shows clearly a lowering towards the south especially for the higher terraces (T1-T5) (Figure 1b). This observation along with the fact that there are no marine terraces at the southern part of the peninsula (between Cape Grosso and Cape Tenaro) indicates that the southern part of the area is being subsiding. The same can be concluded from the absence of the lowermost marine terraces T13 and T12 south of Cape Grosso. This finding is in agreement with the results of the research of Kelletat *et al.* (1976) which point out a continuous uplift of more than 400 m during the Quaternary in the northwestern part of the peninsula till Kardamili and a long-lasting subsidence of its extreme southern part except of the Cape Grosso peninsula which rose to about 300 m during the period of Upper Quaternary. The tectonic subsidence of the southern part of the peninsula is also evidenced by the presence of submerged ruins of the ancient town Kainipolis (flourished at the 3rd century B.C) near Kyparissos village. It is worth mentioning that along the western coast of the Grosso peninsula, beaches corresponding to the previous interglacial period (5e OIS) are not significantly uplifted, but are located just above sea-level covered by scree deposits of the last glacial period. This observation implies that either the offshore fault is not

active for the last 100.000 years or that it is connected with the subduction zone and with a downward movement is affecting the area.

Future work includes dating of at least one of the uplifted palaeoplatforms in order to correlate the marine terraces of in space and time and to estimate the long-term uplift rates along the western coast of the Peninsula during the Quaternary.

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A Mineralogical and Geochemical Cement Study of a Beachrock Slab: The Case Study of Peristeria, Salamis Island

G. Saitis [1], E. Koutsopoulou [2], N. Evelpidou [3], S. Kawasaki [4]

(1) National and Kapodistrian University of Athens, Panepistimioupoli, Athens, Greece, saitij@geol.uoa.gr
(2) Institute of Geology and Mineral Exploration, Acharnes, Athens, Greece, ekoutsop@upatras.gr
(3) National and Kapodistrian University of Athens, Panepistimioupoli, Athens, Greece, evelpidou@geol.uoa.gr
(4) University of Hokkaido, Kita 8, Nishi 5, Sapporo, Hokkaido, Japan, kawasaki@geo-er.eng.hokudai.ac.jp

Introduction

Beachrocks are consolidated sedimentary formations and are composed of coastal sediments, which are cemented through the precipitation of carbonates. The lithification takes place in the intertidal zone and can include various sediments, such as sands and gravels of clastic and biogenic origin. This study deals with the cements' mineralogical and geochemical features of a beachrock outcrop and its aim is the contribution for further understanding on the cementation process of beachrocks. (e.g. Vieira and Ros, 2007; Vousdoukas *et al.,* 2007; Karkani *et al.,* 2017).

Study Area

The site of study is a beachrock outcrop at Peristeria area of Salamis Island which is located at the southeast of the island, 13 km from the city of Salamis (Figure 1).
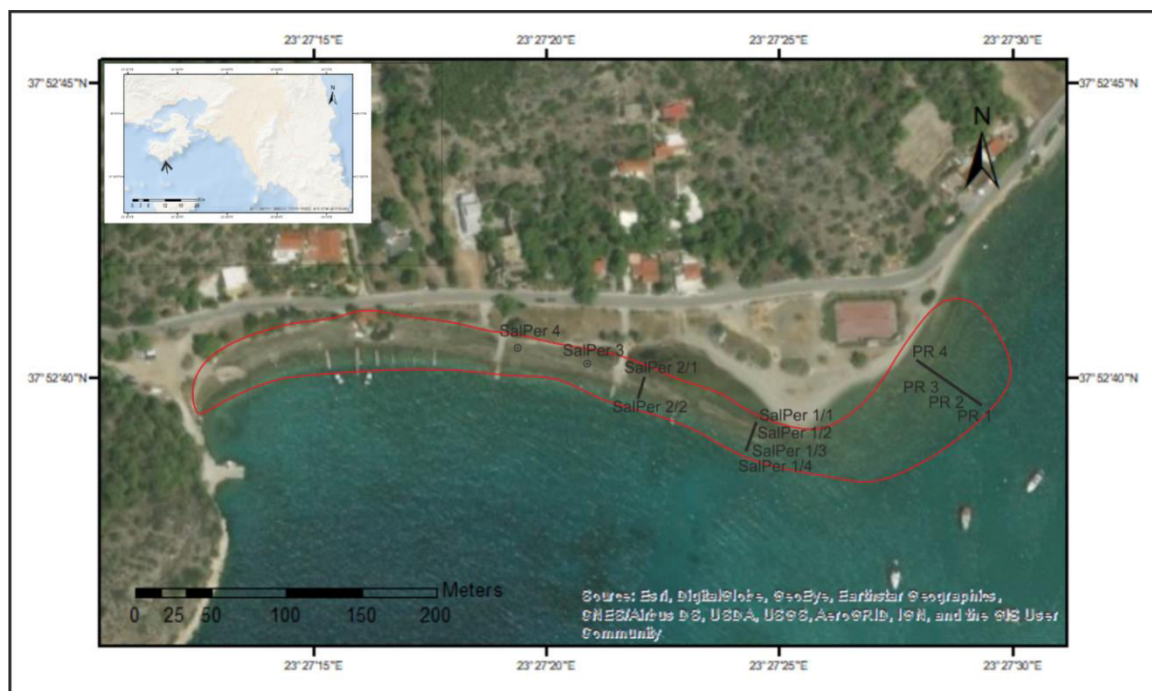
Figure 1. The red circled area indicates the beachrock slab; the lines indicate the morphological cross sections and beachrock samples (code SalPer and PR).

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In the coastal area a stream that provides fresh water. The anthropogenic impact is highly evident as there are a number of constructions (basketball court, small piers). The beach has an orientation from East to West and its sediment is characterized as gravely sand. The beachrock slab covers an area of 1.36 km^2 with a length 453 m and maximum width of 50 m (Figure 1). The examined beachrock has a mean dip of 13.5^o seawards.The beachrock mean height (from sea level) is 50 cm and it continues at about 1.5 m below sea-level. The outcrop has no evidence of vertical to shoreline (channels) erosion but a sea intrusion at its Eastern part. There the sea erodes the beachrock from the landward part and Contributes to new sediment accumulation.

Methodology

The fieldwork detailed mapping of the beachrock slab was performed measuring width, height/depth with respect of the sea level. Additionaly, 12 samples were collected derived by the front and the end of the slabs and sediment bedding. Thin sections were prepared from the beachrocks and samples were studied for their mineralogical and morphological features with a petrographic polarized microscope and confirmed with Scanning Electron Microscope (SEM). Additionally, bulk material was examined for the mineralogical and geochemical composition with X-Ray diffraction (XRD) and Energy Dispersive X-ray Florescence Spectroscopy (XRF).

Results and Discussion

From the analysis of the beachrock samples, High Magnesium Calcite [(Ca,Mg)CO$_3$] cement in micritic form is most common (7% wt of MgO in samples) with microfossils. Sparitic formation of cement indicated a well grown crystallization or cement precipitation in the meniscus of sediment by mixing sea water and fresh ground water with higher influence by the marine phase. During the polarized and scanning electron microscopy needles of aragonite have been also observed which reveals a low energy coastal environment. Peristeria beachrock mineralogy is evenly distributed between Mg-calcite, Quartz and Calcite. SEM and XRD analysis also revealed the participation of clay minerals in the matrix cement in full accordance with the mineralogical results that showed the presence of clay minerals in the beachrocks (Figure 2).
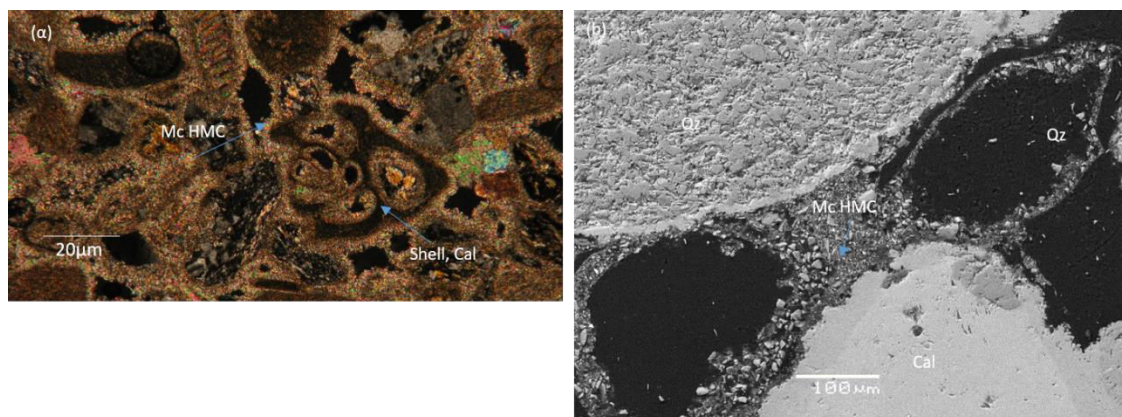
Figure 2. a) Polarized microscopy, the samples are characterized by micritic and sparitic HMC cement that coat Quartz and shell fragment. (b) SEM analysis, micritic cement coat Calcite and Quartz grains and matrix of HMC and fine particles (e.g. clay minerals) cement, are observed.

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Conclusion

The Peristeria beachrock outcrop has a very compact and thick morphology with a variety of sediment particles. An alternation in precipitation events seems to have taken place which initiates with a mixed environment of sea water and fresh ground water, was later succeeded with a period of saturation from sea water and lastly with a mixed sea/fresh water environment. The prevalence of the sea water influence in the precipitation of the cement could be due to a sea-level rise, for a time period, and then followed by a sea-level retreat.

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Seafloor Structure of the Argostoli Gulf (W. Cephalonia).

Aik. Giannikopoulou [1], S. Harris [2], N. Evelpidou [1], S. Poulos [1]

(1) Departmentof Geography and Climatology, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, Panepistimiopolis, Zografou, Athens 15784, Greece, _katagiann@geol.uoa.gr_
(2) Department of Geology and Environmental Geosciences, School of Sciences and Mathematics, College of Charleston, 66 George Street, Charleston, SC 29424, USA

Introduction

Marine environment acoustic methods and devices are used to map the seafloor and to obtain information used to investigate the seafloor and its features (Micallef, 2018). Data acquired with single-beam echo-sounder are used to produce hydrographic maps. Side-Scan sonar backscatter imaging, contrasted surfaces and pattern depiction, reveal topographic features, textural differences and artifacts on the seabed (Blondel, 2009). High resolution chirp sub-bottom profiles (seismic reflection data) provide insight about near-surface geological and geomorphological features, as the reflection surfaces on seismic images may correspond to sediment sequences, lithological boundaries or faults (Boggs, 2014; Crutchley and Kopp, 2015).

The scope of this work is the investigation of the seabed topography and texture and the upper Quaternary stratigraphy of the northern (Livadi bay) and southern (Argostoli bay) parts of the semi-enclosed shallow embayment of Argostoli Gulf, in Cephalonia Island. The island is located in the Ionia Sea, along the northwestern edge of the Hellenic Trench, which is a highly active seismo-tectonic area, subjected to long-term uplift (Stiros _et al._, 1994, Karymbalis _et al._, 2013, Briole _et al._, 2015). The surrounding geological formations at the Argostoli Gulf include mainly limestones, alluvium and conglomerates, while the hydrographic network of the wider area is underdeveloped (Hunter, 2013).

Methodology

The methodologies used in the framework of the present work include:

- Fieldwork: Bathymetric data were collected with 200-kHz single beam profiles. Subbottom profiling data were collected with an Edgetech 216s chirp SBP (2-10 khz at 4Hz). Sidescan sonar data were collected with a 430-470 kHz chirp system. An area of 3.04 km^2 and of 6.6 km^2 was covered of Argostoli and Livadi bay respectively. Also 13 surface sediment samples were collected from Argostoli and 16 from Livadi. Four more samples along the shoreline were collected from Livadi area.

- Post - processing of the bathymetric data and the sonar images was conducted with the combined use of Chesapeake Tech SonarWiz 7, Sonar Viewer, and Arcmap software.

- Laboratory analyses: Grain size analysis conducted with dry sieving method (coarse – grained material) and laser multi-sizer (fine-grained material, <0.0625 mm). The statistical grain size analysis and textural classification (according to Folk's classification system) were calculated

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using the GRADISTAT program (Blott *et al.*, 2001).

Results

Results on Sea bed texture: Inspection of the side scan sonar mosaics from Argostoli and Livadi bay, led to the conclusion that high backscatter values indicate sloping surfaces facing towards the towfish and topographic elevations, marine vegetation and fish schools, coarse sediments, rocks and human structures. Low backscatter values, on the other hand, are indicative of a) sloping surfaces facing away from the towfish and topographic depressions, fine-grained sediments, shadows of high features. In Argostoli bay sediments of the seafloor and local topography are highly disturbed by anthropogenic activities, reflected by the mixed high-low backscatter area along the central portion of the bay (noted with question marks).
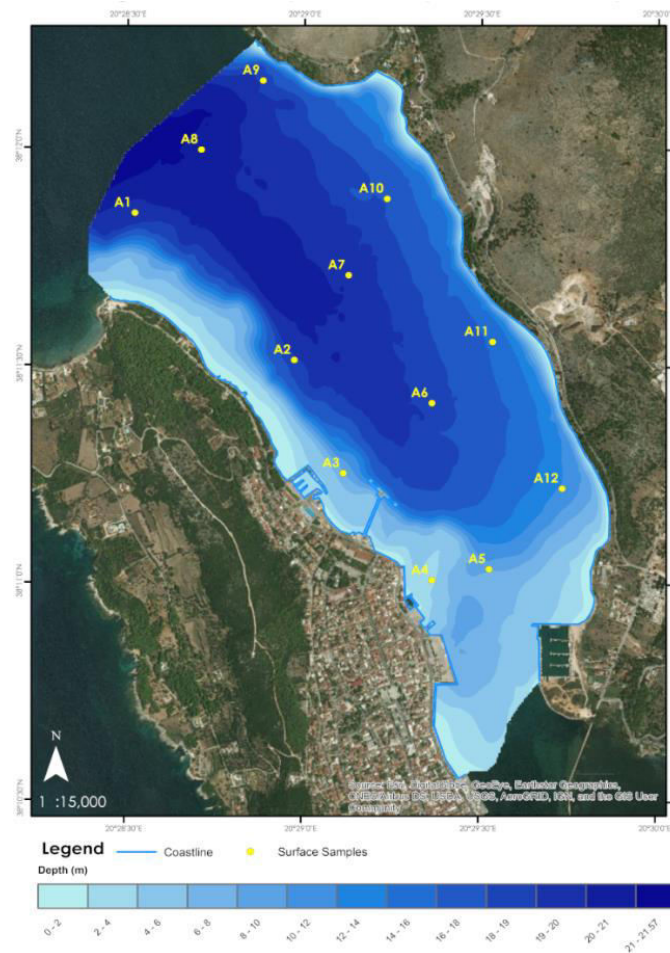
Figure 1. Bathymetric map of Argostoli bay. Position of surface samples are indicated with yellow dots.

Results on Grain Size Analysis: Locations of the Argostoli bay samples are depicted in Figure 1. Most deep samples (>12 m) are classified as silty to silty sandy. All the sediments are generally poorly sorted. Textural classification and sorting values are considered to be reflective of the low energy marine conditions within the bay. Locations of the Livadi bay samples are depicted in Figure 2. Marine sediments are generally more fine-grained than coastal samples. Samples located

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in <3 m depth are well sorted, in contrast with those located in >3 m depth that are very poorly to poorly sorted. These results suggest that the depositional environment along the north western coastline is affected by typical coastal processes, while the inner part of the bay corresponds to lower energy conditions.
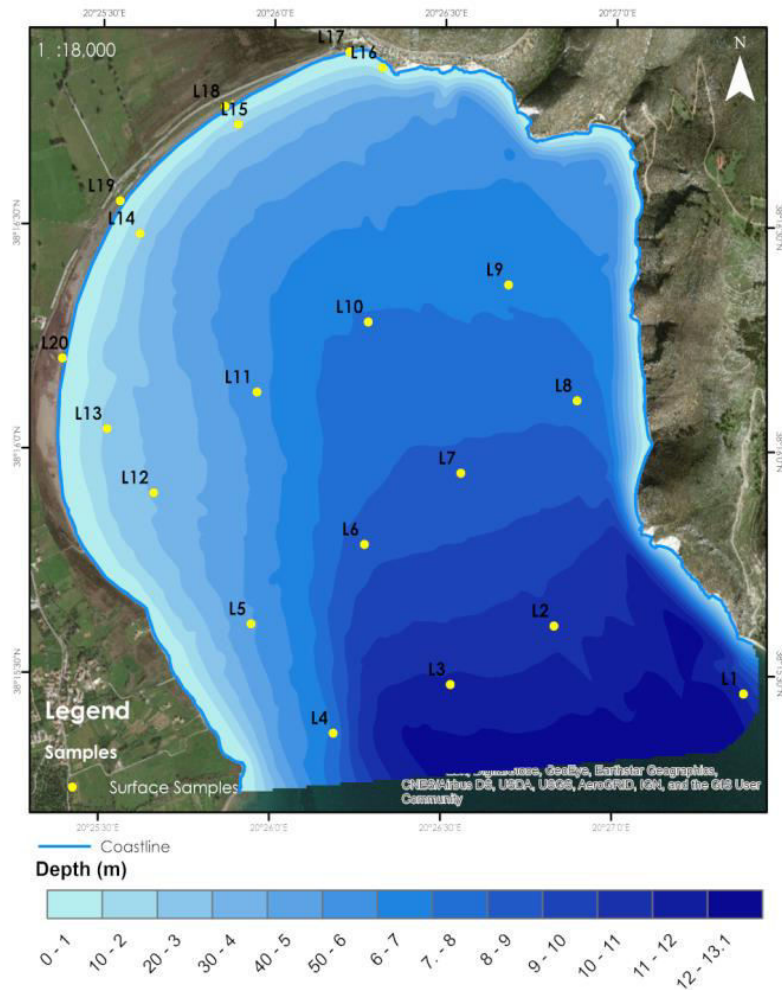
Figure 2. Bathymetric map of Livadi bay. Position of surface samples are indicated with yellow dots.

Results on Subbottom stratigraphy: In the subbottom profiles of Argostoli bay (Figure 3), the high amplitude horizontal reflection surface R1 is interpreted to be the area's base reflector and is thought to represent an erosional palaeosurface, previously exposed to subaerial conditions. Unit U1 onlaps R1 and is characterized by stratified layers, continuous, parallel reflectors. It is interpreted to be a Holocene depositional sequence. U1 corresponds to generally stable and homogenous conditions during sedimentation in the basin. On all seismic profiles of the area of Livadi the main distinguishable feature is the presence of high amplitude reflection surfaces that cause acoustic blanking, which is attributed to the presence of gas in the shallow sediments. Acoustic windows allow the appearance of inner parallel, horizontal – sub-horizontal, continuous reflectors of medium amplitude. In combination with the results of Hunter (2013) study, it is deducted that these layers are part of the same sequence (U1) as the one identified in Argostoli bay.

Conclusions

Examined characteristics of the surface sediment samples reflect the low energy conditions that characterize both areas. Sub bottom profiles revealed a main sedimentary sequence, laying on top of the acoustic basement of the profiles, marking a time boundary for marine transgression in the area. The configuration of the identifid sedimentary sequence corresponds to generally stable and homogenous conditions during sedimentation in the basin.
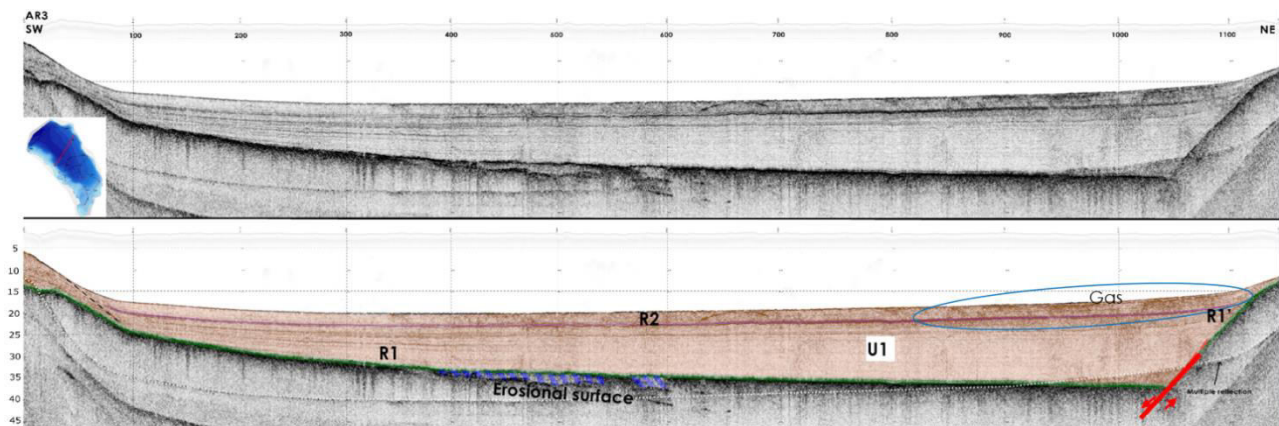
Figure 3. Argostoli bay profile AR3 (length 1.14 km). Vertical and horizontal axes are in meter scale. Gas accumulation, near NE, is circled, surfaces R1 and R1' are noted with green color and high amplitude reflector R2 is indicated with a purple line, representing high energy transported sediments. Blue dashed shade marks visible features under R1 surface. They are indicative of erosional action. Holocene sedimentary sequence U1 is shaded in orange. Black dashed line marks the point that differentiation in internal reflectors configuration of U1 unit occurs. Red dashed line U1 thickness reaches a maximum of ~20 m. The anaglyph of Argostoli bay in combination with morphological features of the R1 surface, to the NE, identified in the subbottom profiles (AR3, AR5 and AR5) indicate the presence of a normal fault along the eastern side of the bay.

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Is the Tsunami-Related Disappearance of the Ancient Helike a Reality or a Myth? The Role of Geology

I. K. Koukouvelas [1]

(1) Department of Geology, University of Patras, 26500 Patras, Greece, iannis@upatras.gr

25 centuries ago an earthquake caused the destruction of ancient Helike in 373 BC. This is reported by ancient Greek and Roman historians. The strong earthquake and an accompanying sea wave(s) (tsunami) destroyed and submerged Helike according to these sources. Between 1950 and 1973 the famous archaeologist Marinatos made several attempts to bring to light Helike with inconclusive results. Nevertheless, he considered a complex process including the effect of an earthquake and a tsunami that demolished the city, in addition to the role of rivers in an active geological environment later on. The role of the rivers considered as crucial for the burial of the ancient capital city of the Achean Dodecapolis under fluvial deposits.

This work is a review of long work in the area and a new approach to the destruction of the Ancient Helike. These results are based on the 20 years long geoarchaeological project which was accompanied by archaeological excavations. This work evaluates the exact role of the earthquake and the accompanying tsunami along with floods acting in the north Peloponnese. The results are summarized as follows. The disaster of Helike appears to be related with a strong earthquake followed by a destructive mudflow generated by breaching of a landslide-dammed lake in the hilly area south of the ancient Helike. Further flooding of the city territories from the west strengthens the hypothesis of heavy rain after the strong earthquake. The ancient city has been demolished during a cascading series of disasters such as mudflows and floods from inland rather than from a tsunami from the sea.

From Traditional to Modern "Full Coverage" Geomorphological Mapping: Advantages and Perspectives

M. Bufalini [1] _, M. Materazzi_ [1]_, M. De Amicis_ [1]_, G. Pambianchi_ [2]

(1) School of Science and Technology, Geology Division, University of Camerino, Via Gentile III da Varano 7, 62032 Camerino, Italy, margherita.bufalini@unicam.it, marco.materazzi@unicam.it, gilberto.pambianchi@unicam.it
(2) Earth and Environmental Sciences Department, University of Milano-Bicocca, Piazza dellaScienza 1, 20126 Milan, Italy, mattia.deamicis@unimib.it

The present work aims to contribute to the modernization process of traditional geomorphological maps, which is becoming an increasingly fundamental tool for the evaluation of the level of hazard of natural processes (landslides, floods, etc.). The geomorphological maps are also present in urban planning activities, for the management of environmental resources and landscape zoning; they are also a preliminary analysis for land management projects and geological risk assessment. Despite this, geomorphological maps have not always managed to assume the role of mandatory and preparatory tool for any action and decision on the territory.

The "traditional" cartographic approach (symbols) is not fully suitable to provide a complete and dimensionally correct representation of the complexity of the physical landscape (landforms deposits and processes) at the various scales (Dramis _et al._, 2011). In the area of application, many disciplines (engineering, hydrological-hydraulic, agronomic, ecological, etc.) require that a modern geomorphological map is also oriented towards a "quantitative" and not only descriptive-qualitative use of the forms of deposits and processes represented (Klimaszewski, 1982; 1990; Ten Cate, 1990; Gustavsson _et al._, 2006; Dramis _et al._, 2011).

In this context, GIS tools are very effective for the management of spatial data sets needed for geomorphological analysis, research and practical applications (Butler and Walsh, 1998). Nevertheless, traditional geomorphological maps cannot be easily used within a GIS because they have to be transformed into classified polygonal maps before digitization (van Westen _et al._, 2003; Cantuni _et al._, 1987; de Graaff _et al._, 1987). If experience-based conversion rules could be formulated, the information contained in these classic geomorphological maps must be converted into functional GIS geomorphological databases, which can then form the basis for further GIS-based analysis.

In this work, a methodology has been applied that has allowed to have a complete coverage of the territory, according to the directive of the working group, formed by ISPRA and AIGEO ("Quaderno 13" - ISPRA, 2018). At the same time, a morphological analysis has been applied starting from LIDAR and DTM data to define the limits of geomorphological units. This was necessary in the absence of an official national BTU (Basic Topographic Units) map, which will be carried out by ISPRA in the coming years.

The new geomorphological map model proposed here is placed in an intermediate position between "traditional" geomorphological cartography, based essentially on field surveys, and semi-automatic methods, based on the recognition of earth shapes by a DTM (Dramis _et al._, 2011; De

Reu *et al.*, 2013; Seif, 2014; Abdullah and Abdulrahman, 2019). This model is a hierarchical multiple-scale type, where the entire topographic surface is represented in terms of forms and their deposits. The term "hierarchical" means that all the geomorphological elements represented are organized in terms of "nested entities" (polygons, lines and points) supported by a list of attributes. Moving upwards to smaller scales, polygons can turn into lines or symbols; moving downwards, symbols can turn into lines or polygons, lines can turn into polygons and polygons can be divided into smaller characteristics. This is a typical "scale-dependent" rendering.

In a detailed geomorphological map, the highest level (level +1) is represented by the so-called "BTU" (Basic Topographic Units), derived from medium-high resolution DTMs (pixel resolution from 30m-SRTM and 1m-LiDAR). The BTUs, in this work, were determined using the GIS procedure developed by Weiss (2001) (Figures 2a; b) and based on the semi-automatic classification of TPI (Topographic Position Index, as defined by Gallant and Wilson, 2000). This procedure and its algorithm, improved by Jenness (2006) in the ESRI-GIS environment, has been tested in many environmental science fields (among others Tagil and Jenness, 2008; Liu *et al.*, 2011; Clark *et al.*, 2012; De Reu *et al.*, 2013, Seif, 2014). Thus, using a simple algorithm (whose tool and instructions can be freely downloaded with the author's permission at http://www.jennessent.com/arcview/tpi.htm), Jenness (2006) demonstrated that using two TPI grids at different scales (with large and small neighborhoods) it is possible to classify the landscape into ten morphological classes (Figure 2c).
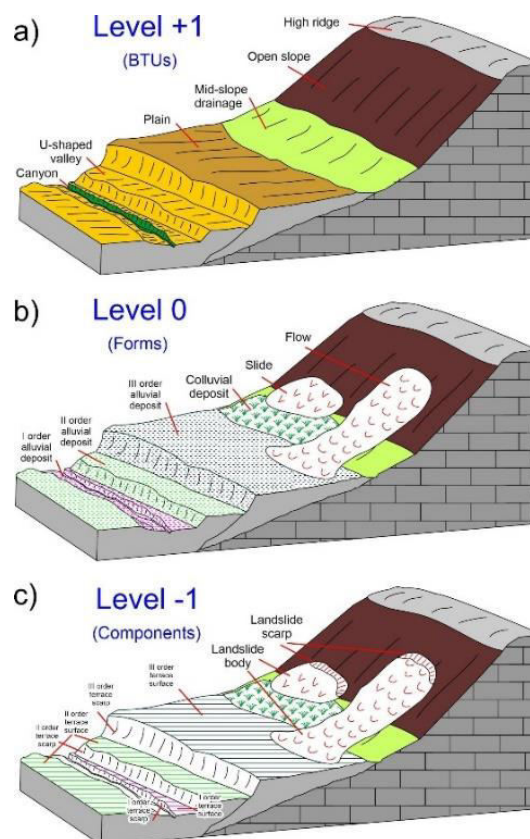
Figure1. Hierarchical levels and "full coverage" concept (from Bufalini et al., 2020, submitted).

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Through an iterative procedure, the TPI neighborhoods (small and large) have been varied to find the best correspondence between the "landforms" obtained by the method and the real morphologies visible on a DEM.

The method has been tested on three DTM with different details (SRTM-30m cell-size, TINITALY-10m cell-size and LiDAR-1m cell-size), to verify also the presence of a possible relationship between the neighborhoods and the pixel resolution.
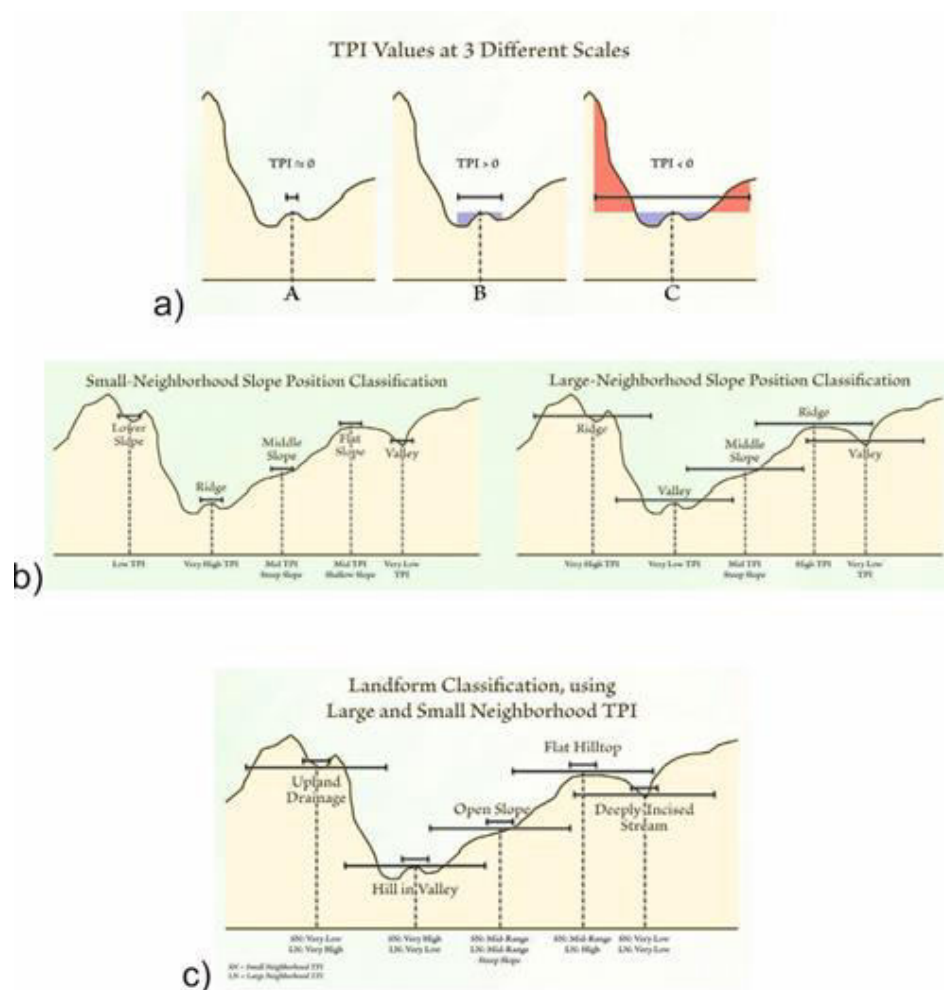
Figure 2. TPI (Topographic Position Index) semi-automatic landform classification. a) TPI at three different scales (Jenness, 2006): A is very small scale it is kind of plain area; B is moderate scale is kind of small hill and C is very large scale it is a kind of valley. b) Slope Position Classification. Weiss (2001) demonstrates one possible classification process using both TPI and slope to generate a 6-category Slope Position grid. c) Landform Classification can be determined using 2 TPI grids at different scales.

The most exhaustive results were obtained using the following combinations: SRTM (small neighbourhood = 10m; large neighbourhood = 40m); TINITALY (small neighbourhood = 7m; large neighbourhood = 45m) and LiDAR (small neighbourhood = 5m; large neighbourhood = 50m). It is interesting to note that there is an almost linear relationship between the ranges (small and large

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neighborhoods) and the resolution of the DTM itself; an increase in resolution generally corresponds to an increase in range.

The proposed methodology certainly offers considerable advantages over traditional cartography.

First of all, the use of a GIS system and a database of georeferenced attributes make this cartographic tool extremely dynamic and able to store and update multiple types of information, which can be subsequently filtered on request. Secondly, the subdivision into hierarchical levels allows a more rational use of geomorphological processes and represented landforms; more detail is fundamental for design purposes, while less detail is more functional to spatial planning studies or hydro-geomorphological risk assessment. Finally, a "complete coverage" allows to have topographical, geological, geomorphological information in every point of the map, regardless of the scale of visualization.

Compared to a traditional cartography, as well as in reality, it is possible to find a "foundation" (geological or simply morphological) in every geomorphological form. The limits of the method, however, are essentially linked to two main aspects, both of which can be traced back to the definition of BTUs.

In conclusion, a "full coverage" geomorphological map, as highlighted in this work, can represent the synthesis between two models of cartography that the scientific and professional worlds have so far adapted only to their needs. In particular, the hierarchical model proposed here allows to reconcile the needs of those who require information of high detail and application type with those who need to maintain canons and rules of an official cartography, structured on a national scale.

In this regard, it should be noted that the advantages of this approach are undoubted: (i) the use of a cartographic system structured and managed within a Geographic Information System (GIS) that allows to work by hierarchical levels and nested entities, thus representing all the elements constituting a typical geomorphological "form" (landslide, alluvial terrace, etc., (ii) The possibility to collect a lot of information and to organize and visualize it in different details, depending on the use and scale of representation, (iii) The possibility to have a "dynamic" cartography, suitable to be continuously updated and implemented with new information.

While, the main problem is essentially related to the definition of BTUs; since a high-resolution DTM (LiDAR) is often not available for the whole national territory, it becomes very difficult to define this level within an official cartography.

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Estimating Potential Evapotranspiration in Mountain Environments: A Case Study in Central Appennines, Italy

G. Matteo [1], _P. Gilberto_ [1], _M. Marco_ [1]

(1) University of Camerino, School of Sciences and Technology, Piazza dei Costanti 4, Camerino, Italy, matteo.gentilucci@unicam.it, gilberto.pambianchi@unicam.it, marco.materazzi@unicam.it

Introduction

Potential evapotranspiration is an important environmental monitoring tool, as it has a great influence both on water resources and on agriculture and vegetation in general. The calculation of potential evapotranspiration (ET0) in mountain environments is very important because the water recharge is greater in these places, due to the magnitude of the atmospheric phenomena, but at the same time it is much more complex to estimate the ET0, compared to other environments. This happens because the formulas developed for the ET0 calculation, are calibrated to be suitable for the most common environments, it follows that under "extreme" environments they may be less accurate. The method considered most reliable by the scientific literature is the simplified Penman-Monteith (sPM) (Allen _et al._, 1998), which has also been chosen by FAO as reference, the sPM is a simplified variant of the complete Penman-Monteith (PM). These equations require many parameters that are not always available, especially in high mountain weather stations, so there is a need for generalizations that give true results, using less data such as the Hargreaves-Samani method (HS). The HS needs only temperature data (maximum, average and minimum) to be estimated, however some studies carried out in mountain environments have highlighted a certain inaccuracy of this method (Almorox _et al._, 2018). Other studies have shown an overestimation of the HS method in mountain environments, in comparison with what observed with sPM (Yang _et al._, 2013), while further studies have revealed a significant underestimation (Garcia _et al._, 2004). On the basis of these considerations, it would be interesting to clarify the reliability of the ET0 calculation methods in a mountain environment. Therefore, the aim of this work is to assess whether the sPM method is the most reliable method for estimating ET0 on the mountain weather stations of the central Apennines, central Italy, or whether other methods requiring less data can be employed.

Methods

Climate data are crucial for the estimation of ET0 in mountain environments, but sometimes they are incomplete and of low quality, so that a very invasive validation process is required. Data from weather stations, for the time span 2010-2020, were collected through the databases of the "Multiple-Risk Functional Centre of the Civil Protection of the Marche Region". In this context the sPM method requires the sampling of some variables such as: solar radiation, humidity, mean wind speed and mean, maximum and minimum temperature. These variables have been collected from 2 mountain weather stations: Monte Bove (1917 m a.s.l.), Monte Prata (1813 m a.s.l.). The data were organized to obtain daily values and an accurate quality control has been set up for

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each individual variable, in order to check its real realiability. Four levels of daily data analysis have been established (Gentilucci *et al.*, 2018; WMO, 2008):

1. Gross error checking - detection of impossible values in absolute terms and in relation to the reference climatic zone.

2. Temporal consistency (Aguilar *et al.,* 2003) - control of persistence and control of maximum variability between continuous days.

3. Spatial consistency - control of the measured values based on the reciprocal variability between neighbouring weather stations, 4 other weather stations (Camerino, Macerata, Pintura di Bolognola, Tolentino) were used for this analysis.

4. Homogeneity test - in order to check if there is any inhomogeneity in the historical time series, due to the lack of instrument calibration or to the weather station displacement.

The validation procedure highlights systematic errors detected for both weather stations, with regard to the solar radiation parameter. The data collected showed a considerable overestimation, after an appropriate comparison with the HELIOSAT (SARAH) satellite data:

- Monte Bove from 2010 to 2017 (period of availability HEOLISAT data) had an average daily measured solar radiation of 15.2 MJ/m^2, while the average measurement from the satellite was 12.4 MJ/m^2.

- Monte Prata from 2010 to 2017 had an average daily measured solar radiation of 15.8 MJ/m^2, while that of HELIOSAT (SARAH) was 13.2 MJ/m^2.

It follows that the data collected have been corrected, homogenizing them with HELIOSAT-SARAH data. Then the ET0 was calculated on the basis of the characteristic equations for each of the 3 chosen methods:

1. Complete Penman-Monteith (PM), $ET_0 = \frac{\Delta(R_n - G) + \rho c_p (e_s - e_a)/r_a}{\Delta + \gamma(1 + r_c/r_a)}$ (Jensen *et al.*, 1990)

2. Simplified Penman-Monteith (sPM); $ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{C_n}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$

3. Hargreaves-Samani (HS); $ET_0 = 0.0023 * 0.408 * R_a * \left(T_{mean\,daily} + 17.8\right) * \left(T_{Max\,daily} - T_{daily}\right)^{0.5}$ (Hargreaves, 1994)

Therefore, while the differences are evident between HS method and the other two, as HS uses almost exclusively the temperature parameter; instead the differences between PM and sPM consist of an approximation of the vegetation coefficient for the simplified method. The use of the standardized values for C_n and C_d, valid only for the presence of a 12 cm grass cover is adopted by the sPM equation, while the PM changes the parameters in relation to the effective ground cover status. In the case of two mountain weather stations as Monte Bove and Monte Prata, located at 1917 and 1813 m, the vegetation cover is fundamental because, in fact they show a bare soil throughout the year, detected calculating the NDVI index, from satellite images (SENTINEL and LANDSAT).

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Results

The daily ET0 of the mountain weather stations (Monte Bove and Monte Prata) was initially calculated using the sPM method. The parameters of the sPM method were calculated separately, following a procedure consisting of several steps (Zotarelli *et al.*, 2010), and they were subsequently merged into the sPM equation (2). Subsequently, the same daily calculation of ET0 was carried out using the HS method and finally with the PM method after the appropriate assessment of the actual vegetation cover. The results have been reported at annual level in the table 1 for both weather stations.

Table1. Annual ET0 for Monte Bove (MB) and Monte Prata (MP), with the 3 different methods sPM, HS, PM.

ET0	MB - sPM	MB - HS	MB - PM	MP - sPM	MP - HS	MP - PM
2010	547.6	519.5	518.5	583.2	540.0	560.7
2011	664.1	551.5	557.7	687.3	572.2	594.9
2012	680.3	578.7	572.0	747.0	604.3	608.4
2013	565.6	521.1	516.4	615.4	545.4	558.4
2014	497.8	503.8	492.9	554.0	559.3	556.4
2015	651.8	559.4	540.3	629.0	572.4	577.7
2016	613.7	570.0	577.3	586.2	547.2	545.8
2017	713.6	642.5	649.8	717.6	618.9	620.7
2018	534.1	555.3	594.3	606.6	587.9	605.2
2019	650.1	562.2	614.0	679.5	589.7	634.5
Average 2010-2020	**611.9**	**556.4**	**563.3**	**640.6**	**573.7**	**586.3**

There is certainly a strong similarity in terms of annual average for the HS and PM methods, while the sPM shows in most cases an overestimation. Moreover, Pearson's correlation coefficient between HS and PM at a monthly level is very high; in fact it is 0.99 for both Monte Bove and Monte Prata, while the value of the latter in relation to sPM never goes beyond 0.96. In order to understand the belonging to the same population and therefore the similarity between the two data distributions, the Wilcoxon signed-rank test was carried out, set with an α significance level of 0.05 (Table 2). This type of non-parametric test was chosen, due to the non-normality of the data, verified by Shapiro-Wilk test. Furthermore, the similarity of the monthly distribution, again in pairs, was also tested by Kolmogorov-Smirnov's test (Table 2).

Table2. Monthly comparison of p-value obtained by Wilcoxon test and by Kolmogorov-Smirnov's test from 2010 to 2020, between sPM – HS-PM, for Monte Bove (MB) and Monte Prata (MP).

Wilcoxon test	sPM-HS	HS-PM	sPM-PM	Kolmogorov-Smirnov	sPM-HS	HS-PM	sPM-PM
p-value MB	0.0001	**0.1203**	0.0007	**p-value MB**	**0.0635**	0.0059	0.0001
p-value MP	0.0001	**0.1706**	0.0013	**p-value MP**	**0.1223**	0.0139	0.0005
α	0.05	0.05	0.05	**α**	0.05	0.05	0.05

The results showed a remarkable similarity for the monthly mean of HS and PM, while the sPM method highlighted a strong overestimation compared with the other methods. On the other hand, as far as data distribution is concerned, it is different for almost all methods, although there

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is a weak relationship between sPM and HS. The similarity of the distribution was also assessed by averaging the values of individual months for all years (2010-2020), with the Kolmogorov-Smirnov test, and this showed a better similarity between HS and sPM distributions (Figure 1).
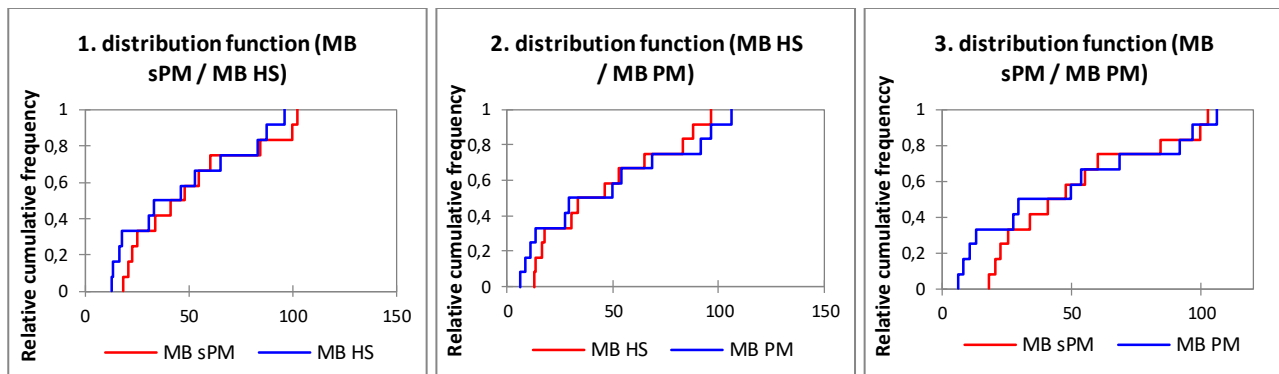
Figure 1. Two by two comparison of the cumulative distribution, between the different ET0 calculation methods.

Conclusion

The in-depth comparison between the different methods has led to some evidence, first of all that the HS and PM methods are much more similar to each other than the sPM. Obviously the PM method is the most complete of all and certainly the most precise, taking into account many more parameters of sPM including the different types of ground vegetation cover. The difference between the PM and sPM method suggests that the latter is not very precise in a mountain environment, also due to poor vegetation which results in lack of transpiration. Moreover, there is an excellent annual correlation between PM and HS method, while at monthly level the HS is much less correlated, although more similar to PM than sPM. It can be deduced that despite the few parameters required, the HS method is more accurate for mountain weather stations in the Apennines of central Italy, compared to sPM. So it follows that in spite of previous research (Garcia *et al.*, 2004; Yang *et al.*, 2013), the Hargreaves-Samani method, in this particular environment, is more reliable than the simplified Penman-Monteith method. It would be interesting to extend this research to other mountain environments as well, in order to generalise this observation, which could avoid particular calibrations of the Hargreaves method and make it easier to calculate ET0, also in terms of data availability. In a context of water reserve management, the assessment of water balance in areas close to the watershed is fundamental.

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Monthly Monitoring of Lake Smokovo Reservoir (Thessaly) with the Use of Optical and SAR Copernicus Satellite Imagery

T. Falaras [1]

(1) Harokopio University, EleftheriouVenizelou 70, Athens, Greece, triantafyllos.falaras@gmail.com

Introduction

Inland waterbodies in the era of Climate Change are crucial to be monitored. Monitoring of inland waterbodies can contribute, during a specified temporal basis, tounderstanding their changes and the impact of the use of their waters but also of factors such as meteorological conditions and the Climate Change. Especially in the cases of reservoirs that have been constructed to serve specific purposes, as well as in other inland waterbodies, monitoring them is an important tool in the management of their water leading to more effective and rational use. Satellite-based earth observation data, as it is proven in many studies, constitute an important tool in inland waterbody monitoring characterized by sufficient accuracy and reliability while the costs can be kept low (Falaras *et al.,* 2019). This study aims for the monitoring of Lake Smokovo reservoir in Thessaly Greece, per month, for 12 months between 2017 and 2018, with the use of optical and SAR imagery to find its fluctuations during a year but also to compare different imagery types. For this purpose, Sentinel-1 SAR and Sentinel-2 optical imagery of the European Union's Copernicus Earth Observation Programme carried out by the European Space Agency (ESA) are utilized which are open and freely available.

Study area

Regarding the area of study, Lake Smokovo reservoir is located in the Municipality of Sofades of the Regional Unit of Karditsa in southwestern Thessaly. The construction started in 1985 with the dam in Sofaditis River and it was completed in 2002 when the reservoir started to be filled with water. It constitutes a multipurpose project for the water supply of a part of the Southwestern Thessaly's basin for irrigation, home use, and power production. Nowadays its water covers the needs of irrigation for an agricultural area of ~100 km^2 out of the planned ~252 km^2. Besides, the lake's waters are used for electricity production andthe Sofaditis river environmental flow (Karavokyris *et al.,* 2008; Tsiastas, 2016).

Methodology

Regarding the methodology, the processing performed at the open and freely available remote sensing software ESA STEP SNAP version 7 while the measurements and the cartographic representation of the results at the commercial GIS software ArcGIS version 10.4, utilizing in both software graph processing chains and batch.

More specifically, a total of 24 optical Sentinel-2 L2A and L1C, and SAR Sentinel-1 GRD satellite imagery (Figure 1) was used as presented in Table 1. The image selection was predominantly

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dependent on cloud-free optical image availability above the reservoir while SAR images were then selected to be acquired with the minimum time difference between acquisitions to retain temporal coherence. Also, the availability of cloud-free images had an impact on the 12-month monitoring plan to study the whole of the 2018 year thus leading to consider the last 2017 months. This issue affected the monitoring of the Lake Karla reservoir (Falaras *et al.,* 2019) in eastern Thessaly in 2018 and this experience gained led to the above-mentioned modificationbecause of similar weather conditions these months in both areas.

Table 1. Twelve-month monitoring 2017-2018.

Year	Month	Optical Imagery(Sentinel-2)	SAR Imagery(Sentinel-1)
2017	November	10/11	12/11
	December	10/12	12/12
2018	January	19/1	17/1
	February	28/2	28/2
	March	15/3	12/3
	April	9/4	11/4
	May	14/5	11/5
	June	13/6	10/6
	July	13/7	10/7
	August	22/8	21/8
	September	11/9	8/9
	October	26/10	26/10

The methodology for the waterbody mapping with the use of optical imagery is based on the application of the McFeeters (1996) Normalized Difference Water Index (NDWI) spectral index. This widely used waterbody mapping index uses the spectral bands of visible Green and Near Infrared (NIR) (1) of the electromagnetic spectrum. It maximizes the water's typical reflectance in Green while minimizes it in NIR enabling the delineation of water due to the high reflectance of land in NIR while its values ranging from -1 to 1 with positive ones corresponding to water (McFeeters, 1996). The images, firstly have been resampled in 10 m resolution and clipped to the area's extent. The waterbody delineation and thus the creation of a binary image of water and non-water areas was based on a dynamic threshold selection manually for each image's NDWI so as to maximize the accuracy of the derived lake's area (Bioresita, 2019).

$$NDWI = (Green - NIR) / (Green + NIR)$$

Regarding the methodology followed for SAR imagery, the backscattering of a water surface is low compared to other types of surfaces. For this reason, water surfaces in SAR images appear dark because they behave like mirrors. The method is based on also dynamic threshold selection as well as previously with the optical imagery. After the needed typical preprocessing sequence of the SAR GRD images including the application of accurate orbits, subset, calibration, speckle filtering, and geometric correction the water delineation was done in VV polarization. Finally, backscatter values that separate the water and land the best which are usually in the valley of the backscatter

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histogram separating the water and non-water curves were selected (Zeng *et al.,* 2017; Serco Italia SPA, 2019).
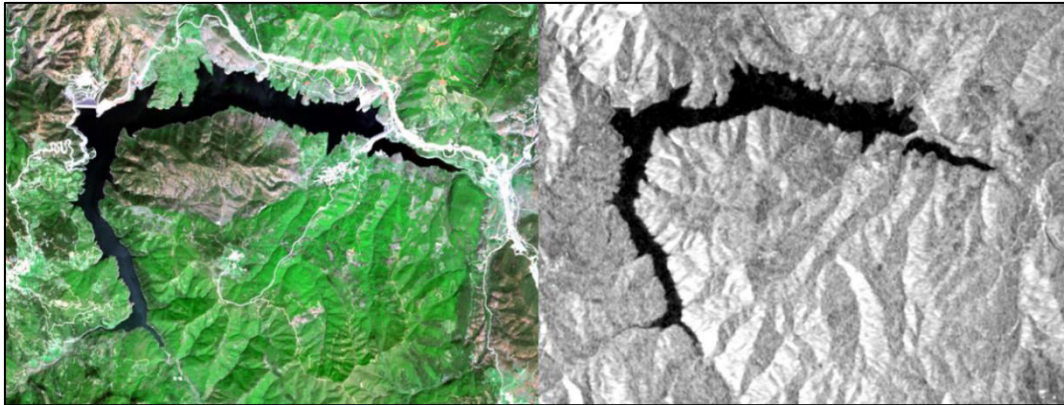
Figure 1. Sentinel-2 (left) and Sentinel-1 (right) images both dated April 2018.

Results

The results (Figure 2) show clearly the fluctuations of the Lake Smokovo reservoir for 12 months. More specifically, during the period from November to April the lake's area increases reaching the maximum in April with 5.92 Km^2 and 5.72 Km^2.
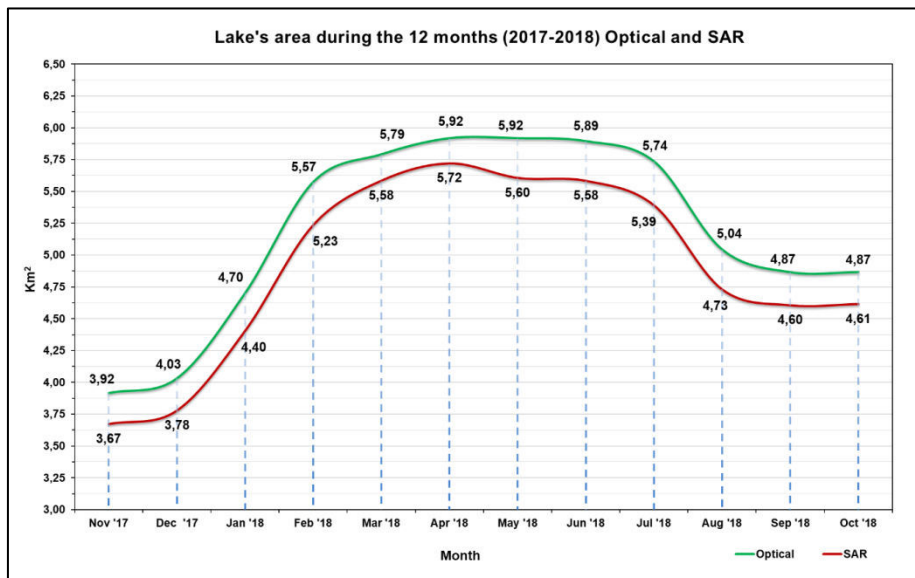
Figure 2. Lake's area during the 12 months (2017-2018) Optical and SAR.

Then with the begging of the irrigation season and the dry period, the area decreases rapidly in summer reaching the lowest in September with 4.87 Km^2 and 4.60 Km^2. Afterward, in October another cycle of the lake's area fluctuation starts. Comparing the results between optical and SAR data, in this case, optical data attribute a larger area to the lake than SAR, they follow almost the same trends during the year with an almost steady difference of an average of 0.28 Km^2. The biggest difference is observed in July with 0.35 Km^2 and the smallest in April with 0.20 Km^2. From a

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spatial point of view, the results derived with optical imagery represent the lake's geometry more accurately than SAR.

Conclusions

An extensive inland waterbody monitoring during a year can help us understand effectively the fluctuations of a reservoir especially when its water is used extensively. Lake Smokovo reservoir's changes during one year are a result of the precipitation through each season and the use of its water for irrigation through the irrigation season when the water demand is high. Taking into consideration a previous study (Falaras, 2020) about the Lake Smokovo reservoir changes on a seasonal basis, the main fluctuations mechanisms of the lake can also be confirmed. Besides, slight differences exist between the results derived from optical and SAR images. Although more accurate results can be extracted from optical images, SAR images have the advantage of providing images unaffected by local weather conditions. To this study's extent, the availability of cloud-free Sentinel-2 images played a major role in its monitoring and planning. In conclusion, as this study also proves among others, remotely sensed earth observation data, and especially open available of Copernicus programme, can constitute an important tool for the monitoring of inland waterbodies providing accurate results with low cost.

Acknowledgments

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Spatial Distribution of Total Suspended Matter in Sea Water and Onshore Correlation Based on Sentinel 2, Local Geomorphology and CLC 2018: The case of Weather Extreme Event at Northern Coast of Crete (November of 2020)

D. Bafi [1], M. Karantzia [1,2]

(1) Harokopio University of Athens, El. Venizelou 70, Athens, Greece, gp219313@hua.gr
(2) National Technical University of Athens, Ir. Politechniou 9, AthensGreece, marianthy_glf@gmail.com

Introduction

Coastal flooding related to marine extreme events has severe socioeconomic impacts, so such an event where there was a large precipitation, occurred in the northern coast of Crete during November 2020 and it has been the main focus of this study. The increasing trend of the occurrence of these events requires the mapping and monitoring of the areas. From satellite observations in the optical part of the spectrum we can estimate the concentrations of different constituents (pure water, chlorophyll, sediments, colored dissolved organic matter) provided we know their effect on the spectral response of the water. Therefore, obtaining the information of Total Suspended Matter (TSM) at high spatiotemporal resolution is necessary for understanding water quality dynamics and identifying their driving forces, and further for managing and protecting aquatic and coastal ecosystems (Wu *et al.,* 2013). Since the launch of SeaWiFS in 1997, ocean colour data from sensors on polar-orbiting platforms have become an established source of information for monitoring of chlorophyll a and TSM in coastal waters (Stumpf, 2001). Sentinel-2 Multispectral Imager (MSI), a constellation of two satellites in sun-synchronous polar orbit, targets land and coastal zone monitoring by providing high spatial (10–60 m) and temporal (2–5 days) resolution images (Malenovský, *et al.,* 2012). The present contribution, reports on efforts towards a metrology of mapping the TSM, which is one of the dominant water constituents in inland and coastal waters and the area of interest is the Northern Coast of Crete. This study also aims at the correlation of local geomorphology and also to monitor the changes in land use in the wider area, which suffered after this natural disaster. In order to characterize the plume and survey a maximum concentration gradients (pure water, chlorophyll, sediments, colored dissolved organic matter) among this weather extreme event, we have used two images from Sentinel-2 1C. The free Copernicus Sentinel-2 satellite data, the free Corine Land Cover 2018 (CLC, 2018) data and DEM with 5 and 30 meters resolution, are exploited for the export of results. The processing was executed in the free and open software SNAP offered by ESA (ESA, 2020) and for the export of the final results the commercial ArcGIS software environment was used. These remote sensing tools can be valuable instruments in the detection and tracking of extreme runoff events and background concentration for monitoring the health and recovery of the Cretan Bay.

Materials and Methods

The data that were used are Sentinel-2 data, Corine Land Cover 2018 (CLC, 2018) and Digital Elevation Models with 30 meters/pixel (ASTER) and 5 meters/pixel (Hellenic Cadastre) resolution.

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Concerning, Sentinel-2 is a European wide-swath, high-resolution, optical multi-spectral imaging mission. The full mission consists of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit time of 5 days (ESA, 2019). Sentinel-2 data are available from the open source of Copernicus Open Access Hub. Furthermore, the Corine Land Cover 2018 (CLC, 2018) data are provided by Copernicus Land Monitoring Service database which is coordinated by the European Environment Agency (EEA) and produces land cover/land use (LC/LU) information. As it was previously mentioned, two Level 1C images have been used after downloading them from Open Access Sentinel Hub platform. They are mostly free of cloud, dated 23/08/2020 and 13/11/2020. The optical Multispectral Instrument (MSI), of Sentinel-2 twins satellites A & B, has 13 spectral bands (VIS, NIR, SWIR), providing appropriate data source to document Concentration of Suspended Particulate Matter (CSPM) variations in coastal and inland waters (Hansen *et al.,* 2017), they are in sun synchronous orbit at 786 km mean altitude, 5 days of repeated cycle with the two satellites and spatial resolution 10, 20 and 60 m/pixel (depending on the band) (Drusch, *et al.,* 2012). The level 1C product/image, is top-of-atmosphere in cartographic geometry about 600 MB covering an area 100x100 km. The processing of the Sentinel-2 1C image could be divided in two steps. The first one is the preprocessing including resembling (in this case 40 m/pixel) in order all bands to have the same spatial resolution and the second step is the subset of the image over the study area. The second one concerns application the Case 2 Regional Coast Color (C2RCC) algorithm in order to detect the amount of sea water suspended matters. Initially developed by Doerffer and Schiller (2007) for the MERIS sensor, and then it was improved through the ESA DUE Coast Colour project (Brockmann *et al.,* 2016). It is applicable to all past and current ocean color sensors (such as Sentinel-3) as well as Sentinel-2. This task requires inversion of the sea water leaving reflectance spectrum, measured at top-of-atmosphere by optical instrument carry by specific satellite including Sentinel-2 MSI (Doerffer and Schiller, 2007; Brockmann *et al.,* 2016). Sea water color refers to the hue of the water caused by the presence of tiny plants that containing the pigment chlorophyll, sediments and colored dissolved organic material. Then the final product in B/W has been colored using a color a palette facilitating the knowledge content the units is cubic gm^{-3} which is unit of volume cubic gigametre. Finally, the data where exported in GeoTIFF format and then imported into ArcGIS software, where the final maps as well as slope and Corine Land Cover 2018 maps for the area of interest are produced.

Results

After the processing is carried out, the results (Figure 1) show that in the image before the event (25/08/2020) the northern coast of Crete has lowest Total Suspended Matter Concentration (TSM) (gm^{-3}) in comparison to the image after the event (13/11/2020). The TSM Concentration ranges from 0 to 100 gm^{-3} and in this case the highest value is 30 gm^{-3}. Before the event TSM Concentration is higher close to the coastline and in lower dispersion, while on November high values around 15-30 gm^{-3} are evident far from the coasts. This reveals big difference between the two dates and the change in Spatial Distribution of TSM after the event.

The analysis of the derived TSM before and after the disaster maps showed the influence of hydrological factors on the TSM seasonal dynamics over two sub-regions of the Cretan Bay, the west and east areas. The western side (Sisses Fodele) is more influenced by inflowing rivers and water level fluctuations with a steeper or a more sturdy coastline with lower values (0.65 gm^{-3}),

while the eastern area (Gournes, Gouves, Kato Gouves, Hersonisos) shows the highest values (15-30 gm^{-3}) and are probably less steep or more loose (Figure 2).

a)
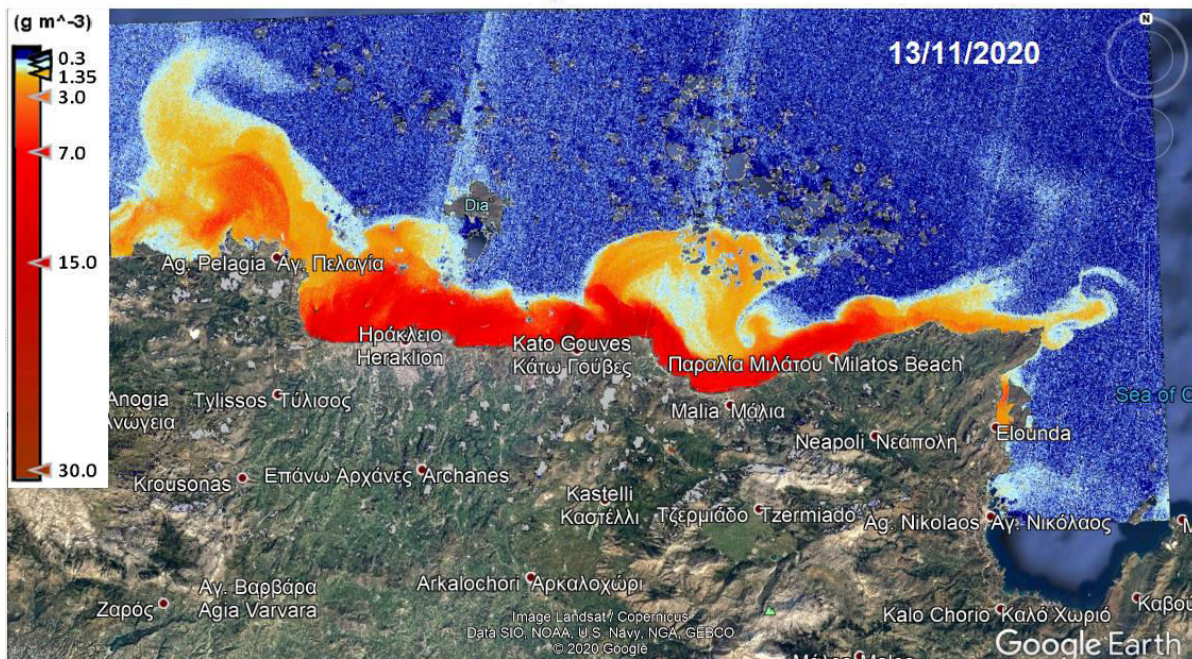
b)

Figure 1. Spatial Distribution of Total Suspended Matter after processing of the 1C initial images a) before the event (25/08/2020) and b) after the event (13/11/2020).

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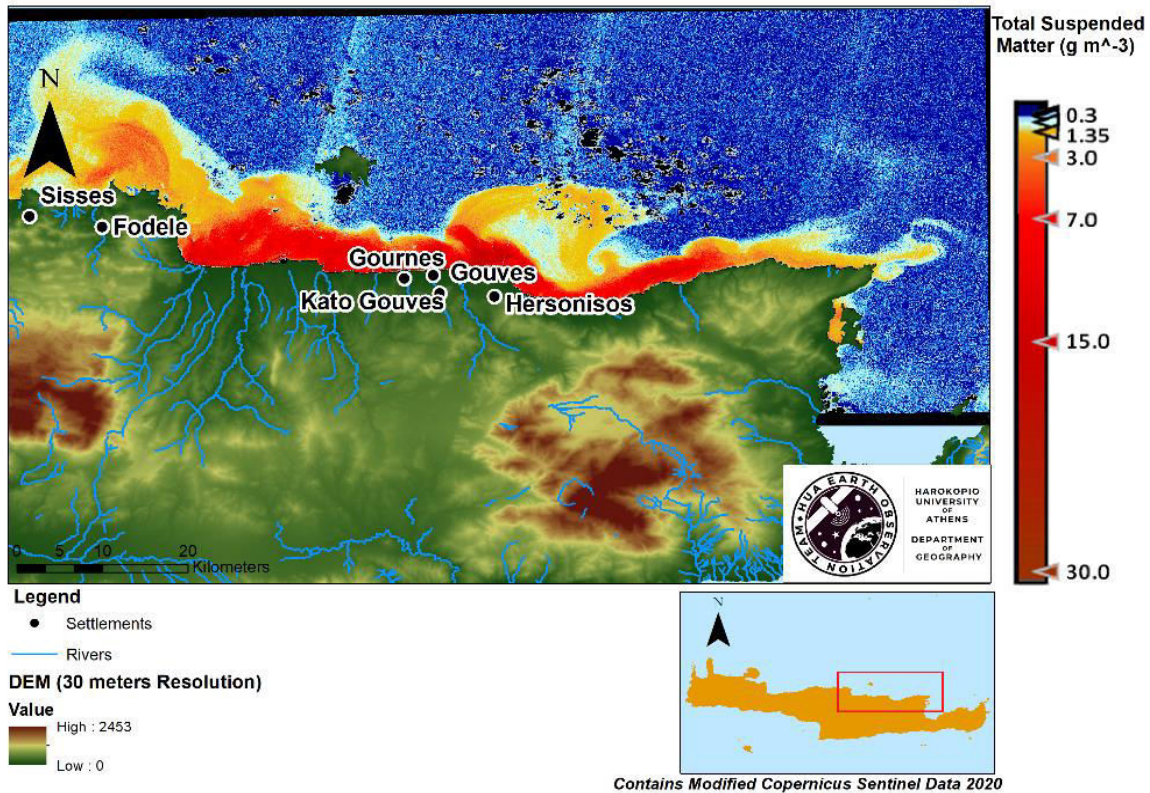
Figure 2. Map of Spatial Distribution of Total Suspended Matter after the event (13/11/2020) with DEM (ASTER) and watercourses.

Discussion - Conclusions

As it is mentioned, Sentinel-2 MSI provides a revisit time of 5-day at the equator with the full operations of the two satellites. Considering its capability, Sentinel 2 MSI should be an ideal free data source for the operational flood hazard monitoring. The high quality SWIR bands of Sentinel 2 MSI also partially contributed to the successful TSM retrieval in this study, because they facilitate the atmospheric correction over case-II waters. Therefore, obtaining the information of TSM at high spatiotemporal resolution is necessary for understanding water quality dynamics and identifying their driving forces, and further for managing and protecting aquatic and coastal ecosystems. It is important to state some issues we have face while working on this project. One issue concerning DEM from the Hellenic Cadastre was the reprojection in order to apply mosaicking and have the same reference system for all the data. To conclude, coastal waters of Crete belong to case-II waters. In water color remote sensing, case-II waters are defined as waters whose optical properties are significantly influenced by total suspended particulate matter, phytoplankton, and colored dissolved organic matter. These waters provide various benefits to society through commerce, aesthetics, tourism, recreation, and biodiversity conservation, which are greatly affected by water quality and of course coastal flooding. A result of this population pressure and its associated urban and agricultural land use/land cover, significant runoff of sediments and nutrients has degraded the health of the complex Cretan Bay ecosystem. Both

natural forces and anthropogenic activities may influence the distribution pattern of TSM. The analysis of the derived TSM before and after the disaster maps showed the influence of hydrological factors on the TSM seasonal dynamics over two sub-regions of the Cretan Bay, the west and east areas. The west areas are influenced less than the eastern areas due differences in geomorphology and land use/cover.

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Copernicus Satellite Data and DEM-Derived Spatial Models Contribution to Map the Spatial Impact of Extreme Weather Event: The Case in Assos (Kefalonia, 2020)

Ath. Mourampetzis [1], A. Petani [1]

(1) Harokopio University of Athens, El. Venizelou Ave. 70, Kallithea, Athens, Greece, th.mourampetzis@gmail.com, gp220312@hua.gr

Introduction

The current research conducts a study regarding the mapping of the spatial impact of extreme weather event. Specifically, a rare Mediterranean cyclone, namely Ianos, struck the Kefalonia Island on September 18, 2020. The intensity of this extreme weather phenomenon was increased due to warm sea surface temperature. Ianos caused to the Kefalonia and specifically the Assos region by high velocity of winds, torrential rain, debris flow, high waves at sea and huge destruction of infrastructures. The present research will map the affected areas and the sediments in the maritime area, at the region of Assos, with the use of Earth Observation Space Data. Sentinel-2 level 2A/1C images were used to map the change detection at the surface and to find the different constituents in the sea.

Many areas are vulnerable to extremes of normal climatic variability and climate change is likely to increase the frequency and intensity of some extreme weather events and disasters (Van Aalst, 2006). In the past years, numerous natural disasters have destroyed communities around the world (Montz *et. al.,* 2017). In many cases, natural disasters are presented in the form of cyclone. Cyclone Ianos, also known as Medicane Ianos, is a rare Mediterranean tropical cyclone. Medicanes are hybrid systems having characteristics representative of both frontal extra-tropical systems and tropical cyclones (Miglietta *et al.,* 2011). The horizontal extent is generally confined to a few hundred km while the intensity rarely exceeds category 1 of hurricane strength (Cavicchia *et al.,* 2014; Miglietta and Rotunno, 2019). However, the intensity of storm increases due to warmer sea surface temperatures. As a result, the storm takes more tropical appearances and characteristics, increasing the wind speeds. This study examines spatial impact of Ianos in the Assos area, Kefalonia, 2020. The cyclone struck the region on September 18, 2020. Atmospheric pressure at the center of Ianos was approximately 1,000 hPa (Athens National Observatory, 2020). There are considered as one of the most dangerous geo-hazards due to their high velocity of winds, torrential rain, floods and mudflows, high waves at sea, huge destruction of infrastructures and loss of human lives.

In particular, mapping the spatial distribution of extreme weather events can contribute to define specific vulnerable zones. The development of real-time systems for such phenomena assessment is an essential operational tool that will provide important information for a timely and precise response (Kritikos and Davies, 2015; Kim *et al.,* 2016). Earth Observation data have been used towards this direction and have proved to be a useful tool due to their synoptic view capability and multispectral property in the case of optical sensors (Youssef *et al.,* 2016; Elkadiri, 2014a; 2014b; Zhang *et al.,* 2006; Crowley *et al.,* 2003). In this study, the use of optical satellite data

contributes to the study of the spatial effects of the phenomena from 2020. Copernicus ESA's (European Space Agency) Sentinel-2 Level 2A optical multispectral images and Level 1C images were used. The data were used to map the affected land areas and the origin of sediments in the maritime area of Assos. Moreover, with the use of SNAP v.8 application provided by ESA, the pre-processing and the final processing was conducted for the data. At the final processing stage VIS and NIR bands from two Sentinel-2 images were layer stacked and PCA were used. Consequently, a Digital Elevation Model (DEM) 5m was used to derive the spatial models of the area (Basin, Drainage Network, Slope etc) as well as to investigate the soil relief of the area and the paths of debris flows.

Study Area

The island of Kefalonia is located in western Greece, in the Ionian Sea. It covers a land of 781 km^2 and the coordinates is 38°15'N 20°30'E (IGME, 2010). The island could be characterized as mountainous in the major part of the land. Different karstic systems create a very interesting hydrodynamic regime, with high capacity aquifers, spring discharges and water outflows in the sea around it (Stefouli, 2013). Our study focuses on the effects of Ianos cyclone to the city of Assos located at the northern part of the island. The city is located at a steep beach front and the surrounding area is characterized by high surface slopes and a long hydrographic network that drains directly from the surrounding slopes into the city, as shown in Figure 1.
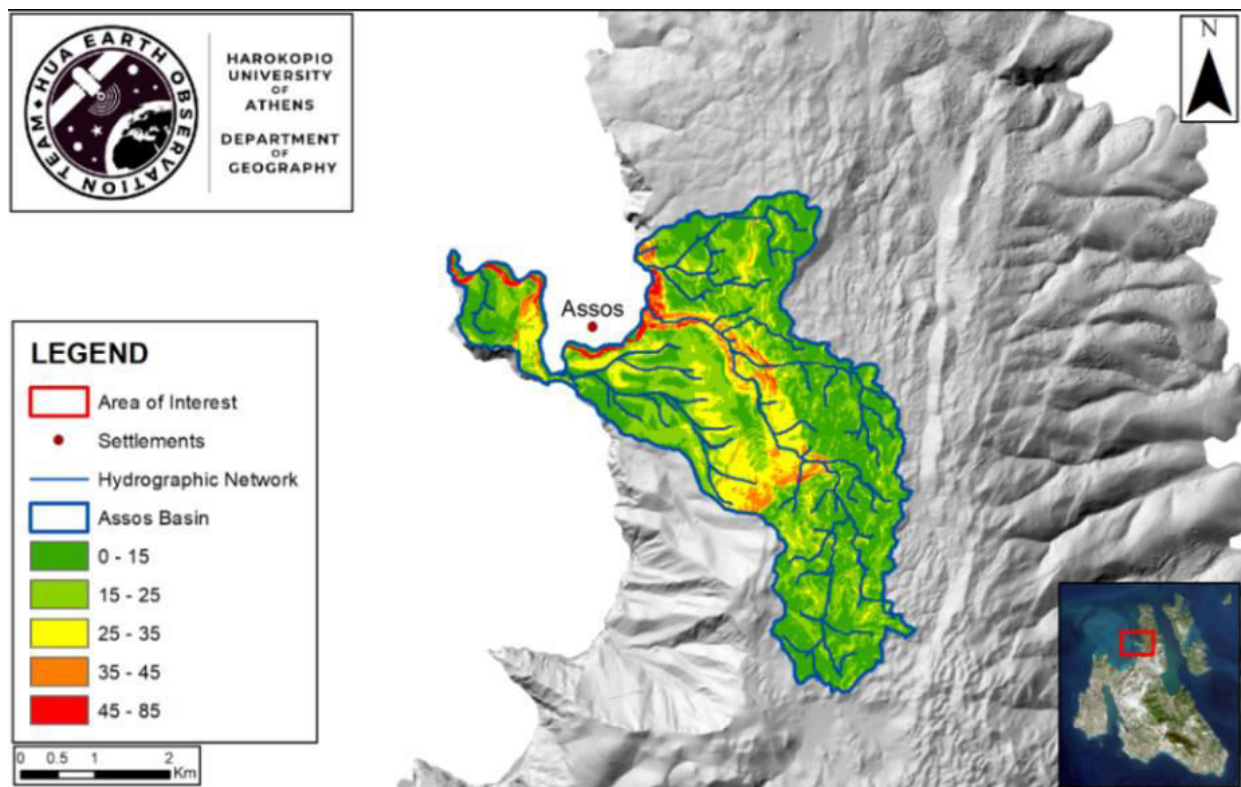

Figure 1. Area and basin of interest, Assos city, Kefalonia Island.

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Data & Methodology

From satellite observations in the optical part of the spectrum we can estimate the concentrations of different constituents (pure water, chlorophyll, sediments, colored dissolved organic matter) provided we know their effect on the spectral response of the water. In this case an image Sentinel-2 level 1C product free of cloud dated 20-9-2020 has been used after downloaded from Open Access Sentinel Hub platform (https://scihub.copernicus.eu). The optical Multispectral instrument (MSI), of Sentinel 2 twins satellites A & B, has 13 spectral bands (VIS, NIR, SWIR), in sun synchronous orbit at 786 km mean altitude, 5 days of repeated cycle with the two satellites and spatial resolution 10, 20 and 60 m/pixel (depending on the band). The level 1C product/image, is top-of-atmosphere in cartographic geometry about 600 MB covering an area 100x100 km.

The processing of the Sentinel-2 1C image could be divided in two steps. The first one is the preprocessing including resembling (in this case 40 m/pixel) in ordered all bands to have the same spatial resolution and the second step is the subset of the image over the study area. The second one concerns application the Case 2 Regional Coast Color (C2RCC) algorithm in order to detect the amount of sea water suspended matters. Initially developed by Doerffer and Schiller (2007) for the MERIS sensor, and then it was improved through the ESA DUE CoastColour project (Brockmann *et al.,* 2016). It is applicable to all past and current ocean color sensors (such as Sentinel-3) as well as Sentinel-2. This task requires inversion of the sea water leaving reflectance spectrum, measured at top-of-atmosphere by optical instrument carry by specific satellite including Sentinel 2 MSI (Doerffer and Schiller, 2007; Brockmann *et al.,* 2016). Sea water color refers to the hue of the water caused by the presence of tiny plants that containing the pigment chlorophyll, sediments and colored dissolved organic material. Then the final product in B/W has been colored using a color a palette facilitating the knowledge content.

In addition, Sentinel-2 level 2A images (Bottom of Atmosphere product) free of cloud dated 10-09-2020 & 20-09-2020 has been used to map the debris flows. At the final processing stage, VIS and NIR bands from two Sentinel-2 images were layer stacked and PCA were used. Also, a DEM 5m was used to produce the products of slope, aspect, hill shade and the drainage network of the region, with all of the above combined we created the spatial model of the basin that drains directly in our area of interest.

Results

The spatial impacts of the Ianos event are showed in the 4th PCA image. Specifically, the table from PCA statistics shows that all the bands from the two different dates for Sentinel-2 2A contribute with different sing to the 4[th]PCA image (Figure 2.)

As for the result of Sentinel-2 (Figure 3.), ocean color refers to the hue of the water caused by the presence of tiny plants that containing the pigment chlorophyll, sediments, and colored dissolved organic material. From satellite observations in the optical part of the spectrum we can estimate the concentrations of different constituents (pure water, chlorophyll, sediments, colored dissolved organic matter) provided we know their effect on the spectral response of the ocean water or sea color.

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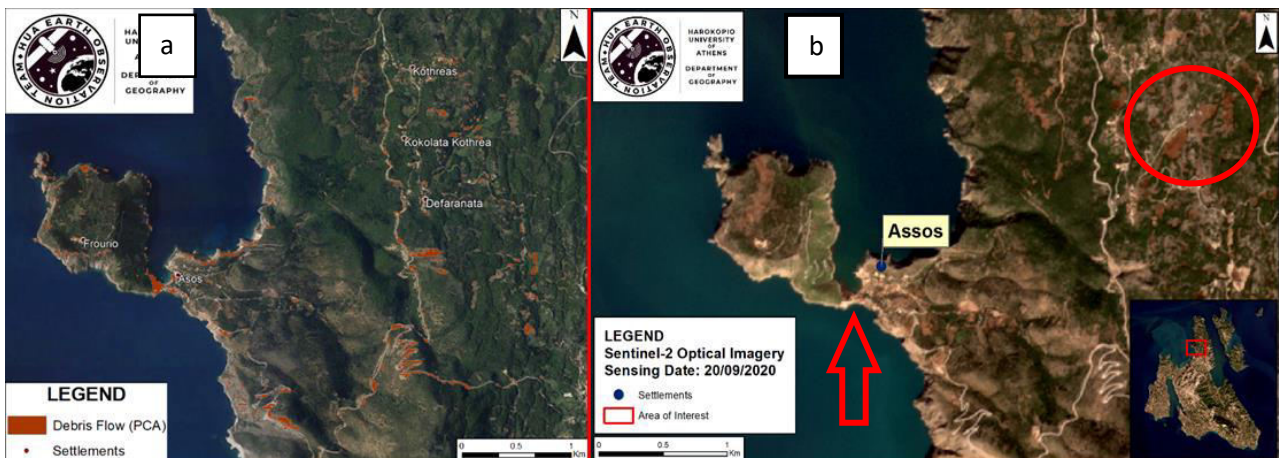
Figure 2. a) Debris flow results from the processing of the 4th PCA image shown in red using as background high resolution optical image in Google Earth environment,b) Sentinel-2 Optical Imagery showing areas covered in mud on the 20/09/2020.
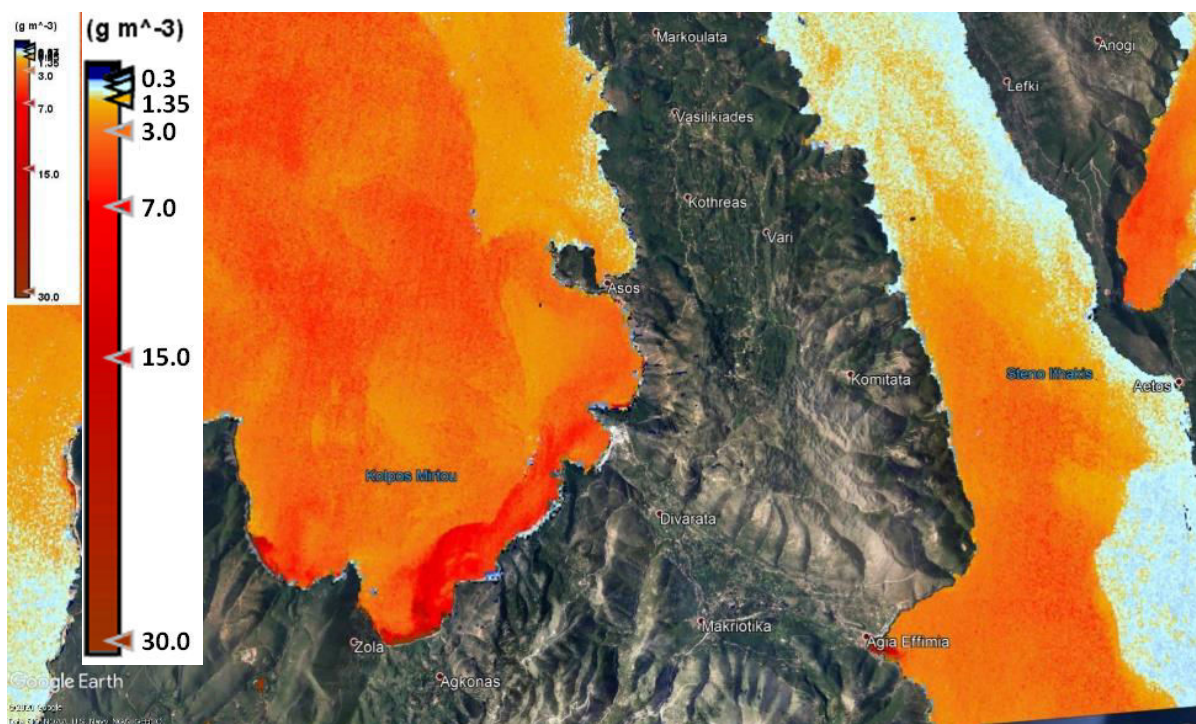
Figure 3. Concentrations of suspended matters in sea water in the vicinity of Assos city, Kefalonia.

Conclusions

- The major impact was at the shoreline and the main stream in the region of Assos
- The important contribution of the free satellite earth observation data of the Copernicus program of the European Space Agency to the elaboration of research studies like the present one.

Acknowledgments

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Flood Hazard Assessment of the Aeson River Catchment, Central Macedonia, Greece

E. Dosiadis [1]

(1) Department of Geography, Harokopio University, 70 EleftheriouVenizelou Str., 17671 Kallithea, Athens, Greece, gp220304@hua.gr

Introduction

Floods are a natural phenomenon occurring globally and may have both a beneficial and a devastating impact on the environment. When they are involved in human activities, they usually cause disasters in crops, structures and infrastructure, often leading to loss of human lives, but also to various socio-economic problems directly or indirectly linked to them. The consequences of these, especially in recent decades, are estimated to account for 40% of the damage caused by all kinds of natural disasters combined (Kourgialas and Karatzas, 2017). The morphology of Greece, as well as its geographical position in the transitional climatic zone of the Mediterranean basin, make its climate diverse with many localities. At the same time, the drainage networks in the country, which are usually small, are subject to great pressure from human activities and their management is often incomplete or non-existent, both regionally and nationally. These factors, in combination with climate change, have significantly increased the otherwise common occurrence of flood phenomena associated with atmospheric disturbances (Tsanakas *et al.,* 2016).

The present study attempts to highlight the areas of the Aeson river basin that have a particularly high natural vulnerability to floods, taking advantage of the technological development that has occured in recent decades in the field of geoinformatics. The methodology adopted for the elaboration of the study is FIGUSED-S, in which seven (7) variables are taken into account and are superimposed after being processed and given weights using the method of Analytical Hierarchy Process (AHP), in order to produce thematic maps in which the high flood risk areas for each variable are indicated. These factors are considered crucial, but not absolute, in determining flood-prone areas and include flow accumulation, rainfall intensity, geology, land uses, slope, elevation and distance from the drainage network (Kazakis *et al.,* 2015).

Study Area

Aeson is an ephemeral river with a dendritic drainage network, located in the southern Central Macedonia region. Its drainage basin covers an area of 645 km^2 and it's crescent-like shaped, spanning from the W-SW to the E. Its springs are located on the mountain slopes of Mt. Olympus, Mt. Titaros and Pieria Mts. with a maximum elevation of 2918 m. After crossing the plain of Katerini, the river discharges into the Thermaic Gulf, in the northern Aegean Sea. The average annual precipitation in the area is approximately 650 mm and the months of its maximum occurrence depends on the altitude, with low-lying areas receiving most of their rainfall during the colder months, in contrast with the higher elevations where there is significant amount of rainfall even during the summer. The downstream areas of the catchment have been characterized by a

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preliminary flood risk assessment conducted by the Ministry of Environment, as one of the 6 areas of the country where flood-related incidents create the greatest disasters financial-wise. One notable such incident being the widespread flood of 15-17 November 2017, when the meteorological station of Dion recorded 419.4 mm of rain.

Methodology

The methodology used in the present study for the flood hazard assessment in the catchment area of the Aeson River, as has been done in similar studies around the world, is that of FIGUSED-S (Kazakis *et al.,* 2015; Patrikaki *et al.,* 2018). This is a model based on a quantitative indicator that operates in a GIS environment and includes 7 parameters, the initial characters of which form the name of the method. These parameters are the following: Flow Accumulation (F), Rainfall Intensity (I), Geology (G), Land Use (U), Slope (S), Elevation (E) and Distance from the drainage network (D). The elevation, slope and flow accumulation values were produced by a 25m x 25m resolution Digital Elevation Model obtained by the European Organization, Copernicus (EU-DEM). The drainage network and in turn the distance from its beds were also extracted by the EU-DEM.
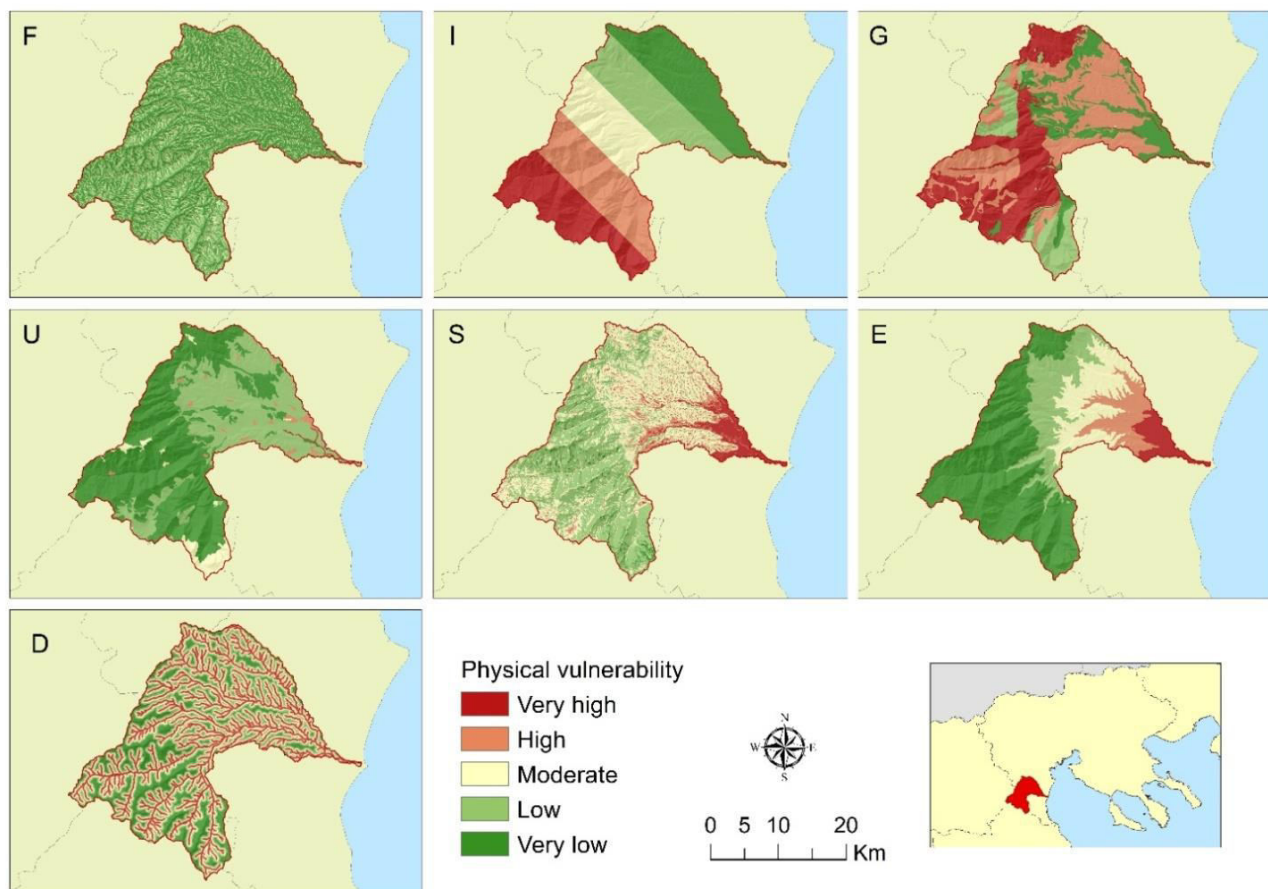
Figure 1. The seven reclassified parameters of FIGUSED.

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The rainfall data was obtained by three meteorological stations of the National Observatory of Athens, which were located inside or in close proximity to the studied river basin. Land use data was acquired by CORINE land cover 2018, while the geological formations were derived from five geological maps of the Institute of Geology and Mineral Exploration of Greece.

In order for the seven parameters to be comparable with each other, they were reclassified in a single ordinal scale of five classes. The limits of the classes of each parameter were defined proportionally to their properties. The spatial analysis of the study area was performed by evaluating each cell for each of the seven parameters, where each cell was calibrated in 5 classes, on a scale from 2 to 10. These parameters were processed and then exported into 7 thematic maps (Figure 1) which were overlaid with weight values determined by the AHP, where the variables of distance from the drainage network and flow accumulation were considered the most significant, thus creating the Flood Hazard Map (FHI). The parameters' values were then imposed into a sensitivity analysis, creating a new and revised flood hazard map (FHIS).

Results and Conclusions

The results of the FHI index are presented in Figure 2a. Areas with very high and high susceptibility to floods cover 8% and 17%, or a total of 25% of the study area respectively. These are concentrated mostly in the central and eastern part of the basin, within short distance from riverbeds and streams. The low and very low risk classes cover almost half of the catchment, as they occupy 47% of the total area of the basin. These areas are located mainly in mountainous areas and ridges, where the slopes are steep, as well as in lowland areas where the distances from the beds of the drainage network are large.

The sensitivity analysis results of the FHIS index are shown in Figure 2b. The revised weights given to each parameter have shifted their significance. Greater significance was appointed to the elevation variable, which is followed by that of the distance from the beds of the drainage network. Smaller significance was given to the geology factor, followed by that of rainfall intensity. As a result, areas with a very high degree of flood hazard are concentrated almost entirely in the lowland part of the catchment, reducing the risk of flooding the more the elevation increases. The coverage rates of the classes remained almost stagnant, with the difference in relation to the FHI index, however, being their area of concentration.

Areas that present a very high risk of flooding are concentrated downstream. Many settlements are located in these areas, the most populous included, such as Katerini, Nea Ephesos and Neokaisaria. Important public infrastructure at risk also includes the national road and railway networks that cross the lower reaches of the drainage network. Areas of ecological and environmental interest and protection are located in areas with very low risk and do not pose any particular risk. Historical floods that have occurred in the past in the study area, are located within the very high-risk zone downstream at a rate of about 70%, significantly confirming the predictions of the model. Although this method helps for measures to be taken in order to prevent disasters and loss of human lives, it is not enough for their absolute protection.
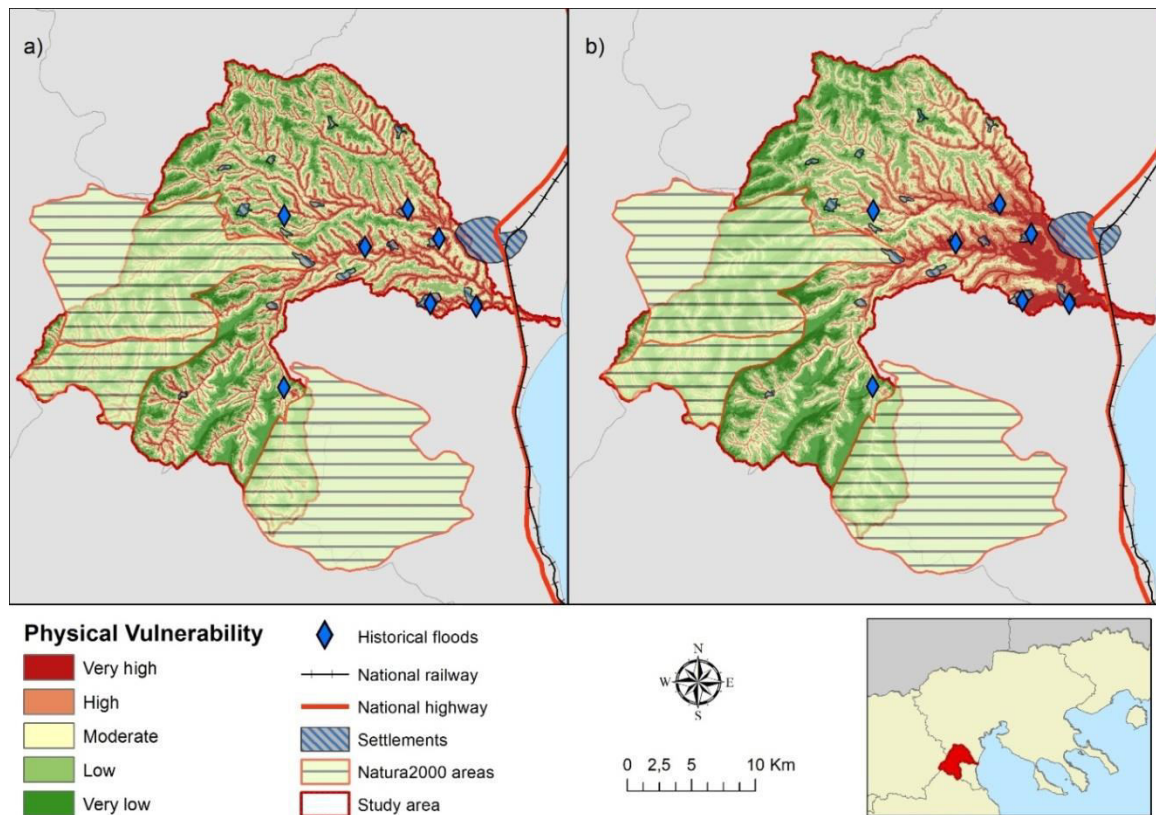
Figure 2. Flood hazard maps of Aeson river basin: (a) FHI index and (b) FHIS index.

As the model of the methodology is static and the data used are based on both natural and anthropogenic variables that constantly change over time, it is of great importance that regular updates of the data are conducted in order for the model to be considered reliable and up to date. Further analysis of the basin would further enhance the results already obtained. Quantitative and hydrological analysis of the drainage network would be useful in the study of flow velocity, flood wave motion, as well as flood passage. Finally, the development of measures for the management of the river basin is considered very important, in order to carry out any necessary flood protection works and to avoid illegal actions that make the surrounding areas more vulnerable. However, it must be borne in mind that floods are a natural phenomenon and despite any human efforts, they cannot be tamed.

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Geospatial Technologies and Open Geomorphologic Data in the Service of Military Science

K. Lymperopoulos [1]

(1) Harokopio University, Eleftheriou Venizelou Ave., 70, Athens, Greece, klymperopoulos@hua.gr

Introduction

Geomorphologic data of terrain are crucial parameters for many different fields of science. One of them is military science, especially to the fields of operational tactics and military geography. The terrain is one of the three pillars which affect the operational enviroment. Moreover terrain affect to the second pillar, the weather, because is determined the regional climate.

In this study there is an example of how to collect and process the most important types of geomorphologic and open data, to estimate the cross country mobility and how to create a combines obstacle overlay.

Methodology

The combined obstacle overlay provides a way to estimate the avenues of approach in an unknown terrain. To create this type of data it is necessary to combined obstacle data with cross - country mobility data. There are several obstacles to vehicular movement such us, built-up areas (land use), slope, soils and hydrology (geomorphology) or vegetation. With a quick look to the data, the geomorphology is a very important factor for the ground mobility of the troops in the field.

In the next table (Table 1) there is list of open social data and environmental data which we used to create a database for the estimation of the mobility to the study area. In this case the study area is the East Thrace which is the part of Turkey that is geographically a part of Southeast Europe. A lot of data exported from the OpenStreetMap and all the Geomorphologic data are downloaded from European Space Agency and the United States Geological Survey.

All the data from Table 1 was used to extract the physical obstacles of the military vehicles. First of all water bodies and rivers are natural linear obstacles. Except OSM water data, we used Copernicus Data, to estimate the permanent and temporary water and wet areas. This way military officers can predict the difference on the ground mobility between summer and winter season. Also this type of data can be combined with surface soil data or meteorological data for more precise results. Wetness layer produce a probability map of a "go" or "no go" terrain.

The rivers layer also can be combined with the transportation data to determine the most important bridges for the operation success. All bridges are located at the intersect points or road and river network. The simultaneous analysis with other data saw the value of the bridge and the need for protection.

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Table 1. Geomorphologic and other open data of study area.

Type	Data	Source	Files
Landuse	CORINElanduse 2018	https://land.copernicus.eu/pan-european/corine-land-cover/clc2018	u2018_clc2018_v2020_20u1_fgdb
Roads Railways Rivers Water	OpenStreetMap Data	https://download.geofabrik.de/europe/turkey.html	gis_osm_roads_free_1.shp gis_osm_railways_free_1.shp gis_osm_water_a_free_1.shp gis_osm_waterways_free_1.shp
Roads	Main Roads	https://data.humdata.org/dataset/roads-in-turkey	tur_roads.shp
DEM	SRTM 1 Arc-Second Global	https://earthexplorer.usgs.gov/	n40_e026_1arc_v3.tif n40_e027_1arc_v3.tif n40_e028_1arc_v3.tif n40_e029_1arc_v3.tif n41_e026_1arc_v3.tif n41_e027_1arc_v3.tif n41_e028_1arc_v3.tif n41_e029_1arc_v3.tif n42_e026_1arc_v3.tif n42_e027_1arc_v3.tif
Forest	Tree Cover Dencity 2018	https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/tree-cover-density-2018	TCD_2018_010m_E59N22_03035_v020.tif TCD_2018_010m_E59N21_03035_v020.tif TCD_2018_010m_E58N22_03035_v020.tif TCD_2018_010m_E58N21_03035_v020.tif TCD_2018_010m_E57N22_03035_v020.tif TCD_2018_010m_E57N21_03035_v020.tif TCD_2018_010m_E57N20_03035_v020.tif TCD_2018_010m_E56N22_03035_v020.tif TCD_2018_010m_E56N21_03035_v020.tif TCD_2018_010m_E56N20_03035_v020.tif
Boundaries	Subnational Administrative Boundaries	https://data.humdata.org/dataset/turkey-administrative-boundaries-levels-0-1-2	tur_polbnda_adm1.shp
Water	Water & Wetness 2018	https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness/status-maps/water-wetness-2018	WAW_2018_010m_E59N22_03035_v020.tif WAW_2018_010m_E59N21_03035_v020.tif WAW_2018_010m_E58N22_03035_v020.tif WAW_2018_010m_E58N21_03035_v020.tif WAW_2018_010m_E57N22_03035_v020.tif WAW_2018_010m_E57N21_03035_v020.tif WAW_2018_010m_E57N20_03035_v020.tif WAW_2018_010m_E56N22_03035_v020.tif WAW_2018_010m_E56N21_03035_v020.tif WAW_2018_010m_E56N20_03035_v020.tif

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Therefore the terrain slope can affect the speed and the direction of the troops. A ground with slope value, more than 45 degrees can not be accusable by a lot of vehicles. In a wet terrain with the same slope this number of vehicles has been decreased significantly. In this example we used SRTM DEM to estimate the slope. There are other open source data like ASTER DEM which are free to use.

Finally we used a combination of Corine Land Use Data and Copernicus forest density data to estimate grounds with more obstacles. Also we identify urban areas because the operation in this field needs a different type of study.
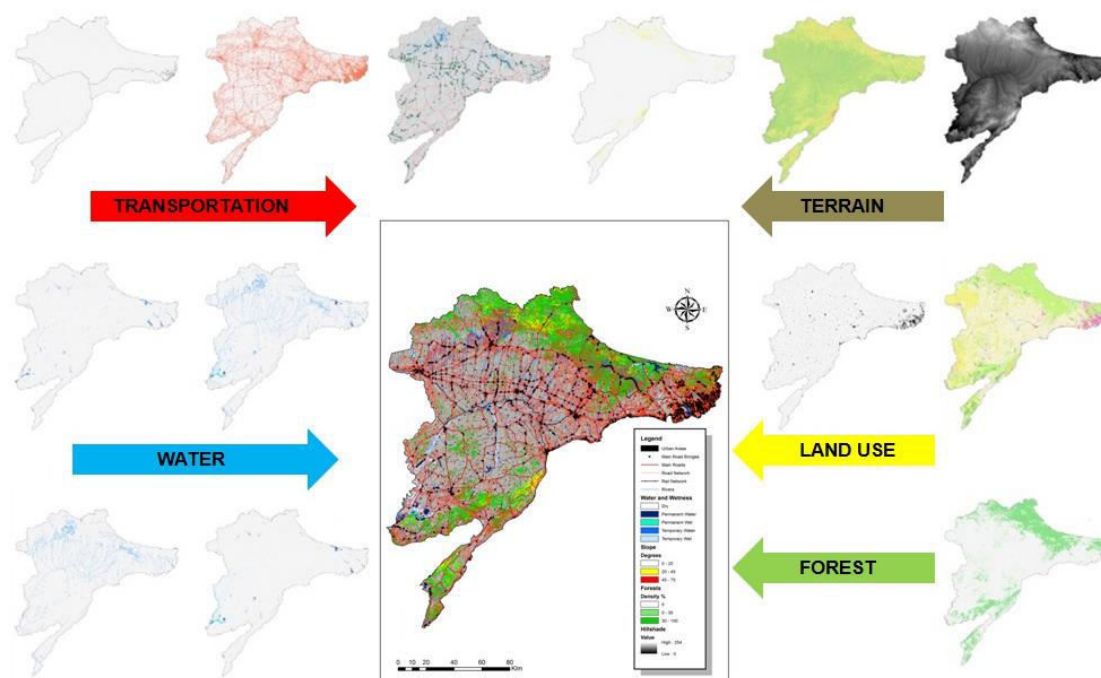
Figure 1. The possess to create a combines obstacle overlay with open free data.

Results

The product of this procedure is a high resolution map with a combine's obstacle overlay which can help the intelligence officers. Same of this data are not appeared in a simple topographic operational map. It is obvious that a carefully study of geomorphologic characteristics of the field is needed to evaluate the mobility, the line of sight or the suitability of the terrain for many different missions.

Conclusions

As a result from this study, the value of satellite data is important, for the mission planning, in the operational field of a military conflict or to control center of a disaster relief mission. In future studies, there is a need for automation and computerisation of production processes, for high resolution open images like Sentinel data. Sentinel 1 images can export the soil moisture, flood

area or ground coherence and Sentinel 2 can provide a true color basemap with many other information from vegetation or natural disaster damages. The availability and the resent time of sensing, of Sentinel image, are very important parameters to use theme in military operations the next years.
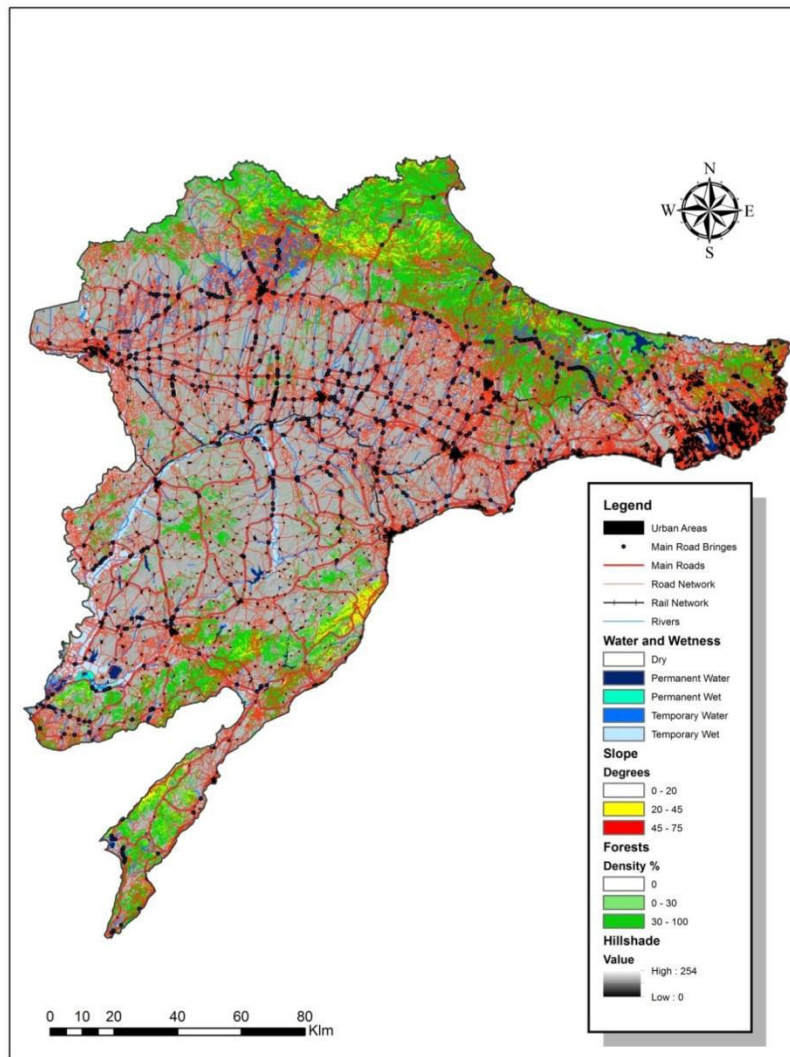
Figure 2. A high resolution map with combines obstacle overlay from open free data.

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Faults, Joints, Uplift Mechanism and Geomorphology

V. Avdis [1]

(1) MSc DIC, (Former IGME, Athens), vaios.avdis@gmai.com

Introduction

There is a lot of literature about Faults and Joints. Holmes (1965) defined the fault as a fracture plane, along which the rocks have been relatively displaced. The vertical and horizontal displacement can reach up to approximately 300 m and 16 km respectively. He considered that joints are the cracks and fractures we see in cliffs and quarries. He claimed that these cracks and fractures are normal to bedding if the rocks are horizontal.

Ramsay (1967) relates the formation of faults and joints with folding. The formation of "joints" is related to the distribution of stress trajectories after the horizontal compression. Price (1966) defined the faults as "planes of Fracture which exhibit obvious signs of differential movement of the rock mass on either side of the rock mass". The same author defined the joints as "cracks and fractures in rock along which there has been extremely little or no movement". He claimed that they happen even in incompetent rocks (even during the sedimentation). He supported that the formation of joints is related to other structures such as the folds which he considered as simultaneous.

The Author's Views

The faults and "joints" as they are displayed on geological maps are straight or quasi straight lines. These have been observed on aerial photographs, satellite images and from a considerable distance. A close up of a fault proves that the faults consist of several blocks. Each block is limited by four of six vertical to sub-vertical faults of small or large scale displacement. Of course the displacement can be seen only if there is a suitable marker horizon.

Figure 1. A road section near Chania (Greece) slightly tilting due to gravity.

The fault surfaces differ considerably in appearance and may be either the exposed scarps ranging from barren or infilled with quartz, calcite or other mobile minerals. In addition, the exposed

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scarps range from fresh to weathered and eroded surfaces. (Sharp features to highly weathered and eroded steps) (Avdis, 1991). It might be argued that some of the topographic steps are the result of the rock sliding; however, it is sometimes possible to find crystal fibers or slickensides. In road sections, quarries, mines and caves, of any direction in competent rocks we usually see blocks of four faults. These faults occur in two sets perpendicular to each other. (Figure 1).

The Blocks together with the basis and the upper surface form primarily prisms (quadrangle or hexagonal). The more homogeneous and brittle the rocks are the more perfect the prisms are. An example from N. Ireland (Giant causeway, photo in Figure 2). We can see the perfect formation of prisms (which will be called Tectonic Units - TU). I am aware that in the international geological literature, it is accepted that the formation of these prisms is comparable to the mund cracks, and they are the result of sudden freeze. In Figure 2 schematically the formation of the slope is depicted (out of scale) more or less all of the displacements are not mappable but their additive result is very important.
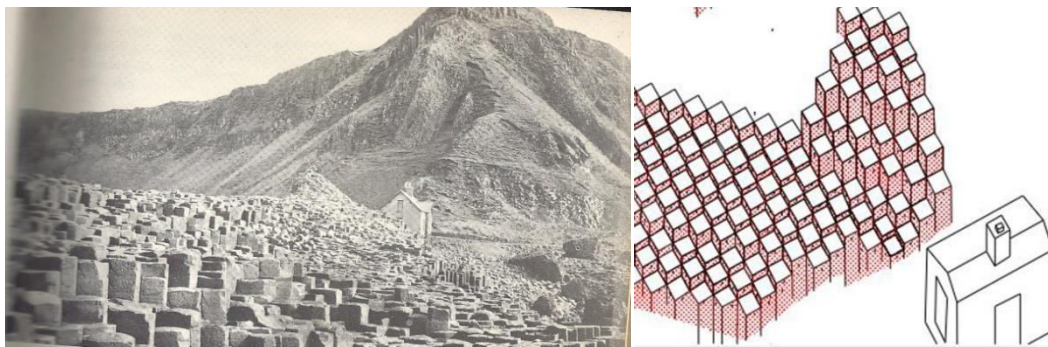
Figure 2. left: A photo from the Giant Causeway the TU display small to large displacementand the faults occur in two sets perpendicular to each other, right: Schematic interpretation of the photo. The hatched surfaces display the fault-planes the white quadrangle displays the upper surfaces of TU. The arrows indicate the sense of movement of the faults. (Out of scale).

To my mind these two are not related since the munds do not display any displacement, they are almost irregular and they are only surficial. On the other hand from empirical experience it is well known that blacksmiths often immerse iridescent iron and they never break into pieces. In competent rocks especially metamorphic rocks we have similar structures. In non-competent rocks these TU are not perfect. However, for simplicity, they will be depicted as perfect TU (Figure 3).

Figure 3.

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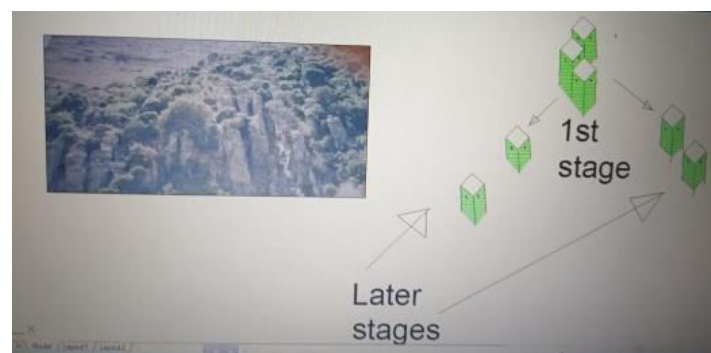
It is worth noting, that from a distance we see lineaments of three kinds. These are mostly optical illusions of three kinds: 1. The contact of hanging wall and the footwall of faults of the successive blocks (these are mostly covered by breccia, soil, grass and vegetation in general). This lineament has nothing to do with bedding. 2. The upper surface of the blocks could usually be eroded locally. They are affected both by faults and the erosion. 3. A conspicuous layer in the successive blocks is affected intensively by the numerous faults. In road (which more or less follow the contours) sections, the displacements are very small and they are not mappable. In quarries and other sections we can see considerable displacements. Anyway, their additive result is very important. (1000 fault displacements of average 30 cm increase the thickness of a rock formation 300 m).

The rocks, of course, are locally folded but the folds were formed when the rocks were at depth where their rheological behavior is ductile. The combination of the formation of domes and local erosion look like folds and they are interpreted erroneously as folds. In addition in the sites, the folds occurring there are not horizontal compression once the air and the water do not exercise any forces on the slopes of the mountains. The rocks at depth form folds because two or more tectonic plates are colliding. Then the rocks are folded but they need space. The only available space is upwards where the rocks are brittle. The rocks above follow the formation of domes by faulting (Avdis, 1991) (Figure 4). The vertical and sub vertical faults leave a trace on the surface and they are called "Joints". Therefore faults and joints are the same thing.

Are there any thrusts and strike-slip faults?

Once there are folds due to the horizontal compression, it is obvious that there are thrusts and strike-slip faults in an area where the rocks behave in intermediate rheological conditions and before uplift. After the uplift the rocks do not undergo any horizontal compression. These faults are not easily distinguished once they leave only a trace similar to the trace of the normal faults.

Sometimes rotations of TU cause the formation of "pseudo thrusts" (Figure 4) due to the formation and a component of gravity.
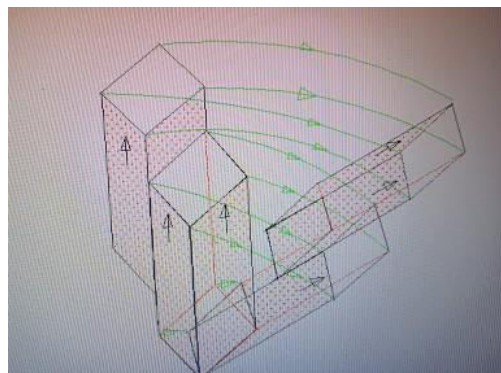
Figure 4.

The vertical to sub vertical faults are very frequent and they can be seen in any section of competent rocks. These are the result of pushing upwards differentially due to folding thrusts etc. at depth.The more homogeneous the rocks are, the more perfect is the formation of prismatic units of four or six lateral planes.

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Uplift Mechanism & Geomorphology

The two sets of faults result in the formation of domes (Figure 5) the orogeny is the formation of a series of domes. The folds contribute less to the formation of domes.
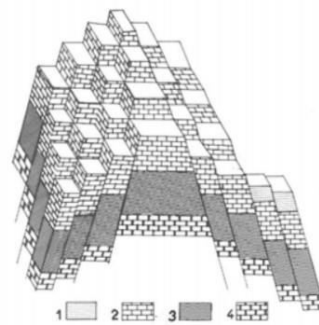
Figure 5.

It is generally accepted that erosion is the main factor of the geomorphology. However, taking into consideration the result of the displacement of numerous high-angle faults (joints) we come to the conclusion that the mountains primarily form tectonic domes. Erosion locally or in general is normally faster at the higher elevation. The rivers, the streams and the glaciers follow the tectonic geomorphology. The lakes are at the tectonic grabens and not the collision of meteorites to the earth.

Case Study: Chania Area, Greece

Tataris and Christodoulou (1969) mapped the sheet Alikianos (geological map at 1:50.000scale). This include the studied area near the Samaria gorge around the Gigilos highland. They did not consider the numerous vertical to sub vertical faults and they invoked five large scale unconformities (photo in Figure 6).
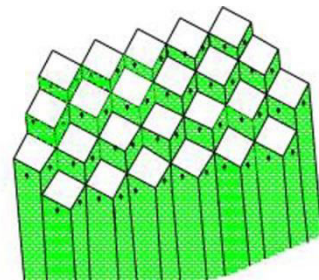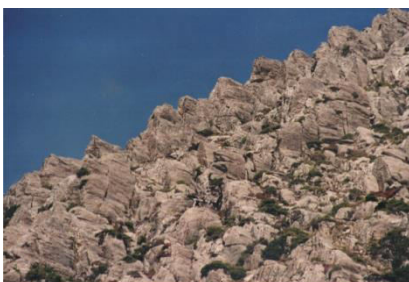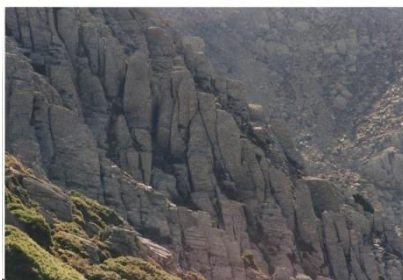
Figure 6.

A simple model of playing cards helps us to visualize the structure of the area, E-W. Unfortunately for the geologists and geology the same structure holds for the N-S direction. Each card depicts the section of a TU. A model of matches (Figure 6) takes into consideration both sets of faults each piece of match depicts a TU.

On the other side of Gigilos we see several "steps". These "steps" are not the result of erosion but the result of the two sets of faults (photo in Figure 6). The Figure 6 indicates schematically the movements of the TU.

Conclusions

The faults occur in two or more sets and the result of these faults is the formation of domes, that is, highlands. The mountains consist of a series of domes. At the beginning we can see the upper surface and repeatedly part of the fault plane.

The local erosion and the gradual erosion cause the occurrence of older rocks at higher elevation. If we ignore these high-angle faults we have to invoke unconformities, thrusts and tectonic nappes.

The rivers, the streams and the glaciers mainly follow the topography and less incise the rocks.

The vertical faults do not indicate either rifting or extension. Of course the non-vertical faults suggest an extension but if examined, adjacent highlands may annihilate the overall extension.

Although the vertical to sub-vertical faults are the most frequent structures visible in the field, they have been ignored as unimportant due to the small displacement they exhibit. These faults are not the result of horizontal stresses but the result of compression upwards due to folding at depth which in turn is the result of horizontal compression possibly due to movement of plates. Applied Mathematics prove the formation of these faults (Avdis in preparation).

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Submarine Geomorphology of the Eastern Continental Platform of the Maltese Archipelago

S. Rossi [1], C. Parenti [1], M. Prampolini [2], P. Coratza [1], M. Soldati [1]

(1) Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Via Campi 103, 41125 Modena, Italy, sofiarossi978@gmail.com (S.R.) carlotta.parenti@unimore.it(C.P.) paola.coratza@unimore.it (P.C.), mauro.soldati@unimore.it (M.S.)

(2) Natural Research Council, Institute of Marine Sciences (CNR-ISMAR), Via Gobetti 111, 40129 Bologna, Italy, mariacristina.prampolini@bo.ismar.cnr.it

Introduction

The goal of this study was to reconstruct the geomorphological evolution of the eastern continental shelf of the Maltese archipelago through the analysis of the main submarine landforms and the production of a synoptic geomorphological map of the area at a 1:50,000 scale.

The study area (Figure 1) is the continental shelf located NE of the Maltese archipelago (central Mediterranean Sea). It was entirely emerged during the Last Glacial Maximum (LGM) and successively submerged during the post-glacial sea-level rise (Figure 2) (Lambeck _et al.,_ 2011). During the last glacial cycle, the sea-level reached its minimum, being approximately 130 m lower than today.
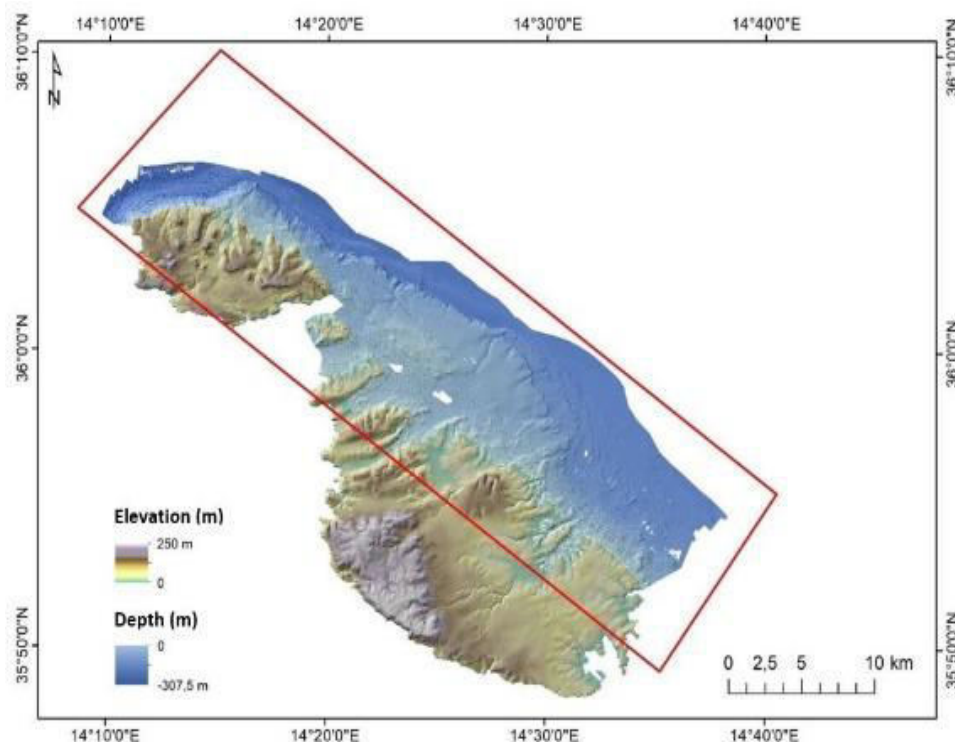
Figure 1. Location of the Maltese archipelago and its continental shelf.

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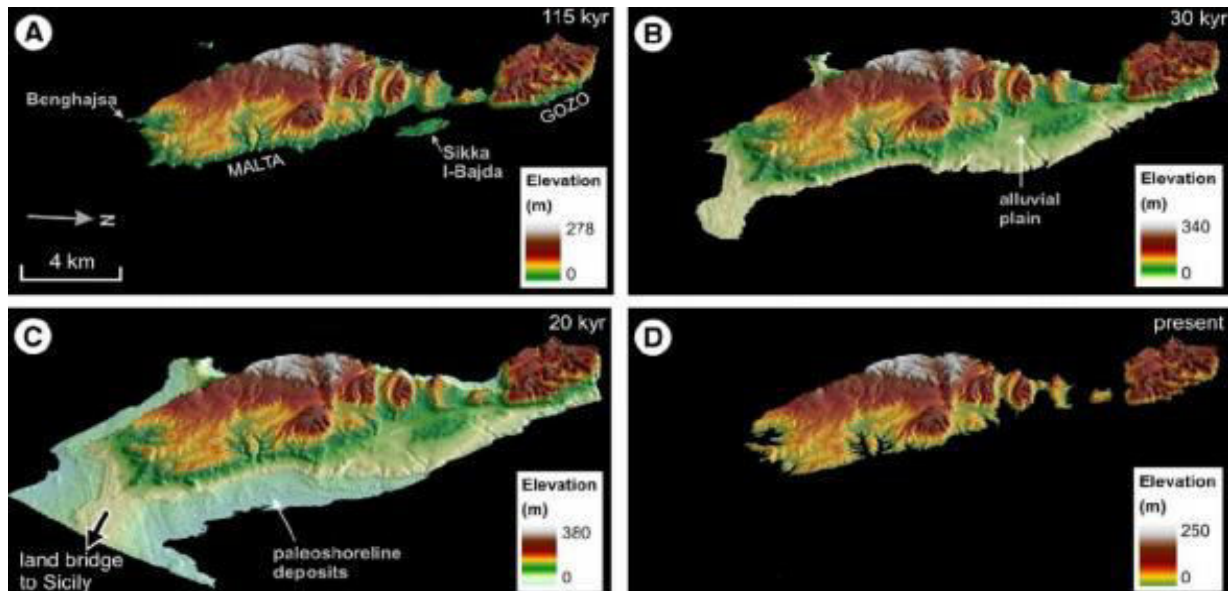
Figure 2. Maltese paleo-geography (115 kyr, 30 kyr, 20 kyr, present) (modified after Foglini et al., 2016).

Marine transgression has not significantly modified the currently submerged landforms, which are still easily recognizable.

The research was carried out as part of the European Marine Observation and Data Network (EMODnet), which aims to share information on the geology of the seabed of Europe. In particular, the data used for geomorphological mapping were elaborated to contribute to the EMODnet Geology portal, as part of Work Package 4 "Seafloor geology/geomorphology" and Work Package 8 "Submerged Landscapes".

Methods

The spatial and chronological data regarding investigated area were organized in a GIS environment; the map was produced by means of ESRI Arcgis 10.1 software, and the legend was based on landform genesis.

Results

The Maltese submerged landscape shows structural, marine and coastal, fluvial, karst, gravity-induced and man-made landforms.

The NE area of the Maltese archipelago includes a sub-planar continental shelf bounded by a continental slope whose base is about -130 m deep. This escarpment is NW-SE oriented, parallel to one of the fault systems characterizing the Maltese area and by which it seems to be controlled (Micallef *et al.,* 2013; 2019).

Other structural escarpments occur on the continental shelf and border the marine terraces; they are mainly oriented NW-SE or ENE-WSW and, being parallel to the fault systems of the Maltese islands, are interpreted as submarine evidence of these faults (Micallef *et al.,* 2013; 2019). Some

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of them are in correspondence of ancient coastline deposits related to the sea-level oscillations. Other structural landforms include outcrops of limestone plateaus, similar to those occurring on land, that are bordered by structural scarps. A remarkable example is given by the Sikkail-Bajda plateau, which is characterized by the superimposition of Upper Coralline Limestone Formation on the Blue Clay Formation. Furthermore, this submerged plateau appears to have been affected by karst processes that have formed a karst pavement on its surface and favored the development of bedrock-collapse sinkholes (up to 250 m of diameter) and solution sinkholes.

The continental slope is characterized by different levels of marine terraces (Figure 3A), with NW-SE orientation, which are interpreted as coastal paleo-platforms formed during the lowstand phases of the sea-level (Micallef *et al.,* 2013; Prampolini *et al.,* 2017). Marine landforms include a contourite deposit of fine elongated sediments SE-NW-oriented, located at a depth greater than -130 m and modelled by bottom currents (Béranger *et al.,* 2004). On the continental shelf, ripple marks modelled by SE-NW oriented background currents occur offshore Mellieha and St. Paul's Bay.
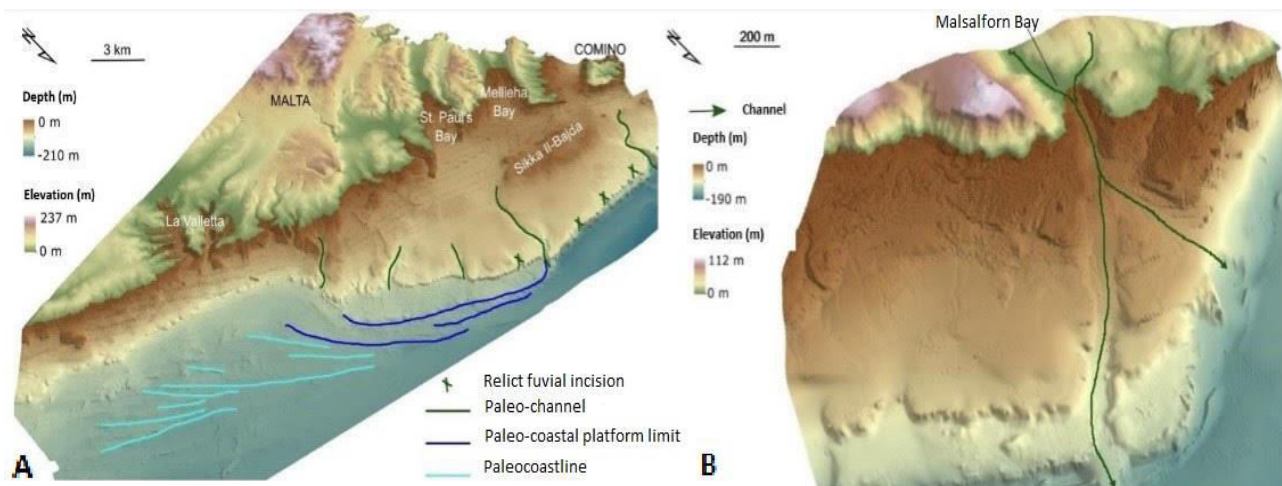
Figure 3. A) Marine terraces interpreted as coastal paleo-platforms; B) Channels of fluvial origin located at Marsalforn Bay (Gozo).

Near shore and below the main escarpment, there are isolated gravity-induced block deposits that can be referred to various types of landslides (lateral spread, block slide, rock fall). The Sikkail-Bajda plateau is surrounded by blocks of large dimensions, which are interpreted as evidence of lateral spreading. Other blocks located at the base of the continental slope have been interpreted as the result of collapses and rock falls associated with coastal erosion. Different types of gravity-induced landforms largely characterize the northeastern coast of Gozo, where limestones overlap clayey terrains favoring the development of lateral spreading, which tend to evolve into block slide that often continue below sea-level (Prampolini *et al.,* 2018). Landslides are mainly controlled by the presence of tectonic discontinuities and lithological structures and likely developed in a subaerial environment, and then submerged during the post-glacial sea-level rise (Soldati *et al.,* 2018).

Other relevant landforms are the ENE-WSW oriented channels, which affect the shelf and indent the continental escarpment. They are located in front of Marsalforn Bay (Gozo) (Figure 3B), facing

the island of Comino and in the area between St. Paul's Bay and St. Julian's Bay (Malta). Upstream of these channels, interpreted as paleo-riverbeds, there are flat areas interpreted as alluvial plains. There are also numerous gullies, channels engraved in clayey slopes and developed in climatic conditions wetter than the current ones.

Man-made landforms are concentrated offshore the capital Valletta. Near the port, dredging, anchoring and material unloading activities have created curvilinear streaks that cross the seabed, which is also characterized by the presence of wrecks sunk during the Second World War and now used as scuba diving sites. On the seabed of Ramla Bay there are remains of historic defense walls, built to protect the bay from possible enemy attacks from the sea.

Conclusions

The eastern Maltese continental shelf is characterized by landforms and deposits typically due to subaerial processes, such as fluvial, coastal, karst and gravitational processes. The landforms deriving from subaerial modeling are still easily recognizable thanks to the carbonate lithology that characterizes the Maltese archipelago and the scarce contribution of terrigenous sediments due to the semi-arid climate of the area. Thus, once submerged, the landscape was only partially modified by erosion and sedimentation processes. The processes that shaped the landscape during the lowstand phases of the sea-level are not currently active and the platform thus hosts predominantly relict landforms.

The marine processes currently taking place on the NE continental shelf of the Maltese islands are mainly attributable to SE-NW oriented bottom currents (Béranger *et al.,* 2004), which led to the formation of ripples and a drift current deposits.

The study made it possible to deepen the knowledge about the landforms of the Maltese submarine landscape from the Last Glacial Maximum until today and to outline its geomorphological evolution. This work also allowed representing data that previously had not been summarized in a synoptic geomorphological map.

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The Role of *Posidonia* Banquettes in Coastline Protection against Erosion, through UAV Technology and Granulometric Analysis: Preliminary Results from the Case of Schinias-Marathon National Park, Attica, Greece

D. Vandarakis [1], M. Salomidi [1], V. Gerakaris [1], Y. Issaris [1], I. Kourliaftis [1], V. Kapsimalis [1], I. Panagiotopoulos [1], C. Agaoglou [2]

(1) Institute of Oceanography, Hellenic Centre for Marine Research (HCMR), 19013 Anavyssos P.C., Greece; divandarakis@hcmr.gr

(2) Department of European Projects Hellenic Society for the Protection of Nature, Department of European Projects, Nikis 20, 105 57 Athens, Greece, chagaoglou@eepf.gr

Abstract

Coastal environments and in particular beaches are valuable natural assets, offering a wide array of ecosystem services and economic benefits (Schlacher *et al*., 2008). At the same time, they are rapidly evolving systems, driven by the continuous interaction of the topography and transport processes with wind, wave and tidal forcing. When seeking to inform coastal management plans, understanding and quantifying coastal morphodynamics is both crucial and challenging, as it largely relies on the acquisition of high-resolution data on beach topographic changes (Casella *et al.*, 2020).

Inrecent years, the use of Unmanned Aerial Vehicles (UAVs) in physical geography, geomorphology, coastal ecology, and similar fields, has significantly increased. In this study,UAV technology with RTK-GPS is used to produce high-resolution mapping of beach morphological characteristics, aiming to assess the impact of beach-cast *Posidonia oceanic* residues (Simeone *et al.,* 2013; 2012). When in large accumulations, these residues may form deposits known as "banquettes" (Boudouresque and Jeudy De Grissac, 1983), which depending on local conditions may vary from few centimeters to several meters thick (De Falco *et al.,* 2003, Simeone and Baroli, 2008; Simeone and De Falco, 2012). In general, *Posidonia oceanic* sheds leaves year-round, but most prominently in late summer and early autumn (Romero *et al.,* 1992). However, the largest amount of dead leaves deposition on the beaches is observed in autumn and winter, when hydrodynamic action (i.e. highwind speeds and waves) causes the leaf litter to be cast ashore (Vacchi *et al.,* 2017).

The principal aim of this research is to evaluate the relation between the banquettes and sediments, as well as the banquettes' significance in beach protection (De Falco *et al.*, 2003). More particularly, the distinctive goals are: a) to identify the differences in volume, shape and area covered by the banquettes, and b) to analyze the relationship between banquette deposition and morphological changes of the underlying sedimentary substrate of the beach.

The study area is located at the coastal plain of Marathon and particularly at Schinias, in the northeast region of Attica Prefecture, with an orientation of NE to SW (Figure 1).

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The coastal area of Schinias, is characterized by smooth slope, relatively low wave energy and sandy sediments. This area also features the estuarine lagoon draining channel, making the sedimentary composition and sediments dynamics more complicated.

Due to the smoothness of the terrain (almost flat as it is a beachfront) the flights are horizontal parallel to the ground at a certain height AGL (Above Ground Level) (Trajkovski *et al.,* 2020). The sensor of the UAV is pointed in 80 degrees (nadir). The images are taken in a specific overlap (80% front, 80% side), in order to achieve very high resolution of 3D reconstruction of the relief, in order to have as accurate measurements as possible, of the different concentrations of the banquettes onshore. Pix4D capture (v.4.12.1) is used to make the flight plans. Through this software, the area of interest, the flight paths (2D, 3D models etc.), the flight height, the front overlap and the side overlap can be defined according to the resolution needed. Then the flight plan is uploaded to the drone and it takes off automatically and completes the acquisition of the images following the waypoints.
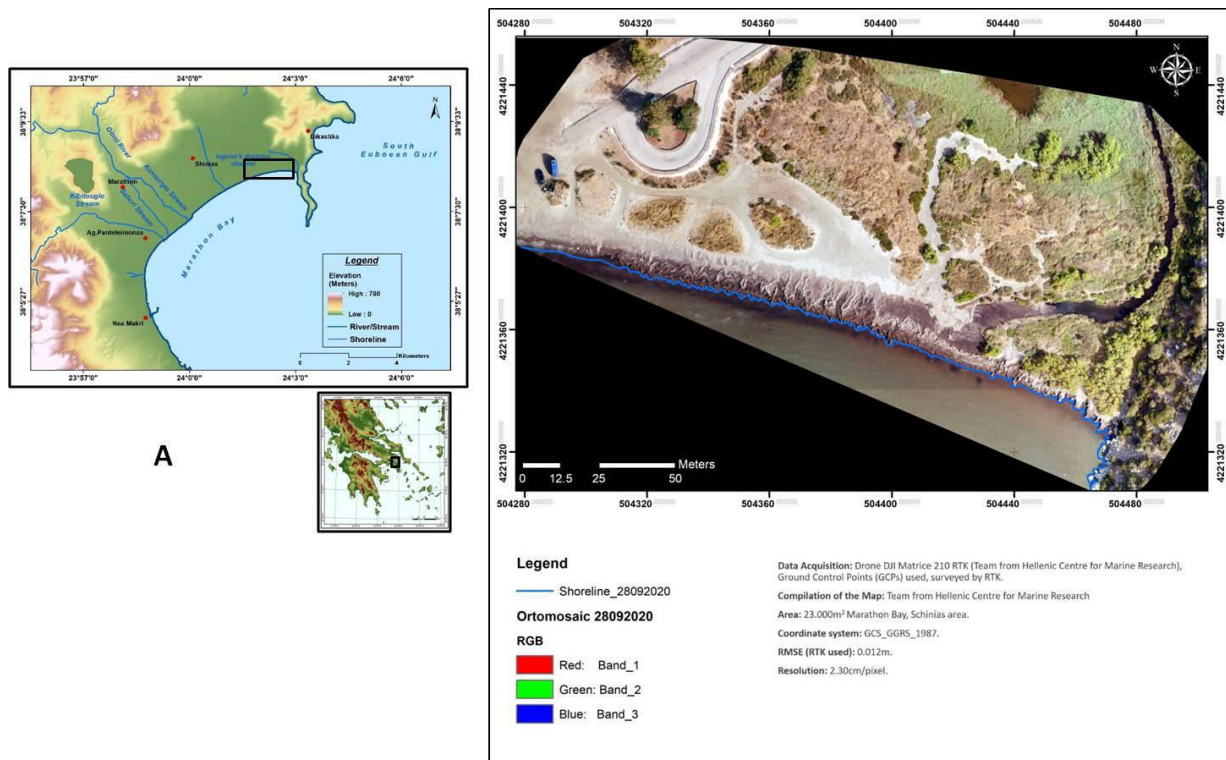
Figure 1. (A) Location of the study area along with physiographic settings of the coastal plain on Marathon (after Kourliaftis et al., 2019). The black rectangle indicates the selected test site. (B) The orthomosaic of the area resulted from images of Mission 2 (September 2020).

The use of Ground Control Points (GCPs) to such a survey is fundamental, because they increase the accuracy of the UAV imagery to centimeter level (2cm) (Fallati *et al.,* 2020; Lu *et al.,* 2020). At least 5 GCPs were used for each mission, which are black and white targets with defined center,

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with exact dimensions of 25cm X 25cm. They also improve the results from the Structure from Motion (SfM) interpretation of the photogrammetry process (Windle *et al.,* 2019). Prior to the flight, the GCPs were surveyed with RTK-GPS.

Sediment samples were collected during the photogrammetry missions (July 2020, September 2020). Samples were acquired along the shoreline segment where banquettes occur, in three transects spaced approximately 50m apart. This allows a holistic approach to understanding the relation between banquettes and sediment granulometry.The granulometric-sedimentological analyses were conducted at the Bio-Geo-Chemical Laboratory (ISO 17025) of HCMR. The samples were dried and sieved (sieves from 4 mm to <63 μm). Results were interpreted statistically through the Gradistat v. 8.0 (Blott *et al.,* 2001), in order to define the quality and the quantity of the distinctive sediment classes.

Results from Mission 1 (July 2020) and Mission 2 (September 2020) showed that the maximum volume of the banquette depositson the beach is $692.57 \pm 8.3 m^3$ (Mission 2) with an outspread of about 2617.43 m^2, after four days of high-velocity eastern winds. The dominant sediment class is "fine sand" with a percentage of over 60% indicating the low energy deposition environment, and therefore the banquette's protective trend against beach erosion.

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Insular Coastal Erosion Detection and Mapping Using Geospatial Technologies: The Case of Rhodes Island (Greece)

I. Gkougkoustamos [1]

(1) Harokopio University, Eleftheriou Venizelou 70, Athens, Greece, johnniegougos@gmail.com

Introduction

The present study focuses on the detection and mapping of coastline changes of Rhodes Island (Greece) utilizing remote sensing techniques. Coastline is the line defined by the intersection of the sea surface with the land. This line does not remain stable but changes over time. These changes involve both short periods of time, such as twenty-four hours, and larger time scales that reach thousands of years (Karymbalis, 2010). Long-term monitoring of these changes is very important for the investigation of their impact on coastal zones, businesses and nearby settlements, as well as for assessing future changes and risks.

Remote sensing, the process of detecting and monitoring physical characteristics of an area by measuring its reflected and emitted radiation at a distance, is a modern way of studying that offers a wide range of applications and techniques with reliable, accurate and low cost results. This study focuses on the mapping of the island's coastline on a large time scale (years: 1990 to 2020) and on a smaller time scale (years: 2016 to 2020), with the use of Normalized Difference Water Index (McFeeters, 1996; 2013), and the calculation of the coastline displacement rates using the USGS (United States Geological Survey) DSAS (Digital Shoreline Analysis System) tool.

Data

The monitoring and mapping of coastlines is executed in two parts. The first part is the pre-processing of the data and the second part is the mapping of the coastlines for each year and the calculation of their displacement rate. For the time scale 1990 - 2020, Landsat 5 and Landsat 8 TOA (Top of Atmosphere) images were used from the Tier 1 collection. Tier 1 images are suitable for time series analysis as they consist of well-characterized radiometry and are inter-calibrated across the different Landsat instruments (Landsat Collection 1, USGS). For the time scale 2016 – 2020, Sentinel-2 Level 1-C optical images were used. Similarly, these images are geometrically and radiometrically corrected and are suitable for time series analysis (Sentinel-2 MSI - Processing Levels, ESA).

Pre-processing

A necessary first step for the pre-processing of Landsat images is to create a stack of spectral bands, since Tier 1 bands are not combined into a single product. Then the pixel resolution of each spectral band is resized from 30m to 10m, and then the NDWI (McFeeters, 1996; 2013) is calculated.

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For the pre-processing of Sentinel-2 images, the first step is resampling, which is the conversion of the resolution of all spectral bands into a common resolution, in this case 10 m. In addition, a mosaic is created for every year as the island is covered by 3 images. This is followed by a subset of the mosaics in the study area and calculation of the NDWI (McFeeters, 1996; 2013).

Table 1. Data.

Date	Data	Pixel resolution
16 / 08 / 1990	Landsat 5 Tier 1	30 m
13 / 07 / 1995	Landsat 5 Tier 1	30 m
11 / 08 / 2000	Landsat 5 Tier 1	30 m
25 / 08 / 2005	Landsat 5 Tier 1	30 m
06 / 07 / 2010	Landsat 5 Tier 1	30 m
05 / 08 / 2015	Landsat 8 Tier 1	30 m
17 / 07 / 2020	Landsat 8 Tier 1	30 m
23 / 08 / 2016	Sentinel-2 Level 1-C	10 m
08 / 08 / 2017	Sentinel-2 Level 1-C	10 m
14 / 06 / 2018	Sentinel-2 Level 1-C	10 m
23 / 08 / 2019	Sentinel-2 Level 1-C	10 m
22 / 08 / 2020	Sentinel-2 Level 1-C	10 m

Main processing

The results of the pre-processing are imported into a GIS software. For the NDWI of every image, a threshold value is selected which creates a new image with two values corresponding to land and sea. This is followed by their conversion to polygons (vector data) and consequently polylines. The result is the mapping of the coastline for the selected years.

The coastline displacement rate is calculated using the USGS DSAS tool. After the coastlines are imported, a reference baseline is defined which is placed on the land. The software generates transects that are cast perpendicular to the reference baseline. These transects intersect with the coastlines of the selected years. The points of intersection, as well as the dates of each coastline, are used to calculate the displacement rate through Linear Regression.

Results

The results are the coastline displacement rates per year at the positions of the transects. Positive values correspond to coastline accretion (in meters / year) while negative values correspond to coastline erosion (in meters / year). The results are visualized on four maps. The first and second maps are the 1990 - 2020 and 2016 - 2020 time scale measurements, classified based on their standard deviation (sd = 0.58 and sd = 0.89 respectively). In the third and fourth maps only the more reliable measurements of these periods are kept (coefficient of determination LR2 > 0.5) and classified based on their standard deviation (sd = 1.07 and sd = 1.19 respectively).

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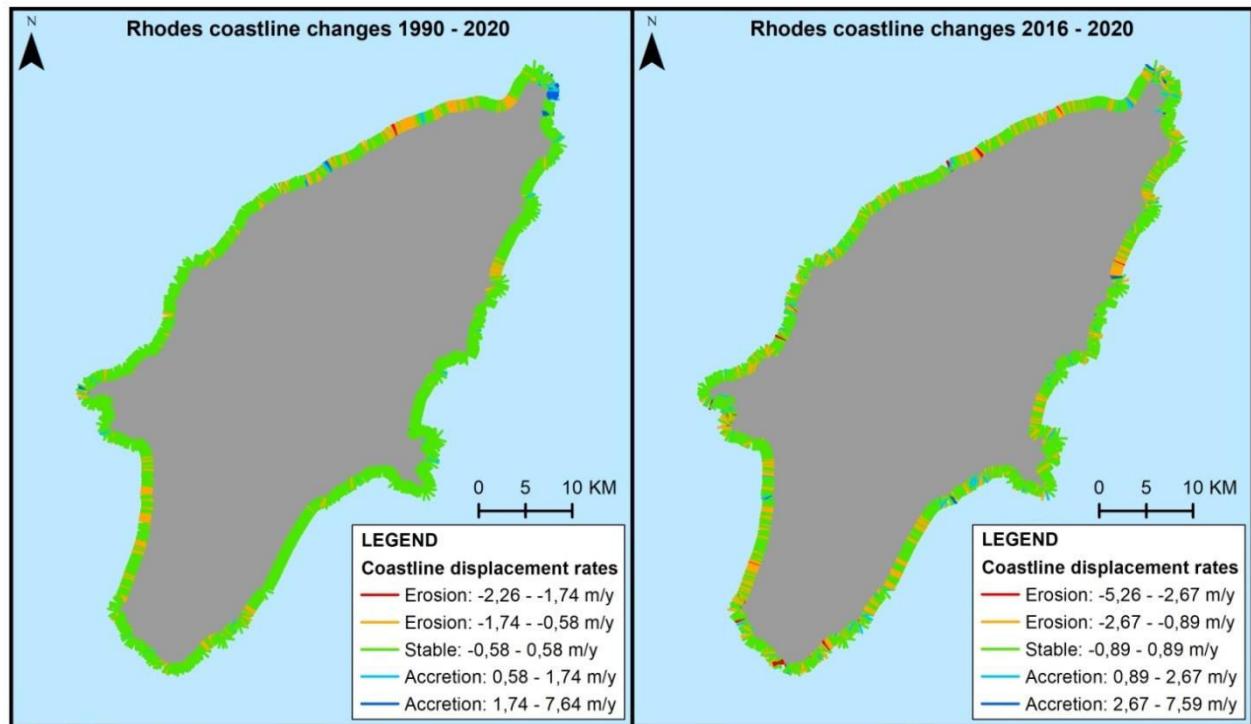
Figure 1. Coastline changes of Rhodes island for the periods 1990 – 2020 (Landsat 5 & 8 results) (left) and 2016 – 2020 (Sentinel-2 results) (right).
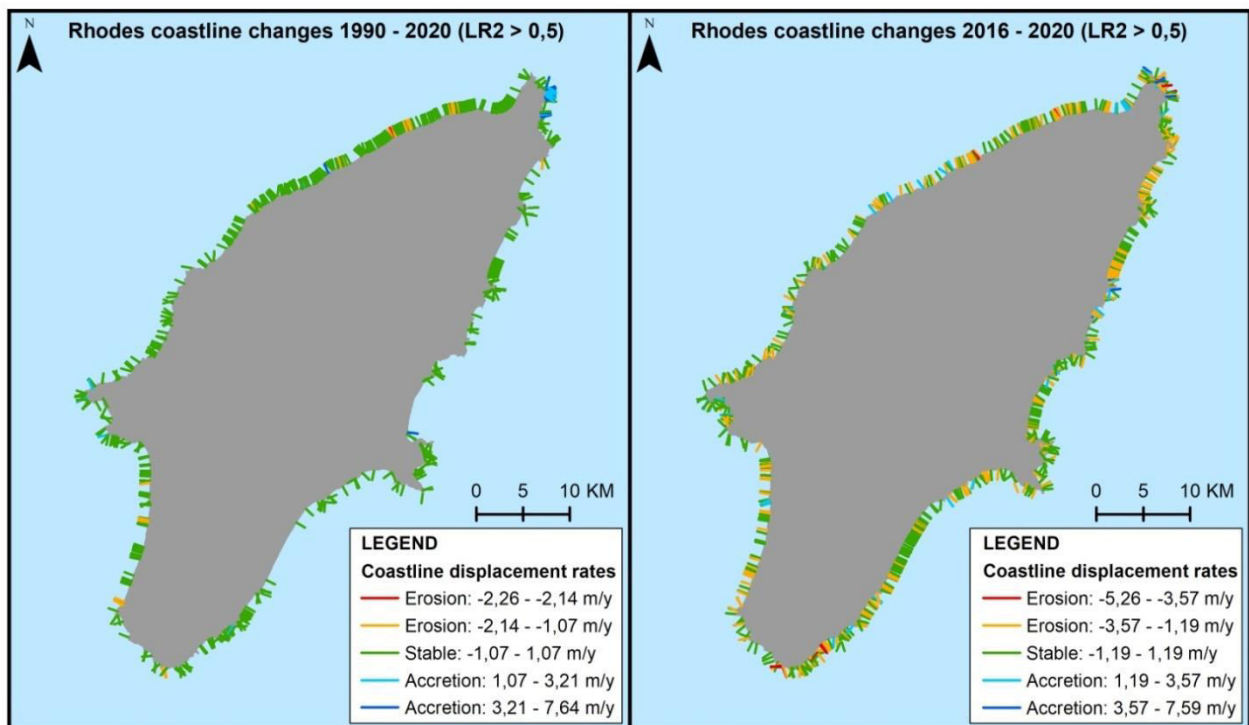
Figure 2. Reliable measurements of coastline changes of Rhodes island for the periods 1990 – 2020 (Landsat 5 & 8 results) (left) and 2016 – 2020 (Sentinel-2 results) (right).

The differences in the deformation rates between the Landsat and Sentinel-2 measurements are a result of three factors: the pixel resolution of each product, the NDWI threshold and the time scale. Therefore field observations are necessary for the verification of these measurements. It is notable that in both Landsat and Sentinel-2 results, there are several locations that have the same type of deformation (accretion or erosion) and others that remain stable. This gives us a good indication about the locations that are probably most prone to problems caused by erosion.

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Sedimentological and Geomorphological Study of Vravrona Beach, East Attica

A. Komi [1], A. Petropoulos [1], N. Evelpidou [1], S. Poulos [1], V. Kapsimalis [2]

(1) National and Kapodistrian University of Athens, Panepistimioupoli, Athens, Greece, akomi@geol.uoa.gr, alexpetrop@geol.uoa.gr, evelpidou@geol.uoa.gr, poulos@geol.uoa.gr
(2) Hellenic Center of Marine Research, Anavyssos, Greece, kapsim@hcmr.gr

Abstract

This study focuses on the sedimentological and morphological features of Vravrona Beach, East Attica, in order to determine the seasonal changes in the textural group classification of the costal sediments, as well as, changes in coastline position. Additionally, Vravrona Beach has been chosen for the assessment of a potential coastal erosion, using the Coastal Vulnerability Index (CVI) through GIS technology, since several incidents of erosion have been identified during the past decades in the broader area of East Attica (Dimou _et al.,_ 2010).

For the composition of the beach profile in seasonal scale, cross sections were conducted along the beach from landward to seaward until approximately 10 m from the coastline. Beach width as well as the current coastline position for each season was measured with a differential GPS (DGPS). The land use at the landward upper limits of the study area was also measured. Along selected cross sections, sediment sampling was also conducted during January 2018 for the composition of the winter profile of the study area and during September 2018 for the composition of the summer profile of the study area.

Sedimentological analyses were based on grain size distribution for the analysis of unconsolidated sediments by sieving and statistical parameters such as sorting, skewness, mean and kurtosis were calculating using GRADISTAT v. 0.4 software in order to determine the sedimentological features of the study area and the transport mechanism at the time of deposition. The textural group of the samples was also determined by Folk and Ward (1957) classification.

The grain size analysis of the samples, collected between the upper limit of the beach and the coastline during summer period, show that the majority of grains is described as slightly gravelly sand and gravelly sand, but during the winter period the grains are between gravely sand and sand. The samples collected from the coastline until approximately 10 m seaward are mainly described as slightly gravelly sand and sandy gravel for both sampling seasons.

DGPS measurements of coastline position indicate changes that vary between 4.38 m to 7.41 m with a maximum value at 8.27 m. In agreement to field observations, DGPS measurements indicate an accumulation of sediments at the northern part of the beach during the winter period, while during summer period there is an accumulation of sediments at the southern part of the beach (Figure 1).
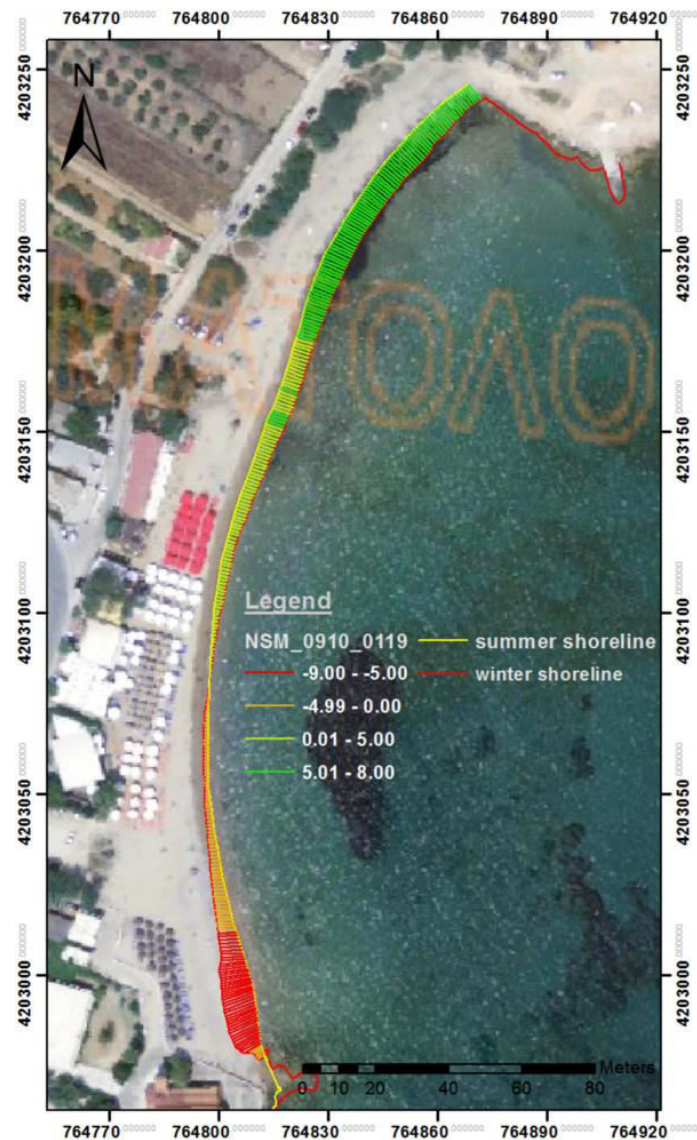
Figure 1. Net shoreline movement. The green lines, vertical to the coastline, indicate an accretion of the coastline at the north part of the beach about 5-8 m seawards. The red vertical lines indicate a retreat of the coastline at the southern part about -9- -5 m landward.

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Geomorphological Parameters for Planning

H. D. Skilodimou [1], **G. D. Bathrellos** [2]

(1) National &Kapodistrian University of Athens, Faculty of Geology &Geoenvironment, Department of Geography & Climatology, University Campus, ZC 15784, Zografos Athens, Greece, hskilodimou@geol.uoa.gr

(2) University of Patras, Department of Geology, Division of General, Marine Geology & Geodynamics, Rio Patras, ZC 26504, Greece, gbathrellos@upatras.gr

Introduction

During the last century, rural depopulation has been observed on a global scale, resulting in the abandonment of villages and the significant reduction of certain rural activities (traditional crop, farming among others). A constant movement of the population from rural to urban areas, which are considered to provide more favourable economic and social conditions, has been recorded.

On the other hand, during the urban planning usually only economic and social parameters are taken into account. As a result, urban areas are susceptible to natural disasters, which cause extensive damages in them, because the cities or towns have been repeatedly located in vulnerable areas.

In Greece, during the last 60 years, the rural depopulation phenomenon has been very intense. More than the 52% of the national population is congregated in the two largest urban complexes of the broader areas of Athens (the capital of Greece) and Thessaloniki. The six biggest cities-towns of Greece host more than 70% of the total population.

In this study, for the protection of human environment,a unique approach of planning and sustainable developmentis presented.The main aims of this study are (a) to demonstrate the usage of natural hazard maps and other physical parameters in land use planning and mainly in urban design, (b) to determinate the unsuitable areas for urban and industrial development and (c) to identify suitable areas for the rural communities (villages with population less than 1,800 inhabitants) and agricultural development based on mainlyphysical geographical - geomorphological factors and hazard maps.

Methods

For the suitability assessment concerning urban growth, rural communities, industrial development, and agricultural development, we used a multi criteria model based on geological, geomorphological and social-economic factors and natural hazard maps.

In this presentation, the AHP and GIS techniques were employed in the land-use decision-making procedure. Usually the planners use social-economics parameters - factors in spatial planning. In this presentation, it should be noted that the selection of factors is not exhaustive and only the physic process parameters were selected, because of the aim of this work is to perform the usage of physic geographical factors in planning.

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Specifically, the slope, the aspect, the elevation, the distance from streams, the lithology, the landslide susceptibility, the earthquake intensity, the distance from flood events, the distance from road network and distance from main towns are used as parameters (factors) for the urban planning. On the other hand, the slope, the elevation, the distance from streams, the lithology, the landslide susceptibility, the earthquake intensity, the distance from flood events, the distance from road network and distance from main towns are used as parameters (factors) for the estimation of industrial development.

For the estimation of rural communities development, the slope, the aspect, the elevation the distance from high order drainage network, the distance from low order drainage network, the lithology, the landslide susceptibility, the seismic intensity, the distance from flood events, the erosion hazard assessment, the distance from national roads (highways), the distance from provincial roads, the distance from villages and settlements are taken into account as parameters (factors).

For the estimation of agricultural development, the slope, the aspect, the elevation the distance from high order drainage network, the distance from low order drainage network, the lithology, the water supply, the landslide susceptibility, the seismic intensity, the distance from flood events, the erosion hazard assessment, the distance from national roads (highways), the distance from provincial roads, the distance from rural roads, the distance from villages and settlements are taken into accountas parameters (factors).

Results

By using the AHP and GIS techniques and the geomorphological parameters, we produced the following suitability maps, the potential suitability map for urban growth (Figure 1), the potential suitability map for industrial development (Figure 2), the potential suitability map for the development of rural communities (Figure 3) and the potential suitability for agricultural development (Figure 4).

Figure 1. Potential suitability for urban growth.

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Figure 2. Potential suitability for industrial development.
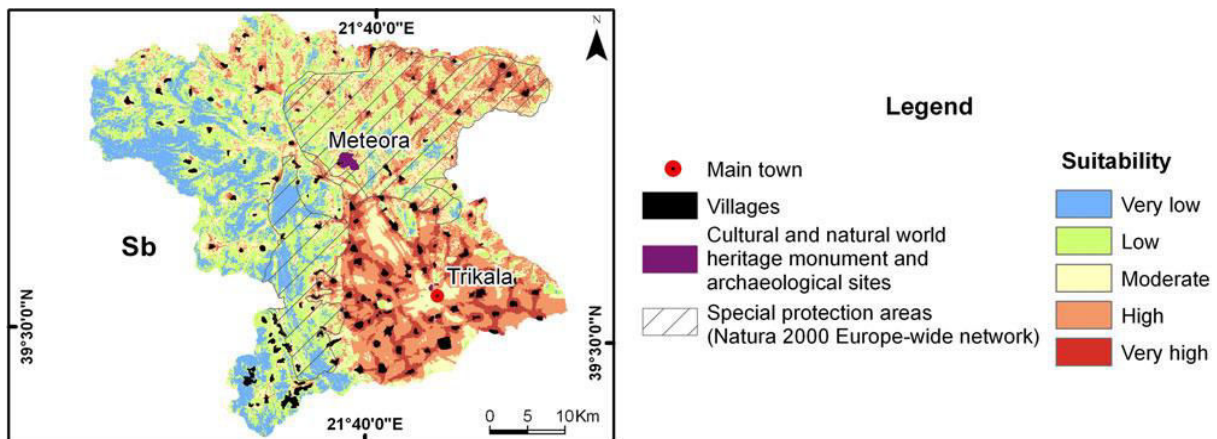
Figure 3. Potential suitability map for the development of rural communities.

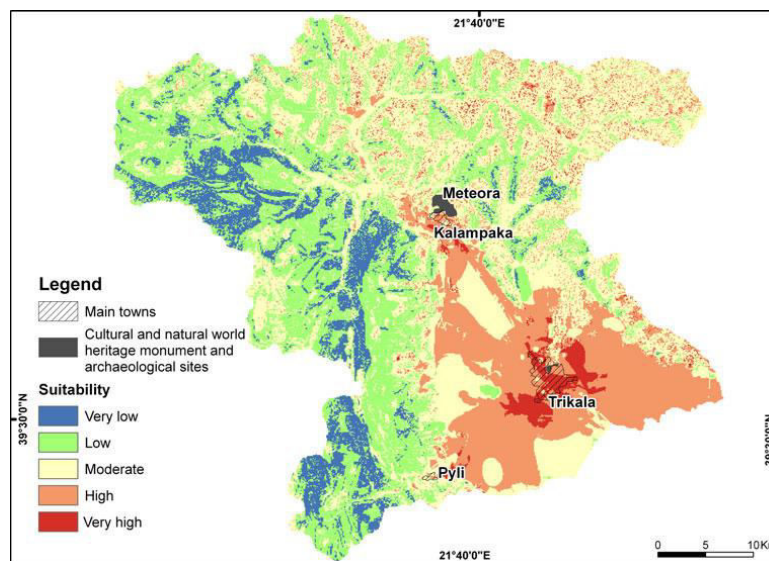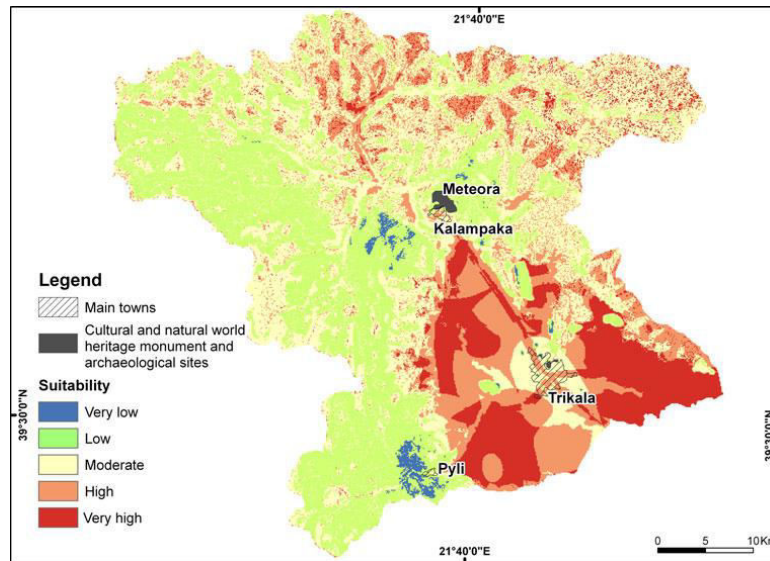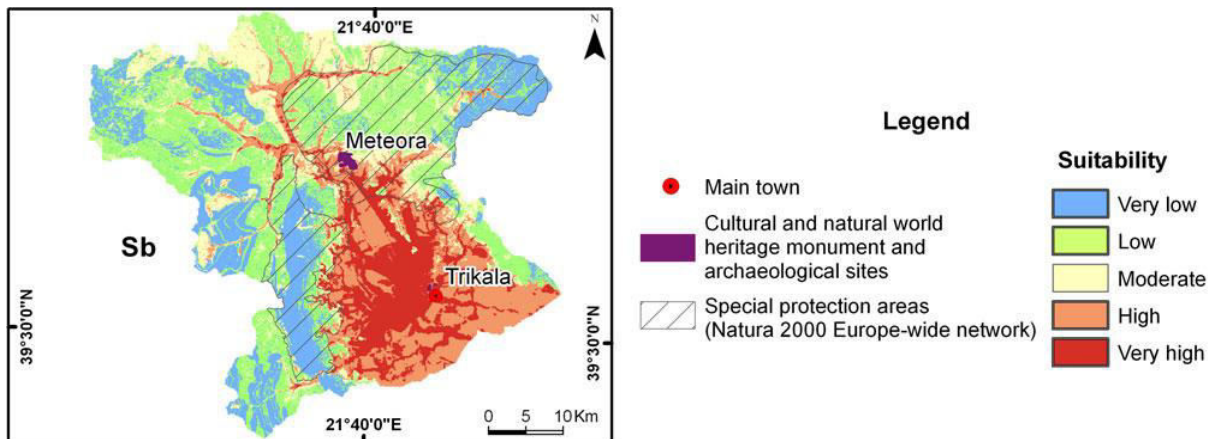*Figure 4. Potential suitability for agricultural development.*

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Conclusions

The geomorphological parameters are crucial, significant and necessary for the planning and estimation urban growth, rural development, industrial development and agricultural development.

It is necessary to be taken into account, not only the economical and social conditions, but also the physical and geomorphological factors.

The produced suitability maps are important and useful tools for planners and environmental managers when selecting favorable locations for land use development.

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Delimiting the Potential Harbor of Poliochni Archaeological Site Using UAV and Bathymetry Survey, Lemnos Island, Greece

D. Vandarakis [1], K. Vouvalidis [2], V. Kapsimalis [1], I. Panagiotopoulos [1]

(1) Institute of Oceanography, Hellenic Centre for Marine Research (HCMR), 19013 Anavyssos P.C., Greece; divandarakis@hcmr.gr

(2) Department of Geology, Aristotle University of Thessaloniki,Panepistimioupolis AUTH, 541 24 Thessaloniki, Greece; vouval@geo.auth.gr

Abstract

The Unmanned Aerial Vehicles (UAVs) have become increasingly utilized in archaeological investigation. In combination with photogrammetric methodology, such systems have proved remarkably useful in the rapid creation of high resolution Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and other aerial sensing data (Field *et al.,* 2017; PAUL, 2018).

Inrecent years, the use of Unmanned Aerial Vehicles (UAVs) in physical geography, geomorphology, archaeology, and similar fields, has significantly increased. In this study, UAV technology with RTK-GPSis used to produce high-resolution mapping of beach morphological characteristics, of Poliochni area in Lemnos Island. In addition, bathymetric survey was conducted to enhance the accuracy and the correctness of the assumptions concerning the present research. Poliochni is an archaeological settlement of the third millennium BC (5000 y BP). Its strategic position made it commercial center of the NE Aegean at that period.

The principal aim of this research is to delimit the potential harbor of this significant archeological site. More particularly, the distinctive goals are: a) to identify the morphological characteristics of the coastal-marine region with very high resolution and accuracy and to consider the sea-level variations during Upper Holocene (Lambeck and Purcell, 2005; Pavlopoulos *et al.,* 2013) of the broader area, in order to identify the exact position of the shoreline at around 5000 y BP.

The study area is located atthe coastal area of Poliochni in Lemnos Island, NE Aegean. The total area surveyed was approximately 0,12 Km^2 in the terrestrial part of the coastal front and 0,41 Km^2 in the marine part (Figure 1).

Poliochni is characterized by coastal cliffs, high wave energy and coarse sediments. The research area also features two estuaries of the torrential hydrographic network, one in the Northern part and the second in the Southern part.

To survey the whole region of interest multiple flights were conducted. They were horizontal parallel to the ground at 100 m altitude AGL (Above Ground Level) (Trajkovski *et al.,* 2020). The sensor of the UAV (Zenmuse X5S) was pointed in 80 degrees (nadir). The images were taken in a specific overlap (80% front, 80% side), in order to achieve very high resolution of 3D reconstruction of the relief, in order to have as accurate measurements as possible. Pix4D capture (v.4.12.1) was used to make the flight plans. Through this software, the area of interest, the flight paths (2D, 3D models etc.), the flight height, the front overlap and the side overlap were defined

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according to the resolution needed. Then the flight plan was uploaded to the drone and it took off automatically and completed the acquisition of the images following specific waypoints.
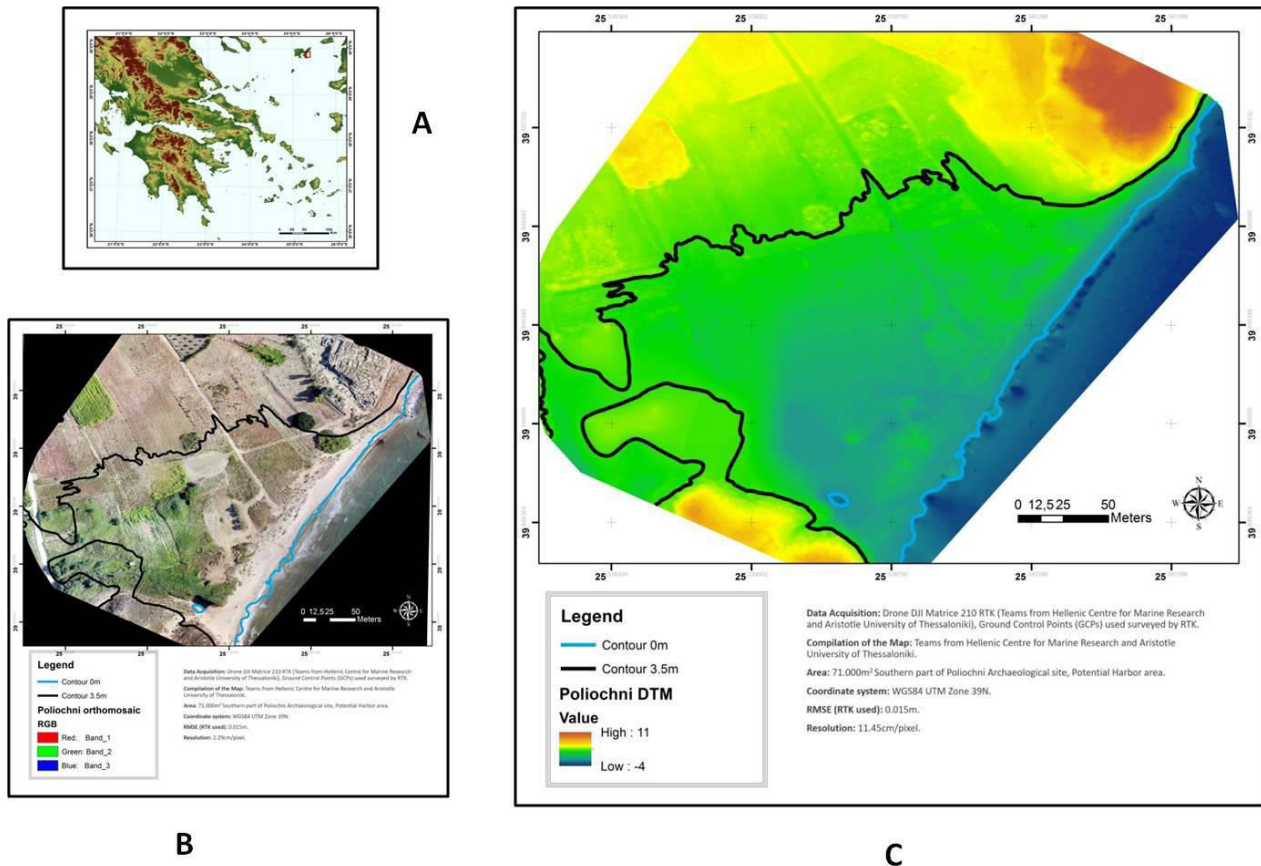
Figure 1. (A) Location of the study area. The red rectangle indicates the study area. (B) The Orthomosaic of the potential location of the harbor and the contour of -3.5 m delimiting the exact position(C) The DTM presenting the altitude of the area and the contour of -3.5 m indicating the shoreline of 5000 y BP.

The use of Ground Control Points (GCPs) to such survey is fundamental, because they increase the accuracy of the UAV imagery to centimeter level (2 cm) (Fallati *et al.,* 2020; Lu and Chyi, 2020). At least 4 GCPs were used for this flight, which are black and white targets with defined center, with exact dimensions of 50 cm X 50 cm. They also improve the results from the Structure from Motion (SfM) interpretation of the photogrammetry process (Windle *et al.,* 2019). Prior to the flight, the GCPs were surveyed with RTK-GPS. Afterwards, through Pix4 mapper v.4.5.6., the orthomosaic, the DSM and the DTM were constructed, but first they had to be corrected from the vegetation, the manmade structures and the errors from the data acquisition, in order to represent as accurately as possible the natural environment. The coordinates from the RTK-GPS were inserted and calculated, perfecting the accuracy of the georeference to cm-level (RMSE: 0.015 m). Then the contour lines were extracted from the DTM with an elevation interval of 0.5 m, starting from the shoreline (contour of 0 m). In addition the results were exported and interpreted with ArcGIS v. 10.7 in order to combine all the data into maps.

The results from the research flight, and the bathymetric survey, combined with the sea-level information, delimit an area of the potential location of the ancient harbor of Poliochni. In particular, the most suitable location of the harbor is presented in the southern part of the study area, where the alluvial plain of the torrent is observed. It is a low inclination area well protected from the northern winds. Also combining the results of the UAV research, the bathymetric survey and the sea-level data, which indicates that in 5000 y BP the sea-level was approximately -3.5 m from its present position, the topographic reconstruction of that period showed an extended embayment, making this area the most suitable anchorage and a safe shelter for the vessels.

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Estimation of Recent Land Subsidence in the Evinos Delta (Western Greece) with the Application of SBAS Interferometry Technique

I. Papadopoulos [1], _A. Karavias_ [1], _I. Parcharidis_ [1], _E. Karymbalis_ [1]

(1) Department of Geography, Harokopio University of Athens, 70 Eleftheriou Venizelou Str. 17671, Athens, Greece, gp219315@hua.gr, gp219309@hua.gr, parchar@hua.gr, karymbalis@hua.gr

Introduction

River deltas are important geomorphic and sedimentary environments, acting as major sinks for fluvially derived sediments in the coastal zone. They have been and continue to be the heart of economic development. Land subsidence is a common phenomenon in modern deltaic plains because of compaction of sediments by consolidation of the dewatered material, compression of the load of the subsequent overlain deposits, and groundwater or oil pumping (Stanley, 2005).

The interferometric Synthetic Aperture Radar (SAR) technique has been proven to be an effective methodology for detecting and monitoring the ground deformation with millimeter accuracy (Parcharidis _et al.,_ 2011).

This study deals with the estimation of subtle ground deformation at millimetric accuracy over the deltaic plain of the Evinos River in western Greece and its spatio-temporal distribution for the period between 2015 and 2020 through the method of Small Baseline Subset (SBAS) Interferometry.

The Evinos River delta is located on the northern shore of the Gulf of Patras, Western Greece. It covers an area of approximately 92 km^2 and belongs to the Messologi wetland, one of the most significant ecosystems in Western Greece protected by the Ramsar Convention (Figure 1).
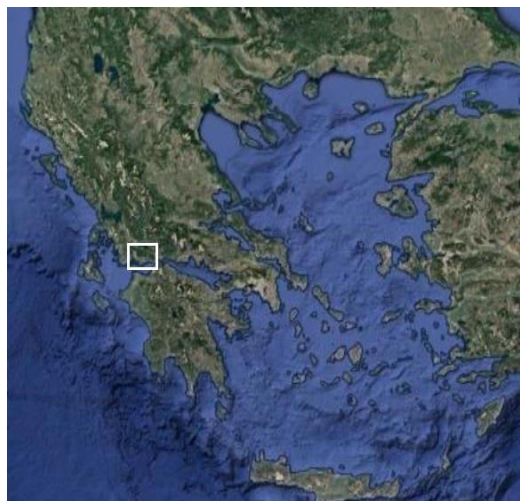
Figure 1. Location map of the Evinos River delta in West-Central Greece.

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Its development began during the Late Holocene with the relative stabilization of the sea-level rise (Karymbalis, 1996; Maroukian and Karymbalis, 2004). According to Galloway's (1975) proposed delta classification it should be classified among those deltas affected by fluvial sediment supply and wave activity. The city of Messologi is located at the northwestern part of the delta while the part of the western deltaic plain is the ecologically important Klisova lagoon, which covers an area of about 25 km^2.

Methodology

In order to analyze the mobility of the Evinos River delta a radar interferometry technique has been carried out. The interferometric method of Small Baseline Subset (SBAS) has been performed using the SARscape software 5.3, which runs on the ENVI platform 5.3 whereas the visualization of the results has been made with ArcGIS 10.4. For the purposes of this study, 100 Single Look Complex (SLC) scenes in ascending orbits, VV polarization and operating C-band (track: 175, frame: 121-122) from Sentinel 1A satellite were used, covering the time period between August 2015 and October 2020.
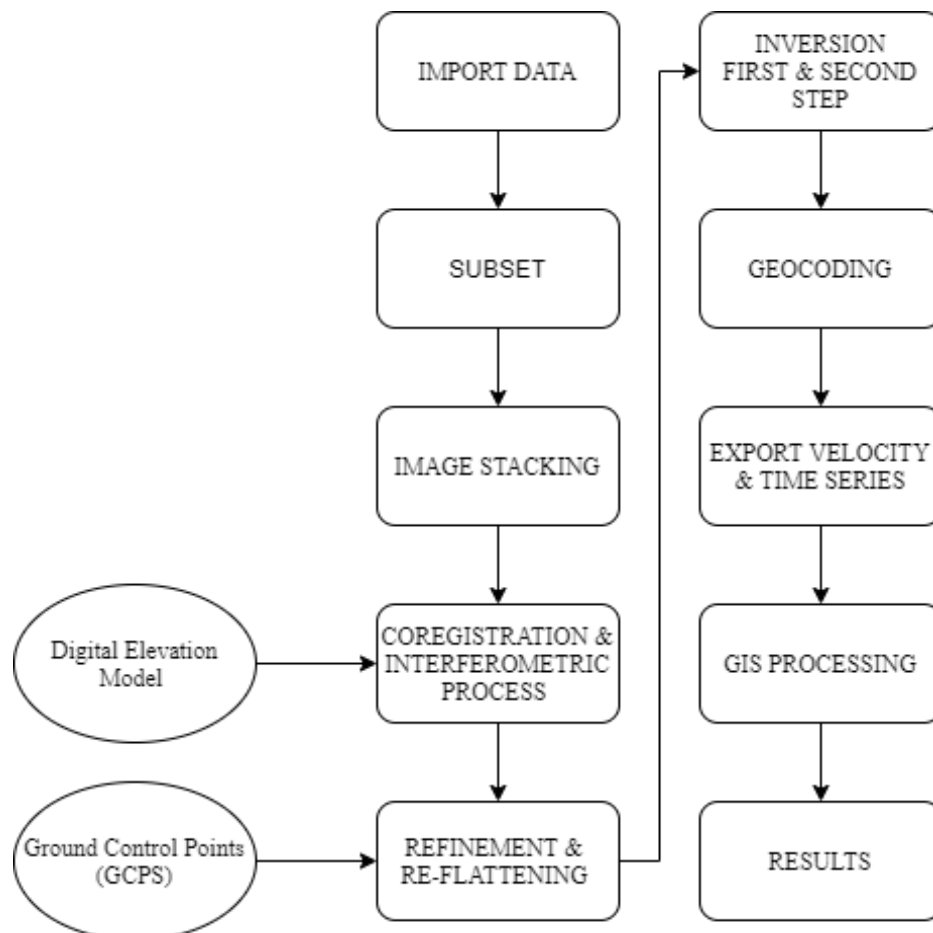
Figure 2. Flow chart of the processing.

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Results and Conclusions

The results indicate that the area of Messologi can be characterized as a stable zone, since the values of velocity are close to 0. This is one of the main reasons that the reference point has been chosen in this area (Figure 3). The relative "stability" of the city can be attributed to the dominance of artificial constructions since it is an urbanized area.

Negative values of velocity, indicative of subsidence, have been recorded at the southeastern part of Louros, west of Akra Evinou (Figure 3). Louros is an elongated low-lying barrier feature, with maximum elevation of about 50 cm, which separates Klissova lagoon from the Gulf of Patras. It is obvious that due to the subsidence in the near future the lagoon will be totally connected to the Gulf of Patras.

Another subsiding part of the deltaic plain is its southern part, on both sides of the lower reaches of the Evinos River main channel (Figure 3). These areas correspond to paleo-distributaries as well as to abandoned mouths of the river. A probable reason for this subsidence is the lack of river sediment supply.

Positive velocity values are displayed along the main distributary channel of the Evinos River as well as along the eastern shore of the Klisova Lagoon (Figure 3). The positive values along the main channel are the result of the bedload sediment transport. The Evinos River has a braided channel with "moving" coarse grained bars. As for the Klisova shore positive velocity values are the result of artificial constructions along the road that connects Akra Evinou with Messologi.
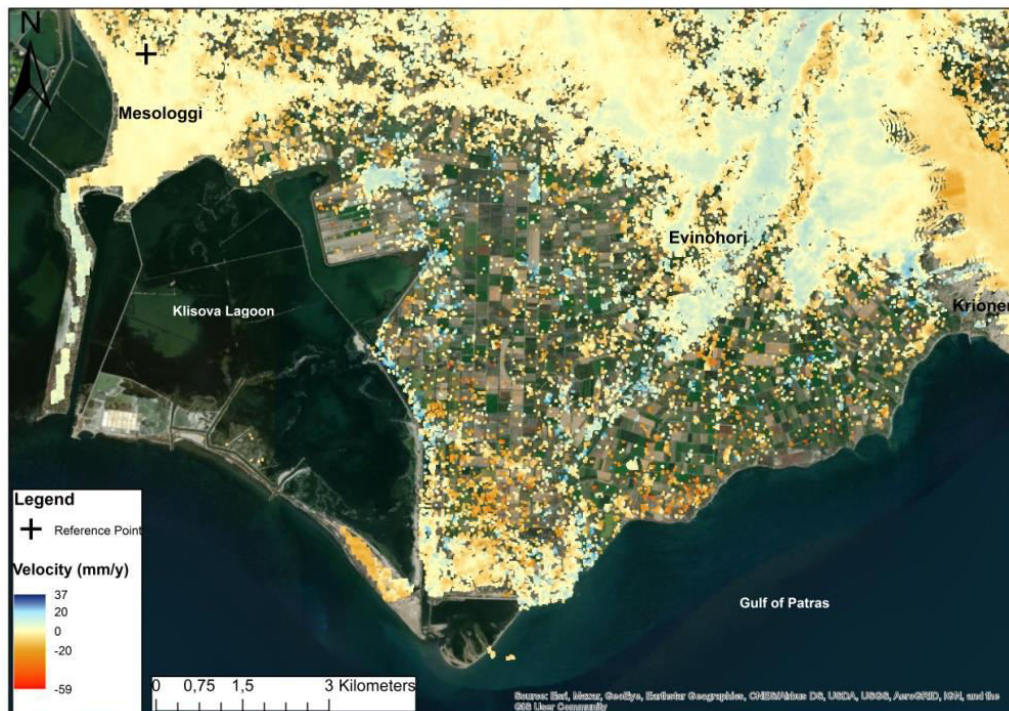
Figure 3. Linear component of ground deformation over Evinos delta broader area for the period 2015 – 2020.

Figure 4 depicts time series plots of the surface displacement of two samples (points A and B respectively) for the period between 2015 and 2020.

Future research could include the performance of further tests for more reliable results and the investigation of the correlation among the rates of subsidence and the grain size of the delta plain sediments from logs of boreholes that have been drilled in the study area.

Figure 4. Time series plot based on the two samples (point A & B) of the Evinos River delta.

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Χρήση της Ευαισθησίας του Μορφοτεκτονικού Δείκτη SL-Index για τον Προσδιορισμό Μεγάλων Τεκτονικών Δομών με Εφαρμογή στη Νήσο Τήνο (Κυκλάδες)

Η. Γερολυμάτος [1]

(1) ΕΥΔΑΠ Α.Ε., Αθήνα, i.gerolymatos@gmail.com

Οι σχηματισμοί των Κυκλάδων ανήκουν στο ενδιάμεσο μεταμορφικό πεδίο των "Ελληνίδων" ("Ενδιάμεση τεκτονομεταμορφική ζώνη των Ελληνίδων"/Papanikolaou 1984), το οποίο εκτείνεται προς βορά μέχρι τη δυτική Μακεδονία και συνεχίζει σε «Γιουγκοσλαβικό» έδαφος. Προς ανατολάς διέρχεται από τον χώρο που περιλαμβάνεται μεταξύ των Δωδεκανήσων, Σάμου και Νισύρου και προεκτείνεται ανατολικά στην περιοχή του Μεντερές.

Το Κρυσταλλοσχιστώδες Υπόβαθρο των νήσων Κυκλάδων παριστά μια πολύπλοκη καλυμματική δομή, στην οποία συμμετέχουν μεταμορφωμένα και μη πετρώματα, διαφορετικής παλαιογεωγραφικής, γεωδυναμικής και γεωτεκτονικής εξέλιξης, μαγματικά σώματα διαφορετικών ηλικιών και παραμόρφωσης και μη μεταμορφωμένα τριτογενή μολασσικά ιζήματα.
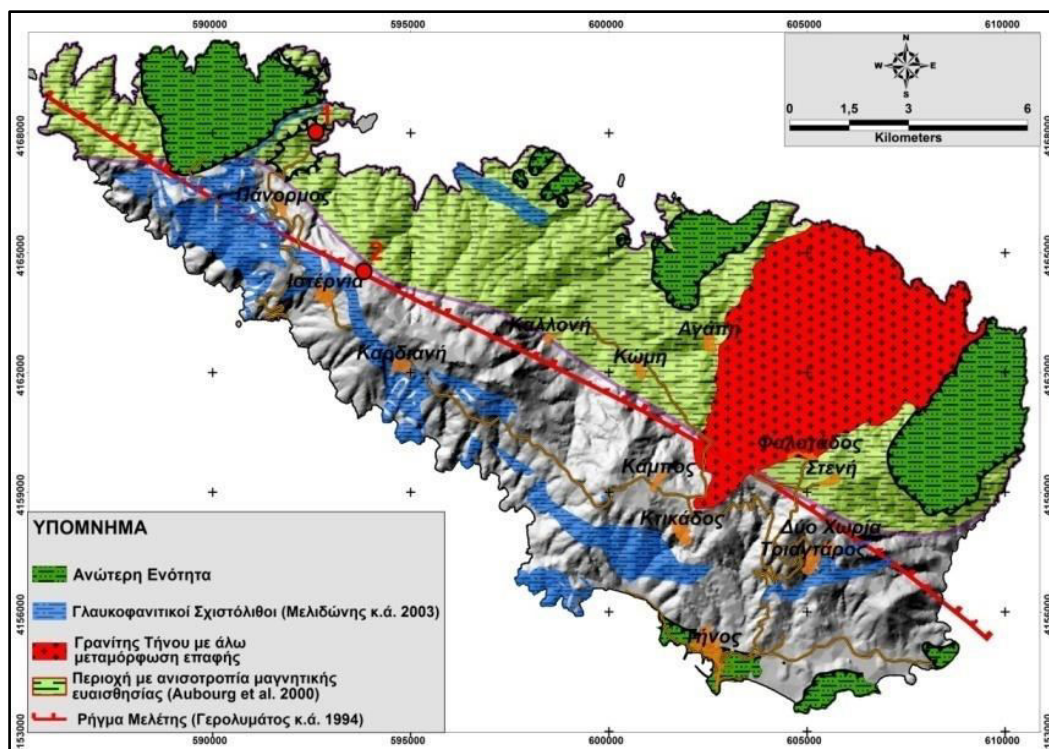
Σχήμα 1. Γεωλογικός χάρτης της νήσου Τήνου στον οποίο απεικονίζονται η Ανώτερη και η κατώτερη ενότητα με τους γλαυκοφανιτικούς σχιστολίθους, ο γρανίτης με την άλω λόγω μεταμόρφωσης επαφής. και οι δύο τεκτονικές ασυνέχειες, οι οποίες χωρίζουν τη νήσο με τον ίδιο τρόπο στο ΒΑ και στο ΝΔ τμήμα.

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Το νησί της Τήνου σχηματίζει μια επιμήκη δομή με διεύθυνση ΒΔ-ΝΑ (μήκος 27 km, πλάτος ~ 12 km) και καλύπτεται από τρεις κύριες λιθολογικές ενότητες (Μελιδώνης *κ.ά.,* 1980):

(1) μια Ανώτερη Οφιολιτική ενότητα η οποία δομείται από μεταβασίτες, κυρίως μεταγάβρους και σερπεντινίτες,

(2) μια Κατώτερη ενότητα, που ονομάζεται επίσης Κυανοσχιστολιθική ενότητα, αποτελούμενη κυρίως από εναλλαγές μεταπηλιτών, μεταηφαιστιτών και μετаανθρακικών πετρωμάτων και

(3) ένα σύνθετο πλουτώνιο σώμα ασβεσταλκαλικής σύστασης (Μελιδώνης *κ.ά.,* 1980) τύπου S, που εμφανίζεται στο ανατολικό τμήμα του νησιού με ένα ΝΑ-ΝΑ επίμηκες σχήμα. Το γρανιτικό αυτό σώμα σχηματίζει περιφερειακά του μια ενδιαφέρουσα άλω πετρωμάτων με μεταμόρφωση επαφής.

Οι Ανώτερη και η Κατώτερη ενότητα της νήσου κατέγραψαν πολύ διαφορετικές μεταμορφικές ιστορίες, όπως φαίνεται από τα πετρολογικά και ραδιοχρονολογικά δεδομένα τους. Η Ανώτερη ενότητα έχει υποστεί μεταμόρφωση τύπουbarrow (LP-HT) περίπου, γύρω στα 70 Ma (Patzak *et al.,* 1994) ενώ η κατώτερη ενότητα υπέστη καθολικό πολυμεταμορφισμό. υψηλής πίεσης-χαμηλής θερμοκρασίας κατά την οποία παρήχθησαν εκλογιτικές και κυανοσχιστολιθικές παραγενέσεις με συνθήκες 12-15 kbar και 450-550 ^{0}C,ηλικίας περίπου 45 Ma (Bröcker *et al.,* 1993). Ακολούθησε μια δεύτερη μεταμορφική φάση που έδωσε πρασινοσχιστολιθικές παραγενέσεις ορυκτών με συνθήκες 5-7 kbar και 400-500 ^{0}C και έλαβε χώρα στα 25 έως 20 Ma (Altherr *et al.,* 1982; Bröcker *et al.,* 1993). Αυτό το μεταμορφικό γεγονός αντικατέστησε σε μεγάλο βαθμό τις παραγενέσεις της πρώτης φάσης. Αν και αυτή η ανάδρομη μεταμόρφωση χαμηλού βαθμού είναι ευρέως διαδεδομένη σε όλη την Κατώτερη ενότητα, αξίζει να σημειωθεί ότι τα λείψανα HP διατηρούνται καλύτερα στο νοτιοδυτικό τμήμα του νησιού παρά στο βορειοανατολικό τμήμα, όπου σπάνια είναι συντηρημένα (Jolivet and Patriat, 1999). Αυτές οι δύο μεταμορφικές φάσεις επηρεάστηκαν τελικά από γρανιτική διείσδυση την περίοδο των 19 έως 14 Ma (Altherr *et al.,* 1982).

Η επαφή μεταξύ της κατώτερης (HP) και ανώτερης ενότητας (LP) είναι ένα τυπικό ρήγμα αποκόλλησης (detachment fault) (Jolivet and Patriat, 1999).

Επιπρόσθετες θέσεις εμφάνισης ρηγμάτων αποκόλλησης παρατηρήθηκαν στην κατώτερη ενότητα της νήσου, στην περιοχή Πανόρμου (Σχήμα 1 / Θέση 1) μεταξύ σχιστολιθικών και υποκείμενων ανθρακικών σχηματισμών (Avigad and Garfunkel, 1989) τριαδικής ηλικίας (Μελιδώνης *κ.ά,* 1980). Οι παρατηρήσεις των Bröcker and Franz, (2005), με βάση πετρολογικά και ραδιοχρονολογικά δεδομένα της περιοχής του Πάνορμου, είναι απόλυτα συμβατές με την ερμηνεία ότι ο υποκείμενος ανθρακικός ορίζοντας των υπερκείμενων φυλλιτών-χαλαζιτών, αποτελεί αναπόσπαστο μέρος της κατώτερης ενότητας της νήσου, όπως είχε αρχικά προτείνει ο Μελιδώνης *κ.ά.,* (1980). Ανάλογη ζώνη παρατηρήθηκε στη κορυφογραμμή που βρίσκεται 800 m ΒΑ (Σχήμα 2 / Θέση 2) από το συνοικισμό Υστέρνια (Parra *et al.,* 2002).

Οι Γερολυμάτος *κ.ά.* (1994) βασισμένοι σε τεκτονικά και μεταμορφικά στοιχεία χωρίζουν τη νήσο Τήνο στα δύο με μια ζώνη αποκόλλησης κατά μήκος της νήσου (Σχήμα 1).

Με τη μελέτη της ανισοτροπίας μαγνητικής ευαισθησίας, οι Aubourg *et al.* (2000) προσδιορίζουν μια εφελκυστική ζώνη πλαστικής παραμόρφωσης που χωρίζει τη νήσο Τήνο σε δύο τμήματα (Σχήμα 1) ανάλογα με αυτή των Γερολυμάτος *κ.ά.* (1994).

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Στην εργασία αυτή έγινε προσπάθεια εφαρμογής στη νήσο του μορφοτεκτονικού δείκτη "Δείκτης Μήκους-Κλίσης Ρέματος SL" (Stream Length – Gradient index) για την καλλίτερη προσέγγιση τέτοιων μεγάλων ζωνών διάτμησης στους μεταμορφωμένους σχηματισμούς, όπως αυτές αναφέρονται πιο πάνω.
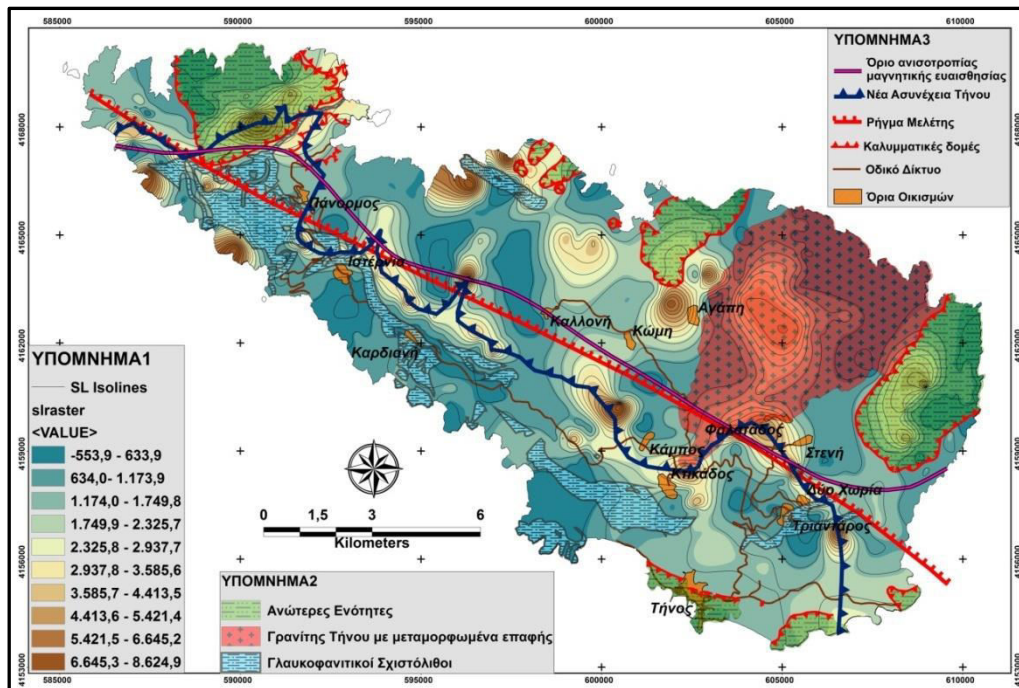
Σχήμα 2. Χάρτης της νήσου Τήνου στον οποίο απεικονίζεται η προτεινόμενη τεκτονική ασυνέχεια ("Νέα Ασυνέχεια της Τήνου"), βασισμένη εκτός των άλλων στο Δείκτη SL Index. Στο Χάρτη φαίνεται η πολύ καλή συσχέτιση της ασυνέχειας αυτής με την παρουσία των σχηματισμών που αναφέρονται ως "Γλαυκοφανιτικοί Σχιστόλιθοι" και με τις από την βιβλιογραφία αναφερόμενες ασυνέχειες ("Ασυνέχεια Μελέτης", Ασυνέχεια που συμπίπτει με το όριο της Ανισοτροπίας Μαγνητικής Ευαισθησίας, σημεία 1 και 2 του Χάρτη στο Σχήμα 1).

Ο δείκτης SL είναι πολύ ευαίσθητος σε αλλαγές της κλίσης της κοίτης των ρεμάτων και αυτή η ευαισθησία επιτρέπει την εκτίμηση της σχέσης μεταξύ πιθανής τεκτονικής δραστηριότητας, της ανθεκτικότητας των πετρωμάτων και της τοπογραφίας. Η χρήση του δείκτη SL είναι διττή καθώς επιτρέπει τόσο τη σύγκριση μεταξύ διαφορετικών λεκανών απορροής, όσο και την αναγνώριση ανώμαλων τιμών κατά μήκος της ίδιας λεκάνης, με κοινό στόχο την ανάδειξη τοπικά ενεργών τεκτονικών ζωνών σε μια περιοχή. Έτσι ο δείκτης SL χρησιμοποιείται για την αναγνώριση πρόσφατης τεκτονικής δραστηριότητας ψάχνοντας για ανώμαλα υψηλές τιμές του (ή σπανιότερα χαμηλές) σε συγκεκριμένο τύπο πετρωμάτων.

Η αποτύπωση των τιμών του Δείκτη SL κατά μήκος ενός ρέματος δίνει σημαντικές πληροφορίες σε σχέση με την αλλαγή της λιθολογίας ή της τεκτονικής, αλλά δεν επιτρέπει την άμεση συσχέτιση της πληροφορίας αυτής με άλλες γεωπαραμέτρους του ευρύτερου χώρου έρευνας μιας περιοχής. Για το λόγο αυτό γίνεται προσπάθεια τα τελευταία χρόνια από την επιστημονική κοινότητα που ασχολείται με το αντικείμενο αυτό να δημιουργήσουν έστω ημιαυτόματα χάρτες με τη κατανομή του Δείκτη SL. Ο Hack (1973) πρότεινε δύο διαφορετικές μεθόδους διαχωρισμού για τον υπολογισμό SL κατά μήκος ενός δεδομένου ρέματος, λαμβάνοντας υπόψη είτε τη

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διαφορά υψομέτρου (dH) ή τη διαφορά μήκους (dL) ως σταθερές. Οι Keller and Pinter (2002) πρότειναν μια απλή μέθοδο για την παραγωγή χάρτη με SL τιμές, βασισμένο σε τοπογραφικούς χάρτες 1:50.000 έως 1:250.000 κλίμακας. Αυτή η μεθοδολογία βασίζεται στις ίσες διαφορές υψομέτρων των ισοϋψών γραμμών ως dH, παρέχοντας μια ακανόνιστη κατανομή των τιμών SL, στην οποία η πυκνότητα των σημείων ήταν μεγαλύτερη κοντά στα ανώτερα σημεία του ρέματος, ως εκ τούτου, όταν οι ισοϋψείς γραμμές βρίσκονται σε μικρότερα διαστήματα η μια με την άλλη (Troiani *et al.,* 2014). Αυτό όμως, όπως αποδεικνύεται από τη δική μας μελέτη δε επιφέρει καμιά αλλοίωση στα σωστά αποτελέσματα της μεθοδολογίας που χρησιμοποιείται εδώ. Τα αποτελέσματα της γεωστατιστικής ανάλυσης των Troiani *et al.* (2014) επιβεβαίωσαν ότι:

1. όπως προτείνεται από Hack (1973), η χρήση των σταθερών υψομετρικών διαφορών είναι χρήσιμο μέσο για το σωστό υπολογισμό του SL από τοπογραφικούς χάρτες που βασίζονται στις ισοϋψείς καμπύλες, και

2. αντιθέτως, μια σταθερή τιμή της παραμέτρου dL, θα δώσει καλύτερα αποτελέσματα, μόνο όταν η χωρική κατανομή του SL προβλέπεται χωρικά από Gaussian διαδικασία παλινδρόμησης (βλ. Pérez-Peña *et al.,* 2009).

Η εφαρμογή του δείκτη SL στη νήσο Τήνο είναι ιδεατή, διότι αφενός μεν το ανάγλυφο της νήσου είναι ήπιο, αφετέρου τα πετρώματα είναι πάνω από 95% (πλην του γρανίτη) εύπλαστα (incompetent), οπότε δεν υπεισέρχεται η παράμετρος της διάβρωσης των πετρωμάτων της νήσου στην αλλοίωση των αποτελεσμάτων του δείκτη SL, που έχουν σχέση με την τεκτονική της περιοχής.

Στην παρούσα εργασία για τον υπολογισμό του δείκτη SL χρησιμοποιήθηκε η μέθοδος του Hack, (1973):

$$SL = (\Delta H / \Delta L)\, L \qquad (\text{Hack, 1973})$$

όπου το πηλίκο *ΔH/ΔL* είναι η κλίση του τμήματος σε συγκεκριμένο σημείο κατά μήκος του ποταμού, *ΔH* είναι η υψομετρική διαφορά ανάμεσα στα άκρα του τμήματος και *ΔL* το μήκος του τμήματος, ενώ *L* το μήκος από το κέντρο του τμήματος, έως το πιο μακρινό σημείο στα ανάντη του ποταμού.

Για τον υπολογισμό του Δείκτη SL και την χαρτογράφηση αυτού χρειάζονται τέσσερα σύνολα δεδομένων σε μορφή vector: 1) Τοπογραφικό Υπόβαθρο. Επιλέγονται ισοϋψείς ανά 40 μέτρα από χάρτες της ΓΥΣ, κλίμακας 1:50.000, 2) Υδρογραφικό δίκτυο από τους ίδιους πιο πάνω χάρτες, 3) Χάραξη των λεκανών απορροής (3ης και ορισμένες 2ης τάξης με καλή κατανομή στο χώρο εργασίας) με βάση τα πιο πάνω στοιχεία και 4) Χάραξη των μέγιστων ρεμάτων των ποιο πάνω λεκανών απορροής.

Για τον υπολογισμό του SL χρησιμοποιήθηκε η ημιαυτόματος μέθοδος του Γερολυμάτου (2016). Με τη μέθοδο αυτή προσδιορίσθηκε η τιμή του δείκτη SL σε 557 σημεία της νήσου, έγινε η χάραξη των γραμμών ισοκατανομής αυτού και η κατασκευή του ανάλογου raster.

Στο χώρο της Κατώτερης ενότητας έγινε προσπάθεια της ένωσης των μεγάλων ανωμαλιών του Δείκτη SL, λαμβάνοντας υπόψη τα στοιχεία εκείνα που συνδέονται με την παρουσία μεγάλων ζωνών παραμόρφωσης, εφελκυστικού χαρακτήρα.

Για τη χάραξη της "Νέας Ασυνέχειας της Τήνου" λήφθηκε επιπλέον υπόψη η ύπαρξη ή μη και η θέση των σχηματισμών με ορυκτά υψηλών πιέσεων, που αντιστοιχούν στο γεωλογικό χάρτη της νήσου στους γλαυκοφανιτικούς σχιστολίθους.

Το αποτέλεσμα αυτής της εργασίας είναι η δημιουργία μια γραμμής, η οποία θεωρείται ότι χωρίζει δύο τεκτονικές ενότητες, που έχουν υποστεί τον ίδιο τεκτονομεταμορφικό κύκλο, αλλά με πολύ διαφορετικές συνθήκες μεταμόρφωσης και τεκτονικής. Η γραμμή αυτή έχει πολύ καλή συσχέτιση με τη ασυνέχεια που ονομάσαμε "ρήγμα μελέτης" καθώς και με την ασυνέχεια που είναι όριο της ανισοτροπίας μαγνητικής ευαισθησίας (Σχήμα 2).

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Γεωμορφολογική Χαρτογράφηση των Ακτών της Νοτιοανατολικής Λαυρεωτικής

Γ. Ταμπουράκη [1]

(1) Χαροκόπειο Πανεπιστήμιο,Τμήμα Γεωγραφίας, Ελευθερίου Βενιζέλου 70, Αθήνα, Ελλάδα,
gtampouraki@gmail.com

Εισαγωγή

Η παρούσα εργασία έχει σαν αντικείμενο μελέτης τη γεωμορφολογία των νοτιανατολικών ακτών του Δήμου Λαυρεωτικής. Η γεωμορφολογική χαρτογράφηση αφορά στον εντοπισμό και την αποτύπωση των γεωμορφών και των χαρακτηριστικών τους και αποτελεί μία σημαντική μεθοδολογία στη γωμορφολογική έρευνα. Ο εντοπισμός, η ανάλυση και η αποτύπωση των γεωμορφών, μπορούν να δώσουν πληροφορίες σχετικά με τις φυσικές διεργασίες που διαμορφώνουν το γήινο ανάγλυφο.

Σκοπός της εργασίας είναι η αναγνώριση και χαρτογράφηση των γεωμορφών που συνθέτουν το ανάγλυφο των ακτών της Νοτιοανατολική Λαυρεωτικής με την αξιοποίηση Γεωγραφικών Συστημάτων Πληροφοριών (ΓΠΣ) και τη χρήση των λογισμικών ArcGIS(10.5) της ESRI και CorelDRAW. Η χαρτογράφηση έγινε σε κλίμακα 1:50.000, καθώς η κλίμακα αυτή θεωρήθηκε κατάλληλη για την απεικόνιση των σημαντικότερων γεωμορφολογικών χαρακτηριστικών και η χαρτογραφική προβολή που χρησιμοποιήθηκε είναι το Ελληνικό Γεωδαιτικό Σύστημα Αναφοράς (ΕΓΣΑ '87). Επιπλέον για τους κυριότερους αιγιαλούς της περιοχής έγινε λήψη δειγμάτων ιζήματος από την ακτογραμμή και ακολούθησε η κοκκομετρική τους ανάλυση (ξηρή κοσκίνιση) στο εργαστήριο Φυσικής Γεωγραφίας του Χαροκοπείου Πανεπιστημίου με σκοπό την αποτύπωση του ιζηματολογικού καθεστώτος κατά την περίοδο της δειγματοληψίας.

Η επιλογή της νοτιοαναλτολικής Λαυρεωτικής ως περιοχή μελέτης έγινε διότι αποτελείται από πολλούς διαφορετικούς γεωλογικούς σχηματισμούς και χαρακτηρίζεται από ένα σύνθετο ανάγλυφο, με μεγάλη ποικιλία γεωμορφών (ιδιαίτερα παράκτιων) τόσο απόθεσης, όσο και διάβρωσης. Επιπλέον η νότια Αττική αποτελεί την μεταβατική γεωμορφολογική ενότητα μεταξύ της ηπειρωτικής Ελλάδας και των Κυκλάδων (Παυλόπουλος, 1992). Τέλος η παράκτια ζώνη της περιοχής μελέτης, που αποτελεί ένα δυναμικά μεταβαλλόμενο σύστημα, εμφανίζει μεγάλο κοινονοικο-οικονομικό εδιαφέρον καθώς συγκεντώνει πολλές ανθρώπινες δραστηριότητες, τόσο εξαιτίας της αισθητικής, όσο και της χρηστικής της αξίας.

Ακολουθεί η περιγραφή της μεθοδολογίς που εφαρμόστηκε, η παρουσίαση και ερμηνεία των αποτελεσμάτων και τα συμπεράσματα που προέκυψαν από την γεωμορφολογική και ιζηματολογική μελέτη.

Γεωγραφική Θέση Περιοχή Μελέτης

Η περιοχή μελέτης περιλαμβάνει τις ακτές που εκτείνονται από τη περιοχή του Σουνίου έως και τον οικισμό Συρί, βόρεια του όρμου Αγίου Νικολάου του Δήμου Λαυρεωτικής. Πιο αναλυτικά περιλαμβάνει τις περιοχές Σούνιο, Κάτω Σούνιο, Κάτω Ποσειδωνία, Λαύριο, Θορικό και Συρί και

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τους Όρμους Θορικού, Νικολάου, Γαιδουρόμανδρου και το Τουρκολίμανο. Ο Δήμος Λαυρεωτικής ανήκει στην Περιφέρεια Αττικής και συστάθηκε με το Πρόγραμμα Καλλικράτης. Προήλθε από τη συνένωση των προϋπαρχόντων δήμων Λαυρεωτικής, Κερατέας και της κοινότητας Αγίου Κωνσταντίνου. Δυτικά και νοτιοδυτικά βρέχεται από τον Σαρωνικό Κόλπο και νότια και ανατολικά από το Αιγαίο Πέλαγος. Η έκταση του δήμου είναι ίση περίπου με 200 χλμ^2, απέχει από την Αθήνα 55 χλμ και ο πληθυσμός του ανέρχεται σε 25.102 κατοίκουςσύμφωνα με την απογραφή του 2011.

Μεθοδολογία

Για την μελέτη των ακτών της νοτιοανατολικής Λαυρεωτικής ακολουθήθηκε η μέθοδος της περιγραφικής γεωμορφολογικής ανάλυσης. Η μέθοδος της περιγραφικής γεωμορφολογικής ανάλυσης βασίζεται στην συλλογή στοιχείων και πληροφοριών για τις γεωμορφές που απεικονίζουν τα χαρακτηριστικά του φυσικού περιβάλλοντος, λαμβάνοντας υπόψιν τους γεωμορφολογικούς παράγοντες και τις συνθήκες που επηρεάζουν και διαμορφώνουν το σημερινό ανάγλυφο της περιοχής μελέτης.

Στα πλαίσια της περιγραφικής γεωμορφολογικής ανάλυσης μελετήθηκε η γεωμορφολογία των νοτιοανατολικών ακτών της Λαυρεωτικής, σκοπεύοντας στον εντοπισμό, προσδιορισμό, χαρτογραφική αποτύπωση και ανάλυση των σημαντικότερων γεωμορφών της περιοχής.

Η περιοχή που χαρτογραφήθηκε εκτείνεται στην ζώνη επίδρασης της κυματικής ενέργειας μέχρι και την ισοβαθή των 15 μέτρων περίπου. Το συνολικό μήκος της ακτογραμμής που χαρτογραφήθηκε και μελετήθηκε ανέρχεται σε περίπου 57 χλμ..

Για την γεωμορφολογική χαρτογράφηση ακολουθήθηκε η παρακάτω μεθοδολογία:

- Επιτόπια έρευνα για τον προσδιορισμό, την καταγραφή, τη λήψη φωτογραφιών και τη χαρτογραφική αποτύπωση των παράκτιων γεωμορφών που αναπτύσσονται κατά μήκος της ακτογραμμής, με σκοπό τον προσδιορισμό των παραγόντων που επέδρασαν στη διαμόρφωση του παράκτιου περιβάλλοντος.

- Δειγματοληψία ιζημάτων από τους κύριους αιγιαλούς της περιοχής και κοκκομετρική ανάλυση των δειγμάτων στο εργαστήριο ώστε να προσδιορισθεί το ιζηματολογικό καθεστώς των αιγιαλών της περιοχής και οι διεργασίες και συνθήκες απόθεσής τους.

Για την περιοχή μελέτης δημιουργήθηκε μια ψηφιακή βάση χωρικών δεδομένων σε περιβάλλον Συστημάτων Γεωγραφικών Πληροφοριών έγινε επίσκεψη στην περιοχή με σκοπό την καταγραφή και αποτύπωση των παράκτιων γεωμορφών και τη λήψη φωτογραφιών και δειγμάτων ιζήματος. Για την ακριβή αποτύπωση των παράκτιων γεωμορφών χρησιμοποιήθηκε GPS (Global Positioning System).

Στα πλαίσια της εργασίας, στη συνέχεια, πραγματοποιήθηκε δειγματοληψία σε 7 αιγιαλούς της περιοχής.Για την κατανόηση των παράκτιων και όχι μόνο διεργασιών που είναι υπεύθυνες για το σχηματισμό συγκεκριμένων γεωμορφών απαιτείται η λήψη δειγμάτων ιζήματος από τα περιβάλλοντα απόθεσης και η κοκκομετρική τους ανάλυση (Καρύμπαλης, 2010).

Κρίθηκε σκόπιμο, η λήψη των δειγμάτων ιζήματος να γίνει από καθορισμένες θέσεις, και η μετέπειτα επεξεργασία τους πραγματοποιήθηκε στο εργαστήριο Φυσικής Γεωγραφίας του

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τμήματος Γεωγραφίας του Χαροκοπείου Πανεπιστημίου. Η δειγματοληψία πραγματοποιήθηκε κατά τον μήνα Δεκέμβριο του έτους 2019 και η πλειοψηφία των δειγμάτων ελήφθη στο σημείο θραύσης του κύματος εκτός από δύο περιπτώσεις κατά τις οποίες ελήφθη δείγμα από τις αποθέσειςαμμωδών θινών στη πρώτη περίπτωση και από την κυματική «σκιά» του τόμπολο που παρατηρήθηκε στην ακτή, στη δεύτερη περίπτωση.

Για την κοκκομετρική ανάλυση των ιζημάτων είναι σημαντική η αντιπροσωπευτική ποσότητα του κάθε δείγματος, καθώς και οι προκαθορισμένες θέσεις λήψης τους. Στη περίπτωση ενός αμμώδους υλικού επαρκής ποσότητα θεωρούνται τα 100 γραμμάρια δείγματος, ενώ για πιο χονδρόκοκκο υλικό συνιστάται μεγαλύτερη ποσότητα δείγματος. Συνολικά, ελήφθησαν 20 δείγματα από 7 αιγιαλούς κατά μήκος των ανατολικών ακτών της Λαυρεωτικής.

Τα αποτελέσματα της κοκκομέτρησης επεξεργάστηκαν και αποτυπώθηκαν σε διάγραμματα αθροιστικών συχνοτήτων για την καλύτερη ερμηνεία τους και για την καλύτερη ποσοτική περιγραφή των χαρακτηριστικών των καμπυλών αυτών έχουν χρησιμοποιηθεί κατά το παρελθόν από πολλούς ερευνητές ορισμένες στατιστικές παράμετροι (Folk&Ward, 1957). Αυτοί οι παράμετροι μπορούν να δώσουν ενδείξεις για τα περιβάλλοντα απόθεσης των περιοχών λήψης των δειγμάτων και αφορούν το μέσο μέγεθος, την ταξινόμηση, την ασσυμετρία και την κύρτωση των κόκκων.

Αποτελέσματα

Σχετικά με την γεωμορφολογική μελέτη, χαρτογράφηση και επιτόπια έρευνα των ακτών της Νοτιοανατολικής Λαυρεωτικής εντοπίστηκαν χερσαίες γεωμορφές διάβρωσης, όπως είναι οι επιφάνειες ισοπέδωσης και παράκτιες γεωμορφές θαλάσσιας διάβρωσης, απόθεσης και αιολικής απόθεσης και προσδιορίστηκε η μορφή των κλιτύων.

Οι παράκτιες γεωμορφές είναι αποτέλεσμα της επίδρασης θαλάσσιων παραγόντων και πιο συγκεκριμένα, στη περιοχή μελέτης συναντώνται παράκτιες γεωμορφές τόσο θαλάσσιας ή αιολικής απόθεσης, όσο και θαλάσσιας διάβρωσης, όπως είναι οι αιγιαλοί,οι αιγιαλοί στον μυχό των κόλπων(PocketBeaches), ψηφιδοπαγείς αιγιαλοί (Beachrocks),τόμπολο, παράκτιοι κρημνοί, παράκτιοι πάγκοι και παράκτιες αμμώδεις θίνες.

Σχετικά με την επεξεργασία των δειγμάτων ιζήματος, το μέγεθος των κόκκων του ιζήματος αποτελεί ένδειξη της ενέργειας του περιβάλλοντος μεταφοράς και απόθεσης τους και από τα αποτελέσματα υπολογισμού της παραμέτρου του μέσου γραφικού μεγέθους προκύπτει ότι τα δείγματα των ιζημάτων από τους 7 αιγιαλούς είναι κυρίως χονδρόκοκκα, πολύ χονδρόκοκκα και μεσόκοκκα. Επομένως, στους εξεταζόμενους αιγιαλούς, ο κυρίαρχος ενεργειακός παράγοντας φαίνεται να είναι ο κυματισμός, ενώ οι αιολικές διεργασίες φαίνεται ότι είναι πιο περιορισμένες.

Η περιοχή της Νοτιοανατολικής Λαυρεωτικής εμφανίζει πολλούς κόλπους, μικρού ή μεγάλου πλάτους, οι οποίοι τροφοδοτούνται από τα υδρογραφικά δίκτυα που εκβάλλουν εκεί. Η ανάπτυξη μικρών αιγιαλών με ομαλές μορφολογικές κλίσεις διαδέχονται τις απόκρημνες ακτές με μεγάλη κλίση.

Τα πετρώματα της περιοχής που κυριαρχούν στη παράκτια ζώνη είναι οι ασβεστόλιθοι, οι σχιστόλιθοι και οι Τεταρτογενείς αποθέσεις. Σε περιοχές με ομαλές μορφολογικές κλίσεις κυριαρχούν οι παράκτιες και αλλουβιακές αποθέσεις, ενώ στις πιο απόκρημνες, οι ασβεστόλιθοι

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και οι σχιστόλιθοι. Συνεπώς η φύση, το είδος και η ανθεκτικότητα των γεωλογικών σχηματισμών που καταλήγουν στην ακτογραμμή είναι μια σημαντική παράμετρος για το είδος των παράκτιων γεωμορφών και τα μορφολογικά τους χαρακτηριστικά.

Συμπεράσματα

Η περιοχή της Νοτιοανατολικής Λαυρεωτικής παρουσιάζει πολύ σημαντικό γεωλογικό, μεταλλευτικό και παλαιοντολογικό ενδιαφέρον. Χαρακτηρίζεται ως τόπος μεγάλης ιστορικής και μνημειακής σημασίας.

Η ολοκλήρωση της περιγραφικής γεωμορφολογικής ανάλυσης και μελέτης των ακτών της Νοτιοανατολικής Λαυρεωτικής, κατέληξε σε συμπεράσματα σχετικά με τη διαμόρφωση της γεωμορφολογίας τους, μέχρι σήμερα. Τα συμπεράσματα εξήχθησαν από την υπαίθρια γεωμορφολογική μελέτη-ανάλυση και την κοκκομετρική ανάλυση δειγμάτων ιζήματος. Κατασκευάστηκε ο γεωμορφολογικός χάρτης της περιοχής μελέτης και μετά από επιτόπια έρευνα εντοπίστηκαν παράκτιες γεωμορφές, όπως αιγιαλοί, beachrocks, θίνες, κρημνοί και τόμπολο (σε συνολικό μήκος ακτογραμμής 57 χλμ. περίπου).

Ειδικότερα, σχετικά με τη γεωμορφολογία των ακτών της Λαυρεωτικής, όπως προέκυψε από τον γεωλογικό και τον γεωμορφολογικό χάρτη που κατασκευάστηκαν, οι ακτές αναπτύσσονται σε σχηματισμούς σχιστόλιθων, ασβεστόλιθων, μαρμάρων και αποθέσεων παράκτιας και αλλουβιακής προέλευσης. Οι σχηματισμοί σχιστόλιθων και οι ασβεστόλιθων εμφανίζονται κυρίως στις βόρειες και νότιες ακτές, ενώ στις κεντρικές κυριαρχούν οι αλλουβιακές και παράκτιες αποθέσεις.Η κατανομή των πετρωμάτων και των πιο χαλαρών υλικών έχουν ως αποτέλεσμα την διαφοροποίηση του αναγλύφου των ακτών που σχηματίζονται σε αυτές. Στα παράκτια τμήματα που αναπτύσσονται σχηματισμοί σχιστόλιθων, ασβεστόλιθων και μαρμάρων, το ανάγλυφο χαρακτηρίζεται από απόκρημνες πλαγιές και κρημνούς μεγάλης ή μεσαίας κλίσης. Αντίθετα, στα τμήματα εκείνα, που αναπτύσσονται χαλαρές αποθέσεις, το ανάγλυφο εμφανίζεται πιο ήπιο και παρατηρούνται σε αυτό κυρίως γεωμορφές παράκτιων αιγιαλών. Επίσης, οι παράκτιοι κρημνοί με μεσαίες και μεγάλες κλίσεις, που παρατηρούνται, δηλώνουν την τάση προέλασης της θάλασσας και υποχώρησης των ακτών από τις θαλάσσιες διεργασίες και η παρουσία beachrocks σε αρκετές παράκτιες θέσεις, ιδιαίτερα τα υποθαλάσσια, υποδεικνύουν την άνοδο της στάθμης της θάλασσας κατά τη διάρκεια του Ολόκαινου.

Σχετικά με τα αποτελέσματα της κοκκομετρικής ανάλυσης, από τα αποτελέσματα υπολογισμού της παραμέτρου του μέσου γραφικού μεγέθους προκύπτει ότι τα δείγματα των ιζημάτων από τους 7 αιγιαλούς είναι κυρίως χονδρόκοκκα, πολύ χονδρόκοκκα και μεσόκοκκα. Επομένως, στη συγκεκριμένη περιοχή μελέτης, το μεγάλο μέγεθος των κόκκων αποτελεί δείκτη περιβάλλοντος μεταφοράς και απόθεσης σχετικά υψηλής ενέργειας.

Από τα αποτελέσματα της αποκλειστικής σταθερής απόκλισης, οι τιμές στη πλειοψηφία τους δείχνουν κακή – φτωχή ταξινόμηση των κόκκων, επομένως και κακή διαλογή τους από τα μέσα μεταφοράς και απόθεσης, που είναι κυρίως ο κυματισμός και τα παράκτια ρεύματα.

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Γεωμορφολογική Μελέτη των Αλλουβιακών Ριπιδίων και των Αντίστοιχων Λεκανών Απορροής του Όρους Όλυμπος με τη Χρήση Σ.Γ.Π.

Ε. Νικόλη [1], Ε. Καρύμπαλης [1], Κ. Τσανάκας [1]

(1) Τμήμα Γεωγραφίας, Χαροκόπειο Πανεπιστήμιο, Ελ. Βενιζέλου 70, Καλλιθέα 17671, Ελλάδα, elisavetnikoli@gmail.com, karymbalis@hua.gr, ktsanakas@hua.gr

Εισαγωγή

Τα αλλουβιακά ριπίδια αποτελούν χαρακτηριστικές γεωμορφές ποτάμιας απόθεσης, που σχηματίζονται στο σημείο εξόδου της κύριας κοίτης ενός υδρογραφικού δικτύου από έναν ορεινό όγκο (Blair and McPherson, 1994; Norini *et al.*, 2016). Από την δεκαετία του 1960 αρκετοί ερευνητές χρησιμοποίησαν ποσοτικά δεδομένα για να προσδιορίσουν τις διεργασίες διαμόρφωσης των αλλουβιακών ριπιδίων (Bull, 1962; Hooke, 1968) και αναπτύχθηκαν αρκετά εμπειρικά μοντέλα που βοήθησαν στην κατανόηση των μαθηματικών σχέσεων που συνδέουν τις λεκάνες απορροής με τα αντίστοιχα αλλουβιακά ριπίδια (Bull, 1962; Hooke, 1968; Church and Mark, 1980; Mills, 1982; Lecce, 1990; Viseras *et al.*, 2003). Στην Ελλάδα έχει εκπονηθεί πλήθος παρόμοιων μελετών σε περιοχές όπως ο Ευβοϊκός Κόλπος (Valkanou *et al.*, 2013) και ο Κορινθιακός Κόλπος (Karymbalis, 2007; Karymbalis *et al.*, 2010; Karymbalis and Gaki-Papanastasiou, 2011; Karymbalis *et al.*, 2018).

Η παρούσα εργασία έχει ως στόχο την οριοθέτηση, χαρτογράφηση και μορφομετρική ανάλυση των λεκανών απορροής και των αντίστοιχων αλλουβιακών ριπιδίων του ανατολικού τμήματος του Όρους Όλυμπος, με κύριο στόχο τη διερεύνηση των μεταξύ τους σχέσεων, εκτιμώντας ένα πλήθος μορφομετρικών παραμέτρων που περιγράφουν τα γεωμορφολογικά τους χαρακτηριστικά, σε περιβάλλον Συστημάτων Γεωγραφικών Πληροφοριών. Επιπλέον, βάσει των ποιοτικών παρατηρήσεων και των ποσοτικών μετρήσεων, επιχειρήθηκε η κατηγοριοποίηση των αλλουβιακών ριπιδίων σε διακριτές ομάδες, ως προς τις βασικές διεργασίες που συνέβαλαν στον σχηματισμό και στη διαμόρφωσή τους. Απώτερο σκοπό της μελέτης αποτέλεσε ο εντοπισμός των αλλουβιακών εκείνων ριπιδίων που φαίνεται να είναι πιο επιρρεπή σε φαινόμενα ακραίων φυσικών κταστροφικών διεργασιών, όπως κινήσεων υλικών λόγω βαρύτητας.

Το όρος Όλυμπος βρίσκεταιστο νοτιοδυτικό άκρο της Κεντρικής Μακεδονίας και οριοθετείται από τον Θερμαϊκό Κόλπο στα ανατολικά, το όρος Όσσα στα νότια και το όρος Τίταρος στα βορειοδυτικά (Σχήμα 1). Η περιοχή μελέτης περιλαμβάνει το σύνολο των υδρογραφικών δικτύων που αποστραγγίζουν το βόρειο και ανατολικό τμήμα του Ολύμπου και τα αντίστοιχα αλλουβιακά τους ριπίδια, και διακρίνεται σε τρεις μορφολογικές ενότητες: την ορεινή, την ημιορεινή και την πεδινή-παράκτια. Η ορεινή ενότητα του Ολύμπου με υψόμετρα 300-2918 m παρουσιάζει έντονο ανάγλυφο με μεγάλες μορφολογικές κλίσεις και αποστραγγίζεται από πλήθος υδρογραφικών δικτύων που διαβρώνουν το ανθρακικό υπόβαθρο και εκβάλλουν στον Θερμαϊκό Κόλπο.Η ημιορεινή ενότητα(30-300 m) αποτελεί τις υπώρειες του Ολύμπου κατά μήκος των οποίων αναπτύσσονται τα υπό μελέτη, Πλειστοκαινικής ηλικίας, αλλουβιακά ριπίδια. Στο μεγαλύτερο μέρος της η ενότητα αυτή εμφανίζει ηπιότερες μορφολογικές κλίσεις οι οποίες ωστόσο

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αυξάνονται στις περιοχές των ενεργών κοιτών των ριπιδίων λόγω έντονης κατά βάθους διάβρωσης. Το πεδινό τμήμα αποτελεί την μορφολογική συνέχεια των ριπιδίων προς τον Θερμαϊκό κόλπο ενώ το μεγαλύτερο τμήμα της παράκτιας ζώνης κυριαρχείται από παράκτιους κρημνούς που έχουν διαμορφωθεί από τη θαλάσσια διάβρωση του «πόδα» των αλλουβιακών ριπιδίων. Τόσο στο παράκτιο-πεδινό, όσο και στο ημιορεινό τμήμα αναπτύσσεται ένα πλήθος οικισμών και άλλων ανθρωπογενών δραστηριοτήτων.
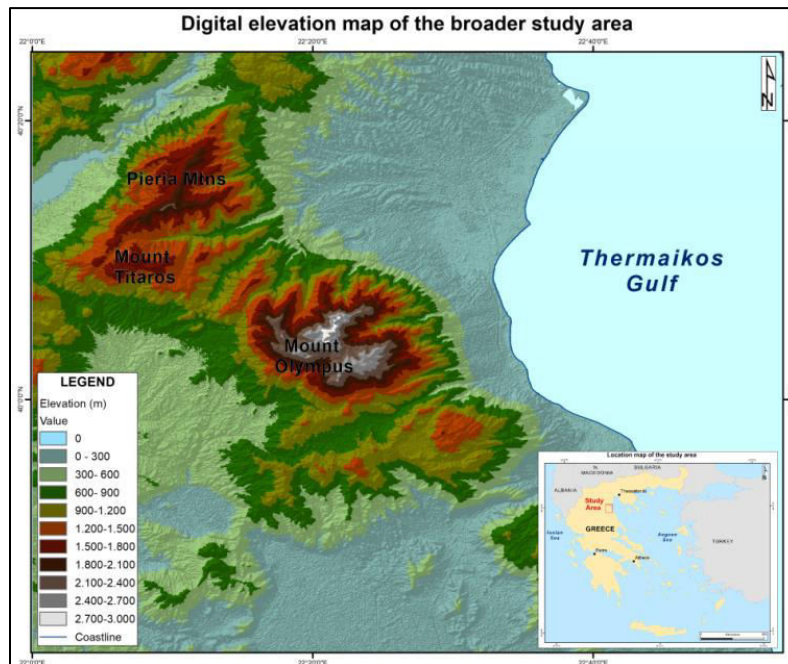
Σχήμα 1. Ψηφιακό Μοντέλο Εδάφους της ευρύτερης περιοχής μελέτης.

Δεδομένα και Μεθοδολογία

Απαραίτητο στάδιο αυτής της μελέτης αποτέλεσε η δημιουργία μιας ψηφιακής βάσης χωρικών δεδομένων, και για το σκοπό αυτό αξιοποιήθηκαν τόσο αναλογικά, όσο και ψηφιακά δεδομένα, στα οποία βασίστηκε η ψηφιοποίηση των υδρογραφικών δικτύων, η οριοθέτηση των λεκανών απορροής και των αλλουβιακών ριπιδίων και η εκτίμηση των μορφομετρικών παραμέτρων, χρησιμοποιώντας το λογισμικό ArcGis 10.4 (ESRI). Τα δεδομένα αυτά περιλαμβάνουν: α) Τοπογραφικούς χάρτες (κλίμακας 1:50.000, ισοδιάστασης 20 m, της Γεωγραφικής Υπηρεσίας Στρατού) και γεωλογικούς χάρτες (κλίμακας 1:50.000, του Ινστιτούτου Γεωλογικών και Μεταλλευτικών Ερευνών), β) Ψηφιακό Μοντέλο Εδάφους (cell size 2 m) το οποίο αποκτήθηκε από το Ελληνικό Κτηματολόγιο και γ) Ψηφιακό Μοντέλο Εδάφους (cell size 30 m) ASTERGDEM (V.3).

Η επιλογή των μορφομετρικών παραμέτρων που εκτιμήθηκαν βασίστηκε στη διεθνή βιβλιογραφία, σύμφωνα με την οποία συγκεκριμένα ζεύγη παραμέτρων λεκανών-ριπιδίων συσχετίζονται πολύ ισχυρά μεταξύ τους και παρέχουν σημαντικές πληροφορίες για τις διεργασίες σχηματισμού των ριπιδίων (Harvey, 1997). Η διερεύνηση των σχέσεων μεταξύ επιλεγμένων μορφομετρικών παραμέτρων των αλλουβιακών ριπιδίων και των λεκανών απορροής πραγματοποιήθηκε με τη σχεδίαση λογαριθμικής κλίμακας διαγραμμάτων διασποράς, τη μελέτη

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των εξισώσεων που περιγράφουν τις σχέσεις αυτές και τον υπολογισμό του συντελεστή συσχέτισης. Το σύνολο των παραμέτρων που εκτιμήθηκαν παρατίθεται παρακάτω:

- Εμβαδόν λεκάνης απορροής (A_b): Η επίπεδη επιφάνεια της λεκάνης απορροής (km^2).

- Κλίση λεκάνης απορροής (S_b): $S_b = e\Sigma L_c / A_b$, όπου e=ισοδιάσταση=20 m.

- Κορυφή λεκάνης απορροής (C_b): Το μέγιστο υψόμετρο της λεκάνης απορροής (m).

- Περίμετρος λεκάνης απορροής (P_b): Το μήκος του υδροκρίτη της λεκάνης απορροής (km).

- Συνολικό μήκος κλάδων (L_c): Το συνολικό μήκος όλων των κλάδων εντός της λεκάνης απορροής (km).

- Ανάγλυφο λεκάνης απορροής (R_b): Η υψομετρική διαφορά μεταξύ της κορυφής της λεκάνης απορροής και της κορυφής του αλλουβιακού ριπιδίου (m).

- Αριθμός τραχύτητας MELTON (M): $M = R_b * A_b - 0.5$.

- Κυκλικότητα λεκάνης απορροής (Cir_b): $Cir_b = 4\pi A_b / P_b^2$.

- Πυκνότητα λεκάνης απορροής (D_b): $D_b = L_c / A_b$ (km/km^2).

- Συνολικό μήκος ισοϋψών καμπυλών εντός της λεκάνης απορροής (ΣL_c): Το συνολικό μήκος των ισοϋψών καμπυλών ανά 20 m εντός της λεκάνης απορροής (km).

- Εμβαδόν ριπιδίου (A_f): Η επίπεδη επιφάνεια του ριπιδίου (km^2).

- Κορυφή ριπιδίου (Ap_f): Το υψόμετρο της θέσης της κορυφής του ριπιδίου (m).

- Μήκος ριπιδίου (L_f): Η οριζόντια απόσταση μεταξύ του πόδα και της κορυφής του ριπιδίου (m).

- Κλίση ριπιδίου (S_f): Η μέση μορφολογική κλίση της επιφάνειας του ριπιδίου.

- Καμπυλότητα ριπιδίου (C_f): $C_f = a/b$, όπου a = η υψομετρική διαφορά μεταξύ του άξονα του ριπιδίου και του κεντρικού σημείου της ευθείας γραμμής που ενώνει την κορυφή του ριπιδίου με τον πόδα και b = η υψομετρική διαφορά μεταξύ του πόδα του ριπιδίου και του κεντρικού σημείου.

Αποτελέσματα

Αναγνωρίσθηκαν και οριοθετήθηκαν οκτώ αλλουβιακά ριπίδια στο ανατολικό τμήμα της περιοχής μελέτης, τα οποία αντιστοιχήθηκαν με οκτώ λεκάνες απορροής. Τα ζεύγη των μορφομετρικών παραμέτρων, των οποίων οι σχέσεις μελετήθηκαν είναι α) το εμβαδόν των λεκανών απορροής (A_b) και το εμβαδόν του αλλουβιακών ριπιδίων (A_f), β) το εμβαδόν των λεκανών απορροής (A_b) και η κλίση των αλλουβιακών ριπιδίων (S_f) και γ) η κλίση των αλλουβιακών ριπιδίων (S_f) και ο Αριθμός Τραχύτητας Melton (M) των λεκανών απορροής. Τα δαγράμματα συσχέτισης παρουσιάζονται στο Σχήμα 2.

Όσον αφορά τη σχέση μεταξύ των παραμέτρων του εμβαδού των λεκανών απορροής και του εμβαδού των αλλουβιακών ριπιδίων, αυτή περιγράφεται από την εξίσωση $A_f = 4,7A_b^{0,34}$ (1) και ο συντελεστής συσχέτισης που υπολογίστηκε είναι ίσος με +0,4. Συνεπώς, προκύπτει ότι η συσχέτιση αυτή δεν φαίνεται να είναι ιδιαίτερα ισχυρή, γεγονός που μπορεί να αποδοθεί στον

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μικρό αριθμό των υπό μελέτη ριπιδίων και λεκανών. Αντιθέτως, ιδιαίτερα ισχυρή αρνητική συσχέτιση εντοπίστηκε μεταξύ των παραμέτρων του εμβαδού των λεκανών απορροής και της κλίσης των ριπιδίων, καθώς υπολογίστηκε ένας συντελεστής συσχέτισης ίσος με -0,92, ενώ η εν λόγω σχέση περιγράφεται από την εξίσωση $S_f = 0,19A_b^{-0,43}$ (2). Εξίσου σημαντικής ισχύος αποδείχθηκε και η συσχέτιση μεταξύ της κλίσης των ριπιδίων και του Αριθμού Τραχύτητας Melton, όπως αυτή περιγράφεται από την εξίσωση $S_f = 0,18M^{1,55}$ (3), καθώς ο συντελεστής συσχέτισης ισούται με +0,87.

Λαμβάνοντας υπόψη τα αποτελέσματα της μορφομετρικής ανάλυσης, τα αλλουβιακά ριπίδια κατηγοριοποιήθηκαν σε τρεις διακριτές ομάδες, όπως φαίνεται στον χάρτη του Σχήματος 2. Η ομάδα Α περιλαμβάνει τα ριπίδια των οποίων η δημιουργία οφείλεται κυρίως στη δράση ροών κορημάτων (ριπίδια 2 & 5) και διακρίνονται από την σχετικά μικρή έκταση και τις υψηλές μορφολογικές τους κλίσεις, ενώ οι αντίστοιχες λεκάνες απορροής τους χαρακτηρίζονται από υψηλές τιμές Αριθμού Τραχύτητας Melton. Στην ομάδα Β κατατάσσονται τα ριπίδια που ο σχηματισμός τους οφείλεται σε έναν συνδυασμό ροών κορημάτων και ποτάμιων διεργασιών (ριπίδια 3, 4 & 7), και τέλος, στην ομάδα C ανήκουν τα ριπίδια που έχουν διαμορφωθεί κυρίως από την δράση ποτάμιων διεργασιών.
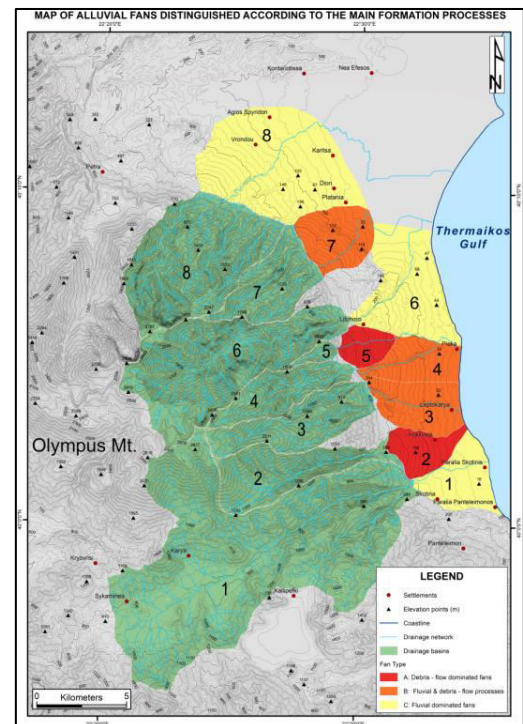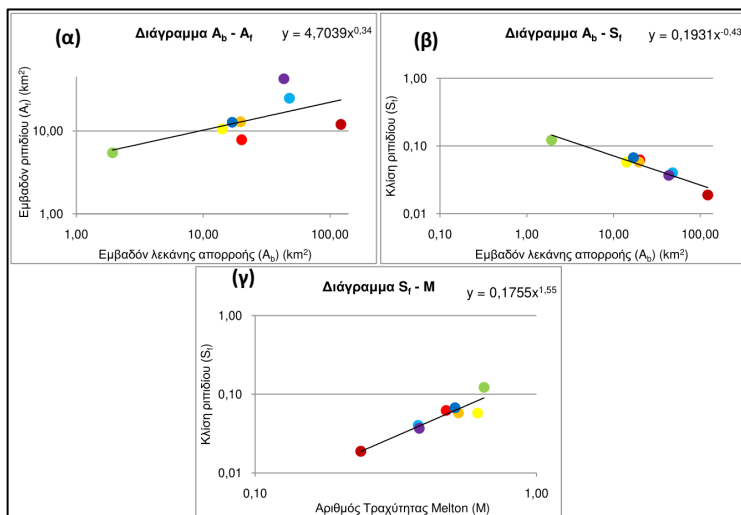
Σχήμα 2. (Αριστερά) Διαγράμματα διασποράς των τιμών των παραμέτρων: (α) A_b- A_f, (β) A_b- S_f και (γ) S_f –M. (Δεξιά) Χάρτης απεικόνισης των αλλουβιακών ριπιδίων της περιοχής μελέτης, όπως αυτά κατηγοριοποιήθηκαν στις ομάδες Α, Β και C, σύμφωνα με την κυρίαρχη διεργασία σχηματισμού τους.

Συμπεράσματα

Λαμβάνοντας υπόψη τη διερεύνηση των συσχετίσεων μεταξύ των μορφομετρικών παραμέτρων και την κατηγοριοποίηση των αλλουβιακών ριπιδίων, συμπεραίνεται ότι τα ριπίδια που ανήκουν στην ομάδα Β (3, 4 & 7) και ιδιαίτερα στην ομάδα Α (2 & 5), είναι σε μεγάλο βαθμό επιρρεπή στις κινήσεις υλικών λόγω βαρύτητας, γεγονός που ενδέχεται να έχει καταστροφικές επιπτώσεις στο ανθρωπογενές περιβάλλον που αναπτύσσεται στην επιφάνειά τους.

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Διερεύνηση της Επιδεκτικότητας των Νοτιοανατολικών Ακτών του Ανατολικού Κορινθιακού (Ηραίον-Λέχαιο Κορινθίας) στους Παράκτιους Φυσικούς Κινδύνους

Χ. Ροδόπουλος [1]

(1) Χαροκόπειο Πανεπιστήμιο,Ελ. Βενιζέλου 70,176 71, Αθήνα, Ελλάδα, christos.rodop@gmail.com

Εισαγωγή

Οι παράκτιες περιοχές αποτελούσαν ανέκαθεν έναν ιδιαίτερης σημασίας χώρο για τις ανθρώπινες κοινωνίες, και συγκεντρώνουν ένα μεγάλο ποσοστό του παγκόσμιου πληθυσμού, λόγω των μοναδικών φυσικών και κοινωνικοοικονομικών χαρακτηριστικών που συγκεντρώνουν. Ωστόσο ο παράκτιος χώρος αντιμετωπίζει αρκετά προβλήματα και δέχεται σημαντικές πιέσεις, τόσο από φυσικούς, όσο και από ανθρωπογενείς παράγοντες. Δεδομένου ότι αποτελεί τη μεταβατική ζώνη μεταξύ χερσαίου και θαλάσσιου περιβάλλοντος, απειλείται και επηρεάζεται άμεσα από την άνοδο της στάθμης της θάλασσας που κατά κύριο λόγο οφείλεται στο φαινόμενο της κλιματικής αλλαγής. Το γεγονός αυτό, καθώς και ο ολοένα αυξανόμενος πληθυσμός που τείνει να συγκεντρώνει και οι μη φιλικές προς το περιβάλλον ανθρωπογενείς παρεμβάσεις, αποτελούν τις βασικές αιτίες για την διάβρωση κκαι την υποβάθμιση των ακτών. Η παράκτια διάβρωση προκαλεί δημιουργεί προβλήματα τόσο σε περιβαλλοντικό, όσο και σε κοινωνικοοικονομικό επίπεδο.

Στόχο της παρούσας εργασίας αποτελεί η εκτίμηση της παράκτιας φυσικής και κοινωνικής τρωτότητας των νοτιοανατολικών ακτών του Ανατολικού Κορινθιακού (Ηραίον-Λέχαιο Κορινθίας), μήκους περίπου 30 χιλιομέτρων, στους παράκτιους φυσικούς κινδύνους που επιφέρει η άνοδος της στάθμης της θάλασσας λόγω της κλιματικής αλλαγής (Σχήμα 1).

Σχήμα 1. Η περιοχή μελέτης, πηγή: Google Earth.

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Για την εκτίμηση της φυσικής τρωτότητας των ακτών, εφαρμόστηκε ο Δείκτης Παράκτιας Τρωτότητας (CVI) που έχει προταθεί για την εκτίμηση της τρωτότητας των ακτών των Η.Π.Α και του Καναδά, ο οποίος έχει εφαρμοσθεί επίσης και στην Ελλάδα. Όσον αφορά την παράκτια κοινωνική τρωτότητα εφαρμόστηκε ένας προτεινόμενος Δείκτης Παράκτιας Κοινωνικής Τρωτότητας (CSoVI), ο οποίος αποτελεί τροποποίηση αυτού που εφάρμοσαν οι Borruf *et al.* (2005) με σκοπό τον υπολογισμό της κοινωνικής τρωτότητας των παράκτιων περιοχών των Ηνωμένων Πολιτειών της Αμερικής.

Μεθοδολογία

Ο Δείκτης Παράκτιας Τρωτότητας (Coastal Vulnerability Index – CVI) αποτελεί ένα δυναμικό, απλό, αντικειμενικό και εύχρηστο μαθηματικό εργαλείο προσδιορισμού της παράκτιας φυσικής τρωτότητας στην μακροχρόνια μελλοντική άνοδο της στάθμης της θάλασσας, αλλά και στις εφήμερες ακραίες μεταβολές λόγω της επίδρασης μετεωρολογικών συνθηκών (Δουκάκης, 2005). Διαμορφώθηκε αρχικά από τους Gorniz *et al.* (1994) και εφαρμόστηκε στις Η.Π.Α. Συνεκτιμά έξι (6) γεωλογικές και ωκεανογραφικές παραμέτρους που επιδρούν στη διαμόρφωση των μορφολογικών χαρακτηριστικών των παράκτιων ζωνών. Οι παράμετροι είναι: (1) η παράκτια γεωλογία και γεωμορφολογία, (2) η παράκτια κλίση, (3) η σχετική μεταβολή της στάθμης της θάλασσας, (4) οι πρόσφατες μεταβολές της ακτογραμμής, (5) το μέσο σημαντικό ύψος των κυμάτων και (6) το μέσο εύρος της παλίρροιας. Ο μαθηματικός τύπος που χρησιμοποιείται για τον προσδιορισμό της φυσικής τρωτότητας των παράκτιων περιοχών είναι η τετραγωνική ρίζα του γινομένου των 6 μεταβλητών διαιρούμενου με το πλήθος τους. Για κάθε μία παράμετρο, τα επιμέρους τμήματα της ακτογραμμής κατηγοριοποιούνται σε πέντε κατηγορίες τρωτότητας ως εξής: «Πολύ χαμηλή» με τιμή 1, «Χαμηλή» με τιμή 2, «Μέση» με τιμή 3, «Υψηλή» με τιμή 4, και «Πολύ υψηλή» με τιμή 5. Τα όρια βαθμονόμησης που χρησιμοποιήθηκαν, είναι αυτά που προτάθηκαν από τους Pendleton *et al.* (2004), και τους Karymbalis *et al.* (2012). Ο Δείκτης Παράκτιας Κοινωνικής Τρωτότητας (CSoVI), αποτελεί έναν εμπειρικό τρόπο αξιολόγησης της κοινωνικής τρωτότητας παράκτιων κοινωνιών που εφαρμόστηκε για πρώτη φορά από τους Borruf *et al.* (2005) και λαμβάνει υπόψη μια πληθώρα κοινωνικοοικονομικών στοιχείων, που επηρεάζουν την τρωτότητα των ανθρώπων και των κοινωνιών στου παράκτιους κινδύνους. Καθότι δεν ήταν εφικτό να υπολογιστούν όλες, λόγω της έλλειψης ελεύθερων δεδομένων της Ελληνικής Στατιστικής Αρχής, πραγματοποιήθηκε τροποποίηση του δείκτη, επιλέγοντας κάποιες από τις μεταβλητές του αρχικού δείκτη για τις οποίες υπήρχαν διαθέσιμα στοιχεία. Οι μεταβλητές περιλαμβάνουν: (1) το ποσοστό των γυναικών στον συνολικό πληθυσμό, (2) το ποσοστό των αλλοδαπών στον συνολικό πληθυσμό, (3) το ποσοστό ατόμων χωρίς απολυτήριο λυκείου στον συνολικό πληθυσμό, (4) το ποσοστό των ανέργων, (5) το ποσοστό του εργατικού δυναμικού, (6) οι χρήσεις γης. Τα στοιχεία των παραπάνω μεταβλητών αφορούν το έτος 2011 και εκτιμήθηκαν σε επίπεδο Καλλικρατικού Δήμου. Η βαθμονόμηση των παράκτιων περιοχών, πραγματοποιήθηκε έχοντας ως παραδοχή πως με υψηλή τρωτότητα χαρακτηρίζονται οι περιοχές, των οποίων οι μεταβλητές υποδεικνύουν χαμηλό κοινωνικοοικονομικό επίπεδο. Καθότι η περιοχή μελέτης περιλαμβάνει μόνο δύο Δήμους, η στατιστική επεξεργασία, πραγματοποιήθηκε χρησιμοποιώντας τις τιμές όλων των παράκτιων Δήμων της Πελοποννήσου, ώστε τα αποτελέσματα να είναι ασφαλέστερα. Η επεξεργασία των δεδομένων έγινε στο Microsoft Excel εφαρμόζοντας την απλή κατανομή, χρησιμοποιώντας τη μέση τιμή και την τυπική απόκλιση των τιμών. Αφού υπολογίστηκαν οι στατιστικές αυτές παράμετροι, κατασκευάστηκαν οι κλάσεις που

αντιπροσωπεύουν τις πέντε κατηγορίες τρωτότητας στις οποίες δόθηκαν οι τιμές από 1 έως 5 όπως και στον δείκτη CVI.

Αποτελέσματα

Έπειτα από τον υπολογισμό των επιμέρους μεταβλητών του δείκτη παράκτιας τρωτότητας, ακολούθησε ο υπολογισμός του δείκτη με τη χρήσει του λογισμικού ArcGis. Ο δείκτης υπολογίστηκε χρησιμοποιώντας τη μαθηματική σχέση υπολογισμού του, ώστε να πραγματοποιηθεί η σύνθεση των επιμέρους επιπέδων που αφορούν τις εμπλεκόμενες παραμέτρους. Στη συνέχεια προέκυψε ένα νέο επίπεδο με τις τιμές της παράκτιας τρωτότητας, που κατηγοριοποιήθηκαν επίσης σε 5 κλάσεις. Το τελικό αποτέλεσμα αποτυπώνεται στον χάρτη (Σχήμα 2) και τον πίνακα (Πίνακας 1) που ακολουθούν.
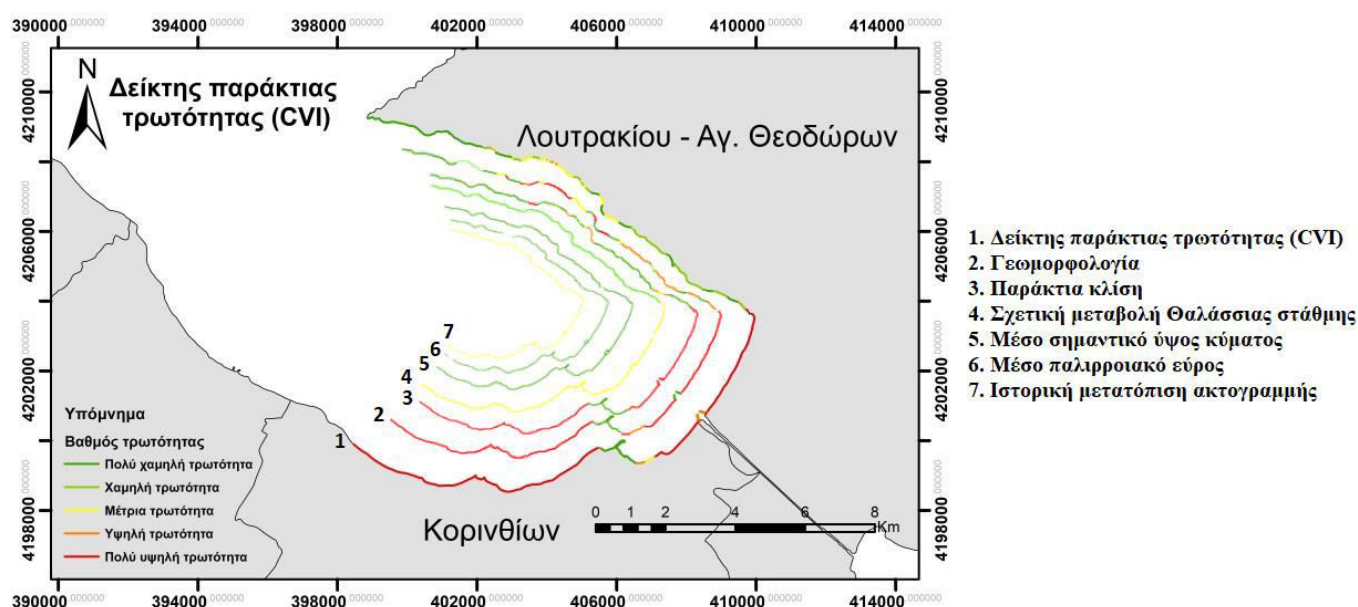
Σχήμα 2. Χαρτογραφική αποτύπωση του Δείκτη Παράκτιας Τρωτότητας (CVI) και των μεταβλητών του.

Πίνακας 1. Βαθμονόμηση της παραμέτρου του Δείκτη Παράκτιας Τρωτότητας.

Δείκτης CVI	1,000000-1,414214	1,414215-2,000000	2,000001-2,449490	2,449491-4,242641	4,242642-6,123724	Σύνολο
Μήκος (%) Βαθμός Τρωτότητας	27,1 Πολύ χαμηλή (1)	15 Χαμηλή (2)	9,1 Μέτρια (3)	4,9 Υψηλή (4)	43,9 Πολύ υψηλή (5)	100

Όπως φαίνεται, το μεγαλύτερο μέρος της ακτογραμμής (43,9%) παρουσιάζει «πολύ υψηλή τρωτότητα» και ακολουθεί το ποσοστό της ακτογραμμής με «πολύ χαμηλή τρωτότητα» (27,1%). Στη συνέχεια η κατηγορία με το τρίτο μεγαλύτερο ποσοστό (15%) είναι η κατηγορία 2 της χαμηλής τρωτότητας. Τέλος ακολουθούν οι κατηγορίες «μέτριας» και «υψηλής» τρωτότητας με μικρότερα ποσοστά (9,1% και 4,9% αντίστοιχα). Όσον αφορά τον προτεινόμενο τροποποιημένο

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![IAG Geomorphology Geomorphologie AIG logo]

Δείκτη Παράκτιας Κοινωνικής Τρωτότητας (CSoVI) έπειτα από τον υπολογισμό των επιμέρους μεταβλητών του, ακολούθησε ο υπολογισμός του με τη χρήσει του λογισμικού ArcGis όπως έγινε και για τον Δείκτη Παράκτιας Τρωτότητας (CVI). Προέκυψε ένα νέο επίπεδο με τις τιμές της παράκτιας κοινωνικής τρωτότητας, στο οποίο, οι βαθμολογίες του δείκτη ταξινομήθηκαν με βάση τις τυπικές αποκλίσεις από το μέσο όρο σε πέντε κατηγορίες (λαμβάνοντας την τιμή 1 για περιοχές πολύ χαμηλής τρωτότητας έως την τιμή 5 για αυτές με πολύ υψηλή τρωτότητα). Το τελικό αποτέλεσμα αποτυπώνεται στον ακόλουθο χάρτη (Σχήμα 3) και πίνακα (Πίνακας 2).
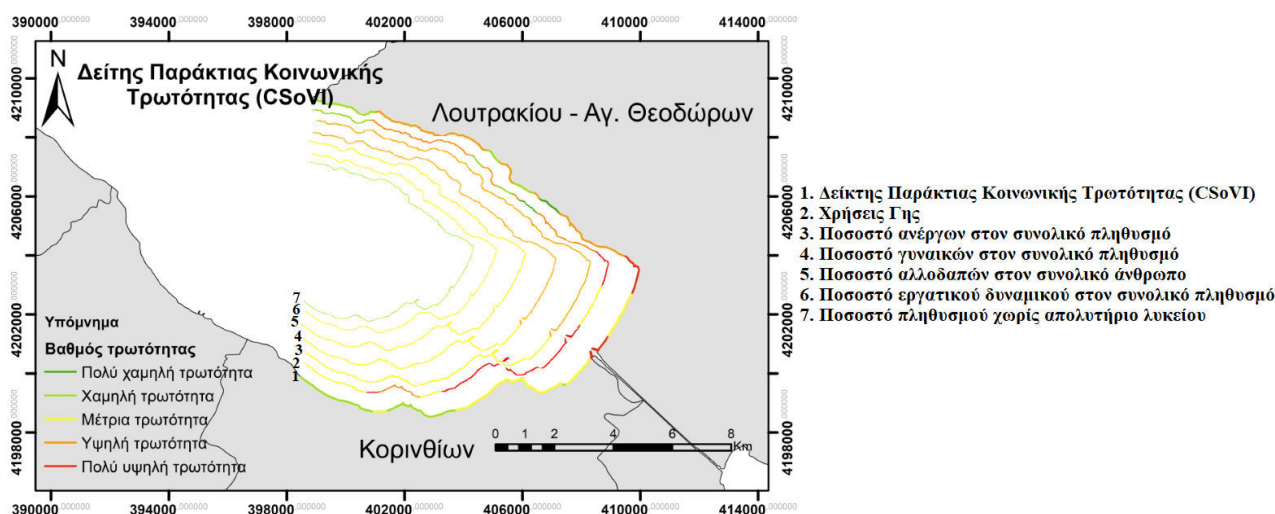
Σχήμα 2. Χαρτογραφική αποτύπωση του Δείκτη Παράκτιας Κοινωνικής Τρωτότητας (CSoVI) και των μεταβλητών του.

Πίνακας 2. Βαθμονόμηση της παραμέτρου του Δείκτη Παράκτιας Κοινωνικής Τρωτότητας.

ΔείκτηςCSoVI	1	2	3	4	5	Σύνολο
Μήκος (%)	2,7	30,8	27,9	28,4	10,2	100
Βαθμός Τρωτότητας	Πολύχαμηλή (1)	Χαμηλή (2)	Μέτρια (3)	Υψηλή (4)	Πολύ υψηλή (5)	

Το μεγαλύτερο τμήμα της ακτογραμμής, με ποσοστό 30,8%, χαρακτηρίζεται ως περιοχή χαμηλής τρωτότητας. Η κατηγορία της υψηλής τρωτότητας καταλαμβάνει ποσοστό 28,4% της ακτογραμμής, ενώ ακολουθεί η κατηγορία της μέτριας τρωτότητας με ποσοστό 27,9%. Τέλος οι κατηγορίες πολύ υψηλής και πολύ χαμηλής τρωτότητας, καταλαμβάνουν τα μικρότερα ποσοστά με 10,2% και 2,7% αντίστοιχα.

Συμπεράσματα

Σε ό,τι αφορά τον δείκτη CVI, συνολικά, το 43,9% της ακτογραμμής εκτιμήθηκε ως ακτογραμμή πολύ υψηλής τρωτότητας και το 4,9% ως υψηλής τρωτότητας. Συνεπώς περίπου το 50% του συνολικού μήκους της ακτογραμμής της περιοχής μελέτης, χαρακτηρίζεται ως αυξημένης φυσικής τρωτότητας. Οι περιοχές οι οποίες χαρακτηρίστηκαν περισσότερο τρωτές, είναι η ακτογραμμής από την Κόρινθο ως το Λέχαιο, η περιοχή της Διώρυγας του Ισθμού, καθώς και η

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πόλη του Λουτρακίου. Οι περιοχές αυτές, συνδυάζουν μικρές παράκτιες κλίσεις και μικρής ανθεκτικότητας γεωλογικούς σχηματισμούς, επιρρεπείς στη διάβρωση. Σχετικά με τον δείκτη CSoVI, η επεξεργασία των μεταβλητών έδειξε πως το 33,5% της ακτογραμμής χαρακτηρίζεται ως χαμηλής και πολύ χαμηλής και το 38,6% ως υψηλής και πολύ υψηλής κοινωνικής τρωτότητας. Ειδικότερα, η ακτογραμμή που διοικητικά ανήκει στον Δήμο Λουτρακίου-Περαχώρας-Αγίων Θεοδώρων εκτιμήθηκε ως πιο τρωτή, συγκεντρώνοντας το μεγαλύτερο ποσοστό αυξημένης κοινωνικής τρωτότητας.

Λαμβάνοντας υπόψη τα αποτελέσματα του δείκτη CVI, η προς μελέτη ακτογραμμή εκτιμάται συνολικά ως μέτριας έως υψηλής τρωτότητας, με το ποσοστό της ακτογραμμής που εκτιμήθηκε ως υψηλής και πολύ υψηλής τρωτότητας να ανέρχεται περίπου στο 48%. Αξίζει να σημειωθεί, πως η υψηλής τρωτότητας ακτογραμμή αντιστοιχεί στις πόλεις της Κορίνθου και του Λουτρακίου, που αποτελούν σημαντικά αστικά κέντρα της Περιφερειακής Ενότητας Κορινθίας. Τα ποσοστά χαμηλής και πολύ χαμηλής τρωτότητας συνολικά δεν μπορούν να αγνοηθούν (42%), ωστόσο τα τμήματα αυτά, αντιστοιχούν σε πολύ αραιοκατοικημένες η μη κατοικημένες περιοχές που ενδεχομένως δεν απαιτείται παρέμβαση.

Εν κατακλείδι, η παρούσα εργασία είχε σαν κύριο σκοπό την ανεύρεση περιοχών, αυξημένης παράκτιας φυσικής και κοινωνικής τρωτότητας, σε μια ακτογραμμή μήκους 30 χιλιομέτρων των νοτιοανατολικών ακτών του Ανατολικού Κορινθιακού κόλπου, με την εφαρμογή των δεικτών CVI και CSoVI. Για τον σκοπό αυτό, αξιοποιήθηκαν γεωλογικά, ωκεανογραφικά και κοινωνικοοικονομικά δεδομένα, τα οποία μπορούν μελλοντικά να εμπλουτιστούν με νέα στοιχεία για περισσότερο ακριβή αποτελέσματα. Η αναγνώριση των περιοχών που παρουσιάζουν υψηλή τρωτότητα είναι ένα από τα πρώτα και πιο σημαντικά βήματα για την ορθή διαχείριση και θέσπιση εθνικών πολιτικών προστασίας της παράκτιας ζώνης έναντι των φυσικών παράκτιων κινδύνων.

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Μελέτη των Ακτών του Κόλπου του Αργοστολίου και της Χερσονήσου της Παλικής (ν. Κεφαλονιά) σε Σχέση με τους Παράκτιους Κινδύνους

Π. Τουμάση [1]

(1) Χαροκόπειο Πανεπιστήμιο, Ελ. Βενιζέλου 70, Καλλιθέα, Ελλάδα, polixenitoumasi@gmail.com

Εισαγωγή

Η παρούσα εργασία πραγματεύεται τον υπολογισμό της παράκτιας τρωτότητας του δυτικού τμήματος της νήσου Κεφαλονιάς, μέσω της χρήσης Συστημάτων Γεωγραφικών Πληροφοριών. Η περιοχή μελέτης περιλαμβάνει τον κόλπο του Αργοστολιού και τη χερσόνησο της Παλικής.

Σε μια προσπάθεια να εκτιμηθεί η φυσική ευπάθεια των ακτών της περιοχής στους παράκτιους κινδύνους και κυρίως σε αυτούς που σχετίζονται με την κλιματική αλλαγή, όπως η μακροπρόθεσμη άνοδος της στάθμης της θάλασσας και η πρόσκαιρη άνοδος και ο κυματισμός που προκαλούνται από ιδιαίτερες μετεωρολογικές συνθήκες, εκτιμήθηκε ο Δείκτης Παράκτιας Τρωτότητας (CVI). Πρόκειται για ένα δείκτη/μαθηματικό τύπο ο οποίος λαμβάνει υπόψη του έξι παραμέτρους που σχετίζονται με τα φυσικο-γεωγραφικά χαρακτηριστικά των ακτών. Ο δείκτης αυτός αρχικά εφαρμόστηκε για την εκτίμηση της φυσικής τρωτότητας των ακτών των ΗΠΑ ενώ αργότερα αξιοποιήθηκε για τη μελέτη των ακτών διαφόρων χωρών μεταξύ των οποίων και της Ελλάδας.

Μεθοδολογία

Για τη δημιουργία των χαρτών γεωγραφικής κατανομής των επιμέρους παραμέτρων αλλά και του ίδιου του δείκτη χρησιμοποιήθηκαν δεδομένα, σε μορφή shapefile, τα οποία επεξεργάστηκαν με το λογισμικό ArcGIS (έκδοση 10.7). Για τη εκτίμηση του δείκτη παράκτιας επικινδυνότητας, ήταν αναγκαία η κατηγοριοποίηση της ακτογραμμής σε πέντε κατηγορίες επικινδυνότητας για κάθε έναν από τους παράγοντες του CVI.

Ο χάρτης για τον παράγοντα της γεωμορφολογίας δημιουργήθηκε από την συνδυαστική μελέτη του χάρτη γεωμορφολογίας και του χάρτη γεωλογίας της περιοχής μελέτης του ΙΓΜΕ (Ινστιτούτο Γεωλογικών και Μεταλλευτικών Ερευνών).

Ο χάρτης για τον παράγοντα της παράκτιας κλίσης δημιουργήθηκε βάσει του χάρτη κλίσεων, ο οποίος διαμορφώθηκε μέσω του ψηφιακού μοντέλου εδάφους.

Όσον αφορά τον χάρτη του παράγοντα ρυθμού μεταβολής ακτογραμμής, προέκυψε από τη σύγκριση της παλιάς ακτογραμμής (ακτογραμμή 1996) με την πιο πρόσφατη ακτογραμμή (2017) του νησιού. Οι τιμές για τους παράγοντες της σχετικής μεταβολής της θαλάσσιας στάθμης, του μέσου σημαντικού ύψους κύματος και του μέσου εύρους παλίρροιας, δόθηκαν βάσει αντίστοιχης βιβλιογραφίας. Οι μεταβλητές του CVI λαμβάνουν ακέραιες τιμές, οι οποίες κυμαίνονται από το ένα (1) έως το πέντε (5). Το 5 να αντιστοιχεί σε πολύ υψηλή τρωτότητα και το 1 να χαρακτηρίζει

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τμήματα της ακτογραμμής με πολύ χαμηλή τρωτότητα ως προς τη συγκεκριμένη παράμετρο όπως φαίνεται και στον Πίνακα 1.

Πίνακας 1. Ταξινόμηση των μεταβλητών του C.V.I.

Παράγοντας	Πολύ μικρή τρωτότητα (1)	Μικρή τρωτότητα (2)	Μέτρια τρωτότητα (3)	Υψηλή τρωτότητα (4)	Πολύ υψηλή τρωτότητα (5)
Γεωμορφολογία	Παράκτιοι βραχώδεις κρημνοί, τεχνητά θωρακισμένες ακτές	Μέσης κλίσης παράκτιοι κρημνοί σχηματισμών ενδιάμεσης αντοχής, εσοχές	Χαμηλοί παράκτιοι κρημνοί χαλαρών σχηματισμών, αλλουβιακές πεδιάδες	Χαλικώδεις αιγιαλοί, εκβολικά συστήματα, λιμνοθάλασσες	Φραγματικοί αιγιαλοί, αμμώδεις αιγιαλοί, ποτάμια δέλτα
Παράκτια κλίση (%)	> 12	12 - 9	9 – 6	6 – 3	< 3
Σχετική μεταβολή της θαλάσσιας στάθμης (mm/έτος)	< 1,8	1,8 - 2,5	2,5 – 3,0	3,0 – 3,4	> 3,4
Προέλαση/υποχώρηση της ακτογραμμής (m/έτος)	> 1,5	1,5 - 0,5	0,5 – (-0,5)	(-0,5) – (-1,5)	< (-1,5)
Μέσο ύψος κύματος (m)	< 0,3	0,3 – 0,6	0,6 – 0,9	0,9 – 1,2	> 1,2
Μέσο εύρος παλίρροιας (m)	< 0,2	0,2 – 0,4	0,4 – 0,6	0,6 – 0,8	> 0,8

Αποτελέσματα - Συμπεράσματα

Όπως φαίνεται και από το Σχήμα 1, η φυσική τρωτότητα είναι πολύ μικρή ως επί το πλείστον στο δυτικό τμήμα της χερσονήσου της Παλικής, όπου υπάρχουν κυρίως βραχώδεις ακτές μεγάλης μορφολογικής κλίσης.

Η εκτίμηση των τιμών του δείκτη CVI, οδήγησε στη διαπίστωση ότι υψηλή επικινδυνότητα εμφανίζουν κυρίως οι παράκτιες περιοχές στο ανατολικό τμήμα της χερσονήσου της Παλικής, όπου υπάρχουν αμμώδεις αιγιαλοί οι οποίοι είναι μικρής μορφολογικής κλίσης και ευδιάβρωτοι, άρα επιρρεπείς στην κατάκλιση από μια ενδεχόμενη άνοδο της θαλάσσιας στάθμης. Μικρό τμήμα των ακτών της περιοχής χαρακτηρίζεται ως μικρής ή μέτριας επικινδυνότητας.

Από το συνολικό μήκος της υπό μελέτη ακτογραμμής (120,36 km), τα 39,12 km χαρακτηρίζονται ως πολύ μικρής τρωτότητας στους παράκτιους κινδύνους, τα 9,14 km ως μικρής τρωτότητας και τα 5,47 km ως μέτριας τρωτότητας. Υψηλή τρωτότητα χαρακτηρίζει τα 35,41 km της συνολικής ακτογραμμής, και πολύ υψηλής τρωτότητας τα 31,15 km. Οι ακτές του κόλπου του Αργοστολίου διαπιστώθηκε ότι διατρέχουν πολύ μεγαλύτερο κίνδυνο, σε σχέση με τις ακτές του δυτικού τμήματος της χερσονήσου της Παλικής.
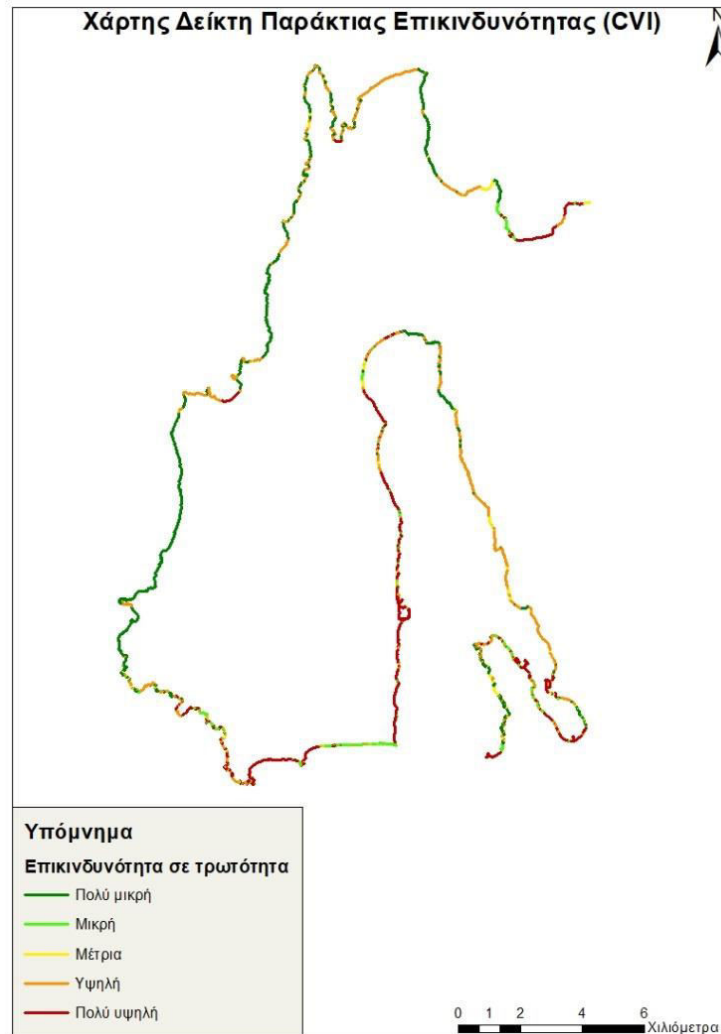
Σχήμα 1. Τελικός χάρτης CVI όπου η ακρογραμμή της περιοχής μελέτης έχει κατηγοριοποιηθεί σε πέντε κατηγορίες φυσικής τρωτότητας στους παράκτιους κινδύνους.

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Εκτίμηση της Επιδεκτικότητας των Ακτών της Νήσου Χίου στους Παράκτιους Κινδύνους με την Χρήση ΣΓΠ

Ι. Ρ. Κυπρίου [1]

(1) Εθνικό & Καποδιστριακό Πανεπιστήμιο Αθηνών ,τμήμα Φυσικής ,Πανεπιστημιούπολη Ζωγράφου Ελλάδα, rafaelakypr@hotmail.com

Εισαγωγή

Αντικείμενο της παρούσας μελέτης είναι η εκτίμηση της επιδεκτικότητας των ακτών της νήσου Χίου στους παράκτιους κινδύνους που σχετίζονται με την κλιματική αλλαγή εφαρμόζοντας τον Δείκτη Παράκτιας Τρωτότητας CVI (Coastal Vulnerability Index). Η κλιματική αλλαγή εντείνει τις παράκτιες διεργασίες (μακροπρόθεσμη άνοδος στάθμης θάλασσας και αύξηση έντασης και συχνοτητας επεισοδίων πρόσκαιρης ανόδου λόγω χαμηλών βαρομετρικών) με αποτέλεσμα οι παράκτιες περιοχές τόσο της Ευρώπης, όσο και της Ελλάδας να εμφανίζουν ευπάθεια στους φυσικούς αυτούς κινδύνους. Εγείρεται λοιπόν ένας σύγχρονος προβληματισμός, σχετικά με την διαχείριση της παράκτιας ζώνης και την επιδεκτικότητα των ακτών στην άνοδο της θαλάσσιας στάθμης, καθώς ένα σημαντικό ποσοστό του παγκόσμιου πληθυσμού που ανέρχεται σε 23% ζει και δραστηριοποιείται στην παράκτια ζώνη.

Μεθοδολογία

Για τους σκοπούς της εργασίας εφαρμόστηκε ένας δείκτη που ποσοτικοποιεί την επιδεκτικότητα των ακτών στη διάβρωση λόγω της ανόδου της θαλάσσιας στάθμης. Η κατηγοριοποίηση των ακτών της Χίου ανάλογα με την φυσική τους ευπάθεια είναι καθοριστικής σημασίας για την ορθή διαχείριση της παράκτιας ζώνης του νησιού. Εκτιμήθηκε ο δείκτης παράκτιας τρωτότητας CVI (Coastal Vulnerability Index) που πρώτοι εφάρμοσαν οι Gornitz and White (1991). Ο εν λόγω δείκτης, αποτελεί έναν μαθηματικό τύπο όπου συνεκτιμώνται έξι παράμετροι: (1) η παράκτια γεωμορφολογία, (2) η παράκτια κλίση, (3) η ιστορική μετατόπιση της ακτογραμμής, (4) η σχετική άνοδος της θαλάσσιας στάθμης, (5) το μέσο παλιρροϊκό εύρος και το (6) μέσο σημαντικό ύψος κύματος. Για κάθε μια παράμετρο η ακτή βαθμονομήθηκε σε πέντε κατηγορίες επικινδυνότητας (1: πολύ χαμηλή έως 5: πολύ υψηλή). Τελικό στόχο αποτελεί η ταξινόμηση όλων των μεταβλητών σε μία ενιαία κλίμακα βαθμονόμησης της παράκτιας επικινδυνότητας, έτσι ώστε να εκτιμηθεί η τιμή του δείκτη CVI σς κάθε επιμέρους τμήμα της ακτογραμμής.

Πέραν της εκτίμησης της παράκτιας επικινδυνότητα επιχειρήθηκε μια ποιοτική αξιολόγηση των χρήσεων γης οι οποίες κινδυνεύουν περισσότερο από μια ενδεχόμενη άνοδο της στάθμης της θάλασσας. Εκτιμήθηκαν οι χρήσεις γης που καταλαμβάνουν τις υψηλής κι πολύ υψηλής τρωτότητας ακτές ενώ ελήφθησαν υπόψη και δεδομένα για τα παραλιακά ξενοδοχεία του νησιού, με σκοπό να συνεκτιμηθούν και οι τουριστικές υποδομές οι οποίες ενδεχομένως πληγούν από τον φυσικό αυτό κίνδυνο. Για τα εύρη τιμών των κατηγοριών επικινδυνότητας της κάθε παραμέτρου, χρησιμοποιήθηκαν τα εύρη τιμών που έχουν προταθεί από τους Karymbalis *et al.*

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(2012) για τις ελληνικές ακτές. Αυτό κάνει συγκρίσιμα τα αποτελέσματα με ανάλογες προσεγγίσεις που αφορούν άλλες παράκτιες περιοχές του ελλδικού χώρου.

Για την επεξεργασία των δεδομένων και την παραγωγή των χαρτών χρησιμοποιήθηκε το λογισμικό Arcgis. Για την εξαγωγή του τελικού δείκτη CVI, όλες οι παράμετροι ταξινομήθηκαν σε μια ενιαία κλίμακα και δημιουργήθηκε ένα νέο Field στο οποίο υπολογίστηκε ο τύπος του δείκτη:

$$CVI = \sqrt{\frac{(a \cdot b \cdot c \cdot d \cdot e \cdot f)}{6}}$$

Στον Πίνακα 1 φαίνονται οι πηγές απ' όπου αντλήθηκαν τα δεδομένα για τον υπολογισμό των παραμέτρων του δείκτη CVI και την παραγωγή των χαρτών.

Πίνακας 1. Πηγές δεδομένων για τα θεματικά επίπεδα που χρησιμοποιήθηκαν.

ΘΕΜΑΤΙΚΑ ΕΠΙΠΕΔΑ	ΠΗΓΕΣ ΔΕΔΟΜΕΝΩΝ
Γεωλογία-Λιθολογία	Ινστιτούτο Γεωλογικών & Μεταλλευτικών Ερευνών (Ι.Γ.Μ.Ε.)
DEM (Ψηφιακό Μοντέλο Εδάφους) 5×5 m	Εθνικό Κτηματολόγιο & Χαρτογράφησης (Ε.Κ.ΧΑ)
Ακτογραμμή έτους 2009	Εθνικό Κτηματολόγιο & Χαρτογράφησης (Ε.Κ.ΧΑ)
Μέσο σημαντικό ύψος κύματος	Soukisian *et al.*, 2007
Ισοβαθείς καμπύλες	Ελληνικό Κέντρο θαλάσσιων ερευνών (ΕΛ.ΚΕ.Θ.Ε)
Χρήσεις γης	Υπουργείο Αγροτικής Ανάπτυξης (2008)
Ορθοφωτοχάρτες 1996	Γ.Υ. Σ.

Από τα δεδομένα αυτά δημιουργήθηκε μια ψηφιακή βάση χωρικών δεδομένων για το νησί σε περιβάλλον Συστημάτων Γεωγραφικών Πληροφοριών.

Αποτελέσματα - Συμπεράσματα

Στους χάρτες του Σχήματος 1 φαίνονται τα τελικά αποτελέσματα της κατηγοριοποίησης των ακτών της Χίου σε πέντε κατηγορίες φυσικής τρωτότητας για κάθε παράμετρο που εμπλέκεται στον υπολογισμό του δείκτη CVI. Στον Πίνακα 2 περιλαβάνονται τα μήκη και τα ποσοστά (%) των ακτών του νησιού ανά κατηγορία επικινδυνότητας από πολύ χαμηλή έως πολύ υψηλή.

Τα αποτελέσματα της επεξεργασίας των δεδομένων δείχνουν ότι το μεγαλύτερο ποσοστό της ακτογραμμής της Χίου ανήκει στις δύο πιο χαμηλές κατηγορίες επικινδυνότητας για όλες σχεδόν τις παραμέτρους. Για την παράμετρο της παράκτιας γεωμορφολογίας μόλις το 12,76 % της ακτογραμμής ανήκει στις δύο υψηλότερες κατηγορίες επικινδυνότητας. Για την παράμετρο τη παράκτιας κλίσης, το 15,8% του συνολικού μήκους της ακτογραμμής χαρακτηρίζεται ως υψηλής και πολύ υψηλής επικινδυνότητας. Ως προς την σχετική μεταβολή της θαλάσσιας στάθμης όλο το μήκος της ακτογραμμής χαρακτηρίζεται από πολύ υψηλή επικινδυνότητα σε αντίθεση με το εύρος παλίρροιας, για το οποίο όλο το μήκος της ακτογραμμής ανήκει στην κατηγορία πολύ χαμηλής επικινδυνότητας. Όσον αφορά την ιστορική μετατόπιση της ακτογραμμής, το 0,4% χαρακτηρίζεται ως υψηλής και το 0,018% ως πολύ υψηλής επικινδυνότητας. Τέλος για την

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παράμετρο του μέσου σημαντικού ύψους κύματος, το 42% του μήκους της ακτογραμμής χαρακτηρίζεται ως χαμηλής επικινδυνότητας ενώ το 58% ως μέτριας.

Ο υπολογισμός του Δείκτη Παράκτιας Επικινδυνότητας, οδηγεί στο συμπέρασμα ότι το 15% του συνολικού μήκους της ακτογραμμής χαρακτηρίζεται ως υψηλής επικινδυνότητας και το 9% ως πολύ υψηλής. Οι παράμετροι που φαίνεται ότι επηρεάζουν το τελικό αποτέλεσμα σε σημαντικό βαθμό είναι η παράκτια γεωμορφολογία και η παράκτια μορφολογική κλίση.
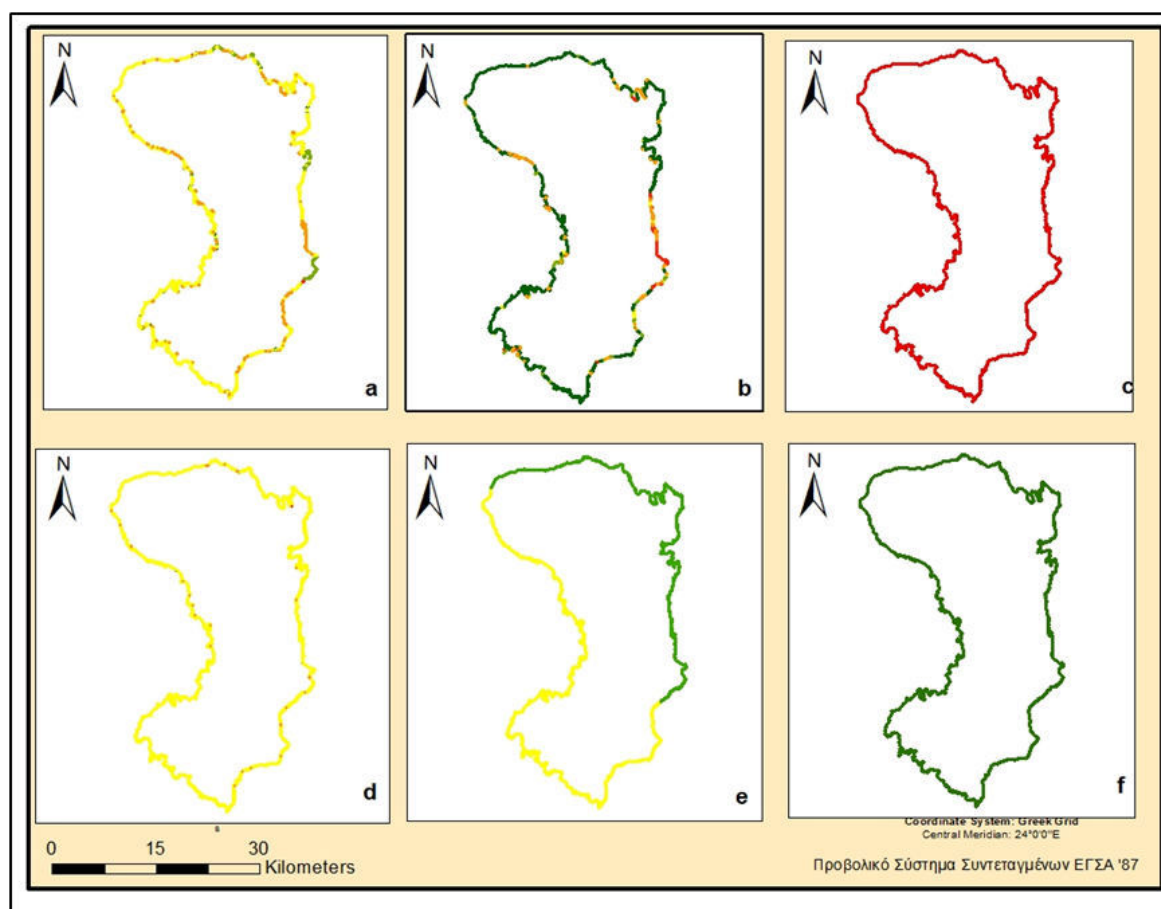
Σχήμα 1. Χαρτογραφική απεικόνιση της κατηγοριοποίησης των ακτών της Χίου σε κατηγορίες επικινδυνότητας για τις έξι παραμέτρους του Δείκτη Παράκτιας Εεπικινδυνότητας (CVI) a) παράκτια γεωμορφολογία, b) παράκτια κλίση, c) ρυθμός μεταβολής στάθμης θάλασσας, d) ιστορική μετατόπιση ακτογραμμής e) μέσο σημαντικό ύψος κύματος, f) μέσο εύρος παλίρροιας.

Πίνακας 2. Μήκη (και ποσοστά) των ακτών της ν. Χίου ανά κατηγορία επικινδυνότητας στους παράκτιους κινδύνους.

Δείκτης παράκτιας επικινδυνότητας	Πολύ χαμηλή (1)	Χαμηλή (2)	Μέτρια (3)	Υψηλή (4)	Πολύ υψηλή (5)	Σύνολο
Μήκος (%)	23	39	14	15	9	100
Μήκος (km)	70,234	117,970	41,986	44,003	27,776	301,972

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Το γεγονός αυτό, δεν καθιστά τα αποτελέσματα της παρούσας μελέτης συγκρίσιμα με άλλες επιστημονικές εργασίες που χρησιμοποιούν τα εύρη τιμών που ανταποκρίνονται σε παγκόσμιο επίπεδο.

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Εκτίμηση Πλημμυρικού Κινδύνου Λεκάνης Απορροής Μεγάλου Ρέματος Ραφήνας (Ανατολική Αττική, Ελλάδα)

Μ. Ανδρέου [1], _Δ. Β. Μπατζάκης_ [1], _Κ. Τσανάκας_ [1], _Σ. Καραλής_ [1], _Ε. Καρύμπαλης_ [1]

(1) Χαροκόπειο Πανεπιστήμιο Αθήνας, Ελευθερίου Βενιζέλου 70, Καλλιθέα, mandreou@hua.gr, mpatzakis@gmail.com, ktsanakas@hua.gr, sotyk@yahoo.gr, karymbalis@hua.gr

Εισαγωγή

Οι πλημμύρες αποτελούν το συχνότερος και πιο καταστροφικό φυσικό κίνδυνο κατέχοντας την πρώτη θέση στην πρόκληση υλικών ζημιών και απωλειών ανθρώπινων ζωών παγκοσμίως. Αντιπροσωπεύουν περίπου το ένα τρίτο των καταστροφικών συμβάντων λόγω φυσικών κινδύνων και επηρεάζοντας σημαντικά τις αναπτυσσόμενες περιοχές (Giannaros _et al._, 2020). Η ταχεία αστικοποίηση σε συνδυασμό με την πληθυσμιακή αύξηση προκαλούν αρνητικές επιπτώσεις στο φυσικό περιβάλλον. Η εκτίμηση του πλημμυρικού κινδύνου είναι καθοριστική για τον περιορισμό των αρνητικών επιπτώσεεων των πλημμυρικών συμβάντων και απαραίτητη στον σχεδιασμό των χρήσεων γης στις περιοχές που είναι επιρρεπείς στον κίνδυνο της πλημμύρας.

Η παρούσα εργασία αποσκοπεί στην εκτίμηση και χαρτογράφηση του πλημμυρικού κινδύνου στη λεκάνη απορροής του Μεγάλου Ρέματος Ραφήνας, μιας περιοχής με μεγάλο ρυθμό ανάπτυξης αστικού πολεοδομικού ιστού, ως μέρος της ευρύτερης περιοχής των Μεσογείων της Αν. Αττικής. Η μεθοδολογία που εφαρμόστηκε συνδύασε Γεωγραφικά Συστήματα Πληροφοριών (GIS) και Αναλυτική Ιεραρχική Διαδικασία AHP (Analytic Hierarchy Process) έξι παραγόντων που θεωρήθηκαν κρίσιμοι για τον προσδιορισμό του κινδύνου πλημμύρας.

Η λεκάνη απορροής του Μ. Ρέματος της Ραφήνας βρίσκεται στην Αν. Αττική και καταλαμβάνει επιφάνεια περίπου 116 τ.χλμ.. Οριοθετείται Β-ΒΑ από το Πεντελικό Όρος (μεγ. υψ. 920 μ.), Δ-ΝΔ από το Όρος Υμηττός (μεγ.υψ.620μ.) και Ν-ΝΑ από λοφώδες εξάρσεις μέγιστου υψομέτρου 300 μ.. Η κεντρική κοίτη του υδρογραφικού δικτύου είναι 6ης τάξης κατά Strahler, έχει συνολικό μήκος 25 χλμ. και ακολουθώντας διεύθυνση ροής Δ.ΝΔ-Α.ΒΑ, εκβάλλει στις δυτικές ακτές του Ν. Ευβοϊκού κόλπου. Το υδρογραφικό δίκτυο είναι καλά ανεπτυγμένο βόρεια της κεντρικής του κοίτης ενώ νότια εμφανίζει περιορισμένη ανάπτυξη που περιορίζεται στην ύπαρξη μικρού αριθμού κλάδων 1ης και 2ης τάξης (Karymbalis _et al._, 2005). Μορφολογικά η λεκάνη μπορεί να χωριστεί σε δύο περιοχές: (α) στο βόρειο και νοτιοδυτικό ορεινό τμήμα που δομείται από μεταμορφωμένα πετρώματα (σχιστόλιθοι και μάρμαρα) και ασβεστόλιθους Μεσοζωϊκής ηλικίας που ανήκουν στην αυτόχθονη γεωτεκρονική ενότητα του Αλμυροποτάμου και (β) στο νότιο πεδινό τμήμα χαμηλών κλίσεων που δομείται από Ανω-Μειοκαινικά κροκαλοπαγή και λιμναίους σχηματισμούς ίδιας ηλικίας καθώς και από Πλειστοκαινικές χερσαίες και ποταμοχερσαίες αποθέσεις (Karymbalis _et al._, 2005). Το κλίμα της περιοχής μελέτης είναι τυπικό υποτροπικό μεσογειακό με ετήσια βροχόπτωση που κυμαίνεται από 362 mm έως 473 mm στις εκβολές του ποταμού ενώ η μέση ετήσια θερμοκρασία του αέρα είναι 17.2 °C.

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Η περιοχή χαρακτηρίζεται από έντονα αυξητικούς ρυθμούς αστικοποίησης με πληθυσμό που ανέρχεται στους 88.000 κάτοικους και από υψηλή επιρρέπεια στον πλημμυρικό κίνδυνο λόγω: (α) των εκτεταμένων διαδοχικών πυρκαγιών που είχαν σαν αποτέλεσμα την αποδυνάμωση της δράσης της μεταπυρικής αναγέννησης, (β) του μεγάλου ρυθμού αστικοποίησης που είναι αποτέλεσμα των μεγάλων κατασκευαστικών έργων στην ευρύτερη περιοχή (γ) της αποστράγγισης των όμβριων της Αττικής Οδού και της Περιφερειακής Υμηττού στον κύριο κλάδο της λεκάνης και της εκτροπής του άνω ρου του Ποδονίφτη με τελικό αποδέκτη επίσης την κεντρική κοίτη του Μ. Ρέματος, μέσω των έργων αποστράγγισης των δύο παραπάνω κατασκευαστικών έργων, (δ) των μικρών τοπογραφικών κλίσεων και (ε) της απουσίας έργων υποδομής για την προστασία από τις πλημμύρες (Giannaros *et al.*, 2020; Karymbalis *et al.*, 2005). Σύμφωνα με το ιστορικό πλημμυρικών συμβάντων για τη χρονική διάρκεια 1988-2019 η μέση συχνότητα εκδήλωσης πλημμυρών είναι 1 πλημμυρικό συμβάν ανά 2.7 έτη (Andreou *et al.*, 2019).

Μεθοδολογία

Για τον εντοπισμό των επιρρεπών στον πλημμυρικό κίνδυνο περιοχών της λεκάνης απορροής, ελήφθησαν υπόψη και εκτιμήθηκαν οι εξής παράγοντες: (α) μορφολογική κλίση, (β) υψόμετρο, (γ) απόσταση από τις ανοιχτές (φυσικές) και κλειστές (τεχνητά καλυμμένες) κοίτες των κλάδων 3ης, 4ης, 5ης και 6ης τάξης (κατά Strahler), (δ) υδρο-λιθολογικά χαρακτηριστικά των γεωλογικών σχηματισμών και (ε) χρήσεις γης (Σχήμα 1).

Ο χάρτης κλίσεων της λεκάνης προέκυψε από λεπτομερές Ψηφιακό Μοντέλο Ανάγλυφου DEM (5x5) και οι τιμές χωρίστηκαν σε 5 κλάσεις (Σχήμα 1α). Το υδρογραφικό δίκτυο ψηφιοποιήθηκε από τοπογραφικούς χάρτες (1:50.000) της Γ.Υ.Σ. και για την απόσταση από τους κλάδους ορίστηκαν ζώνες εκατέρωθεν των κοιτών (Σχήμα 1γ). Ο γεωλογικός χάρτης της υδρολογικής λεκάνης δημιουργήθηκε από τρία φύλλα γεωλογικών χαρτών του Ι.Γ.Μ.Ε (Φύλλο Κηφισιά, Φύλλο Κορωπί-Πλάκα, Φύλλο Ραφήνα). Οι γεωλογικοί σχηματισμοί της λεκάνης ταξινομήθηκαν σε τρείς κατηγορίες ανάλογα με την υδρο-λιθολογική τους συμπεριφορά (Σχήμα 1δ). Ασβεστόλιθοι, μάρμαρα, ψαμμίτες και αλλουβιακές αποθέσεις ανήκουν στην κατηγορία των διαπερατών σχηματισμών, μάργες και κροκαλοπαγή στους ημιπερατούς ενώ οι σχιστόλιθοι στους αδιαπέρατους. Για τον χάρτη χρήσεων γης αντλήθηκε πληροφορία από τα προγράμματα Corine CLC2000 και CLC 2012. Δημιουργήθηκαν 5 κατηγορίες περιοχών ανάλογα με τη χρήση τους: (1) πυκνά αστικοποιημένες, (2) αραιά αστικοποιημένες, (3) καλλιεργήσιμες εκτάσεις (4) αραιής βλάστησης και (5) δασικές εκτάσεις (Σχήμα 1ε).

Όλοι οι παράγοντες ταξινομήθηκαν με το εργαλείο Reclassify (Spatial Analysis Toolbox, GIS) σε πέντε βαθμούς ποσοτικοποίησης του κινδύνου από 0 έως 4 (0: χαμηλός βαθμός, 4: πολύ υψηλός βαθμός) (Πίνακας 1). Εφαρμόστηκε η μέθοδος AHP και για τον καθορισμό των τελικών βαρών των παραγόντων ακολουθήθηκε η προσέγγιση των Bathrellos *et al.* (2016) σε όμορη λεκάνη απορροής με χαρακτηριστικά παρόμοια με την υπό μελέτη λεκάνη. Για την επαλήθευση των αποτελεσμάτων, ο τελικός χάρτης επικινδυνότητας πλημμύρας, συγκρίθηκε με τον χάρτη χωρικής κατανομής των σοβαρών πλημμυρικών συμβάντων που έχουν κατά καιρούς σημειωθεί στη λεκάνη απορροής του Μ. Ρέματος. Η επαλήθευση έγινε με τον υπολογισμό της κατανομής συχνότητας των συμβάντων πλημμύρας για κάθε βαθμό ποσοτικοποίησης του βασικού χάρτη H_basic (Σχήμα 1στ).

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Αποτελέσματα - Συζήτηση

Σύμφωνα με το χάρτη H_basic (Σχήμα 1στ), ζώνες πολύ υψηλού και υψηλού πλημμυρικού κινδύνου εντοπίζονται κύρίως εκατέρωθεν των κοιτών των κλάδων μεγάλης τάξης, στα σημεία συμβολής τους με την κεντρική κοίτη, κατά μήκος της κεντρικής κοίτης του ποταμού και στην ευρύτερη περιοχή των εκβολών του. Στο μεγαλύτερο ποσοστό τους χαρακτηρίζονται από χαμηλό υψόμετρο, και μικρές μορφολογικές κλίσεις < 3^0.
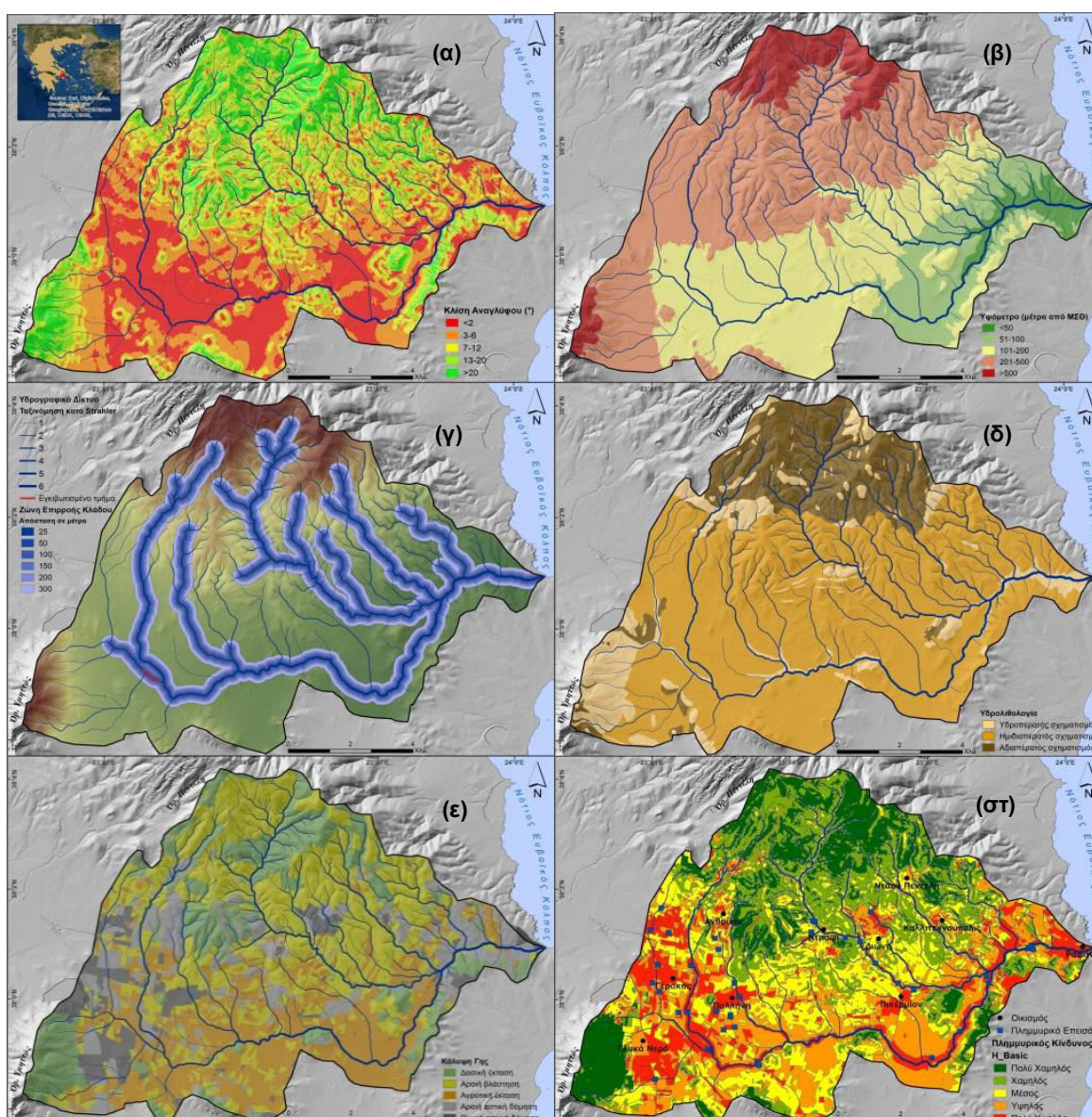
Σχήμα 1. Χάρτες (α) κλίσεων σε μοίρες, (β) αναγλύφου (υψόμετρα σε μ.), (γ) αποστάσης από τις κοίτες των κλάδων του υδρογραφικού δικτύου, (δ) υδρολιθολογίας των γεωλογικών σχηματισμών, (ε) χρήσεων γης, (στ) Πλημμυρικού Κινδύνου H_basic, της λεκάνης απορροής του Μ. Ρέματος Ραφήνας.

Στις παραπάνω ζώνες ανήκουν εκτεταμένες περιοχές του δυτικού και νότιου τμήματος της λεκάνης. Είναι φανερό ότι η αυξημένη τρωτότητα των συγκεκριμένων περιοχών σχετίζεται άμεσα

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με την έντονη αστικοποίηση και πληθυσμιακή αύξηση των οικισμών Παλλήνης, Γέρακα, Ανθούσας, Παιανίας και Σπάτων. Στο βόρειο τμήμα παρατηρούνται επίσης ζώνες υψηλού και πολύ υψηλού κινδύνου στους οικισμούς Διώνη, Καλλιτεχνιούπολης και Ντράφι. Τα ποσοστά των επιφανειών πολύ υψηλού και υψηλού κινδύνου στο σύνολο της έκτασης της λεκάνης ανέρχονται σε 22.89 % και 13.59 % αντίστοιχα (Πίνακας 2). Για την επαλήθευση της εγκυρότητας του παραγόμενου χάρτη χρησιμοποιήθηκε το πλημμυρικό ιστορικό της χρονικής περιόδου 1988-2019. Λαμβάνοντας υπόψη τη χωρική κατανομή των πλημμυρών διαπιστώθηκε ότι 44 από τα 53 συμβάντα βρίσκονται εντός των ζωνών πολύ υψηλού και υψηλού κινδύνου (Πίνακας 2, Σχήμα 1στ).

Πίνακας 2. Οι κλάσεις και οι συντελεστές βαρύτητας ανά παράμετρο.

Παράμετρος	Κλάση	Συντελεστής	Παράμετρος	Τάξη κλάδου	Κλάση	Συντελεστής
Κλίση σε μοίρες	<2	4	Απόσταση από τη φυσική κοίτη (σε μέτρα)	3ης τάξης	25 μέτρα	4
	3-6	3			50 μέτρα	3
	7-12	2			100 μέτρα	2
	13-20	1			150 μέτρα	1
	>20	0			>150 μέτρα	0
Υψόμετρο μέτρα από ΜΣΘ	<50	4		4ης τάξης	50 μέτρα	4
	51-100	3			100 μέτρα	3
	101-200	2			150 μέτρα	2
	201-500	1			200 μέτρα	1
	>500	0			>200 μέτρα	0
Υδρολιθολογία σχηματισμού	Αδιαπέρατος	3		5ης τάξης	50 μέτρα	4
	Ημιδιαπερατός	2			100 μέτρα	3
	Υδροπερατός	1			200 μέτρα	2
Κάλυψη γης	Πυκνή αστική	4			300 μέτρα	1
	Αραιή αστική	3			>300 μέτρα	0
	Καλλιέργειες	2		6ης τάξης	100 μέτρα	4
	Αραιή βλάστηση	1			150 μέτρα	3
	Δάσικη έκταση	0			200 μετρά	2
					300 μέτρα	1
					>350 μέτρα	0
			Απόσταση εγκιβωτισμένης κοίτης (σε μέτρα)	3ης τάξης	25 μέτρα	4
					50 μέτρα	3
					100 μέτρα	2
					200 μέτρα	1
					>200 μέτρα	0

Πίνακας 2. Συχνότητας πλημμυρικών συμβάντων ανά ζώνη πλημμυρικού κινδύνου του χάρτη H_basic.

Πλημμυρικός Κίνδυνος	Έκταση τ.χλμ	Έκταση %	Επεισόδια	Επεισόδια %	Συχνότητα
Πολύ Χαμηλός	18.58	16.01	0	0.00	0.00
Χαμηλός	25.10	21.62	0	0.00	0.00
Μέσος	30.06	25.90	9	16.98	0.66
Υψηλός	26.57	22.89	20	37.74	1.65
Πολύ Υψηλός	15.77	13.59	24	45.28	3.33
Σύνολο	116.08	100.00	53	100.00	1.00

Η συμφωνία μεταξύ της στατιστικής ανάλυσης της συχνότητας των συμβάντων και του τελικού χάρτη κινδύνου πλημμύρας είναι αξιοσημείωτη καθώς υπάρχει αναλογική σχέση συχνότητας - βαθμού κινδύνου (Πίνακας 2). Συγκρίνοντας τα αποτελέσματα με αυτά της οριοθέτησης πλημμυρικών ζωνών μετά την εφαρμογή υδραυλικής προσομοίωσης (HEC-RAS) (Andreou *et al.,* 2019) κατά μήκος των τελευτίων 4 χλμ. της εντικής κοίτης του ποταμού παρατηρείται ότι οι

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εκτάσεις που προέκυψαν από την προσομοίωση βρίσκονται εντός των περιοχών πολύ υψηλού και υψηλού κινδύνου του χάρτη H_basic. Τέλος, τα αποτελέσματα της παρούσας προσέγγισης συμφωνούν με τα αποτελέσματα της ποσοτικής γεωμορφολογικής ανάλυσης του υδρογραφικού δικτύου του Μ. Ρέματος (Karymbalis *et al.,* 2015). Η ανάλυση του δικτύου έδειξε ανωμαλίες στην διαδοχική κατά τάξη απορροή με συνέπεια την αυξημένη επικινδυνότητα συγκεκριμένων περιοχών στον πλημμυρικό κίνδυνο. Αφορά κυρίως κλάδους 4^{ης} τάξης που συμβάλλουν απευθείας στον κύριο κλάδο 6^{ης} τάξης όπως η εκφόρτιση του ρέματος του Ν. Βουτζά (4^{ης} τάξης) στην κεντρική κοίτη του κύριου κλάδο στην περιοχή της Ραφήνας. Αυτή η υπόθεση υποστηρίζεται πλήρως από το χάρτη κινδύνου πλημμύρας της παρούσας εργασίας στην οποία η περιοχή συμβολής αυτών των δύο κλάδων ανήκει σε ζώνη πολύ υψηλού κινδύνου.

Συμπεράσματα

Από το χάρτη εκτίμησης του πλημμυρικού κινδύνου φαίνεται πως οι ζώνες υψηλού και πολύ υψηλού πλημμυρικού κινδύνου εντοπίζονται κυρίως στο νότιο και δυτικό τμήμα της λεκάνης απορροής και καλύπτουν επιφάνεια περίπου 42 τ.χλμ. που αντιστοιχεί στο ~36% του συνολικού εμβαδού της υδρολογικής λεκάνης. Πρόκειται για περιοχές με έντονη κοινωνικο-οικονομική και οικιστική ανάπτυξη. Σύμφωνα με τα στοιχεία της ΕΛ.ΣΤΑΤ. από την απογραφή του 2011 ο πληθυσμός της περιοχής μελέτης ανέρχεται στους 88.908 ενώ ο ρυθμός αύξησης του πληθυσμού κατά τη διάρκεια της δεκαετίας 2001-2011 είναι 3240 κάτοικοι/έτος. Η προτεινόμενη μεθοδολογία είναι ιδιαίτερα χρήσιμη για τον σχεδιασμό των χρήσεων γης όσον αφορά την πρόβλεψη και πρόληψη του προ-καταστροφικού σταδίου σε αστικά αναπτυσσόμενες περιοχές. Η αυξημένη τρωτότητα της περιοχής στον κίνδυνο της πλημμύρας αποδίδεται κυρίως σε δύο σημαντικούς παράγοντες: (α) στις εκτεταμένες πυρκαγιές που έχουν πλήξει το βόρειο τμήμα της λεκάνης και δημιούργησαν τις προϋποθέσεις μετατροπής δασικών εκτάσεων σε αστικό ιστό, και (β) στην κατασκευή μεγάλων τεχνικών έργων (Αττική Οδός - Περιφερειακή Υμηττού) που αφενός μετέτρεψαν ένα ρέμα εφήμερης ροής σε συνεχούς ροής λόγω της αποστράγγισης των έργων και της εκτροπής του άνω ρου του Ποδονίφτη με τελικό αποδέκτη τον κύριο κλάδο του Μ. Ρέματος (απουσία έργων υποδομής) και αφετέρου συνέβαλαν στην αστική και πληθυσμιακή έξαρση μετατρέποντας καλλιεργήσιμες εκτάσεις σε αστικό ιστό χωρίς τον κατάλληλο σχεδιασμό.

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Τρωτότητα Μεσογειακών Πόλεων Έναντι Πλημμυρικών Φαινομένων και Ξηρασίας ως Συνέπειες της Κλιματικής Αλλαγής: Αθήνα, Θεσσαλονίκη, Νάπολη, Βαλένθια

Κ. Συνάνη [1]

(1) Χαροκόπειο Πανεπιστήμιο , Ελ. Βενιζέλου 70, Αθήνα, Ελλάδα, synanil@hua.gr

Εισαγωγή

Στην Ευρώπη, οι επιπτώσεις της κλιματικής αλλαγής (ΚΑ) πλήττουν την υγεία και την ευημερία των κοινωνιών και σχετίζονται κυρίως με ακραία καιρικά φαινόμενα, με αλλαγές στα περιβαλλοντικά συστήματα και τις κοινωνικές συνθήκες, στην ενεργειακή ζήτηση και τη χωρική κατανομή των οικονομικών δραστηριοτήτων, στην κατανομή των κλιματικά ευαίσθητων ασθενειών, καθώς και στα επίπεδα τρωτότητας των κοινωνικών ομάδων και περιοχών (ΕΕΑ, 2012; IPCC, 2013) Οι επιπτώσεις της παρατηρούμενης και προβλεπόμενης κλιματικής αλλαγής στα ανθρώπινα και φυσικά συστήματα στην Ευρώπη δεν κατανέμονται εξίσου (ΕΕΑ, 2013). Η εκτίμηση του επιπέδου επικινδυνότητας αποτελεί υπόβαθρο και προϋπόθεση για την άσκηση πολιτικών μετριασμού και προσαρμογής. Για τον λόγο αυτό έχουν οικοδομηθεί μεθοδολογίες εκτίμησης και χαρτογράφησης της τρωτότητας και κατ' επέκταση της επικινδυνότητας (ΕΕΑ, 2017). Με βάση τον παραπάνω προβληματισμό, η παρούσα εργασία φιλοδοξεί να αποτελέσει μία συγκριτική μελέτη εκτίμησης του αστικού κινδύνου καθώς και της τρωτότητας έναντι της κλιματικής αλλαγής, τεσσάρων μεγάλων μεσογειακών πόλεων, της Αθήνας, της Θεσσαλονίκης, της Νάπολης και της Βαλένθια. Στόχος της παρούσας εργασίας είναι η αποτύπωση και ανάλυση των επιπτώσεων της κλιματικής αλλαγής και των φυσικών φαινομένων στα οποία επιδρούν και τα καθιστούν μη ανεκτά, αιφνίδια και ακραία, αλλά και η διαβάθμιση και σύγκριση των τεσσάρων πόλεων ως προς τη συνολική τους τρωτότητα έναντι της κλιματικής αλλαγής με την αξιοποίηση και τη συνθετική θεώρηση και μελέτη του κινδύνου που απειλεί τα αστικά συγκροτήματα μελέτης.

Μελέτη των Φαινομένων

Με τον όρο επιπτώσεις της κλιματικής αλλαγής αναφερόμαστε στις παρατηρούμενες ή τις προβλεπόμενες μεταβολές στα φυσικά και ανθρώπινα συστήματα. Η πλειοψηφία των φυσικών επικινδυνοτήτων που οφείλονται στην κλιματική αλλαγή ανήκουν στην κατηγορία των μετεωρολογικών, υδρολογικών και κλιματικών. Η συχνότητα και η ένταση αυτών των επικινδυνοτήτων και των αντίστοιχων κινδύνων επηρεάζονται από το μέγεθος της αλλαγής. Για παράδειγμα, η εμφάνιση πλημμυρών αναμένεται να αυξηθεί ακόμα περισσότερο λόγω της αυξημένης συχνότητας εμφάνισης ακραίων καιρικών φαινομένων (Καρτάλης κ.ά., 2017). Η περιοχή της Μεσογείου έχει παρουσιάσει μεγάλες κλιματικές μεταβολές στο παρελθόν και έχει αναγνωριστεί ως ένα από τα σημαντικότερα "Hot Spots" στις μελλοντικές προβλέψεις για την αλλαγή του κλίματος (Giorgi, 2006). Οι πλημμύρες σε αστικές περιοχές προκαλούνται από έντονες και/ή παρατεταμένες βροχοπτώσεις που κατακλύζουν την ικανότητα του αποχετευτικού

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συστήματος και σε αντίθεση με άλλα είδη πλημμυρών, είναι άμεσες, γρήγορες και τοπικά εντοπισμένες. Συχνά συμβαίνουν χωρίς δυνατότητα έγκαιρης προειδοποίησης και σε περιοχές που δεν είναι προφανώς επιρρεπείς σε πλημμύρες, καθιστώντας δύσκολη την πρόβλεψη και τον χειρισμό την κρίσιμη ώρα και αποτελούν μία από τους κυριότερες επικινδυνότητες στις σύγχρονες πόλεις που συχνά οδηγούν σε σημαντικές οικονομικές απώλειες και καταστροφικές κοινωνικές και περιβαλλοντικές επιπτώσεις. Η πιθανότητα εμφάνισης αιφνίδιων πλημμυρών αυξάνεται στις αστικές περιοχές λόγω της μεγάλης αναλογίας των πλακόστρωτων/λείων επιφανειών, έναντι του εδάφους, που περιορίζουν τη διείσδυση νερού και αυξάνουν την ποσότητα και την ταχύτητα ροής του νερού και ασκούν μεγάλη πίεση στα υπάρχοντα συστήματα αποστράγγισης (Climate Adapt, 2017). Η ξηρασία μειώνει την υγρασία του εδάφους και επηρεάζει τα οικοσυστήματα, την ανάπτυξη των φυτών, τις ροές των ποταμών και τη γεωργία. Ο κίνδυνος ξήρανσης του εδάφους (δηλ. η μείωση της υγρασίας του εδάφους), αυξάνεται στα δυτικά της περιοχής της Μεσογείου και μειώνεται στην Κεντρική και Ανατολική Ευρώπη. Τα πρότυπα αλλαγής υποδηλώνουν τη συνέχιση των τάσεων ξήρανσης και διαβροχής που παρατηρούνται σε ολόκληρη την Ευρώπη τα τελευταία 50 χρόνια (Soria, 2018).

Η ποσοτική εκτίμηση των επιπτώσεων της αλλαγής του κλίματος είναι γενικά πολύπλοκη. Η αβεβαιότητα που συνδέεται με τις προβολές των αλλαγών στις παραμέτρους που σχετίζονται με το κλίμα, στις οποίες βασίζεται η ανάλυση των επιπτώσεων, αποτελεί σημαντικό περιορισμό, όπως και η δυσκολία στη διαμόρφωση της σχέσης μεταξύ πιθανών διακυμάνσεων των κλιματικών παραγόντων και των επιπτώσεων που προκύπτουν αλλά και η πολυπλοκότητα των επηρεαζόμενων συστημάτων και η ελλιπής κατανόηση των οικολογικών διεργασιών που ενεργοποιούνται με την κλιματική αλλαγή.

Μεθοδολογία

Στόχος της ποσοτικής μας μελέτης, είναι ο εντοπισμός της επικινδυνότητας έναντι των ακραίων καιρικών φαινόμενων που εμφανίζονται όλο και συχνότερα εξαιτίας της κλιματικής αλλαγής. Τα συστήματα που μας ενδιαφέρουν είναι το κοινωνικό σύνολο (κοινωνική τρωτότητα) και ο άνθρωπος (ατομική διακινδύνευση). Η Πολυκριτηριακή Ανάλυση (ΠΚΑ) είναι μια μεθοδολογία που αναπτύχθηκε για να χειριστεί την πολλαπλή διάσταση των φυσικών και κοινωνικοοικονομικών φαινομένων που χαρακτηρίζουν τα χωρικά και τα φυσικά συστήματα, που καλείται να συμβάλει στην εκτίμηση προβλημάτων και αναγκών, με σκοπό τη λήψη αποφάσεων και τη χάραξη πολιτικών. Ο κύριος σκοπός της πολυκριτηριακής ανάλυσης είναι η δημιουργία ενός εργαλείου «ποσοτικοποίησης» του προβλήματος ή του κινδύνου και της διαβάθμισης των αναγκών παρέμβασης.

Αρχικά γίνεται ο προσδιορισμός του γενικού προβλήματος, καθώς και των επιμέρους στόχων και η ανάλυση βασίζεται στην εξέταση κριτηρίων με μετρήσιμες περιγραφές που σχετίζονται με το γενικό πρόβλημα (Χαλκιάς, 2015). Για την κατασκευή των κριτηρίων πρέπει οι τιμές όλων των μεταβλητών που τα συνθέτουν να επαναταξινομηθούν. Η κατηγοριοποίηση πρέπει να ακολουθεί ενιαία κλίμακα για κάθε μεταβλητή, προκειμένου να είναι συγκρίσιμες μεταξύ τους και να αποδώσουν μια τιμή για κάθε κριτήριο. Συνεπώς, για κάθε μεταβλητή επιλέγεται η κατηγοριοποίησή της σε τακτική κλίμακα ταξινόμησης 4 κατηγοριών (όσες και οι προς μελέτη επιλεγμένες πόλεις) με βάση την ένταση του φαινομένου που αντιπροσωπεύει (χαμηλός κίνδυνος = 2, μεσαίος κίνδυνος = 3, μεγάλος κίνδυνος = 4, πολύ μεγάλος κίνδυνος = 5). Τα όρια

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των κατηγοριών για κάθε μεταβλητή καθορίζονται με την μέθοδο της Φυσικής Κατανομής (Natural Breaks) (Jenks, 1977), που χαρακτηρίζεται για τη δημιουργία διακριτών κατηγοριών οι οποίες εμφανίζουν εσωτερική συνοχή. Με βάση τα βήματα μιας ΠΚΑ ακολουθήθηκε η παρακάτω μεθοδολογία:

Βήμα 1ο: επιλέχθηκαν τα αστικά συγκροτήματα με κριτήριο να είναι μεσογειακές ευρωπαϊκές πόλεις, να είναι παράκτιες και να έχουν παρόμοιες σχετικά κοινωνικό-οικονομικές συνθήκες.

Βήμα 2ο: προσδιορίστηκαν τα προς μελέτη φαινόμενα, που προέκυψε από τη βιβλιογραφική ανασκόπηση ότι εντείνονται από την κλιματική αλλαγή: Οι αστικές ή και παράκτιες πλημμύρες και η ξηρασία - έλλειψη διαθεσιμότητας υδάτινων πόρων.

Βήμα 3ο: η παρούσα μελέτη αποσκοπεί στον προσδιορισμό, στο μέτρο του εφικτού, του κινδύνου και της ατομικής τρωτότητας μέσα σε ένα κοινωνικοοικονομικά μεταβαλλόμενο πλαίσιο, όπως αυτό διαμορφώνεται από την επίδραση των επιπτώσεων της κλιματικής αλλαγής. Έτσι καθορίστηκαν μεταβλητές που συνιστούν παράγοντες έκθεσης, επικινδυνότητας, τρωτότητας και ικανότητας αντιμετώπισης για το κάθε φαινόμενο μελέτης. Με γνώμονα τα παραπάνω, ακολουθεί ο Πίνακας 1 όπου αναγράφονται οι συνιστώσες μελέτης μας για κάθε φαινόμενο και για κάθε παράγοντα που συμμετέχει στον υπολογισμό του κινδύνου, και συνέβαλαν στον υπολογισμό του κινδύνου, σύμφωνα με την εξίσωση που ακολουθεί (βασισμένη στον Alexander (2002):

$$\frac{ΕΚΘΕΣΗ \; x \; ΤΡΩΤΟΤΗΤΑ \; x \; ΕΠΙΚΙΝΔΥΝΟΤΗΤΑ}{ΙΚΑΝΟΤΗΤΑ \; ΑΠΟΚΡΙΣΗΣ} = ΚΙΝΔΥΝΟΣ$$

Επειδή κάθε μία από αυτές τις παραμέτρους εξαρτάται από ποικιλία παραγόντων, επιλέχθηκαν δύο με τρεις πιο καθοριστικοί παράγοντες για κάθε μία από αυτές, που παρουσιάζονται συνοπτικά στους Πίνακες που ακολουθούν.

Πίνακας 1. Μεταβλητές μελέτης ανά φαινόμενο μελέτης και συνιστώσα κινδύνου.

Μελέτη κινδύνου	Επιλεγμένες μεταβλητές για τις αστικές & παράκτιες πλημμύρες	Επιλεγμένες μεταβλητές για την ξηρασία & έλλειψη διαθεσιμότητας υδάτινων πόρων
Επικινδυνότητα (Hazard)	Ετήσια βροχόπτωση	Μεταβολή βροχόπτωσης για τις περιόδους 1979-2005 και 2071-2100
	Ακραία τιμή βροχόπτωσης (% της ετήσιας)	Ετήσιος αριθμός ωρών ηλιοφάνειας
Έκθεση (Exposure)	% στεγανότητας εδάφους	Ποσότητα ηλιακής ακτινοβολίας
	% αστικού πρασίνου	Ετήσια κατά κεφαλήν κατανάλωση νερού
	% ιδιόκτητων κατοικιών ως προς το σύνολο της χώρας	% ευάλωτων πληθυσμιακών ομάδων (> 5 ετών & < 75 ετών)
Τρωτότητα (Vulnerability)	Ποσότητα άντλησης επιφανειακών υδάτων	Αναμενόμενη μεταβολή της θερμοκρασίας σε μελλοντική περίοδο
	% μονομελών νοικοκυριών	Άντληση υδάτων σε hm^3 & Δείκτης εκμετάλλευσης υδάτων
Ικανότητα απόκρισης (Coping Capacity)	% ατόμων που καλύπτεται από το σύμφωνο των δημάρχων για την καταπολέμηση της κλιματικής αλλαγής	
	% ενεργού πληθυσμού με τριτοβάθμια εκπαίδευση	
	Μέγεθος πληθυσμού	

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Βήμα 4ο: Χρησιμοποιώντας μια τακτική κλίμακα ταξινόμησης, γίνεται επαναταξινόμηση των μεταβλητών, προκειμένου να είναι συγκρίσιμες μεταξύ τους. Θεωρώντας ότι η επικινδυνότητα μειώνεται όταν αυξάνει η ικανότητα απόκρισης, η κλίμακα για τις μεταβλητές που τη συνιστούν αντιστρέφεται και 2 λαμβάνει η χώρα με τη μικρότερη ικανότητα απόκρισης.

Πίνακας 2. Ενδεικτικός πίνακας επαναταξινομημένου παράγοντα. (Πηγή δεδομένων: Climate - Adapt, 2019).

	Συνολική κατανάλωση νερού κατά κεφαλήν	
Πόλεις (έτος δεδομένων)	m³ ανά άτομο	Ενιαία τακτική κλίμακα ταξινόμησης
Αθήνα (2004)	57.35	4
Θεσσαλονίκη(2004)	59.22	5
Νάπολη(2008)	56.32	3
Βαλένθια(2011)	55.78	2

Βήμα 5ο: Η συλλογή των δεδομένων που συνιστούν τις μεταβλητές έγινε με γνώμονα το ότι βρέθηκαν διαθέσιμα αξιόπιστα δεδομένα (κυρίως από τη βάση δεδομένων του Climate Adapt και της Eurostat).

Η μέθοδος της φυσικής κατανομής που επιλέχθηκε για την κατηγοριοποίηση των τιμών των μεταβλητών, ανέδειξε τις διαφοροποιήσεις που εμφανίζουν οι χωρικές μονάδες μεταξύ τους σε κάθε μεταβλητή. Κατά τον υπολογισμό του κινδύνου και σύμφωνα με την εξίσωση που χρησιμοποιήθηκε το εύρος τιμών που μπορεί να λάβει ο δείκτης που προσπαθήσαμε να υπολογίσουμε είναι από 4 έως 62,5 και με βάση αυτές τις τιμές θα γίνει προσπάθεια κατάταξης των περιοχών μελέτης ως προς τον κίνδυνο.

Αποτελέσματα - Συμπεράσματα

Ακολουθώντας τα παραπάνω προκύπτει η ταξινόμηση του επίπεδου κινδύνου που αντιμετωπίζουν οι περιοχές μελέτης για κάθε μία από τις επικινδυνότητες που μελετήσαμε. Κατά αυτό τον τρόπο μπορούμε να προβούμε σε μία υποτυπώδη διαβάθμιση προκειμένου να έχουμε μία σχετική εικόνα για τις μελετώμενες περιοχές.

Από το παραπάνω γράφημα διαπιστώνουμε ότι η Αθήνα βρίσκεται σε μεγαλύτερο κίνδυνο, σε σχέση πάντα με τις 4 επιλεγμένες πόλεις μελέτης για τις επικινδυνότητες που μελετήθηκαν. Ο διαβαθμισμένος πίνακας αποτυπώνει τη συνολική κατάταξη του κινδύνου των τεσσάρων μελετώμενων πόλεων κι αφορά αποκλειστικά τη μεταξύ τους διαβάθμιση. Είναι προφανές ότι αυτό δεν τις καθιστά περισσότερο ή λιγότερο ασφαλείς, αλλά αποτελεί ίσως ένα επιπλέον μέσο που μπορεί να ληφθεί υπόψη κατά τον στρατηγικό σχεδιασμό των πόλεων προκειμένου να είναι σε θέση να επιτύχουν πιο στοχευμένες δράσεις προσαρμογής και να αυξήσουν την ικανότητα απόκρισης έναντι ορισμένων φαινομένων στο μέτρο πάντα του εφικτού.

Η αύξηση της θερμοκρασίας αναμένεται να οδηγήσει και σε δραματική αύξηση της κατανάλωσης ενέργειας, ενώ θα εντείνει την επίπτωση πλημμυρών και θα επιδεινώσει την ατμοσφαιρική ρύπανση. Παρόλα αυτά από μια σύντομη βιβλιογραφική ανασκόπηση - που προηγήθηκε - και συνεκτίμηση των χαρακτηριστικών κάθε μελετώμενης περιοχής διαπιστώθηκαν και ποιοτικές διαφοροποιήσεις μεταξύ των πόλεων, τις οποίες λάβαμε υπόψη μας στην τελική διαβάθμιση του κινδύνου. Συγκεκριμένα για την πόλη της Βαλένθια προκειμένου να την κατατάξουμε ως προς την επικινδυνότητα της πλημμύρας, λάβαμε υπόψη ότι είναι η μόνη πόλη που διαρρέεται από ποτάμι, επομένως ενέχει έναν επιπλέον

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βαθμό τρωτότητας σε σχέση με τη Θεσσαλονίκη για την οποία βρήκαμε δείκτη παραπλήσιο. Έτσι στην τελική μας διαβάθμιση η Θεσσαλονίκη είναι αυτή με τον μικρότερο κίνδυνο έναντι της πλημμύρας.
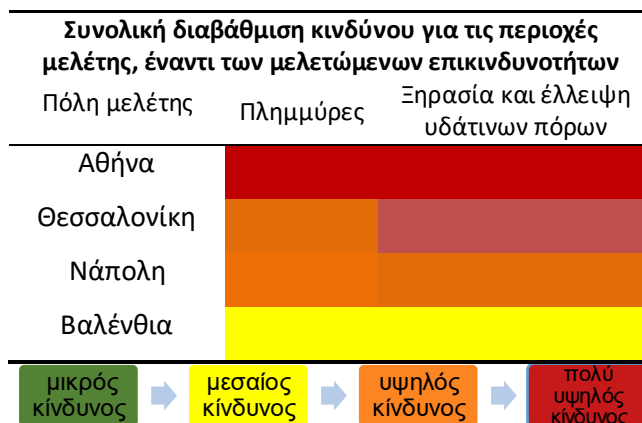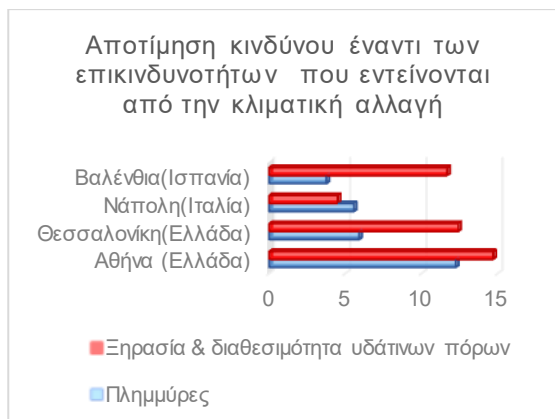
Σχήμα 1. Γράφημα απεικόνισης της διαβάθμισης του κινδύνου έναντι των επικινδυνοτήτων που προκύπτουν ως συνέπειες της κλιματικής αλλαγής.

Η Αθήνα είναι μια πόλη που πλήττεται από καύσωνες, τοπικές πλημμύρες και κακή ποιότητα του αέρα και αποτελεί μια πόλη που παραδοσιακά κατασπαταλάει, κακομεταχειρίζεται και κακοδιαχειρίζεται τους φυσικούς της πόρους. Είναι απαραίτητη η αλλαγή νοοτροπίας ώστε οι αρμόδιες αρχές που λαμβάνουν αποφάσεις για την διαχείριση να μπορέσουν να κατανοήσουν, να υποστηρίξουν και να προάγουν τις πράσινες, αλλά και τις γαλάζιες της υποδομές. Η πόλη πρέπει να διαχειριστεί καλύτερα τους υφιστάμενους χώρους πρασίνου αλλά και να δημιουργήσει νέους. Η στροφή προς τέτοιου είδους λύσεις θα υποστηρίξει και την κοινωνία και την οικονομία της πόλης.

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Ταξινόμηση των Μορφολογικών Χαρακτηριστικών του Αναγλύφου με τη Χρήση Τεχνικών ΣΓΠ: Η Περίπτωση της Βόρειας Εύβοιας, Ανατολική Στερεά Ελλάδα

__Κ. Βαλκάνου__ [1], Ε. Καρύμπαλης [1], Δ. Παπαναστασίου [2], Χ. Χαλκιάς [1], Κ. Γάκη-Παπαναστασίου [3]

(1) Τμήμα Γεωγραφίας, Χαροκόπειο Πανεπιστήμιο, Ελ. Βενιζέλου 70, 17671, Αθήνα, Ελλάδα, elnel@otenet.gr, karymbalis@hua.gr, xalkias@hua.gr

(2) Γεωδυναμικό Ινστιτούτο, Εθνικό Αστεροσκοπείο Αθηνών, Λόφος Νυμφών,11810, Θησείο, Αθήνα, Ελλάδα, d.papan@noa.gr

(3) Τομέας Γεωγραφίας - Κλιματολογίας, Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη, 15771, Ιλίσια, Αθήνα, Ελλάδα, gaki@geol.uoa.gr

Εισαγωγή

Η ταξινόμηση των μορφολογικών χαρακτηριστικών του αναγλύφου αποτελεί μια βασική επιστημονική προσέγγιση ιδιαίτερα χρήσιμη τόσο για την αναγνώριση, όσο και για τη χαρτογράφηση των γεωμορφών μιας περιοχής καθώς κατηγοριοποιεί το ανάγλυφο σε διακριτές κατηγορίες με διαφορετικά μορφολογικά χαρακτηριστικά (Strobl, 2008). Τα τελευταία χρόνια η αλματώδης εξέλιξη των Συστημάτων Γεωγραφικών Πληροφοριών (ΣΓΠ) επιτρέπει την κατηγοριοποίηση αυτή του αναγλύφου με την εφαρμογή ημι-αυτοματοποιημένων τεχνικών. Η αξιοποίηση των τεχνικών αυτών παρέχει πρόσθετες πληροφορίες σχετικά με την επιφανειακή απορροή, τις ιδιότητες των γεωλογικών σχηματισμών ή ακόμη και τις συνθήκες ευστάθειας μιας περιοχής (Burrough *et al.*, 2000).

Η γεωμορφομετρία, που περιλαμβάνει την ποσοτική μελέτη των γεωμορφών χρησιμοποιώντας τα μαθηματικά και την πληροφορική, αποτελεί ένα σημαντικό εργαλείο για την κατανόηση και τη μελέτη των διεργασιών που δρουν στην γήινη επιφάνεια και διαμορφώνουν το ανάγλυφο (Wilson and Bishop, 2013). Αν και συνήθως η σύνδεση των γεωμορφών με τις διεργασίες που τις σχημάτισαν είναι εύκολα αντιληπτή υπάρχουν περιπτώσεις που η πολυπλοκότητα της τοπογραφίας κάνει δύσκολη τη διερεύνηση της σχέσης αυτής. Η ανάλυση του αναγλύφου συνδέεται στενά με τη χωρική ανάλυση και αποτελεί βασικό γνωστικό αντικείμενο της επιστήμης των ΣΓΠ (Wilson and Deng, 2008). Τα αποτελέσματα της ανάλυσης της γήινης επιφάνειας και της μελέτης των γεωμορφών σε συνδυασμό με άλλα δεδομένα, όπως η γεωλογία, η βλάστηση κ.α., είναι ιδιαίτερα χρήσιμη για το σχεδιασμό του χώρου και τη χωροθέτηση χρήσεων γης. Τα τελευταία χρόνια, η ανάλυση αυτή γίνεται μέσω του υπολογισμού μορφομετρικών παραμέτρων και δεικτών, αξιοποιώντας λογισμικά και μοντέλα που διαχειρίζονται υψομετρικές κυρίως πληροφορίες (Pike *et al.*, 2009).

Στην παρούσα εργασία, επιχειρείται η ταξινόμηση των μορφολογικών χαρακτηριστικών του αναγλύφου του βόρειου τμήματος της νήσου Εύβοιας (ανατολική Στερεά Ελλάδα), χρησιμοποιώντας το Ψηφιακό Μοντέλο Εδάφους (ΨΜΕ) της περιοχής και αξιοποιώντας τις λειτουργίες των ΣΓΠ με την εφαρμογή κατάλληλων αλγόριθμων. Η ταξινόμηση της περιοχής ως προς τα μορφολογικά χαρακτηριστικά του αναγλύφου της υλοποιείται με την εκτίμηση του Τοπογραφικού δείκτη εντοπισμού (Topographic position index - Tpi) και των κριτηρίων που έχουν προταθεί από τον Weiss (2001).

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Μεθοδολογία

Για τους σκοπούς της εργασίας έγινε αρχικά η εξαγωγή/άντληση των τοπογραφικών χαρακτηριστικών του αναγλύφου και στη συνέχεια το ανάγλυφο διακρίθηκε σε χωρικές οντότητες (Wilson and Bishop, 2013) για να ακολουθήσει ο υπολογισμός των κύριων και δευτερευουσών τοπογραφικών παραμέτρων. Οι κύριες παράμετροι προέκυψαν απευθείας από τα υψομετρικά δεδομένα της περιοχής και περιλαμβάνουν τις μεταβλητές του υψόμετρου, της κλίσης και της καμπυλότητας. Οι δευτερεύουσες παράμετροι, που είναι ο τοπογραφικός δείκτης ύγρανσης, ο δείκτης ορμητικότητας ρέματος και ο τοπογραφικός δείκτης εντοπισμού, προέκυψαν από συνδυασμούς των κύριων παραμέτρων και αποτελούν δείκτες που περιγράφουν ή χαρακτηρίζουν τη χωρική μεταβλητότητα συγκεκριμένων διεργασιών που διαμόρφωσαν το ανάγλυφο της περιοχής (Moore *et al.*, 1991; Wilson and Deng, 2008).

Ο δείκτης Tpi προτάθηκε από τον Weiss (2001) και ισούται με τη διαφορά μεταξύ του υψομέτρου σε ένα κελί και του μέσου υψομέτρου μιας περιοχής που περιβάλλει το κελί αυτό (η περιοχή αυτή ορίζεται από τον εκάστοτε ερευνητή ανά περίπτωση) και έχει σημαντικό ρόλο στην ταξινόμηση του αναγλύφου. Οι θετικές τιμές του δείκτη δείχνουν πως το κελί έχει υψόμετρο μεγαλύτερο από τη γειτονική του ζώνη (συνεπώς αντιστοιχεί σε ράχη) ενώ οι αρνητικές τιμές δείχνουν πως το κελί βρίσκεται σε χαμηλότερο υψόμετρο (αντιστοιχεί σε κοιλάδα). Τιμές του δείκτη κοντά στο μηδέν (0) αντιστοιχούν είτε σε επίπεδες περιοχές (όταν η κλίση είναι κοντά στο μηδέν) είτε σε περιοχές με σταθερή κλίση (όταν η κλίση στο κελί είναι σημαντικά μεγαλύτερη από το μηδέν) (Ilia *et al.*, 2013). Ο εν λόγω δείκτης παρέχει έναν απλό τρόπο για την ταξινόμηση του αναγλύφου μιας περιοχής σε μορφολογικές τάξεις (Jenness *et al.*, 2013). Για τον υπολογισμό του Tpi χρησιμοποιήθηκε το ΨΜΕ με μέγεθος κελιού 20x20 μ και αξιοποιήθηκε το λογισμικό των Jenness *et al.* (2013). Μετά από πολλές επαναληπτικές προσπάθειες εύρεσης του πλέον κατάλληλου μεγέθους γειτονίας ορίστηκε κυκλική γειτονία με ακτίνα 50 μ και 150 μ.

Ο υπολογισμός του εν λόγω δείκτη (Tpi) σε διάφορες κλίμακες, σε συνδυασμό με την εκτίμηση της μορφολογικής κλίσης, καθιστά δυνατή την αναγνώριση και χαρτογράφηση γεωμορφών όπως ράχες, κοιλάδες με πλαγιές ήπιας μορφολογικής κλίσης και κοιλάδες που έχουν διαμορφωθεί από έντονη κατά βάθος διάβρωση (φαράγγια) (Jenness *et al.*, 2013). Η ταξινόμηση αυτή εξαρτάται από την κλίμακα υπολογισμού η οποία καθορίζεται από το μέγεθος του κελιού του ΨΜΕ και τη γειτονία και έχει εφαρμοστεί από αρκετούς ερευνητές, σε διάφορες κλίμακες (Tagil and Jenness, 2008; Ilia *et al.*, 2013; Skentos and Anagnostopoulou, 2017).

Το πρώτο στάδιο της ταξινόμησης συνίσταται στον καθορισμό της "θέσης στην κλιτύ". Για το σκοπό αυτό χρησιμοποιούνται οι τιμές του δείκτη Tpi και συνδυάζοντας δύο ιδιότητες: το πόσο ακραίες είναι οι τιμές του δείκτη και η κλίση σε κάθε κελί. Όπως είναι λογικό, υψηλές τιμές του δείκτη αναμένονται σε κορυφές και ράχες, χαμηλές τιμές αναμένονται στη μισγάγγεια των κοιλάδων (δηλαδή στις κοίτες) και τιμές κοντά στο μηδέν (0) αναμένονται σε επίπεδες επιφάνειες ή σε περιοχές μέσης κλίσης. Για τη διάκριση μεταξύ επίπεδων επιφανειών και περιοχών μέσης κλίσης χρησιμοποιείται η τιμή της κλίσης (Tagil and Jenness, 2008). Στις περισσότερες εφαρμογές χρησιμοποιείται η ταξινόμηση σε τέσσερις (4) κατηγορίες (κοιλάδα, επίπεδη επιφάνεια, μέση κλίση και κορυφή) ή σε έξι (6) κατηγορίες (κοιλάδα, χαμηλή κλίση, επίπεδη περιοχή, μέση κλίση, μεγάλη κλίση, ράχη). Επιπλέον καθορίζεται η τιμή για το κατώφλι τόσο του δείκτη Tpi (για την αναγνώριση κορυφών και κοιλάδων), όσο και της κλίσης (για τον καθορισμό μεταξύ επίπεδων περιοχών και

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περιοχών μέσης κλίσης) καθώς επίσης και ο τύπος γειτονίας και η ακτίνα, εάν έχει επιλεγεί κύκλος, ή αν έχει επιλεγεί διαφορετικό του κύκλου σχήμα οι διαστάσεις του σχήματος αυτού. Στην παρούσα εργασία χρησιμοποιήθηκε το κανονικοποιημένο υψόμετρο το οποίο ισούται με το λόγο της τιμής του δείκτη Τρι προς την τυπική απόκλιση της γειτονίας και οι μονάδες αντιστοιχούν σε "τυπική απόκλιση". Τιμή κανονικοποιημένου υψομέτρου ίση με τη μονάδα (1) σημαίνει πως το κελί αυτό είναι μια τυπική απόκλιση υψηλότερο από το μέσο υψόμετρο της γειτονίας του (Jenness *et al*., 2013). Να σημειωθεί πως ο τύπος γειτονίας που επιλέχτηκε στην παρούσα εφαρμογή είναι κύκλος με κέντρο το κελί και διάφορες ακτίνες. Με βάση όσα περιγράφηκαν παραπάνω, και εφόσον τα κατώφλια του δείκτη τοπογραφικής θέσης ακολουθούν τις μονάδες αυτού, τα τελευταία είναι ίσα με μείον μία (-1) τυπική απόκλιση και με συν μία (+1) τυπική απόκλιση το ελάχιστο και μέγιστο αντίστοιχα (δηλαδή ±SD), ενώ το κατώφλι της κλίσης είναι ίσο με δέκα (10) μοίρες για την ταξινόμηση σε τέσσερις (4) τάξεις ενώ για την ταξινόμηση σε έξι (6) τάξεις χρησιμοποιήθηκαν επιπλέον τα κατώφλια (-0,5) και (+0,5) τυπική απόκλιση.

Το τελικό στάδιο της ταξινόμησης αφορά στην κατηγοριοποίηση του ανάγλυφου ώστε να εντοπιστούν οι διαφορετικοί και περισσότερο σύνθετοι τύποι γεωμορφών. Χρησιμοποιήθηκαν δύο κάναβοι του τοπογραφικού δείκτη εντοπισμού (με ακτίνα γειτονίας 50 μ και 150 μ) και συνδυάστηκαν με την κλίση. Για την ταξινόμηση χρησιμοποιήθηκαν τα κριτήρια που έχουν προταθεί από τον Weiss (2001) και τα οποία φαίνονται αναλυτικά στον Πίνακα 1, ώστε να εντοπισθούν δέκα (10) κατηγορίες γεωμορφών.

Πίνακας 1. Ταξινόμηση γεωμορφών με βάση τις τιμές του δείκτη Τρι και της κλίσης για δύο διαφορετικά μεγέθη γειτονίας (πίνακας τροποποιημένος από Weiss (2001)).

	Κριτήρια για τιμές του δείκτη Τρι και για την κλίση	
	Μικρή ακτίνα γειτονίας\50μ	Μεγάλη ακτίνα γειτονίας\150μ
Φαράγγια, έντονη κατά βάθος διάβρωση κλάδων υδρογραφικού δικτύου	Τρi≤-1SD	Τρi≤-1SD
Κλιτύες μέσης κλίσης, μικρού βάθους κοιλάδες	Τρi≤-1SD	-1SD<Τρi<1SD
Ορεινή αποστράγγιση-πηγές νερού	Τρi≤-1SD	Τρi≥1SD
Κοιλάδες μορφής U	-1SD<Τρi<1SD	Τρi≤-1SD
Πεδιάδες	-1SD<Τρi<1SD	-1SD<Τρi<1SD και κλίση≤10°
Ανοιχτές κλιτύες	-1SD<Τρi<1SD	-1SD<Τρi<1SD και κλίση >10°
Πολύ υψηλές κλίσεις κλιτύων	-1SD<Τip<1SD	Τρi≥1SD
Τοπικές –μεμονωμένες ράχες, λόφοι σε κοιλάδες	Τρi≥1SD	Τρi≤-1SD
Ράχες ενδιάμεσης κλίσης, μικροί λόφοι σε πεδιάδες	Τρi≥1SD	-1SD<Τip<1SD
Κορυφές βουνών, ράχες	Τρi≥1SD	Τρi≥1SD

Αποτελέσματα - Συμπεράσματα

Ο τοπογραφικός δείκτης εντοπισμού για ακτίνες γειτονίας 50 μ και 150 μ, κυμαίνεται από (-3,34) έως 3,81 και από (-2,51) έως 4,02 αντίστοιχα, με τις χαμηλές τιμές να αντιστοιχούν μορφολογικά σε κοιλάδες και τις υψηλές θετικές τιμές του δείκτη να αντιστοιχούν σε κορυφές και ράχες.

Με βάση την ταξινόμηση σε τέσσερις (4) τάξεις με ακτίνα γειτονίας 50 μ, το 7,2% της περιοχής μελέτης ταξινομείται ως κοιλάδες, το 29,7% ως περιοχές ήπιας μορφολογικής κλίσης, το 56,1% ως περιοχές απότομης κλίσης και το 7,0% ταξινομείται ως ράχες. Συνεπώς η μισή σχεδόν έκταση του βόρειου τμήματος της Εύβοιας χαρακτηρίζεται από απότομες μορφολογικές κλίσεις. Η αντίστοιχη

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ταξινόμηση σε έξι (6) τάξεις χωρίζει την περιοχή ως εξής: 7,2% κοιλάδες, 18,8% πολύ χαμηλές μορφολογικές κλίσεις, 17,2% ήπιες κλίσεις, 36,2% απότομες κλίσεις, 13,6% πολύ μεγάλες κλίσεις και 7,0% ράχες.

Στην επόμενη φάση έγινε η τελική ταξινόμηση των μορφολογικών χαρακτηριστικών του αναγλύφου. Στην περιοχή μελέτης απαντώνται οκτώ (8) από τις δέκα (10) τάξεις που περιλαμβάνει η μέθοδος. Η χωρική κατανομή των μορφολογικών αυτών χαρακτηριστικών φαίνεται στο Σχήμα 1. Αναφορικά με το ποσοστό της έκτασης, που καταλαμβάνει κάθε τάξη υπολογίστηκε πως το μεγαλύτερο τμήμα της περιοχής μελέτης (49.6%) χαρακτηρίζεται ως ανοικτές κλιτύες ενώ το 25.6% της περιοχής καταλαμβάνεται από πεδινές εκτάσεις. Όλη η υπόλοιπη περιοχή μελέτης μοιράζεται με μικρά ποσοστά από 2.9% έως 5.6% στις υπόλοιπες κατηγορίες του Πίνακα 1, εκτός των κατηγοριών ορεινή αποστράγγιση και τοπικές ράχες που δεν εντοπίστηκαν στην περιοχή μελέτης κατά την εν λόγω ταξινόμηση.

Ακολούθως εντοπίστηκαν οι σχέσεις μεταξύ των ταξινομημένων μορφολογικών χαρακτηριστικών του αναγλύφου και των παραμέτρων επιφανείας, δηλαδή των ψηφιδωτών αρχείων κλίσης, δείκτη ύγρανσης, ορμητικότητας ρεμάτων, καμπυλότητας και υψομέτρου, μέσω στατιστικής ανάλυσης ανά ζώνες. Όπως ήταν αναμενόμενο οι μικρότερες κλίσεις εντοπίζονται στις πεδιάδες ενώ οι μεγαλύτερες τιμές τόσο του τοπογραφικού δείκτη ύγρανσης, όσο και του δείκτη ορμητικότητας ρεμάτων, παρατηρούνται στα φαράγγια και στις κοιλάδες. Τέλος σε ότι αφορά την καμπυλότητα κάθετα στη διεύθυνση της μέγιστης κλίσης, οι μικρότερες αρνητικές της τιμές εντοπίζονται στα φαράγγια και τις κοιλάδες, ενώ η μεγαλύτερη τιμή παρατηρείται στις κορυφές των ορέων. Συνεπώς, οι μικρές τιμές καμπυλότητας αντιστοιχούν σε μικρές τιμές τοπογραφικού δείκτη εντοπισμού για μικρή ακτίνας γειτονίας, ενώ οι μεγάλες τιμές αντιστοιχούν σε μεγάλες τιμές του δείκτη Τρι τόσο μικρής, όσο και μεγάλης ακτίνας γειτονίας.

Τέλος διερευνήθηκαν οι σχέσεις μεταξύ των ταξινομημένων μορφολογικών χαρακτηριστικών του αναγλύφου και των γεωλογικών σχηματισμών. Τα αποτελέσματα έδειξαν πως στην κατηγορία κοιλάδες επικρατούν οι αλλουβιακές προσχώσεις και οι ευδιάβρωτοι γεωλογικοί σχηματισμοί, στην κατηγορία κλιτύες μέσης κλίσης επικρατούν οι ανθεκτικοί αλλά απαντώνται και ευδιάβρωτοι σχηματισμοί, στις κοιλάδες μορφής U αντιστοιχεί η μεγαλύτερη ποικιλία γεωλογικών σχηματισμών και οι πεδιάδες καταλαμβάνονται κυρίως από ευδιάβρωτους σχηματισμούς αλλά και από αλλουβιακές αποθέσεις και ανθεκτικούς σχηματισμούς. Όσον αφορά τις κλιτύες, το 50% των ανοιχτών κλιτύων αναπτύσσεται σε ανθεκτικά πετρώματα ενώ οι υπόλοιπες τόσο σε ευδιάβρωτα, όσο και σε μέτριας ανθεκτικότητας πετρώματα. Οι πολύ υψηλές κλίσεις κλιτύων έχουν αναπτυχθεί σε ανθεκτικούς σχηματισμούς και τέλος οι ράχες ενδιάμεσης κλίσης και οι ράχες απαντώνται τόσο σε ευδιάβρωτους, όσο και σε μεγάλης ανθεκτικότητας σχηματισμούς. Το 69% των περιοχών που καταλαμβάνονται από φυλλίτες και σχιστόλιθους μορφολογικά χαρακτηρίζονται από ανοικτές κλιτύες ενώ μόνο το 10% αυτών χαρακτηρίζεται από πεδιάδες. Οι πεδινές εκτάσεις εντοπίστηκαν κυρίως σε περιοχές που καταλαμβάνονται από ευδιάβρωτους σχηματισμούς. Από τα παραπάνω γίνεται φανερή η επίδραση που έχει η λιθολογία στη διαμόρφωση των χαρακτηριστικών του αναγλύφου.

Η εφαρμογή των τεχνικών που περιγράφηκαν οδήγησαν στον εντοπισμό, με ημι-αυτοματοποιημένο τρόπο, συγκεκριμένων μορφολογικών χαρακτηριστικών του αναγλύφου. Είναι προφανές ότι η μεθοδολογία αυτή αποτελεί ένα αρχικό στάδιο για τη γεωμορφολογική χαρτογράφηση της περιοχής.

Η ερμηνεία της γεωγραφικής κατανομής των γεωμορφολογικών χαρακτηριστικών στην περιοχή σε συνδυασμό με την εργασία πεδίου μπορεί να οδηγήσει σε σημαντικά συμπεράσματα για τις διεργασίες διαμόρφωσης του ανάγλυφου και τον εντοπισμό περιοχών που κυριαρχεί η επίδραση της πρόσφατης τεκτονικής δραστηριότητας.
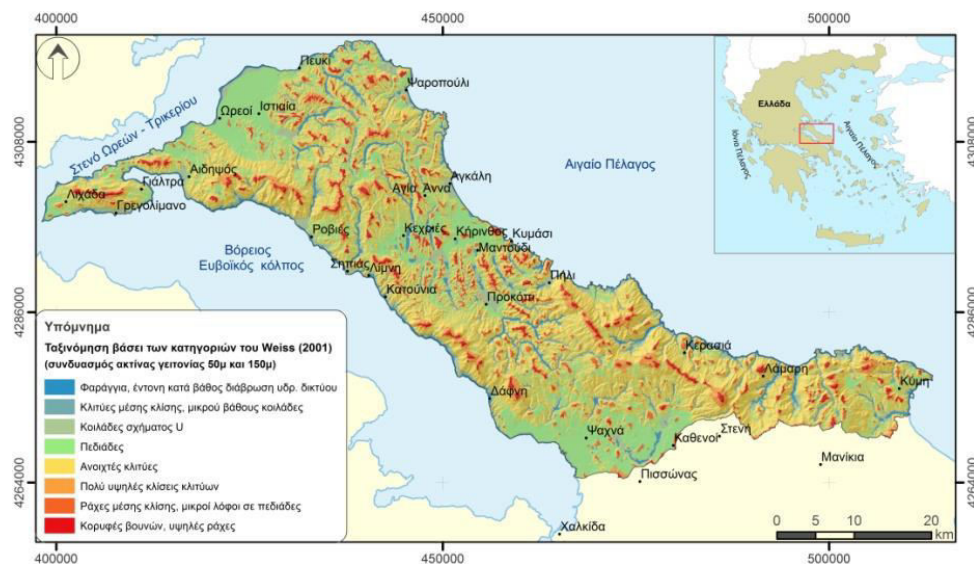
Σχήμα 1. Ταξινόμηση των μορφολογικών χαρακτηριστικών του αναγλύφου της βόρειας Εύβοιας με βάση τις κατηγορίες που έχουν προταθεί από τον Weiss (2001) και με εφαρμογή ακτίνας γειτονίας 50 μ και 150 μ.

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Εφαρμογή Ημι-αυτοματοποιημένης Μεθόδου για την Αναγνώριση και Χαρτογράφηση των Ποτάμιων Αναβαθμίδων στη Βόρεια Εύβοια (Ανατολική Στερεά Ελλάδα)

Κ. Βαλκάνου [1]*, Ε. Καρύμπαλης* [1]*, Δ. Παπαναστασίου* [2]*, Χ. Χαλκιάς* [1]*, Κ. Γάκη-Παπαναστασίου* [3]

(1) Τμήμα Γεωγραφίας, Χαροκόπειο Πανεπιστήμιο, Ελ. Βενιζέλου 70, 17671, Αθήνα, Ελλάδα, elnel@otenet.gr, karymbalis@hua.gr, xalkias@hua.gr

(2) Γεωδυναμικό Ινστιτούτο, Εθνικό Αστεροσκοπείο Αθηνών, Λόφος Νυμφών,11810, Θησείο, Αθήνα, Ελλάδα, d.papan@noa.gr

(3) Τομέας Γεωγραφίας - Κλιματολογίας, Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη, 15771, Ιλίσια, Αθήνα, Ελλάδα, gaki@geol.uoa.gr

Εισαγωγή

Οι ποτάμιες αναβαθμίδες, αλλουβιακές ή πετρώδεις, αποτελούν σημαντικές γεωμορφές, που αναπτύσσονται κατά μήκος των κοιτών των υδρογραφικών δικτύων, και παρέχουν σημαντικές πληροφορίες για τις γεωμορφολογικές, τεκτονικές και υδρολογικές διεργασίες εντός των λεκανών απορροής (Bull, 2007). Ο σχηματισμός τους είναι η απόκριση του ποταμού τόσο σε μεταβολές του βασικού επιπέδου που οφείλονται σε αλλαγές των κλιματολογικών συνθηκών ή/και στον τεκτονισμό, όσο και σε μεταβολές της ποτάμιας παροχής και στερεοπαροχής εξαιτίας κλιματικών αλλαγών.

Μορφολογικά αποτελούνται από μια επίπεδη επιφάνεια οριοθετημένη από τα "τοιχώματα" - τις κλιτύες - της κοιλάδας και από ένα απότομης κλίσης μέτωπο προς την πλευρά της κοίτης του ποταμού. Οι αλλουβιακές αναβαθμίδες αντιστοιχούν σε κύκλους ποτάμιας απόθεσης και διάβρωσης. Η εγκαταλειμμένη αρχική πεδιάδα μένει σαν ένας επίπεδος πάγκος - αναβαθμίδα - και διακρίνεται από την νέα (κατώτερη αναβαθμίδα) με ένα απόκρημνο μέτωπο (Summerfield, 1991). Οι διαστάσεις, η γεωμετρία και ο αριθμός των αναβαθμίδων κατά μήκος ενός ποταμού ποικίλει σημαντικά. Μπορούν να είναι μεμονωμένες ή ανά ζεύγη, εκατέρωθεν της κοίτης, ή να είναι πολλές και σε διαφορετικά ύψη από τον πυθμένα της κοίτης.

Τα τελευταία χρόνια, είναι ευρέως διαθέσιμα υψηλής ανάλυσης Ψηφιακά Μοντέλα Εδάφους (ΨΜΕ) τα οποία δίνουν την ευκαιρία άντλησης πληροφοριών που χρησιμεύουν στην οπτικοποίηση και στην ανάλυση των γεωμορφολογικών χαρακτηριστικών του αναγλύφου. Η επεξεργασία αυτών των ΨΜΕ οδήγησε στην ανάπτυξη διαφόρων μεθόδων αναγνώρισης και χαρτογράφησης των αναβαθμίδων. Οι μέθοδοι αυτές είναι αρκετά οικονομικές και γρήγορες και μπορούν να αποτελέσουν το αρχικό στάδιο μιας "προκαταρκτικής" χαρτογράφησης των ποτάμιων αναβαθμίδων πριν την λεπτομερή επιτόπια έρευνα που πάντα θεωρείται απαραίτητη.

Για τον αρχικό εντοπισμό των ποτάμιων αναβαθμίδων έχουν χρησιμοποιηθεί γεωμετρικές προσεγγίσεις όπως για παράδειγμα αυτή των Demoulin *et al*. (2007), οι οποίοι συνδύασαν την τοπική κλίση και το υψόμετρο κάθε κελιού σε σχέση με το υψόμετρο της κοίτης. Η ανάγκη όμως χαρτογράφησης των αναβαθμίδων σε ευρύτερη κλίμακα οδήγησε στην περαιτέρω ανάπτυξη σχετικών μεθοδολογιών. Μεταξύ άλλων (πχ. Finnegan and Balco, 2013; Clubb *et al*., 2017), οι

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Stout and Belmon (2014) ανέπτυξαν μια ημι-αυτοματοποιημένη μέθοδο χαρτογράφησης αναβαθμίδων και προσχωσιγενών πεδιάδων, που λειτουργεί μέσω ενός κώδικα python ή μέσω μιας εργαλειοθήκης (TerEx) στα πλαίσια των λειτουργιών του λογισμικού ArcGIS, με στόχο τον εντοπισμό επίπεδων επιφανειών που ενδέχεται να αντιστοιχούν σε επιφάνειες ποτάμιων αναβαθμίδων. Η μέθοδος βασίζεται σε ένα λεπτομερές ΨΜΕ, στο ψηφιοποιημένο υδρογραφικό δίκτυο και σε διάφορες παραμέτρους όπως το μέγεθος του εστιακού παραθύρου, το τοπικό ανάγλυφο, η ελάχιστη έκταση και η μέγιστη απόσταση από την κοίτη. Το εργαλείο αυτό, μετά την "χειροκίνητη" διόρθωση των επιφανειών, που βελτιώνει την ακρίβεια των αποτελεσμάτων, υπολογίζει την έκταση της επιφάνειας των αναβαθμίδων και το ύψος τους πάνω από την ποτάμια κοίτη.

Στην παρούσα εργασία επιχειρείται η εφαρμογή της ημι-αυτοματοποιημένης μεθόδου των Stout and Belmon (2014), αξιοποιώντας την τεχνολογία των Συστημάτων Γεωγραφικών Πληροφοριών (ΣΓΠ), για τη χαρτογράφηση ποτάμιων αναβαθμίδων που έχουν αναπτυχθεί κατά μήκος κεντρικών κοιτών υδρογραφικών δικτύων του βόρειου τμήματος της νήσου Εύβοιας στην ανατολική Στερεά Ελλάδα.

Μεθοδολογία

Για την εφαρμογή της μεθόδου χρησιμοποιήθηκε το λεπτομερές ΨΜΕ με μέγεθος κελιού 5x5 μ (Ε.Κ.ΧΑ. Α.Ε., Copyright ©2012, National Cadastre and Mapping agency S.A.), το υδρογραφικό δίκτυο της περιοχής ενώ ήταν αναγκαία η ρύθμιση κρίσιμων τιμών/κατώφλια ορισμένων απλών παραμέτρων που σχετίζονται με το παραγόμενο αποτέλεσμα.

Στο πρώτο στάδιο χρησιμοποιήθηκε η εργαλειοθήκη TerEx για να προκύψει ένας αρχικός χάρτης με τις θέσεις εμφάνισης επίπεδων τοπογραφικά εκτάσεων πλησίον των ποτάμιων κοιτών. Στο στάδιο αυτό έγιναν περισσότερες από 20 δοκιμές διαφορετικών τιμών των παραμέτρων με σκοπό τόσο τον επαναπροσδιορισμό των θέσεων με μεγαλύτερη ακρίβεια, όσο και τον καθορισμό των βέλτιστων τιμών των παραμέτρων για το καλύτερο δυνατό χαρτογραφικό αποτέλεσμα. Οι παράμετροι αυτές σχετίζονται με το μέγεθος του εστιακού παραθύρου, την ελάχιστη έκταση της επιφάνειας, την απόσταση από την κοίτη, το τοπικό ανάγλυφο καθώς και με μεταβλητές που αφορούν την εξομάλυνση. Τελικά από το συνδυασμό του ΨΜΕ με το "κινητό εστιακό παράθυρο" εμβαδού ίσου με 64 μ^2 εντοπίστηκαν οι επίπεδες επιφάνειες με έκταση μεγαλύτερη από 5.000 μ^2, σε απόσταση έως 1.500 μ από την κοίτη και με τοπικό ανάγλυφο μικρότερο από 0,75 μ.

Ακολούθως οι επιφάνειες που προέκυψαν με τον παραπάνω τρόπο τροποποιήθηκαν χειροκίνητα. Αφαιρέθηκαν τα πολύγωνα που αντιστοιχούν σε δρόμους, αλλουβιακά ριπίδια, λίμνες και επιφάνειες απόθεσης ενώ τα εναπομείναντα πολύγωνα επανασχεδιάστηκαν με τη χρήση του σκιασμένου αναγλύφου, του χάρτη αναγλύφου, αεροφωτογραφιών, του χάρτη υποβάθρου του Arcmap, εικόνων Google Earth Pro, εργασίας πεδίου και με τη μελέτη των τοπογραφικών τομών που σχεδιάστηκαν εγκάρσια στις κεντρικές κοίτες των δικτύων. Με τη χρήση του δεύτερου βήματος του εργαλείου TerEx, από τις "επεξεργασμένες" θέσεις εμφάνισης των αναβαθμίδων προέκυψε ο τελικός χάρτης που περιλαμβάνει επιπλέον πληροφορίες χρήσιμες για περαιτέρω μελέτη, όπως το ύψος στο οποίο αναπτύσσονται πάνω από τον πυθμένα της κοίτης καθώς και η έκταση της επιφάνειάς τους.

Τα αποτελέσματα της παραπάνω μεθοδολογίας και κυρίως η χωρική κατανομή των αναβαθμίδων

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και το ύψος αυτών πάνω από την κοίτη, συγκρίθηκαν με αποτελέσματα παρόμοιων μελετών που έχουν δημοσιευθεί για την περιοχή μελέτης ενώ επιπλέον επαληθεύτηκαν με εργασία πεδίου σε επιλεγμένες περιοχές ιδιαίτερου ενδιαφέροντος.

Αποτελέσματα - Συμπεράσματα

Από τη χρήση της εργαλειοθήκης TerEx, προέκυψε ένας χάρτης τοπικού αναγλύφου, τα τμηματοποιημένα υδρογραφικά δίκτυα στα οποία εντοπίστηκαν αναβαθμίδες και ένας χάρτης με τα πολύγωνα που πληρούν τα κριτήρια που ορίσθηκαν και που αντιστοιχούν σε πιθανές ποτάμιες αναβαθμίδες και/ή σε προσχωσιγενείς πεδιάδες. Κατά το πρώτο στάδιο της ανάλυσης εντοπίστηκαν εννέα (9) υδρογραφικά δίκτυα που χαρακτηρίζονται από την ύπαρξη σχετικά εκτεταμένων επίπεδων επιφανειών εκατέρωθεν των κεντρικών τους κοιτών. Μετά τον επαναπροσδιορισμό και τη διόρθωση των πολυγώνων που ενδέχεται να αντιστοιχούν σε ποτάμιες αναβαθμίδες βάσει της προαναφερθείσας μεθοδολογίας προέκυψε ο τελικός χάρτης του Σχήματος 1. Στον χάρτη αυτό φαίνεται πως η κύρια εμφάνιση ποτάμιων αναβαθμίδων περιορίζεται στα δίκτυα του Ξηροπόταμου (Ιστιαία), του Νηλέα (Κεχριές), του Μεσσάπιου (Ψαχνά), του Κηρέα (Προκόπι) και ενός Ανώνυμου ρέματος (ανατολικά της περιοχής Πευκί). Επιπλέον αυτών, εντοπίστηκαν κάποιες μεμονωμένες εμφανίσεις πιθανών αναβαθμίδων σε σχετικά μεγαλύτερα υψόμετρα.
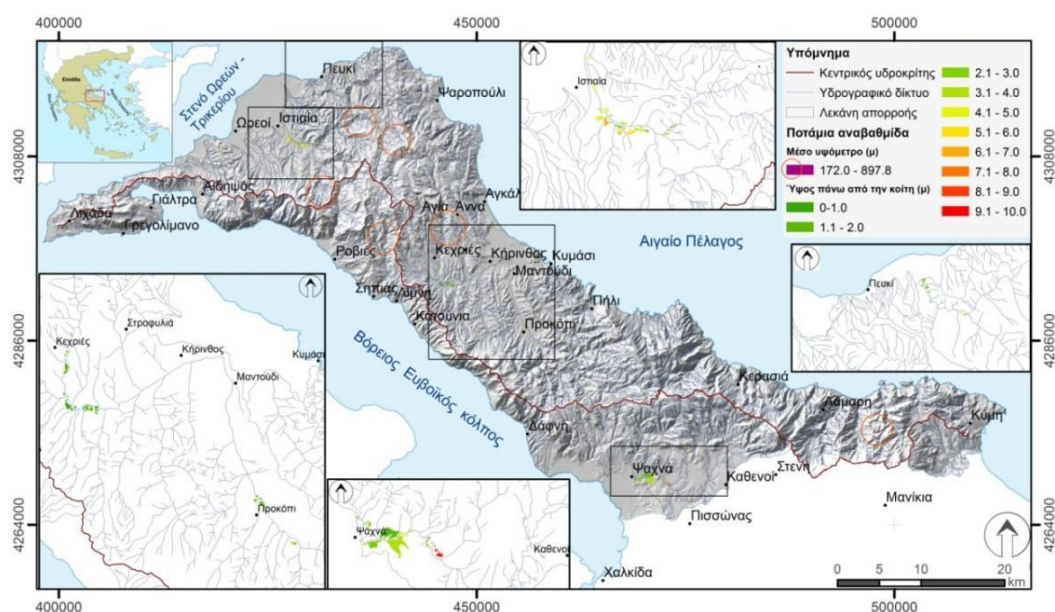
Σχήμα 1. Ποτάμιες αναβαθμίδες που εντοπίστηκαν στην περιοχή μελέτης με την εφαρμογή της ημι-αυτοματοποιημένης μεθόδου.
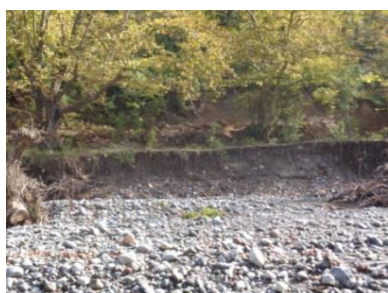
Αναλυτικά, η έκταση των επιφανειών των αναβαθμίδων κυμαίνεται από 5.127 έως 72.882 μ² στον Ξηροπόταμο, από 7.376 έως 83.349 μ² στον ποταμό Νηλέα, από 5.476 έως 481.057 μ² στον ποταμό Μεσσάπιο, από 5.928 έως 34.191 μ² στον ποταμό Κηρέα και από 5.712 έως 26.703 μ² στο Ανώνυμο ρέμα. Τα ύψη τους πάνω από το επίπεδο της κοίτης κυμαίνονται από 1,2 έως 6,9 μ στον ποταμό Ξηροπόταμο, από 1 έως 2,5 μ στον ποταμό Νηλέα, από 1,3 έως 9,4 μ στον ποταμό Μεσσάπιο, από 1,6 έως 4,9 μ στον ποταμό Κηρέα και από 1,5 έως 3,5 μ στο Ανώνυμο ρέμα. Αναφορικά με τα απόλυτα υψόμετρα των αναβαθμίδων, αυτά κυμαίνονται από 31,8 έως 96,3 μ

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στον Ξηροπόταμο, από 49 έως 94,4 μ στον ποταμό Νηλέα, από 17,4 έως 49,2 μ στον ποταμό Μεσσάπιο, από 47,4 έως 68,6 μ στον ποταμό Κηρέα και από 17,5 έως 55,7 μ στο Ανώνυμο ρέμα. Η πιο εκτεταμένη αναβαθμίδα εντοπίζεται πλησίον των εκβολών του Μεσσάπιου όπου παρατηρούνται και οι χαμηλότερες υψομετρικά αναβαθμίδες ενώ τα χαμηλότερα ύψη αναβαθμίδων απαντώνται στο Νηλέα. Οι αναβαθμίδες που εμφανίζονται μεμονωμένες, κυρίως στο υδρογραφικό δίκτυο του Μεσσάπιου, εντοπίζονται εντός της ζώνης μαιανδρισμού φανερώνοντας αργή κατά βάθος διάβρωση και πλευρική μετανάστευση της κοίτης. Εκτός από τις αναβαθμίδες που εντοπίστηκαν σε μεγάλα υψόμετρα, οι υπόλοιπες ταξινομήθηκαν σε δέκα (10) κατηγορίες με βάση το ύψος τους πάνω από την κοίτη.

Μεμονωμένες αναβαθμίδες σε μεγάλα υψόμετρα και σε μεγάλα ύψη από την κοίτη εντοπίζονται δυτικά της Κύμης σε υψόμετρα περίπου 897 μ και 864 μ και θα μπορούσαν να συσχετιστούν με πειρατεία δικτύου. Ομοίως και ΝΑ και Ν της Ιστιαίας σε υψόμετρα 222 μ, 479 μ και 367 μ, 363 μ αντίστοιχα, καθώς και ΒΑ των Ροβιών σε υψόμετρο 309 μ. Με την τεκτονική δραστηριότητα στην περιοχή και με φαινόμενα πειρατείας θα μπορούσε επίσης να συνδέεται η παρουσία αναβαθμίδων σε υψόμετρα 215 μ και 172 μ μεταξύ των περιοχών Αγ. Άννα και Κεχριές. Προκειμένου να επιβεβαιωθεί η συσχέτιση των αναβαθμίδων αυτών με φαινόμενα πειρατείας απαιτείται περαιτέρω διερεύνηση, ερευνητική προσέγγιση μεγαλύτερης κλίμακας καθώς και εργασία πεδίου.

Τα αποτελέσματα της εφαρμογής της ημι-αυτοματοποιημένης μεθόδου γενικά συμφωνούν με τη χαρτογράφηση των αναβαθμίδων της Εύβοιας από τον Genre (1999). Πρέπει να σημειωθεί ότι η κλίμακα προσέγγισης είναι διαφορετική αυτής του Genre συνεπώς η επαλήθευσης αφορά κυρίως τις κεντρικές κοίτες των δικτύων που αναγνωρίστηκαν αναβαθμίδες και όχι συγκεκριμένα χαρακτηριστικά των εμφανίσεων όπως έκταση και υψόμετρο. Επιπλέον για ορισμένα ποτάμια έγινε χαρτογράφηση με εργασία πεδίου από την οποία επιβεβαιώθηκαν οι θέσεις και τα υψόμετρα των χαρτογραφημένων με την ημι-αυτοματοποιημένη μέθοδο επιφανειών (Σχήμα 2). Σε συγκεκριμένες θέσεις των κεντρικών κοιτών άλλων υδρογραφικών δικτύων όπως του Ξηροπόταμου και του Νηλέα, έγιναν λεπτομερείς εγκάρσιες προς την κοίτη τοπογραφικές τομές, οι οποίες παρουσιάζονται στο Σχήμα 3. Στις τομές αυτές παρατηρούνται αναβαθμίδες τόσο ανά ζεύγη, όσο και μεμονωμένες. Για τα συγκεκριμένα ποτάμια, έχει αναφερθεί από τους Λεοντάρη και Γκουρνέλλο, (1991) η ύπαρξη τριών τουλάχιστον αναβαθμίδων σε ύψη μεταξύ 1,5 και 7μ.

Παρά την προσπάθεια επαλήθευσης των αποτελεσμάτων της μεθοδολογίας που ακολουθήθηκε, θα πρέπει να αναφερθεί πως απαιτείται λεπτομερής αποτύπωση στο πεδίο όλων των αναβαθμίδων που εντοπίστηκαν. Επιπλέον η χρονολόγηση των αναβαθμίδων αυτών σε συνδυασμό με ιζηματολογικές παρατηρήσεις του υλικού τους θα επέτρεπε την αναπαράσταση του προφίλ των ποταμών σε παλαιότερες εποχές ενώ θα έδινε πολύτιμες πληροφορίες για τους κύκλους πρόσχωσης-διάβρωσης, για την τεκτονική δραστηριότητα στην περιοχή και για την απόκριση των ποταμών στις μεταβολές των κλιματικών συνθηκών.
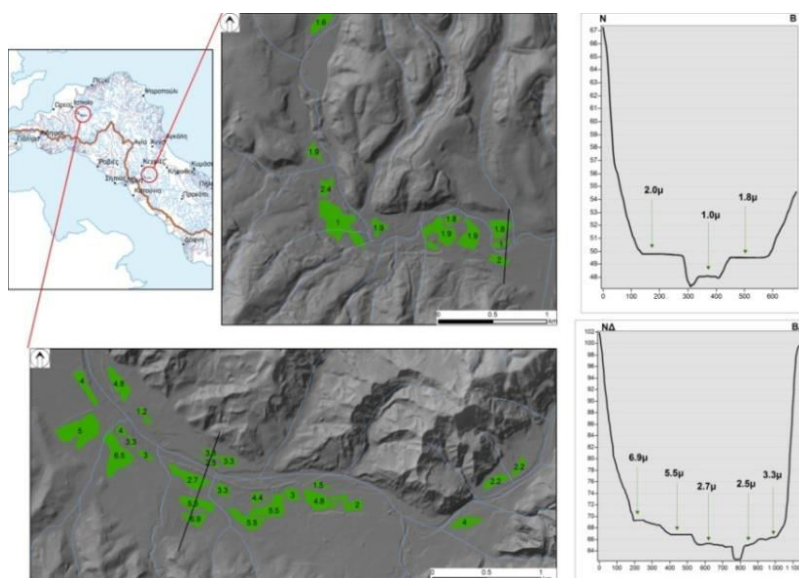
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Σχήμα 2. Ποτάμιες αναβαθμίδες των ποταμών (α) Κηρέα στην περιοχή Προκόπι και (β) Μεσσάπιου στην περιοχή Ψαχνά.

Σχήμα 3. Ενδεικτικές τοπογραφικές τομές εγκάρσια στις κεντρικές κοίτες των υδρογραφικών δικτύων Ξηροπόταμου και Νηλέα όπου αναπτύσσονται ποτάμιες αναβαθμίδες.

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Αυτοματοποιημένη Αναγνώριση Σημείων Κάμψης σε Υδρογραφικά Δίκτυα της Βόρειας Εύβοιας (Ανατολική Στερεά Ελλάδα)

Κ. Βαλκάνου [1], _Ε. Καρύμπαλης_ [1], _Δ. Παπαναστασίου_ [2], _Χ. Χαλκιάς_ [1], _Κ. Γάκη-Παπαναστασίου_ [3]

(1) Τμήμα Γεωγραφίας, Χαροκόπειο Πανεπιστήμιο, Ελ. Βενιζέλου 70, 17671, Αθήνα, Ελλάδα, elnel@otenet.gr, karymbalis@hua.gr, xalkias@hua.gr

(2) Γεωδυναμικό Ινστιτούτο, Εθνικό Αστεροσκοπείο Αθηνών, Λόφος Νυμφών,11810, Θησείο, Αθήνα, Ελλάδα, d.papan@noa.gr

(3) Τομέας Γεωγραφίας - Κλιματολογίας, Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη, 15771, Ιλίσια, Αθήνα, Ελλάδα, gaki@geol.uoa.gr

Εισαγωγή

Ένα σημαντικό γεωμορφολογικό χαρακτηριστικό των υδρογραφικών δικτύων είναι τα σημεία κάμψης. Πρόκειται για σημεία κατά μήκος της κοίτης ενός ποταμού όπου παρατηρείται μια απότομη αλλαγή στην κλίση της κοίτης ανάντη και κατάντη αυτών (Whipple and Tucker, 1999). Τα σημεία κάμψης είναι μεταξύ των χαρακτηριστικών γεωμορφών που αποτελούν ενδείξεις πρόσφατης τεκτονικής δραστηριότητας (Leeder _et al._, 1991; Gaki-Papanastassiou _et al._, 2007; Burbank and Anderson, 2008). Σε τεκτονικά ενεργές περιοχές, τα σημεία κάμψης είναι το αποτέλεσμα της απόκρισης του υδρογραφικού δικτύου στη δραστηριότητα των τοπικών ρηγμάτων. Υπάρχουν περιπτώσεις όπου τα σημεία κάμψης σχετίζονται με αλλαγή στη λιθολογία (επαφή μεταξύ γεωλογικών σχηματισμών με διαφορετική ανθεκτικότητα στην ποτάμια διάβρωση) κατά μήκος της κοίτης.

Συχνά η γεωμορφολογική έρευνα και η μορφομετρική ανάλυση μιας περιοχής περιλαμβάνει τον εντοπισμό των σημείων κάμψης (Crosby and Whipple, 2006; Wobus _et al._, 2006), η αναζήτηση των οποίων προϋποθέτει την κατασκευή των επιμηκών προφίλ των κοιτών των υδρογραφικών δικτύων που είναι μια διαδικασία χρονοβόρα. Τα τελευταία χρόνια έχουν αναπτυχθεί μέθοδοι και εργαλεία που επιταχύνουν την ανάλυση για την αναγνώριση των σημείων κάμψης. Τα εργαλεία αυτά χρησιμοποιούν το Ψηφιακό Μοντέλο Εδάφους (ΨΜΕ) και μειώνουν το χρόνο ενώ παράλληλα αυξάνουν την ακρίβεια και τη λεπτομέρεια του αποτελέσματος (πχ. Hayakawa and Ogushi, 2009; Schwanghart and Scherler, 2014; Queiroz _et al._, 2015; Demoulin, _et al._, 2017; Mudd _et al._, 2019).

Στην παρούσα εργασία επιχειρείται η αναγνώριση των σημείων κάμψης στα υδρογραφικά δίκτυα του βόρειου τμήματος της νήσου Εύβοιας (ανατολική Στερεά Ελλάδα) με τη χρήση της εργαλειοθήκης "Knickpoint finder" (Queiroz _et al._, 2015) που λειτουργεί μέσω ενός κώδικα python ή ως επέκταση στην πλατφόρμα ArcGIS και επιταχύνει τις αναλύσεις διευκολύνοντας τη διεξαγωγή μορφοτεκτονικών και νεοτεκτονικών μελετών.

Μεθοδολογία

Το εργαλείο που χρησιμοποιήθηκε για τον εντοπισμό των σημείων κάμψης κατά μήκος των κοιτών των υδρογραφικών δικτύων της περιοχής μελέτης βασίζεται στις μεθόδους των Hack

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(1973) και Etchebehere *et al*. (2004) και συνδυάζει το ΨΜΕ (με μέγεθος κελιού 25x25 μ για την παρούσα εφαρμογή) και ορισμένες ρυθμίσεις όπως η ισοδιάσταση (ίση με 20μ για την παρούσα εφαρμογή).

Για κάθε σημείο που εντοπίστηκε, υπολογίστηκε το RDEs (παράγωγος του δείκτη Hack (SL)-δείκτης κλίσης-μήκους ρέματος που αποτελεί μία ένδειξη της ενέργειας ροής σε ένα συγκεκριμένο τμήμα της κοίτης) και το RDEt (που αφορά στο συνολικό μήκος ενός ποταμού και λαμβάνει υπόψη τη συνολική κλίση μεταξύ του ανώτερου σημείου της κοίτης και των εκβολών). Τελικός στόχος ήταν η σύγκριση των τιμών των RDEs και RDEt ώστε να φανεί ποια τμήματα της κοίτης εμφανίζουν ανωμαλίες στην κλίση. Υπολογίστηκε ο λόγος RDEs/RDEt που φανερώνει το βαθμό ανωμαλίας στην κλίση της κοίτης του ποταμού που αναλύεται. Όταν ο λόγος είναι ≥ 2 θεωρείται πως υπάρχει ανωμαλία στην κλίση της ποτάμιας κοίτης. Συγκεκριμένα όταν κυμαίνεται μεταξύ 2 και 10 η ανωμαλία αυτή θεωρείται 2ης τάξης ενώ όταν είναι > 10 (όταν δηλαδή το RDEs είναι τουλάχιστον 10 φορές μεγαλύτερο από το RDEt) η ανωμαλία θεωρείται 1ης τάξης.

Μετά τον εντοπισμό των σημείων κάμψης, δημιουργήθηκε ο χάρτης χωρικής τους κατανομής, με τη χρήση της μεθόδου εκτίμησης πυκνότητας πυρήνα (Kernel density). Τέλος η χωρική κατανομή των σημείων κάμψης συγκρίθηκε με τα γεωλογικά, γεωμορφολογικά και σεισμικά δεδομένα της περιοχής για την αναζήτηση ενδεχόμενης συσχέτισης μεταξύ των σημείων κάμψης με λιθολογικές αλλαγές, ρήγματα, επίκεντρα σεισμών και άλλες ανωμαλίες του υδρογραφικού δικτύου (Queiroz *et al.*, 2015; Moussi *et al.*, 2018).

Αποτελέσματα - Συμπεράσματα

Εφαρμόζοντας την ανωτέρω μεθοδολογία στην περιοχή μελέτης εντοπίστηκαν συνολικά 2.486 σημεία κάμψης (Σχήμα 1) με ποικιλία στο βαθμό ανωμαλίας (από 2,0 έως 69,09). Δεδομένου ότι εντοπίστηκε ένας πολύ μεγάλος αριθμός σημείων, αξιολογήθηκαν μόνο τα 139 σημεία τα οποία αντιστοιχούν σε ανωμαλίες πρώτης τάξης (RDEs/RDEt>10) (Σχήμα 1).
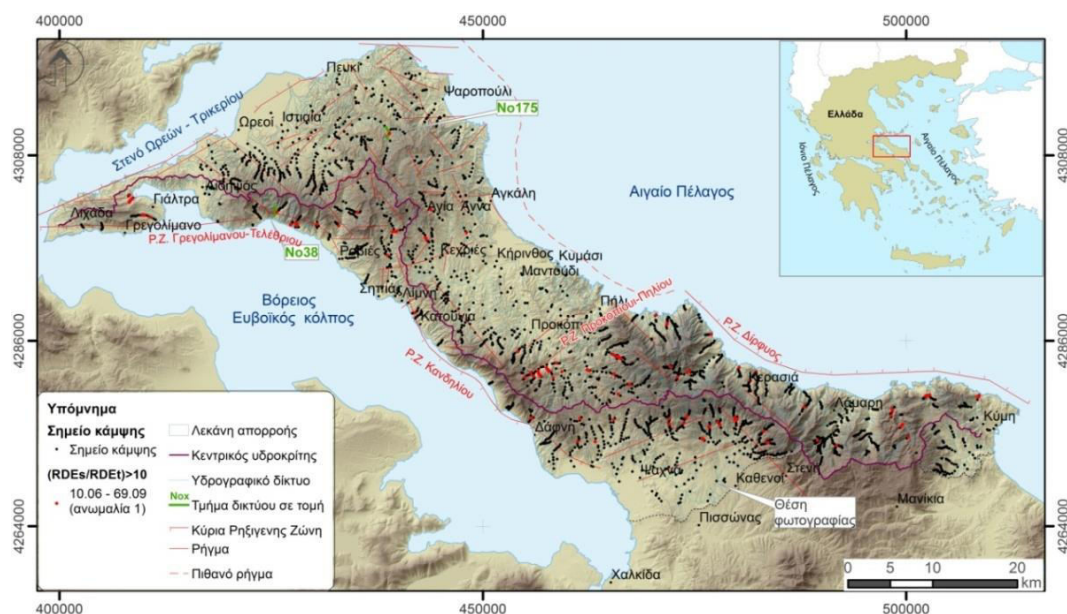
Σχήμα 1. Σημεία κάμψης που εντοπίστηκαν στην περιοχή μελέτη με την εφαρμογή αυτοματοποιημένης μεθόδου.

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Μετά τον εντοπισμό των σημείων κάμψης, επιχειρήθηκε η αναζήτηση πιθανών σημαντικών συσχετίσεων των σημείων αυτών με τα φυσικά χαρακτηριστικά του αναγλύφου που μπορεί να οφείλονται σε τοπικές τοπογραφικές ανωμαλίες ή σε τεκτονική παραμόρφωση. Αρχικά επιχειρήθηκε η σύγκριση με το λιθολογικό χάρτη της περιοχής.
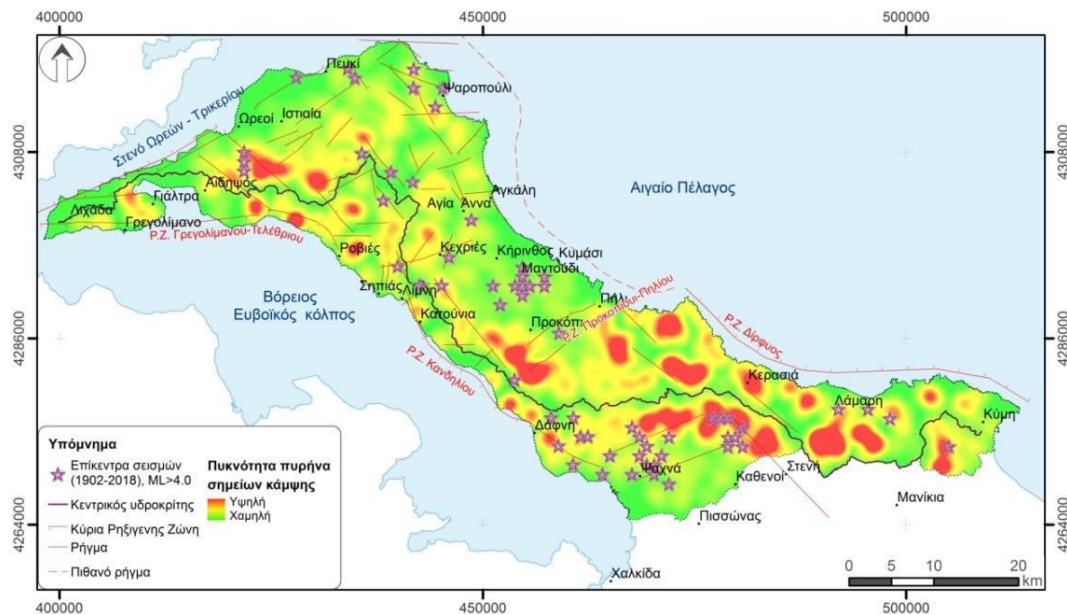
Σχήμα 2. Χάρτης πυκνότητας σημείων κάμψης και επικέντρων των κύριων σεισμών της περιοχής (φαίνονται μόνο τα επίκεντρα που βρίσκονται εντός της περιοχής μελέτης).

Διαπιστώθηκε πως τα 40 από τα 139 σημεία κάμψης ήταν λιθολογικά καθώς οφείλονται σε αλλαγές της λιθολογίας των γεωλογικών σχηματισμών από τους οποίους διέρχονται οι κοίτες. Από τη σύγκριση του χάρτη των σημείων κάμψης με τον χάρτη των ρηγμάτων της περιοχής, φάνηκε πως τα 39 από αυτά ήταν τεκτονικής προέλευσης καθώς αντιστοιχούσαν σε σημεία τομής της κοίτης από ρήγματα. Τα υπόλοιπα 60 σημεία κάμψης συναξιολογήθηκαν με τις φωτογραμμώσεις της περιοχής μελέτης που προέκυψαν από τους χάρτες σκιασμένου αναγλύφου και διαπιστώθηκε ότι επτά (7) νέες γραμμώσεις τέμνουν τα προφίλ ποταμών και ενδεχομένως αντιστοιχούν σε ρήγματα. Τα υπόλοιπα σημεία είναι πιθανό να έχουν "μετατοπισθεί" από την αρχική τους θέση με τη διεργασία της οπισθοδρομούσας διάβρωσης.

Ένα άλλο συμπέρασμα που μπορεί να εξαχθεί από τη μελέτη των σημείων κάμψης είναι πως εφόσον αυτά δεν σχετίζονται με την λιθολογία, σχετίζονται με τον κύκλο διάβρωσης. Αποτελούν δηλαδή σημεία που ορίζουν δύο διαφορετικές φάσεις εξέλιξης της περιοχής όπως αποτυπώνεται από τη διαφορετική κλίση της κοίτης ανάντη και κατάντη αυτών. Η τάση είναι η αφομοίωση της μεταβολής αυτής της κλίσης, δηλαδή ισχυρή διάβρωση και εκβάθυνση πάνω από το σημείο της κάμψης ώστε το σημείο αλλαγής της κλίσης να μετακινηθεί ανάντη και σταδιακά να εξαφανιστεί ώστε τελικά να επιτευχθεί ένα εξισορροπημένο επίμηκες προφίλ κοίτης.

Έτσι σε ορισμένες περιπτώσεις, όπως για παράδειγμα σε υδρογραφικό δίκτυο της ρηξιγενούς ζώνης Δίρφυος (ΝΑ της περιοχής Λάμαρη) εντοπίζονται σημεία κάμψεις και κατάντη αυτών φαράγγια, ενώ σε άλλες περιπτώσεις, όπως για παράδειγμα στα υδρογραφικά δίκτυα που αποστραγγίζουν το ανυψούμενο τέμαχος της ρηξιγενούς ζώνης Τελέθριου, τα σημεία κάμψης

βρίσκονται σε χαμηλά υψόμετρα και λόγω νεότητας δεν έχει αρχίσει ακόμη η προς τα ανάντη μετατόπισή τους μέσω της οπισθοδρομούσας διάβρωσης. Επίσης στην ρηξιγενή ζώνη Δίρφυος τα σημεία κάμψης φαίνεται να αντιστοιχούν στο όριο μεταξύ της αναγεννημένης περιοχής και της περιοχής που διανύει το στάδιο ωριμότητας. Είναι χαρακτηριστικό ότι πάνω από το όριο αυτό εμφανίζονται επιφάνειες επιπέδωσης. Τέλος επισημαίνεται η μεγάλη συγκέντρωση σημείων κάμψης (Σχήματα 1 και 2) στα δίκτυα που αποστραγγίζουν το ανερχόμενο τέμαχος του νότιου τμήματος της ρηξιγενούς ζώνης Προκοπίου Πηλίου, καθώς και στο ανερχόμενο τέμαχος της ρηξιγενούς ζώνης Κεχριών, στη ρηξιγενή ζώνη Τελέθριου και στο ορεινό τμήμα της λεκάνης του Μεσσάπιου. Η παρουσία αυτών των σημείων κάμψης αποτελεί ένδειξη της ενεργότητας των εν λόγω ρηξιγενών ζωνών. Εκτός της συσχέτισης μεταξύ της πυκνότητας εμφάνισης σημείων κάμψης με τα ενεργά ρήγματα της περιοχής, διαπιστώθηκε ανάλογη θετική συσχέτιση με τα επίκεντρα των σεισμών. Η συσχέτιση αυτή φαίνεται στον χάρτη του Σχήματος 2.

Επιπλέον σχεδιάστηκαν ενδεικτικά οι επιμήκεις τομές των κοιτών των υδρογραφικών δικτύων στη στενή περιοχή εμφάνισης ορισμένων σημείων κάμψης, δύο από τις οποίες απεικονίζονται στο Σχήμα 3(α). Το χαμηλότερο υψομετρικά σημείο κάμψης του τμήματος του δικτύου Νο38 οφείλεται στην τομή της κοίτης από τη ρηξιγενή ζώνη Τελέθριου, ενώ εκείνο που βρίσκεται σε μεγαλύτερο υψόμετρο οφείλεται σε λιθολογική επαφή. Το σημείο κάμψης στο δίκτυο Νο175 συνδέεται με τον αγκώνα σύλληψης που έχει εντοπιστεί στο ίδιο σημείο και οφείλει τη δημιουργία του στην έντονη διάβρωση κατάντη λόγω της αύξησης της παροχής από τη σύλληψη του γειτονικού δικτύου. Πολλά από τα σημεία κάμψης που προσδιορίστηκαν με την αυτοματοποιημένη μέθοδο πιστοποιήθηκαν με εργασία πεδίου (Σχήμα 3(β)) ενώ επιπλέον για τα σημεία με 1^{ης} τάξης ανωμαλία έγινε λεπτομερής παρατήρηση εικόνων Google Earth όπου διαπιστώθηκε πως τουλάχιστον οι "γνωστοί" επισκέψιμοι καταρράκτες της περιοχής μελέτης συγκαταλέγονται μεταξύ των σημείων κάμψης που εντοπίστηκαν.

Ο αυτοματοποιημένος προσδιορισμός των σημείων κάμψης βοηθάει σημαντικά στον αρχικό τους εντοπισμό προκειμένου να διευκολυνθεί η εργασία πεδίου. Η ανάλυση που πραγματοποιήθηκε επιβεβαιώνει πως τα σημεία κάμψης της περιοχής μελέτης στην πλειονότητά τους έχουν τεκτονική προέλευση και ελέγχονται από το νεοτεκτονικό καθεστώς ενώ σχετίζονται με τη σεισμική δραστηριότητα. Υπάρχουν όμως και σημεία που σχετίζονται με αλλαγές στη λιθολογία.
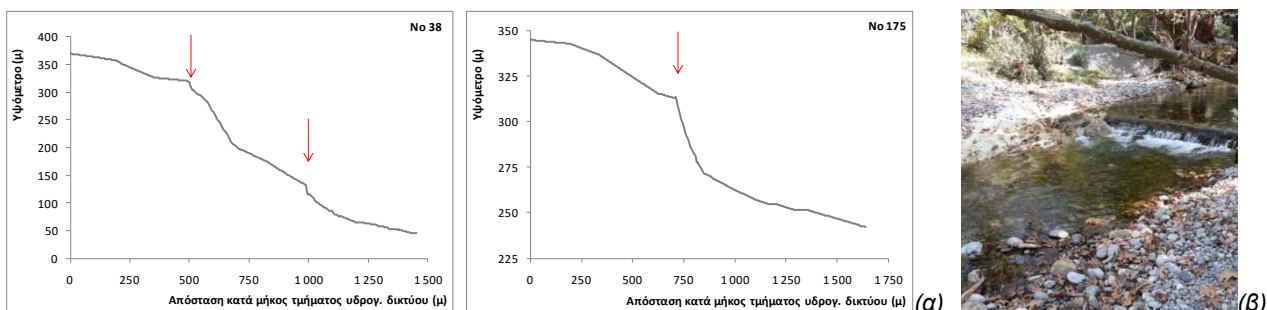
Σχήμα 3. (α) Ενδεικτικές επιμήκεις τομές σε επιλεγμένα τμήματα των κοιτών υδρογραφικών δικτύων στα οποία εντοπίστηκαν σημεία κάμψης (Νο38 και Νο175) και (β) Φωτογραφία σημείου κάμψης που οφείλεται σε λιθολογικά αίτια (περιοχή Έρια βόρεια των Καθενών). Οι θέσεις των τριών δικτύων φαίνονται στο Σχήμα 1.

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Χωρική Κατανομή των Σπηλαίων της Κρήτης

Ε. Αντωνίου [1,2]*, Φ. Λιβανός* [1]*, **Χ. Σκυλοδήμου** [1]*, Γ. Μπαθρέλλος* [2]

(1) Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη Ζωγράφου 15784, Ελλάδα, eiriniantoniu@gmail.com, fotis-22@hotmail.com, hskilodimou@geol.uoa.gr
(2) Τμήμα Γεωλογίας, Πανεπιστήμιο Πατρών, Ρίο Πάτρα 26504, Ελλάδα, gbathrellos@upatras.gr

Εισαγωγή

Η Κρήτη είναι το μεγαλύτερο νησί της Ελλάδας με έκταση 8.303 τετρ. χλμ. Το μήκος του νησιού φτάνει τα 260 χλμ, ενώ το πλάτος του κυμαίνεται από 60 έως 12 χλμ. Οι ακτές της είναι πολυσχιδείς ενώ το συνολικό τους μήκος τους είναι μεγαλύτερο από 1.000 χλμ.

Το νησί βρίσκεται στο εξωτερικό τμήμα του ελληνικού τόξου, στη ζώνη υποβύθισης της Αφρικανικής στην Ευρασιατική πλάκα. Η τοπογραφία της Κρήτης, εξαιτίας της θέσης της στο γεωτεκτονικό καθεστώς του Αιγαίου, χαρακτηρίζεται κυρίως από ένα ορεινό ανάγλυφο, το οποίο υποδηλώνει πρόσφατη και γρήγορη ανύψωση (Meulenkamp *et al.,* 1988; Kokinou *et al.,* 2013). Το ορεινό ανάγλυφο περιλαμβάνει υψηλούς ορεινούς όγκους όπως: τα Λευκά Όρη στα δυτικά τμήμα της με μέγιστο υψόμετρο 2.453 μ., στο κεντρικό τμήμα τον Ψηλορείτη που φτάνει τα 2.456 μ. και τη Δίκτη με υψόμετρο 2.148 μ, ενώ στα ανατολικά εκτείνονται τα Όρη της Σητείας, με υψόμετρο 1.476 μ. Τα υψηλά όρη πλαισιώνουν χαμηλότεροι ορεινοί όγκοι.

Η Κρήτη είναι από τις περιοχές στην Ελλάδα που παρουσιάζουν έντονα φαινόμενα καρστικοποίησης. Οι επικρατούσες γεωλογικές και κλιματικές συνθήκες ευνοούν την ανάπτυξη καρστικών μορφών. Η έντονη μορφολογία του νησιού είναι άμεσα συνδεδεμένη με την εμφάνιση επιφανειακών και υπόγειων καρστικών μορφών. Στο νησί υπάρχουν περίπου εκατό φαράγγια ένα εκ των οποίων είναι το φημισμένο φαράγγι της Σαμαριάς, πόλγες, δολίνες και λιμνοδολίνες. Όσον αφορά τις ενδοκαρστικές μορφές περισσότερα από 4.500 σπήλαια και σπηλαιοβάραθρα έχουν χαρτογραφηθεί σε ολόκληρη την Κρήτη. Αξίζει να σημειωθεί πως τα τρία βαθύτερα σπηλαιοβάραθρα που έχουν εξερευνηθεί, βρίσκονται στο νησί (Μπορνόβας, 1999; Φασουλάς, 2001; Kokinou *et al.,* 2015).

Η σπηλαιολογική και οικολογική σημασία πολλών σπηλαίων της Κρήτης είναι τεράστια. Περιοχές που φιλοξενούν μεγάλο αριθμό σπηλαίων, ιδανικές για όσους ασχολούνται με σπηλαιολογία, είναι η περιοχή του όρους Στρούμπουλα στο Ηράκλειο, τα Γεωπάρκα Σητείας και Ψηλορείτη και το Μελιδόνι στα Λευκά Όρη (Πετροχείλου, 1984; Αδαμόπουλος, 1993).

Σκοπός της παρούσας εργασίας είναι η καταγραφή και η μελέτη σπηλαίων στην Κρήτη. Τα σπήλαια που καταγράφηκαν εισήχθησαν σε βάση δεδομένων και στη συνέχεια πραγματοποιήθηκε η στατιστική επεξεργασία των δεδομένων. Μελετήθηκε η χωρική κατανομή των σπηλαίων σε κάθε περιφερειακή ενότητα του νησιού, η πυκνότητά τους και συσχετιστήκαν τα σπήλαια με το υψόμετρο στο οποίο εμφανίζονται.

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Μεθοδολογία

Στο πλαίσιο της παρούσας μελέτης, αρχικά πραγματοποιήθηκε η συλλογή των σπηλαίων που βρίσκονται στην Κρήτη. Η συλλογή των δεδομένων βασίστηκε σε σχετικές καταγραφές σπηλαιολογικών εταιριών, ορισμένων ταξιδιωτικών ιστοτόπων και σε επιστημονικές εργασίες (Πετροχείλου, 1984; Αδαμόπουλος, 1993; Μπορνόβας, 1999). Στη συνέχεια δημιουργήθηκε μια βάση δεδομένων στην οποία ενσωματώθηκαν πληροφορίες όπως η γεωγραφική θέση του κάθε σπηλαίου, η περιφερειακή ενότητα στην οποία ανήκει, ο τύπος του, η προσβασιμότητά του, η ύπαρξη ύδατος, το υψόμετρο του, το μήκος του και το βάθος του. Η βάση δεδομένων εισήχθη σε ένα Γεωγραφικό Σύστημα Πληροφοριών και το λογισμικό το οποίο χρησιμοποιήθηκε είναι το ArcGIS 10.3. Στο πλαίσιο της παρούσας εργασίας αναλύθηκε η χωρική κατανομή των σπηλαίων στην Κρήτη ανά περιφερειακή ενότητα και μελετήθηκε η πυκνότητά τους ανά 100 τετρ. χλμ. Επίσης διερευνήθηκε η κατανομή των σπηλαίων σε σχέση με το υψόμετρο στο οποίο βρίσκονται. Η επιλογή της μελέτης των συγκεκριμένων στοιχείων βασίστηκε στο γεγονός ότι περιέχουν τις πλέον ολοκληρωμένες πληροφορίες.

Αποτελέσματα

Ο συνολικός αριθμός των σπηλαίων που καταγράφηκαν στη βάση δεδομένων είναι 170. Στο Σχήμα 1 παρουσιάζεται η χωρική κατανομή των σπηλαίων που μελετήθηκαν στην Κρήτη, οι κυριότερες πόλεις, το υδρογραφικό και το οδικό δίκτυο του νησιού καθώς και η κατανομή των υψομέτρων σε αυτό. Όπως διακρίνεται στο Σχήμα 1 οι μεγαλύτερες χωρικές συγκεντρώσεις σπηλαίων παρατηρούνται στο δυτικό και στο κεντρικό τμήμα του νησιού.
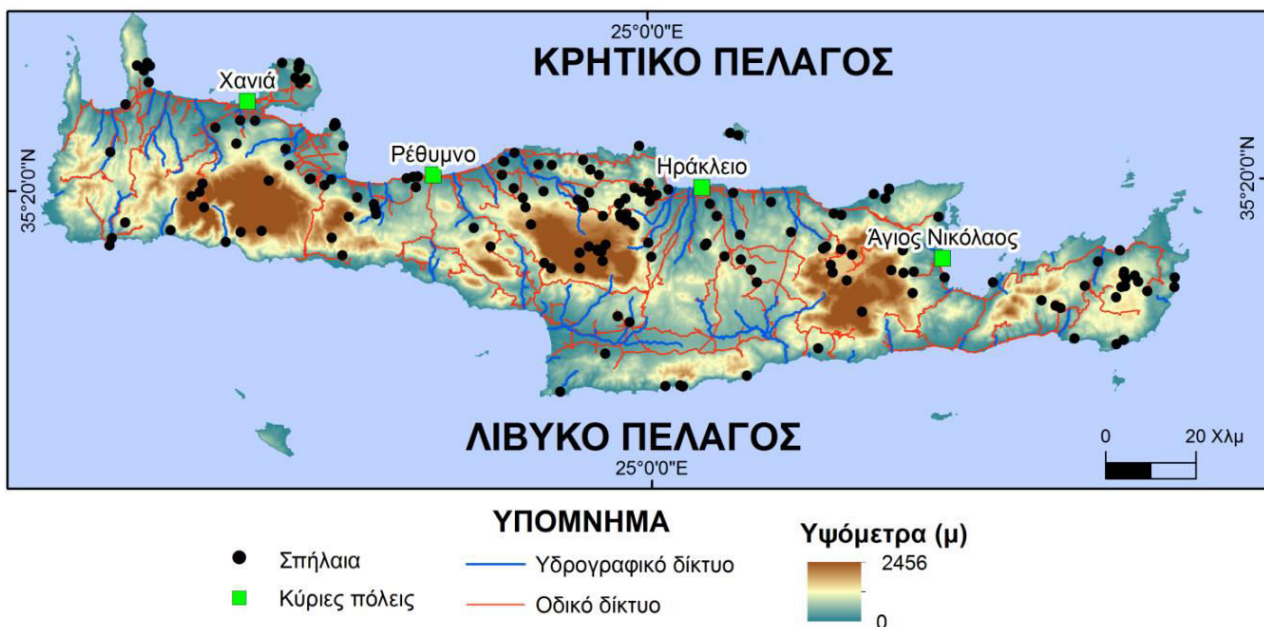
Σχήμα 1. Χάρτης της Κρήτης με τα σπήλαια που μελετήθηκαν, το υδρογραφικό και το οδικό δίκτυο του νησιού καθώς και η κατανομή των υψομέτρων του.

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Τα αποτελέσματα της στατιστικής επεξεργασίας των δεδομένων με την κατανομή των σπηλαίων σε κάθε νομό της Κρήτης δίνονται στο Σχήμα 2. Η περιφερειακή ενότητα που συγκεντρώνει τα περισσότερα από τα καταγεγραμμένα σπήλαια και σε ποσοστό 32% είναι ο νομός Χανίων. Ακολουθούν ο νομός Ηράκλειου και Λασιθίου, ενώ ο μικρότερος αριθμός των καταγεγραμμένων σπηλαίων διαπιστώθηκε στο νομό Ρεθύμνου.
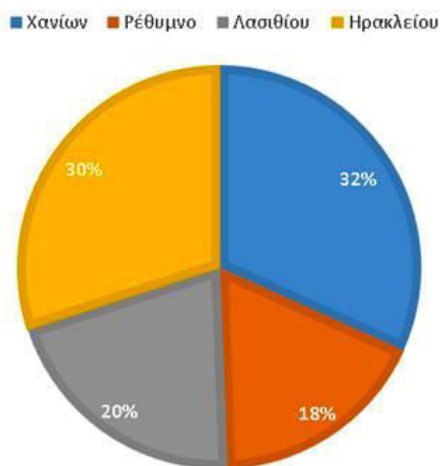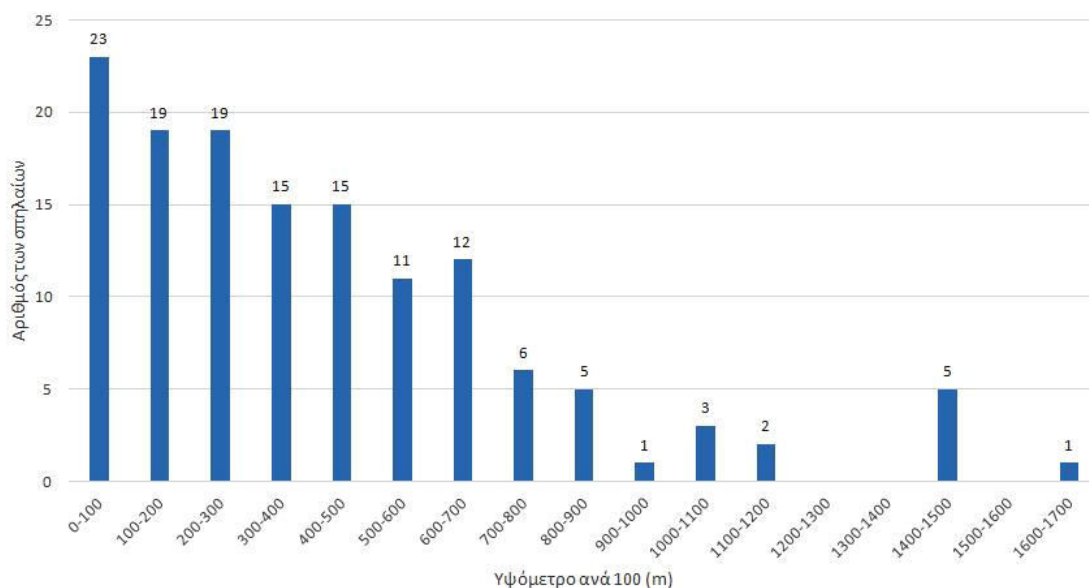

Σχήμα 2. Η κατανομή των σπηλαίων ανά περιφερειακή ενότητα.

Στον Πίνακα 1 παρουσιάζονται οι νομοί της Κρήτης, η έκτασή τους, το πλήθος των σπηλαίων σε κάθε νομό και η πυκνότητα των σπηλαίων ανά 100 τετρ. χλμ. Στον νόμο Χανίων βρίσκεται το μεγαλύτερο πλήθος των σπηλαίων. Η πυκνότητά τους σε αυτή την περιφερειακή ενότητα είναι η μεγαλύτερη και ίση με 2,3 σπήλαια ανά 100 τετρ. χλμ. Οι υπόλοιπες περιφερειακές ενότητες παρουσιάζουν την ίδια πυκνότητα περίπου, ίση με 2 σπήλαια ανά 100 τετρ. χλμ.

Πίνακας 1. Η έκταση των νομών της Κρήτης, το πλήθος των σπηλαίων σε κάθε νομό και η πυκνότητα των σπηλαίων ανά 100 τετρ. χλμ.

Νομός	Έκταση (Km^2)	Πλήθος σπηλαίων	Πυκνότητα των σπηλαίων ανά 100 Km^2
Χανίων	2376	54	2,3
Ρεθύμνου	1494	30	2
Λασιθίου	1827	35	1,9
Ηρακλείου	2641	51	1,9

Στο Σχήμα 3 δίνεται η κατανομή των σπηλαίων σε σχέση με το υψόμετρο που βρίσκονται. Τα περισσότερα σπήλαια εμφανίζονται σε υψόμετρο μικρότερο των 100 μέτρων. Το πλήθος των σπηλαίων μικραίνει όσο αυξάνει το υψόμετρο. Γενικότερα, η πλειοψηφία των σπηλαίων αναπτύσσεται σε υψόμετρο μικρότερο των 700 μέτρων. Το μικρότερο πλήθος σπηλαίων παρατηρείται σε υψόμετρα μεγαλύτερα από 900 μέτρα.

Σχήμα 3. Η κατανομή των σπηλαίων σε σχέση με το υψόμετρο τους.

Συμπεράσματα

Η επεξεργασία των δεδομένων έδειξε ότι η περιφερειακή ενότητα που συγκεντρώνει τα περισσότερα από τα καταγεγραμμένα σπήλαια είναι ο νομός Χανίων. Η πυκνότητα των σπηλαίων στα Χανιά είναι ίση με 2,3 σπήλαια ανά 100 τετρ. χλμ. Τα περισσότερα σπήλαια απαντώνται σε υψόμετρο μικρότερο των 700 μέτρων. Το πλήθος των σπηλαίων μικραίνει όσο αυξάνει το υψόμετρο.

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Βραχογραφίες και Σπήλαια στην Ελλάδα

*Δ. Κοματέα [1], **Χ. Σκυλοδήμου** [1], Γ. Μπαθρέλλος [2]*

(1) Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη Ζωγράφου 15784, Ελλάδα, dimitra@komateas.gr, hskilodimou@geol.uoa.gr
(2) Τμήμα Γεωλογίας, Πανεπιστήμιο Πατρών, Ρίο Πάτρα 26504, Ελλάδα, gbathrellos@upatras.gr

Εισαγωγή

Οι βραχογραφίες είναι η ζωγραφική σπηλαίου δηλαδή καλλιτεχνικές αναπαραστάσεις και σχέδια που βρίσκονται στην επιφάνεια των φυσικών τοιχωμάτων των σπηλαίων. Οι βραχογραφίες συνιστούν την πρώτη εκδήλωση τέχνης των προϊστορικών ανθρώπων. Πρόκειται για πανάρχαιες απεικονίσεις, κυρίως ειδών της πανίδας, που υπήρχαν στην εκάστοτε περιοχή. Παρουσιάζονται μοτίβα και μορφές από ελάφια, ζαρκάδια, μικρά ζώα, λύκους, αλεπούδες, τσακάλια και σκύλους. Συχνά, διακρίνεται το φύλο τους. Στην θεματολογία κατατάσσονται επίσης ανθρώπινες φιγούρες, σκηνές κυνηγιού και όπλα, κυρίως τόξα και δόρατα. Όλες οι απεικονίσεις είναι συμβολικές. Εκφράζουν τις αντιλήψεις του προϊστορικού ανθρώπου για το μυστήριο της ζωής και του θανάτου, καθώς και την αγωνία της επιβίωσης (Καραφυλιά, 2019).

Οι βραχογραφίες χρονολογούνται στην προϊστορική εποχή. Η ακριβής χρονολογική τοποθέτηση, δεν είναι εφικτή λόγω έλλειψης γραπτών πηγών και σταθερής χρονολογικής βάσης. Ωστόσο, σε ένα ευρύτερο εννοιολογικό πλαίσιο, η προϊστορική εποχή αρχίζει από τα 2.5 Ma και τελειώνει στα 600 π.Χ. Οι παλαιότερες βραχογραφίες που είναι γνωστές έως σήμερα, είναι στα Σπήλαια Chauvet στην Γαλλία και χρονολογούνται 32.500 χρόνια πριν από σήμερα (Cigna, 2005).

Τα σπήλαια, χρησίμευαν στον άνθρωπο ως ασφαλή καταφύγια κι αργότερα ως οικισμοί. Αποτελούσαν χώρους εύρεσης φυσικών πόρων, ιατρικής περίθαλψης αλλά και θρησκευτικών τελετουργιών. Αποτελούσαν αξιόπιστες πηγές νερού ενώ ορυκτά και άργιλοι εξορύσσονταν τόσο για καθημερινή, όσο και για τελετουργική χρήση (Stevanović, 2015) Τα σπήλαια, αποτέλεσαν καταφύγια και του Homo Sapiens και ήταν οι κύριοι οικισμοί των ανθρώπων κατά την ανώτερη Παλαιολιθική περίοδο (Cigna, 2005).

Στην Ελλάδα, έχουν ανακαλυφθεί βραχογραφίες σε διάφορες περιοχές όπως στο Παγγαίο όρος, στην Αλιστράτη Σερρών, στο σπήλαιο Πετραλώνων Χαλκιδικής, στους Φιλίππους Καβάλας, στο Γονικό 'Εβρου, στα Πετρωτά Ροδόπης, στην Αριδαία Πέλλας, στη Χαλκιδική και στη χερσόνησο του Άθω, στη λίμνη Χειμαρίτιδα Φλώρινας, στην Κρήτη, στη Μάνη, στην Εύβοια, στη Νάξο, στη Μήλο, στη Φολέγανδρο, στην Κέρο Κυκλάδων, στη Γιούρα Αλοννήσου, στη Θάσο κ.α.. Ωστόσο, οι πληροφορίες για αρκετές από τις περιοχές αυτές είναι ελλιπείς. Οι βραχογραφίες, εντοπίζονται τόσο σε σπήλαια, όσο και στο ύπαιθρο, σε μεγάλες επιφάνειες βράχων. Η ηλικία τους, εκτιμάται κατά πολλούς ερευνητές και επιστήμονες, σε εκατοντάδες χιλιάδες έτη (Πουλιανός, 2011). Οι παλαιότερες, είναι οι βραχογραφίες στο Παγγαίο Όρος, στη Μακεδονία. Όμως, η ακριβής χρονολόγηση των χαραγμάτων είναι δύσκολη, καθώς δεν έχει πραγματοποιηθεί η απλή καταγραφή τους. Γίνεται γενικά δεκτό ότι οι παλαιότερες βραχογραφίες ανάγονται στο 3.000 π.Χ., στην όψιμη εποχή του χαλκού (Ατακτίδης, 2006).

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Σκοπός της παρούσας εργασίας είναι να καταγράψει και να παρουσιάσει τις κυριότερες βραχογραφίες που έχουν εντοπισθεί στον Ελλαδικό χώρο. Επιπλέον γίνεται μία προσπάθεια να συσχετισθεί η θεματολογία τους καθώς η λιθολογία στην οποία αναπτύσσονται.

Μεθοδολογία

Η μεθοδολογία της παρούσας εργασίας περιλαμβάνει τη συλλογή δεδομένων, και τη στατιστική επεξεργασία τους. Συγκεκριμένα, για τη διεξαγωγή της παρούσας μελέτης, χρησιμοποιήθηκαν βιβλιογραφικά δεδομένα και μελετήθηκαν οι βραχογραφίες σε εννέα σπήλαια του Ελλαδικού χώρου και σε πέντε γεωγραφικές θέσεις στο ύπαιθρο. Έγινε στατιστική επεξεργασία των δεδομένων, από τα οποία δημιουργήθηκαν αναλυτικοί και συγκεντρωτικοί πίνακες αποτελεσμάτων και γραφήματα. Με τον τρόπο αυτό αναλύεται η σχέση της θεματολογίας των βραχογραφιών στα σπήλαια και στο ύπαιθρο, αλλά και η σχέση τους με την λιθολογία της περιοχής που εμφανίζονται.

Αποτελέσματα

Οι βραχογραφίες στην Ελλάδα, διακρίνονται σε δυο μεγάλες κατηγορίες σε εκείνες που εντοπίζονται σε σπήλαια και σε εκείνες που υπάρχουν στο ύπαιθρο. Στην παρούσα εργασία εξετάζονται οι βραχογραφίες που εντοπίζονται στα παρακάτω σπήλαια: Αλιστράτης στις Σέρρες (Σχήμα 1), Πετραλώνων στη Χαλκιδική, Καταρρακτών στην Έδεσσα, Δράκος στην Καστοριά, Καστριάς, στα Ιωάννινα, Διρού, Καλαμάκι και Απήδημα στη Μάνη καθώς και στο σπήλαιο Σκορδαλάκια, στην Κρήτη.

Σχήμα 1. Βραχογραφία στο σπήλαιο Αλιστράτης (πηγή: Σπηλαιολογία Σ.Χ.Ο. Καβάλας, 2018).

Επίσης εξετάστηκαν οι βραχογραφίες που εντοπίστηκαν στο ύπαιθρο στις περιοχές: Γονικό στον Έβρο, Παγγαίο Όρος στην ανατολική Μακεδονία (Σχήμα 2), Φιλίππους στην Καβάλα, Στρόφιλας στην Άνδρο και Κορφή τ' Αρωνιού στη Νάξο. Η ηλικία των βραχογραφιών, καλύπτει ένα ευρύτατο φάσμα από τους προϊστορικούς μέχρι τους μεσαιωνικούς χρόνους. Στο Γονικό Έβρου μάλιστα, εντοπίζονται βραχογραφίες με κυκλικά ή ημικυκλικά σχήματα που παραπέμπουν στον ήλιο και τη

Σελήνη, με πιθανή ηλικία 1.100-900 π.Χ. Η παλαιότερη σε ηλικία βραχογραφία, τοποθετείται στο 3.000 π.Χ. (Ατακτίδης, 2006) και εντοπίζεται στο Παγγαίο Όρος (Σχήμα 2), με τη χαρακτηριστική απεικόνιση των αστερισμών και του «Πανάρχαιου Ζωδιακού».
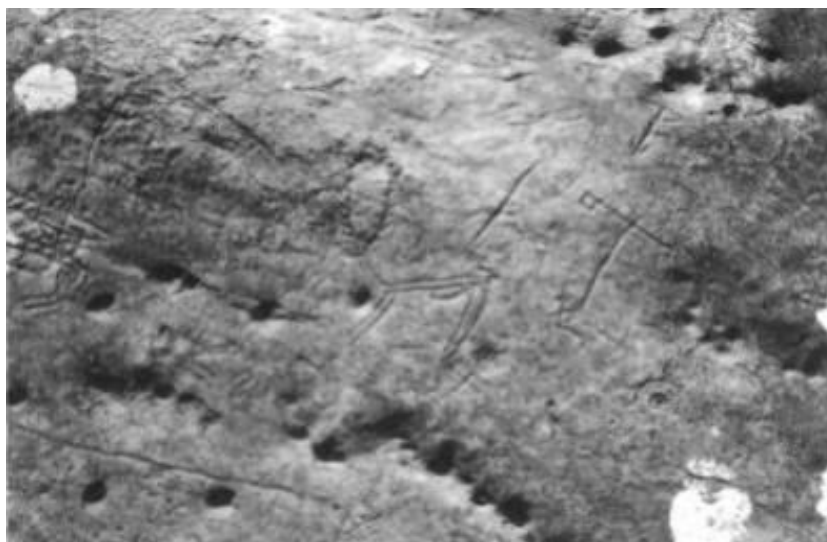
Σχήμα 2. Βραχογραφία στο Παγγαίο Όρος, Πανάρχαιος Ζωδιακός (πηγή: Βογιατζής, 1996).

Η θεματολογία των βραχογραφιών ποικίλλει. Στις θέσεις που εξετάστηκαν παρατηρούνται φιγούρες ανθρώπων και ζώων σε αρμονία ή σε σκηνές κυνηγιού. Εντοπίζονται ακόμη, αφηρημένα χαράγματα και γραμμικά σύμβολα που αντιστοιχούν στα πρώτα σημάδια γραφής (Πίνακας 1). Όπως προκύπτει από τον Πίνακα 1 τα σύμβολα αποτελούν την πλέον συνηθισμένη θεματολογία σε ποσοστό περίπου 60%, ενώ η λιγότερο συχνές θεματολογίες είναι τα ζώα καθώς τα ζώα και οι άνθρωποι. Οι ηλικίες τους, προσδιορίζονται στην προϊστορική εποχή, χωρίς όμως να υπάρχουν σαφείς χρονολογήσεις.

Πίνακας 1. Θεματολογία βραχογραφιών στα σπήλαια.

Θεματολογία	Πλήθος	Ποσοστά (%)
Ζώα και σύμβολα	2	22,22
Ζώα	1	11,11
Σύμβολα	5	55,56
Ζώα και άνθρωποι	1	11,11
Σύνολο	9	100,00

Στο ύπαιθρο, οι βραχογραφίες βρίσκονται εκτεθειμένες στις ατμοσφαιρικές συνθήκες και στη δράση των εξωγενών παραγόντων. Εντοπίζονται χαραγμένα σε μάρμαρα, άνθρωποι και θεοί, ζώα, όπλα και γραμμικά σχέδια με χαρακτηριστικές σπείρες και μαιάνδρους. Σε αυτή την κατηγορία, οι πιο συχνές θεματολογίες που εντοπίζονται, σε ποσοστό που φτάνει το 60%, είναι μορφές ζώων, ανθρώπων, σύμβολα και όπλα (Πίνακας 2).

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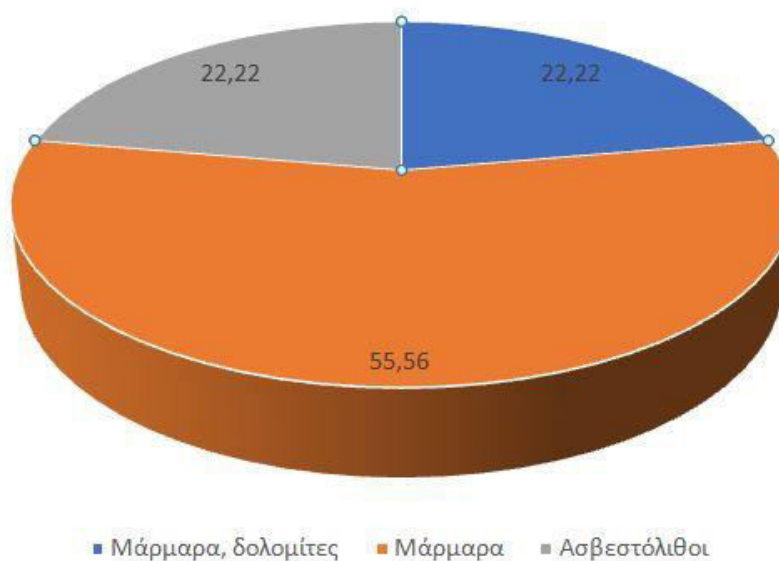Bulletin of the Geological Society of Greece, Sp. Pub. 8, 2021

Συνολικά, μελετώντας τη θεματολογία και των δύο κατηγοριών, εμφανίζονται μορφές ανθρώπων και ζώων στο 50% των βραχογραφιών, τα σύμβολα απαντούν στο 40%, ενώ τα όπλα εντοπίζονται μόλις στο 10% των βραχογραφιών.

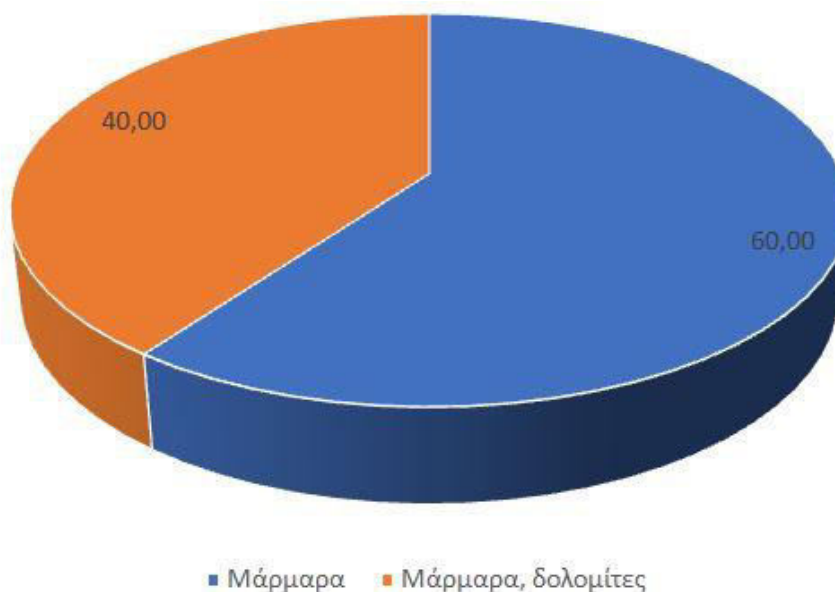*Πίνακας 2. Θεματολογία βραχογραφιών στο ύπαιθρο.*

Θεματολογία	Πλήθος	Ποσοστά (%)
Ζώα, άνθρωποι, σύμβολα	1	20,00
Ζώα, άνθρωποι, σύμβολα, όπλα	3	60,00
Ζώα, άνθρωποι, σύμβολα, πλοία	1	20,00
Σύνολο	5	100,00

Τα σπήλαια που μελετήθηκαν, ανήκουν σε γεωτεκτονικές ενότητες, με βασικό κοινό τους χαρακτηριστικό, τις μεγάλες ανθρακικές ακολουθίες. Τα σπήλαια που εντοπίζονται βραχογραφίες, εμφανίζονται σε ιζηματογενή και μεταμορφωμένα πετρώματα με αναλογία περίπου 1:3. Απαντούν κυρίως σε ασβεστόλιθους, δολομίτες και μάρμαρα. Η πλειοψηφία τους αναπτύσσεται κυρίως σε μάρμαρα και σε ποσοστό περίπου 56% (Σχήμα 3).

Η λιθολογία των βραχογραφιών που εντοπίστηκαν στο ύπαιθρο παρουσιάζεται στο Σχήμα 4. Η συντριπτική πλειοψηφία αυτής της κατηγορίας και σε ποσοστό 60% έχουν χαραχτεί σε μάρμαρα.

Σχήμα 3. Η λιθολογία των βραχογραφιών στα σπήλαια.

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Σχήμα 4. Η λιθολογία των βραχογραφιών στο ύπαιθρο.

Συνολικά, βρέθηκε ότι 86,71% των βραχογραφιών έχουν χαραχθεί σε μάρμαρα, ενώ το 13,29% σε ασβεστόλιθους. Το γεγονός αυτό εξηγείται, καθώς τόσο τα σπήλαια όσο και οι ορεινοί όγκοι που έχουν μελετηθεί, αναπτύσσονται σε καρστικές περιοχές όπου επικρατούν τα ανθρακικά πετρώματα. Επομένως οι βραχογραφίες, που εντοπίζονται τόσο στα σπήλαια, όσο και στο ύπαιθρο στον ελλαδικό χώρο, αποτελούν αδιάψευστες μαρτυρίες για τους γηγενείς κατοίκους και αποδεικνύουν τη διαχρονική σχέση του ανθρώπου με το καρστ.

Συμπεράσματα

Μελετώντας τη θεματολογία των βραχογραφιών εμφανίζονται μορφές ανθρώπων και ζώων στο 50% των βραχογραφιών, τα σύμβολα απαντούν στο 40%, ενώ τα όπλα εντοπίζονται μόλις στο 10% των βραχογραφιών. Τα αποτελέσματα έδειξαν ότι το 87% των βραχογραφιών έχουν χαραχθεί σε μάρμαρα, ενώ το 13% σε ασβεστόλιθους. Οι βραχογραφίες, που εντοπίζονται στον ελλαδικό χώρο αποδεικνύουν τη διαχρονική σχέση του ανθρώπου με το καρστ.

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Περιβαλλοντικές και Ιζηματολογικές Μεταβολές στην Κοιλάδα του Ανθεμούντα Ποταμού

Σ. Δοάνη [1], *I. Hildebrandt-Radke* [2], *Κ. Βουβαλίδης* [1], *Κ. Αλμπανάκης* [1], *Γ. Συρίδης* [3]

(1) Τομέας Φυσικής και Περιβαλλοντικής Γωγραφίας, Τμήμα Γεωλογίας, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, 541 24 Θεσσαλονίκη, doanisofia@geo.auth.gr, vouval@geo.auth.gr, albanaki@geo.auth.gr
(2) Department of Quaternary Geology and Palaeogeography, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, Krygowskiego Str. 10, 61-680 Poznań, Poland, hilde@amu.edu.pl
(3) Τομέας Γεωλογίας, Τμήμα Γεωλογίας, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, 541 24 Θεσσαλονίκη, syrides@geo.auth.gr

Εισαγωγή

Η κοιλάδα του Ανθεμούντα βρίσκεται στην ανατολική πλευρά του κόλπου του Θερμαϊκού, στην Βόρεια Ελλάδα. Η κοιλάδα ονομάστηκε έτσι λόγω του ποταμού Ανθεμούντα ο οποίος ρέει από Ανατολικά προς τα Δυτικά και έχει μήκος 40 χλμ. Πολλές παλαιοπεριβαλλοντικές έρευνες για την περιοχή της Μεσογείου έχουν επικεντρωθεί στις περιβαλλοντικές και κλιματικές αλλαγές του Ολοκαίνου, χρησιμοποιώντας κυρίως δεδομένα από την θάλασσα, λίμνες, λιμνοθάλασσες, δέλτα και σπήλαια, με διάφορες μεθοδολογίες. (e.g., Vött, 2004; Vouvalidis *et al*., 2005; Evelpidou *et al*., 2010; Vouvalidis *et al*., 2010; Fletcher and Zielhofer, 2013; Triantaphyllou *et al*., 2016; Avramidis *et al.*, 2017; Colonese *et al.*, 2018; Koukousioura *et al.*, 2019; Roberts *et al.*, 2019). Ωστόσο, πολύ λιγότερες μελέτες επικεντρώνονται σε δεδομένα ποταμών που αποκαλύπτουν περιβαλλοντικές αλλαγές. Διάφοροι ερευνητές υποστηρίζουν ότι οι ποτάμιες αποθέσεις μπορούν να χρησιμοποιηθούν για την ανακατασκευή παλαιότερων διεργασιών απόθεσης μέσω των ιδιοτήτων των ιζημάτων. Ο Zielhofer (2008) υποστηρίζει ότι παρόλο που τα δεδομένα που προέρχονται από ποτάμια δεν είναι σαφείς κλιματολογικοί δείκτες, όπως αυτά από πάγους ή την θάλασσα, ωστόσο θα μπορούσαν να καταγράψουν αποτελεσματικά τις γεωμορφολογικές αντιδράσεις σε κλιματολογικές αλλαγές.

Πιο συγκεκριμένα, τα δεδομένα που προέρχονται από ποτάμια ουσιαστικά αντιπροσωπεύουν μια ολόκληρη λεκάνη απορροής και μπορούν έτσι να προσφέρουν μια γενικότερη εικόνα των περιβαλλοντικών διεργασιών της περιοχής. Η ανάλυση του μεγέθους των κόκκων έχει χρησιμοποιηθεί εκτενώς σε παλαιοπεριβαλλοντικές μελέτες για να ανιχνεύσει την προέλευση διαφόρων ιζημάτων, όπως αναφέρουν οι Opreanu *et al*. (2007), Mycielska-Dowgiałło and Ludwikowska-Kędzia (2011). Η χρήση κοκκομετρικών αναλύσεων καθιστά δυνατή τη συλλογή πληροφοριών όχι μόνο για περιβάλλοντα απόθεσης αλλά και για την ενέργεια και τη φύση του μέσου μεταφοράς. Ακόμη, σύμφωνα με τον Benito *et al.*, (2015) μπορούν να εντοπιστούν μεταβολές μεταξύ περιόδων υψηλής και χαμηλής απορροής μέσω ιζηματολογικών δεδομένων.

Η παρούσα μελέτη επικεντρώνεται σε ποτάμιες ακολουθίες ιζημάτων βάθους πάνω από 20 μ. που δεν έχουν μελετηθεί έως τώρα στην κοιλάδα του Ανθεμούντα. Συγκεκριμένα, γίνεται η συσχέτιση μεταξύ των ποτάμιων διεργασιών και των φάσεων απόθεσης των ιζημάτων χρησιμοποιώντας την κοκκομετρική ανάλυση προκειμένου να γίνουν υποθέσεις σχετικά με τις

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επικρατούσες περιβαλλοντικές συνθήκες του Α. Πλειστοκαινου και Ολοκαίνου. Η ανάλυση των ιζηματογενών αποθέσεων και η διαίρεσή τους σε ζώνες μπορούν να βοηθήσουν στον προσδιορισμό του ιζηματογενούς περιβάλλοντος και στην καλύτερη κατανόηση των διεργασιών κατά τη διάρκεια της ιζηματογένεσης.

Μεθοδολογία

Στις εργασίες πεδίου που εκπονήθηκαν, περιλαμβάνονται παρατηρήσεις σε σχέση με την γεωμορφολογία της περιοχής καθώς και την στρωματογραφία. Με τη βοήθεια λογισμικού G.I.S έγινε χρήση και ερμηνεία ιστορικών, γεωλογικών χαρτών και δορυφορικών εικόνων από το Google Earth για την εξαγωγή πληροφοριών σχετικά με τη γεωμορφολογική εξέλιξη και τα χαρακτηριστικά της περιοχής μελέτης. Λήφθηκαν συνολικά οκτώ πυρήνες γεωτρήσεων και ο καθένας φωτογραφήθηκε και περιγράφηκε στο πεδίο ως προς τη λιθολογία και το χρώμα (Munsell Soil Color Chart).

Πραγματοποιήθηκε ιζηματολογική ανάλυση για 631 δείγματα από δύο πυρήνες, που επιλέχθηκαν ως οι πιο αντιπροσωπευτικοί. Το σύνολο των δειγμάτων κοσκινίστηκε για τα κλάσματα των κόκκων > 2 mm με μια σειρά κόσκινων ανα μισό phi (φ). Τα πιο λεπτόκοκκα μέρη αναλύθηκαν χρησιμοποιώντας το Malvern Master Sizer Hydro 2000, μετά την απομάκρυνση της οργανικής ύλης με H_2O_2 (10%) (Trautmann *et al*., 2000a; b).

Τα στατιστικά στοιχεία υπολογίστηκαν με το λογισμικό Gradistat (Blott and Pye, 2001), χρησιμοποιώντας την μέθοδο των Folk και Ward (1957). Υπολογίστηκαν η μέση διάμετρος των κόκκων (M_z), η λοξότητα (Sk_I), η ταξινόμηση ($σ_I$) και η κύρτωση ($K_{.I}$), και οι κατανομές μεγέθους κόκκων εκφράστηκαν σε διαγράμματα ως αθροιστικές καμπύλες και καμπύλες συχνότητας. Η σύγκρισή τους χρησιμοποιήθηκε για την αναπαράσταση των διεργασιών απόθεσης (Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011). Στη συνέχεια, εφαρμόστηκε η μέθοδος loss-on-ignition (L.O.I) για τον υπολογισμό του ποσοστού της οργανικής ύλης και του ποσοστού ανθρακικού ασβεστίου. Σύμφωνα με την συγκεκριμένη μεθοδολογία, η καύση πραγματοποιείται στους 550^oC για 4 ώρες και στους 950^oC για 2 ώρες (Dean, 1974; Heiri *et al*., 2001). Τα αποτελέσματα που προέκυψαν από την ανάλυση των πιο λεπτόκοκκων ιζημάτων και τα αποτελέσματα την ανάλυσης με την μέθοδο L.O.I επεξεργάστηκαν περαιτέρω χρησιμοποιώντας το πακέτο λογισμικού TILIA (Grimm, 1993). Έτσι, ορίστηκαν οι στρωματογραφικές ζώνες.

Επιπλέον, δημιουργήθηκαν λογαριθμικά διαγράμματα CM σύμφωνα με τη μέθοδο Passega (1957; 1964). Τα σημεία που αντιπροσωπεύουν κάθε δείγμα στο διάγραμμα CM, δίνουν πληροφορίες για το περιβάλλον της μεταφοράς και της απόθεσης. Η ραδιοχρονολόγηση με την μέθοδο [14]C - A.M.S. πραγματοποιήθηκε για δέκα δείγματα από τους πυρήνες E2-1 και TP1-1. Τα δείγματα βαθμονομήθηκαν χρησιμοποιώντας το OxCalonlinev. 4.3 (Bronk Ramsey, 2009a; Bronk Ramsey and Lee, 2013) και την καμπύλη IntCal 13 (Reimer *et al.*, 2013).

Αποτελέσματα - Συμπεράσματα

Η λιθοστρωματογραφία των πυρήνων E2-1 και TP1-1 (Πίνακας 1) βασίζεται στην κοκκομετρική ανάλυση και την μακροσκοπική περιγραφή των ιζημάτων. Έτσι, οι πυρήνες E2-1 και TP1-1 αποτελούνται από επτά και οκτώ λιθολογικές ζώνες αντίστοιχα. Οι περιβαλλοντικές φάσεις

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προσδιορίστηκαν με την βοήθεια των ιζηματολογικών δεικτών και των διαγραμμάτων, ενώ η ηλικία - περίοδος από την ραδιοχρονολόγηση.

Πίνακας 1. Περιβαλλοντικές φάσεις και χρονοστρωματογραφική περιγραφή των ζωνών, γεωτρήσεις Ε2-1 καιΤΡ1-1.

Γεώτρηση	Βάθος (cm asl)	Ζώνη	Βάθος (cm)	Ηλικία (^{14}CyrBP)/ Περίοδος	Περιβαλλοντικές φάσεις
TP1-1	+1100 – +795	7	0-305	Late Holocene	Overbank-pool & overbank current
	+795 – +620	6	305-480	Late Holocene (2910 ± 30)	Overbank-pool & overbank current
	+620 –+490	5	480-610	Late Holocene	Overbank-pool
	+490 –+190	4	610-910	Late Holocene (3630 ± 35)	Overbank current
	+190—80	3	910-1180	Middle Holocene	Overbank current
	-80—280	2	1180-1380	Early Holocene	River channel
	-280—960	1b	1380-2060	Late Pleistocene	River channel-thalweg & overbank current
	-960—1300	1a	2060-2400	Late Pleistocene	Overbank-pool
E2-1	+800—+650	7	0-150	Late Holocene	Overbank-pool
	+650—+250	6	150-550	Late Holocene	River channel & overbank current
	+250—400	5	550-1200	Late Holocene (2930 ± 30)	Overbank-pool
	-400—825	4	1200-1625	Early Holocene (9020 ± 50)	Overbank-pool
	-825—1100	3	1625-1900	Late Pleistocene	River channel-thalweg & overbank current
	-1100—1350	2	1900-2150	Late Pleistocene (26760 ± 190)	Overbank-pool
	-1350—1595	1	2150-2400	Late Pleistocene	River channel & overbank current

1. Από τα παραπάνω αποτελέσματα, συμπεραίνεται ότι η παλαιοπεριβαλλοντική εξέλιξη της περιοχής μελέτης θα μπορούσε να εκφραστεί μόνο ως μια γενική τάση. Αυτό συμβαίνει γιατί υπάρχει επιβεβαιωμένο στρωματογραφικό κενό στην ιζηματογένεση κατά τη μετάβαση από το Πλειστόκαινο προς το Ολόκαινο υποδηλώνοντας έντονη διάβρωση, ενώ η έλλειψη υλικού απαγορεύει τη λεπτομερή ραδιοχρονολόγηση σε όλο το μήκος των πυρήνων. Παρόλα αυτά, οι παράλληλες περιβαλλοντικές διεργασίες είναι ιδιαίτερα σαφείς.

2. Η ιζηματολογική ανάλυση δεν έδειξε στοιχεία για την ύπαρξη θαλάσσιου περιβάλλοντος, άρα η σταδιακή άνοδος της θάλασσας κατά το Ολόκαινο δεν έφτασε ποτέ σε αυτό το σημείο της κοιλάδας. Η σύγκριση μεταξύ των δύο πυρήνων αποκάλυψε σημαντικές διαφορές μεταξύ τους. Αρχικά, οι αποθέσεις του πυρήνα ΤΡ1-1 αποτελούνται κυρίως από υλικά που μεταφέρονται από τις βόρειες πλαγιές της κοιλάδας, ειδικά κατά το Α. Πλειστόκαινο έως το Μ. Ολόκαινο. Τα πιο αδρόκοκκα υλικά των ζωνών 1a, 1b, 2 και 3 επιβεβαιώνουν την έντονη πρόσχωση που συνέβαινε κατά το Πλειστόκαινο καθώς και την υψηλή υδρολογική δραστηριότητα στις αρχές του Ολοκαίνου. Η ενέργεια μεταφοράς τότε ήταν σχετικά υψηλή

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καθώς υπάρχουν και υλικά που μεταφέρονται από το σύστημα των αλλουβιακών ριπιδίων. Ωστόσο, κατά το Α. Ολόκαινο, υπάρχει μια αλλαγή στο περιβάλλον με την παρουσία έντονων πλημμυρικών πεδίων.

3. Ο πυρήνας Ε2-1 αποτελείται από ακολουθίες πλήρωσης της κεντρικής κοιλάδας με εναλλαγές ιζημάτων που προέρχονται εντός και εκτός της ποτάμιας κοίτης και κάποια πλημμυρικά πεδία. Συνοπτικά, η ιζηματογένεση του Ολοκαίνου αποτελείται από πιο λεπτόκοκκα υλικά ενώ οι ζώνες των πιο αδρόκοκκων ιζημάτων δηλώνουν την παρουσία υλικών πρόσχωσης που συνέβαινε κατά το Πλειστόκαινο από τη διάβρωση της λεκάνης απορροής.

4. Μετά από 3500 cal. B.P. και οι δυο γεωτρήσεις επηρεάζονται από τον πιθανό σχηματισμό ενός bay-head δέλτα, με παρουσία ιζημάτων μεγέθους άμμου ποτάμιας προέλευσης και εκτεταμένα πλημμυρικά πεδία.
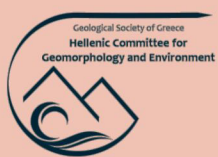
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