FORMALISATION OF A GIS-BASED METHODOLOGY FOR LANDSCAPE CHANGE ANALYSIS: EXAMPLE OF EROSION ON NAXOS ISLAND, AEGEAN SEA, GREECE

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1. Introduction

A Geographical Information System (GIS) utilises specialised software for spatial analyses. Early computer programs for GIS were introduced in the United States in the late 1950s by the U.S. Census (Clarke 2002). In the early 60s the development of Canada Geographic Information Systems (CGIS) commenced, led by Roger Tomlinson, aiming to analyse Canada's national geographic inventory. At about the same time, Howard Fisher developed Synagraphic Mapping System (SYMAP), a pioneering automated computer mapping application. He started these developments at the North-western Technology Institute, University of Chicago, and completed them at the Harvard Lab for Computer Graphics and Spatial Analysis. GIS has, for decades, been seen only as a software package which may help to accomplish spatially related analytical tasks. It is often associated with the software used for the implementation of a GIS technical structures and concepts, which enables combining data coming from different sources and in various formats, capturing, storing, manipulating, analysing, and displaying spatially referenced data. GIS has grown as a field, at first expanding in local and regional governmental sectors (Greene and Pick 2006). Today, GIS has been applied in many different areas such as transportation, landscape changes analysis, emergency management, city and regional planning, to mention only a few.

The experience gained from all these experiments and applications of using a GIS for spatial analysis often resulted in a set of procedures that need to be undertaken in order to get research results. In this article this set of procedures and tasks based on GIS software are called a GIS-based methodology. The need for formal approaches in designing a GIS-based methodology is stressed. An example of slope erosion and discussion of the steps that need to be taken in order to get the research results are presented. The advantage of a formalised methodology is that it is documented and can be used by other researchers in the same research area.

The article is organised as follows: The next section provides an introduction into the research in landscape change. The third section explains the situation on the island of Naxos, the erosion processes on the island and their consequences. We summarise the main research issues and stress the need for a formalisation of a GIS-based methodology for the estimation of erosion risk. Section 4 is dedicated to the theoretical approach to the methodology, which is implemented on the study case of Naxos Island

and presented in the following section. The final section provides suggestions for formal languages which could be used for the formalisation of GIS-based methodologies. We conclude the article with a discussion and further research directions.

2. Research in Landscape Change

Landscape refers to a common perceivable part of the Earth's surface (Zonneveld 1995). After Hartshorne "landscape" is defined as the external surface of the Earth beneath the atmosphere (Hartshorne 1939). It is an arbitrarily defined section of the Earth's surface which can be scientifically analysed under certain factors such as the elements, composition, structures and functions of the landscape. Archaeologists, geographers, geomorphologists, historians, landscape planners and other related researchers are interested in understanding landscapes and their changes through time and space. The research of landscape alterations includes many separate stages which depend on the nature of the studied changes and the time during which they took place. These changes are caused either by the natural factors or human activities. Natural forces have the power to exert tremendous changes on the structure and functions of landscapes. Research in this area focuses upon different phases of the change process such as the identification of change influencing factors, the change itself, and its consequences (figures 1a, b, c and d). Research in landscape change includes the analysis of factors involved in preventing potential altering events and studies possible scenarios and decision making in landscape planning in order to understand, affect and potentially control landscape change.

Researchers in the field of slope erosion analyse the influencing factors, for example, how the amount of superficial water runoff determines the amount of the transported sediment, the vulnerability of certain areas, or the impact of the erosion and its consequences (Sabot *et al.* 2002; Gournelos *et al.* 2004). The morphological slope strongly influences the speed of water runoff and, if severe, results in decreasing landscape diversity which in turn makes landscapes more vulnerable to erosion (figure 2) (Marin-Yaseli and Lasanta Martinez 2003). This is of major importance for some environments, e.g.

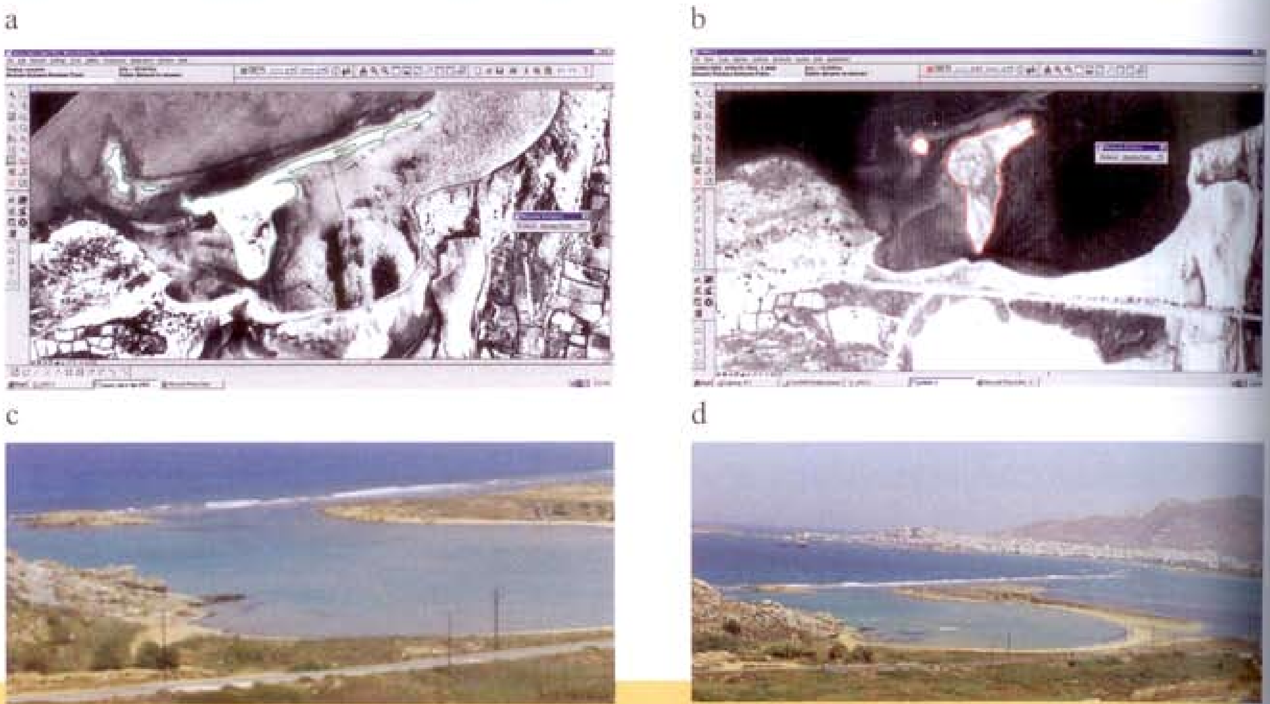


Figure 1: Coastal zone evolution in relation to sea-level rise in the case of the Agios Georgios bay of the island of Naxos. Image (a) corresponds to an aerial photograph of 1960 and (b) of 1988 (from Evelpidou 2001), while photographs (c) and (d) are taken in 2000 and 2007 accordingly (©Vassilopoulos and Evelpidou 2000; 2007). Apart from the rapid change of Manto Island, the tombolo has eventually been created only in the image (d)

Figure 2: Hogbacks in the eastern part of the island, formed because of the differential erosion of the geological formations (©Vassilopoulos and Evelpidou 2005)

Figure 3: Coastal erosion in the western part of Naxos, causing the retreating of sand dune fields (©Vassilopoulos and Evelpidou 2005)

Figure 4a/b: Erosion caused because of a floods in Naxos, 2003 (© Kontopoulos 2003)

he Mediterranean, where active processes of :rosion are observed on soil and surface rocks Poesen and Hooke 1977). Soil thinning makes t rather time consuming, and even impossible to ıdequately reestablish the centuries-old terraces 'or fruitful cultivation.

:oastal erosion due to wave action often threat- :ns coastal areas and formations (figure 3), undermining the natural environment as well as human constructions.

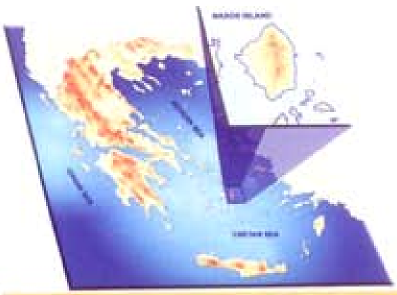


Figure 5: Naxos Island

Coastal erosion studies depend upon several factors, such as the type of rocks in the coastal zone, their inner structure (discontinuities, fissures, cracks, etc.), currents along a shore, wave regime, etc.

Last but not least, erosion occurs because of flooding. Figure 4 shows an example of Naxos Island after the flood which took place in 2003.

3. Case Study: Erosion on Naxos Island

3.1 Current Situation

A characteristic example from the Mediterranean is Naxos Island. Naxos is the biggest island of the Cyclades island group in the Aegean Sea (Greece) with a surface of 430 km^2 (figure 5).

Naxos is the most fertile island of the Cyclades. It has a relatively good supply of water in a region where water is usually inadequate. Mount Zas (1,001 m) is the highest peak in the Cyclades, permitting greater rainfall which has made agriculture an important economic factor. Naxos, like the rest of the Cyclades, receives very little precipitation (Theocharatos 1978). The mean annual precipitation in Naxos is 366,8 mm (figure 6).

Month	Precipitation (mm)
January	67,6
February	54,2
March	45,8
April	17,4
May	9,8
June	2,6
July	6
August	2
September	5,5
October	36,6
November	50,6
December	68,7

Figure 6: Annual variation of precipitation for the last 10 years, averaged

Naxos Island, along with the rest of the islands in Cyclades, has experienced tremendous landscape changes during the last 50 years. Many residents abandoned the cultivated land in high slope areas. These slopes required the construction and maintenance of terraces in order to keep the soil from eroding (figure 7), which required a significant cost in time and money. The size and shape of the (small) terraces inhibited machinery, which further reduced viability and productivity. The result of the abandonment of terraces is the progressive loss of the soil's resources, leading to soil thinning and shrub growth.

Figure 7: Well preserved cultivation terraces near Koronos village, which is now rarely found in the Cyclades (©Vassilopoulos and Evelpidou 2000)

3.2 Research Questions

The initial question concerned the determination of areas on the island of Naxos, which are particularly vulnerable to erosion due to runoff. However, we needed to ask some other preliminary questions first. Some of the additional research questions were:

- What are the main parameters affecting erosion?
- What are their co-relation and impact?
- How can the individual parameters be estimated?
- Do some of these parameters depend upon a series of other sub-parameters that need to be considered?
- How does every sub-parameter weigh in the determination of the general one? And what is their relevant importance in the determination of the erosion risk index?
- Which model shall be used for the analysis of the selected study area?
- Which model best fits to the data available for the study area?
- Would it be better to develop a specific model for the study area or select an existing one?

Research questions related to the modelling:

- Which logic should the model follow?
- How credible are the results of the model? How can they be cross-tested?
- How can the model be improved?
- Are there any similar models available from other researchers?

Our research aims at better understanding of the erosion processes in the selected area. A selection of the parameters influencing the landscape change caused by erosion and an appropriate model can improve the analysis of the study area. New software tools such as geoinformation systems (GIS) and remote sensing can improve the analytical process.

4. Designing a GIS-Based Methodology

GIS-based systems are becoming increasingly complex and there is a need for extensive design/preparation prior to embarking upon costly implementation phases. Very often they are loosely integrated with other IT tools and methods such as, for example, remote sensing interpretation methods and procedures. This makes the system and the combination of different software packages even more complex. All these different components support separate tasks and processes and are very often implemented spontaneously, depending on the current ideas and needs of the researchers. A more systematic approach to modelling such complex systems is needed. The characteristics of a good methodology are:

- The methodology is *adaptive*, which means that the new findings gained in the process can be implemented in the methodology; such methodologies try to be processes and sets of tasks that can adapt and thrive on change, even to the point of changing the methodology itself;
- The methodology is *exchangeable*, which means that it can be exchanged by research groups and individuals; when used by different researchers it will bring the same results no matter who has implemented it. The advantage lies in a methodology which is developed, formalised and efficient, and can be repeated in various research studies within the same or similar research areas.

The development of a methodology prior to executing the computer-based analysis may bring many benefits to the researchers.

4.1 Methodological aspects

A methodology has the following aspects: cognitive, social and technological. All three aspects are interlinked and have an impact on the final results of the research. Usually software design processes focus on the technological aspects of the methodology. Technologically considered, a GIS-based methodology represents a set of procedures defined and applied by the landscape change researcher using GIS and other IT products. It mainly focuses on the technical part of the methodology and its implementation in the process of analysis.

The cognitive part of the methodology tries to be sensitive to human perception and to the way the human mind perceives, understands and interprets (geo)information. This is especially relevant for the satellite and areal images which consist of pixels. A computer image is made up of raw pixels of different colours. By the first grouping rule, humans identify neighbouring pixels that have the same colour as belonging to the same coloured patch. By the second grouping rule, they identify chains of pixels that describe straight and curving lines. By the third grouping rule, the more complex textures, such as cross-hatched shading can be identified. In the end, we do not perceive the raw pixels, but instead perceive the shapes and outlines. The "figure-ground effect" describes how certain coherent shapes become detached from the background, which is the process of visual abstraction.

The social aspects of a methodology deal with the social implications of the technology-based methodology. It considers social effects of implementing new techniques and procedures within the research team or organisation. Such effects include changing the educational demands for the employees, the need for less employees (but more skilled), changing the tasks that need to be performed and their impact on the changes of the organisation, and process reengineering.

4.2 Methodology design loop

A GIS-based methodology for landscape change research starts with a research question, or a set of research questions. The question is the initial trigger for the design of a GIS-based methodology, its implementation and final presentation of the research results. The initial trigger is followed by a methodology loop which includes a description of the steps and phases necessary to undertake the landscape change research (figure 8). A methodology loop consists of the methodology design, its implementation and completion criteria (revisited after) (Krek and Evelpidou 2008). The methodology loop concept stresses the need of revisions as the result of the new insights gained in the process of research and methodology implementation. For example, in the phase of the use of a GIS tool, the researchers might recognise the need for using other analytical tools. This new knowledge should reflect itself in the methodology design, including new software tools, into the methodology design. The implementation of the new methodology design follows the goal of the completion criteria. In case the completion criteria are fulfilled and the research hypothesis has been either proved or rejected, then the scientific results in landscape research can be presented. Examples of the scientific result(s) presentation include creation of digital maps with a variety of representational possibilities offered by GIS software, or computer based simulation, for example, for the cases of emergency such as flood or fire.

4.3 Methodology design elements

Methodology design includes defining the elements of the GIS-based methodology (figure 9). These elements are data sources, input information and knowledge, data needed for research, steps and procedures that need to be undertaken in the process of research, GIS and other IT tools needed to support the analytical functions, and expected scientific results.

Several factors influence the selection of the methodological procedures and software which can support the researcher. When dealing, for example, with erosion processes, the researcher has to clarify the interactive factors in order to attain erosion's final result. In this case, the first step is to analyse and to understand the role of each factor in an erosion process, and then to define the way these factors interact in order to simulate them and generate a "forecast" which contains the requested result (Krek and Evelpidou 2008).

The design of the methodology is followed by the actual use and implementation of the software in the phases defined within the methodology (figure 9). The use of particular GIS functionalities depends on the analysis supported by the software. In the analysis of the erosion processes, for example, the researcher conducts a simulation with the help of GIS tools. If the simulation is perceived as a function and the rest of the factors as variables, then the first case is to import the influencing factors into the GIS. In the final stage the landscape researcher performs a scientific analysis of the results gained from the use of GIS and other analytical tools.

4.4 Methodology path

The methodology path describes the shortest path from the research question to the accomplishment of the researcher's aim and presenta-

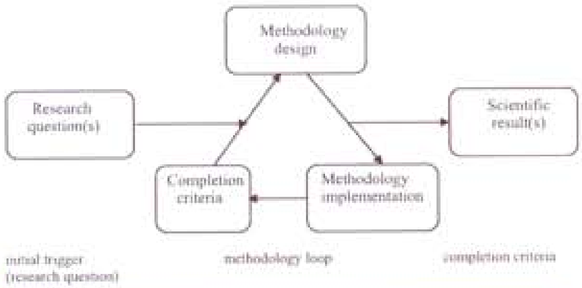


Figure 8: Methodology design loop

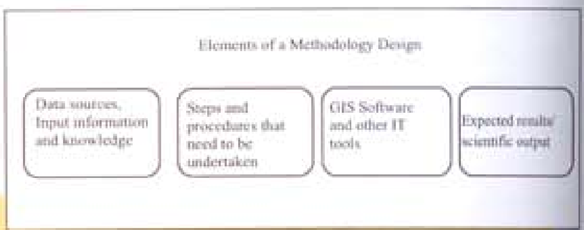


Figure 9: Elements of a methodology design (revisited after Krek and Evelpidou 2008)

tion of the scientific results. On this path each technique builds on the results produced by earlier techniques used in the early phases of the research. All techniques are chosen for their fitness-of-purpose and are evaluated in their originally intended context of usage. The methodology path is the shortest path and therefore utilises the most efficient use of techniques in the phases where such support is needed.

5. Design of a GIS-Based Methodology for Studying Erosion on Naxos Island

The main research question was to determine the erosion vulnerability for the whole island of Naxos. The complete set of research questions were presented above. This section concentrates on the methodology designed for our analysis. Figure 10 shows an example of the elements used within the methodology designed for the analysis of the spatial distribution of erosion risk's (Sabot *et al.* 2002; Gournelos *et al.* 2004). This analysis is determinative for the prevention of forthcoming erosion events and focuses on the investigation of erosion risk in the selected area. The methodology based on a GIS used for analysis and predictions, enables one to depict results on thematic maps (figure 10).

5.1. Data sources

Data are derived from different sources, including printed maps, aerial photos, satellite images, fieldwork data, and the literature relevant for the analysis of erosion risk. The already existing printed maps were used, which were mainly geological and topographical maps. The working scales for the topographical and geological maps are 1:25 000 and 1:50 000 respectively. The aerial photos used for stereo-interpretation were acquired in stereo-pairs in a 1:33 000 scale. Two different timescale aerial photos were obtained; 1960 and 1988. The satellite image was used in order to map the present day geomorphological and environmental characteristics.

Fieldwork took place from 2005 to 2007 in different time periods. During fieldwork the geomorphological cartography of the area took place in order to develop the geomorphological map of Naxos in a scale of 1:25 000. Additionally, discontinuities were measured, and samples of healthy and weathered rock were taken for the determination of Slake Durability in the laboratory.

The development of erosion risk maps involves a series of different stages, such as:

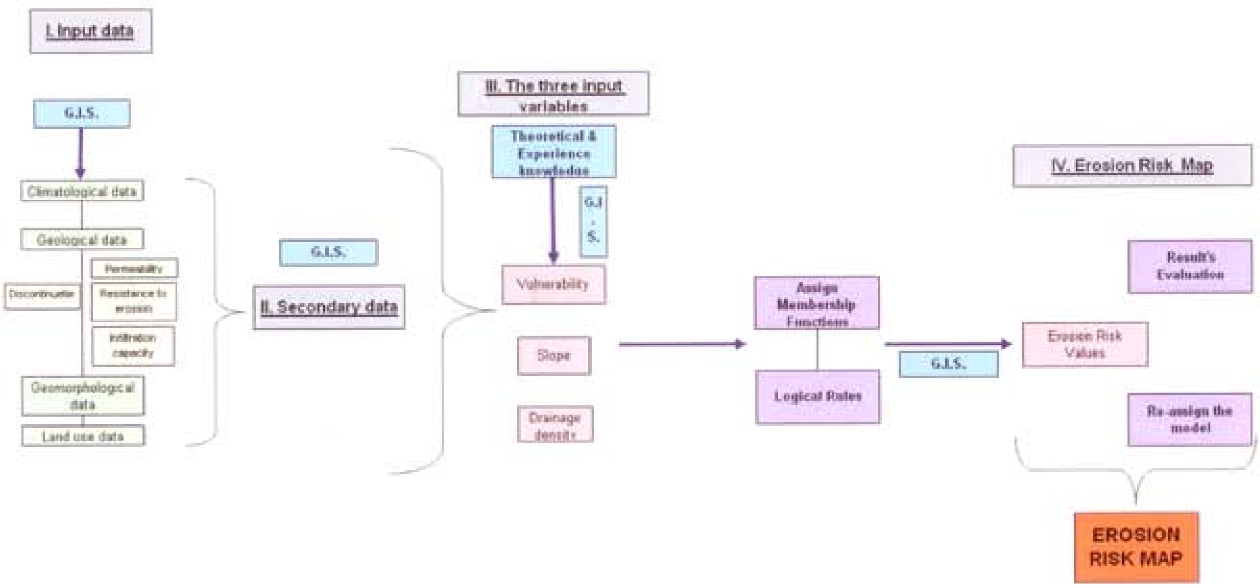


Figure 10: A methodology for the estimation of erosion risk

a

b

Figure 11: a) Recumbent fold inside the marble-schist system, with an axis of NNE-SSW direction; b) Veins inside marbles and posterior tectonics

- Fieldwork for the mapping of geomorphological, geological (e.g. discontinuities) (figure 11a/b) and environmental elements, for sampling where necessary (rock sampling for Slake Durability lab testing) and for measurements of the discontinuities' direction and gradient;
- Aerial photo stereo-observation in order to map the geological (figure 12) and geomorphological features as well as the land uses;
- Digitisation of primary data e.g. geological, topographical and morphological, deriving from pre-existant maps, as well as data deriving from photointerpretation and fieldwork;
- Definition of the input and output variables;
- Establishment of logical rules between the input and the output variables;
- Primary results check;
- Calibration of the model and reprocess;
- Analysis and visualisation of the results.

5.2. Followed methodology

GIS was used in most of the above stages, while fuzzy sets theory was used in some of them.

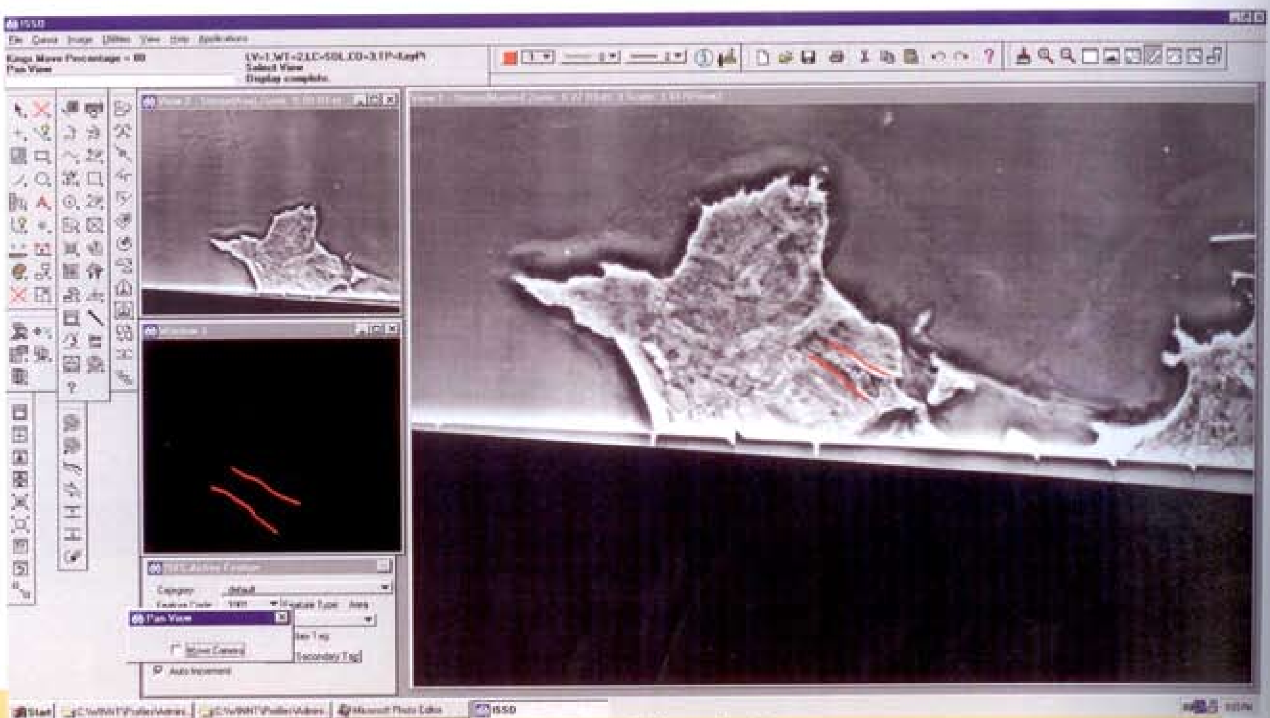


Figure 12: Aerial photo stereo-observation and mapping of discontinuities

The principal variables used for the estimation of Naxos' erosion risk model, which were cal-ulated for each pixel, are listed (following).

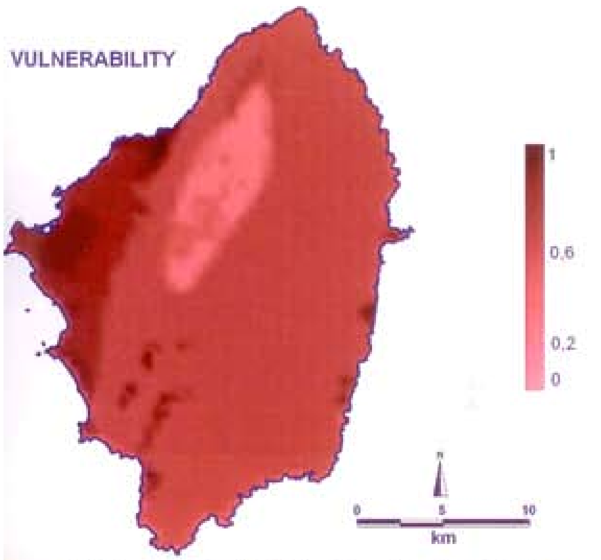
. Vulnerability of the rocks in erosion

The vulnerability to erosion variable (figure 13) s very complicated as it depends on the physi-al and chemical composition of the rock and he existence of major (folds, faults) and minor bedding, foliation and joints) tectonical struc-ures. The mineral composition is critical as well, is it has been proved that olivine, augite, horn-lende, biotite and in general, dark-coloured ninerals are more susceptible to weathering han orthoclase, muscovite, quartz, and other ight-coloured minerals (Sparks 1965). Gen-erally, the vulnerability of the rock to erosion lepends on the lithology involving the rock's iardness, permeability, infiltration capacity, the nicro-tectonic structures of the rocks and the nacro-tectonic structures of the area, the proc-ss involved in any protective mechanisms, and inally the geomorphological status.

ithology is connected to the hardness of the ocks and the resistance to erosion. This variable s difficult to measure directly. Some observa-ions on the resistance of rocks to abrasion have een compiled into a rock list with decreasing resistance to erosion (Kuenen 1956). On the other hand, Selby has proposed a rock mass strength classification and rating to express the resistance to erosion (Selby 1987). In the above classification, limestones are more resistant to erosion than schists.

The grain's form and size define rocks' perme-ability. This variable controls the quantity of the runoff water, which is the dominant erosion factor. Three categories of permeability values may be distinguished: very low (10-12 – 10-8 m/s), low to medium (10-8 – 10-5 m/s) and high (10-5 – 10-2 m/s) (Bolton 1979). Metamorphic schists are considered to have very low perme-ability while marbles are quite permeable forma-tions. The amount of runoff and underground water depends on the surface deposit's infiltra-tion properties. In general, coarse grain deposits present high infiltration rates. The infiltration ca-pacity of the surface deposit strongly influences erosion (Horton 1945; Kirkby 1969).

The geomorphological status of the region is also important since, according to the geomor-phological features, the amount of water runoff is changing. For example, in planation surfaces the water runoff takes place in sheets rather than in streams, favouring uniform erosion.



igure 13: Geographical distribution of vulnerability nput variable on Naxos Island

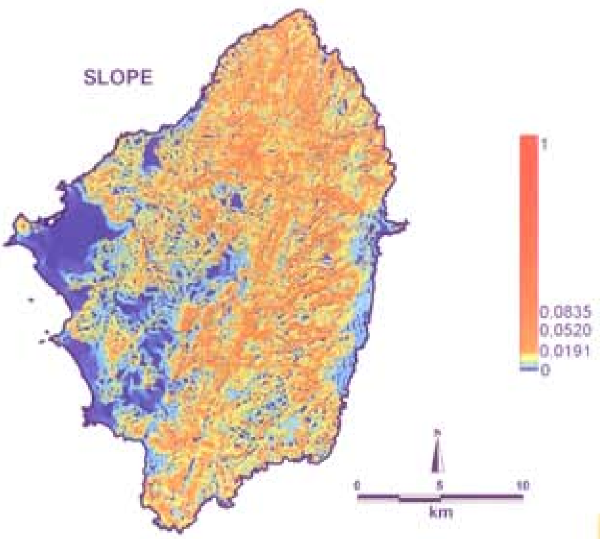


Figure 14: Geographical distribution of morphological slope input value

Finally, the existence of vegetation acts as a protective mechanism for erosion processes and has to be taken into account. Land use is responsible either for the change of infiltration rates (e.g. the sealed surface of an urban region has almost zero infiltration, favouring runoff) or the alteration of runoff speed (e.g. an area covered with grass) has slower runoff and thus lower sediment transfer capacity than an area with bare rocks.

To ascertain the weathering processes, the Slake Durability test was used. Thus, in order to estimate the vulnerability for erosion, sampling took place during fieldwork in both healthy and weathered rock, which was then tested in the laboratory for the determination of the rock's durability. This test estimates the rock's resistance to the degradation that occurs through a specific cycle of desiccation and wetting. The main purpose of this test is to calculate the rock's resistance to weathering. The slake durability index is being determined and used for comparative study. This test accelerates weathering, by combining the fragmentation and sieving procedures. Each dissection of the nodules begins defragmentation processes in the new faces opened. Lastly, in order to examine the impact of the discontinuities (minor and major) on the rock's durability, their exact position and direction was determined through fieldwork.

b. Slope gradient of the morphology

The second variable that has been processed is the morphological slope gradient of each pixel (figure 14). Apart from the slope gradient, form (convex or concave), aspect (figure 15) are also important factors. It is obvious that slope steepness is critical to the erosion intensity. Schumm proved that there is an exponential relation between average slope and sediment-yield (Schumm 1977).

c. Drainage density

Finally, the last input variable was drainage density, which is defined as the ratio of the total stream lengths to the drainage basin's area, and highly related to water's runoff quantity and the substratum's permeability (figure 16). In general, drainage density is high at basins of weak impermeable rocks and low in basins of resistant and permeable rocks. It has been shown that drainage density increases according to the basin's average slope (Gregory and Wallig 1973).

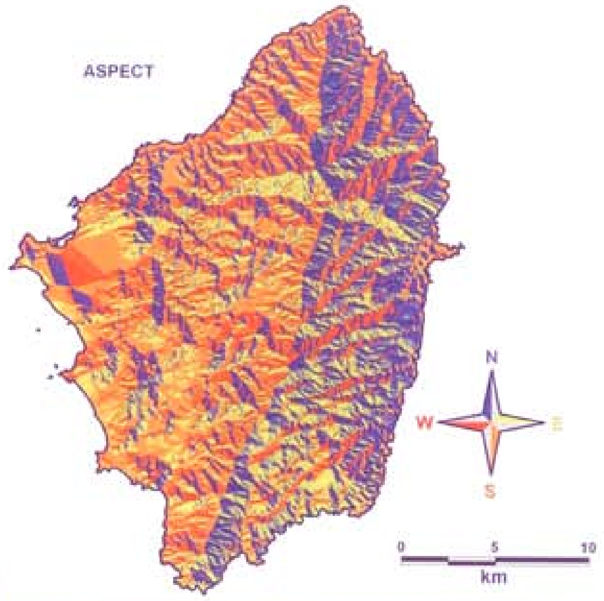


Figure 15: Geographical distribution of morphological aspect input value

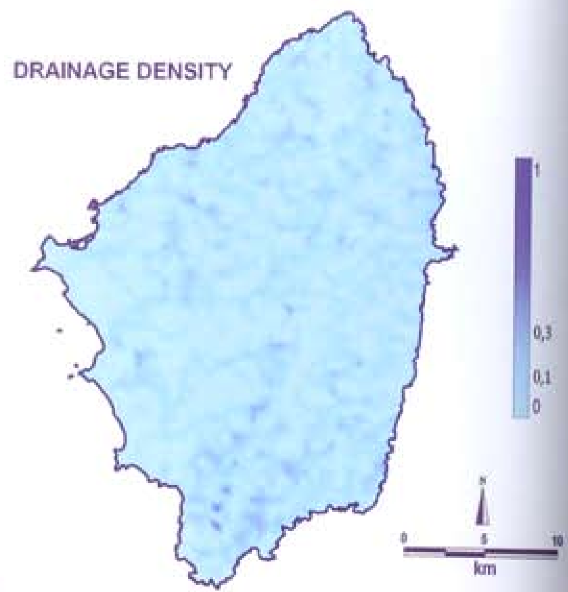


Figure 16: Geographical distribution of drainage density input variable

The rocks' vulnerability to erosion, the slope inclination, the drainage density values and the corresponding thematic maps have all been derived from the initial data described in subsection 5.1. The calculation of the input factors' values was an automated process induced by the GIS with the use of algorithms that were created for this study in the programming platform of MapBasic Software. In order to combine data layers, all the original data have been normalised dividing them by their maximum value. In the present study, the gradation of the input variables was "low" (0-0,5), "medium" (0,25-0,75) and "high" (0,5-1) and one category is coinciding with the other, following the triangular functions which were adopted from the fuzzy set theory. The next step was to formulate proper logical rules in order to produce the final erosion risk values and map. Logical rules, mainly based on empirical knowledge, were applied on all input variables to deduce degrees of erosion risk. All the above variables were characterised by fuzzy set values and expressed by a corresponding membership function (Mamdani and Assilian 1975).The application of the rules that were developed was accomplished with the use of Matlab Software in order to extract the output variable which was characterised by "very low", "low", "medium" and "high" erosion risk degrees. Extensive fieldwork within the case study confirms, in many steps, the erosion risk map which was empirically created in order to check and calibrate the model.

5.3 Software used

The following software was used in order to develop the erosion risk model of Naxos Island:

Software	Realised actions
MapInfo G.I.S.	• Automatic input of fieldwork data • Depiction, correlation and analysis of geographical data • Creation of secondary parameters from primary data • Combination of individual data with gravity indexes for the export of the model's input parameters • Logical rules application in order to export the final parameter of erosion risk index • Thematic Maps
ISPM - Image Station Photogrammetric Manager	• Determination of photogrammetric work parameters
ISDM - Image Station Digital Mensuration	• Image orientation
ISSD - Image Station Stereo Display	• Stereoscopic observation, on the computer screen
ISDC – Image Station DTM Collection	• DTM (Digital Terrain Model) calculation and corrections
IRAS C	• Photomosaic production
Image Analyst	• Radiometric amplification • Geometrical corrections • Spatial amplification
Image Station OrthoPro	• Image correction • Ortho-aerial photos production
Vertical Mapper	• Grid file creation • 3D model development • Database updating with constant variables values (e.g. topographic gradient) • Special symbols creation for the construction of the geomorphological map
Matlab	• Fuzzy variables estimation • Conversion of fuzzy values in defuzzy ones (defuzzyfication)

MapInfo

The Geographical Information System MapInfo Professional was used in almost all stages of the workflow. The geographical databases and the primary and secondary data were developed in MapInfo. The secondary data were derived from the spatial and sometimes statistical analysis of the primary data and processed with the MapInfo, Vertical Mapper software and the photogrammetric Image Station system. All the analyses for the creation of input variables and the application of logical rules for the export of the output variable, erosion risk index were executed in MapInfo.

MapBasic

MapBasic programming language was used for the development of algorithms used to estimate various geomorphological parameters and tectonic features.

Vertical Mapper

Vertical Mapper calculated the trivariate parameters that were used for the input variables estimation. The trivariate parameters depend on the calculated situation, for example, for DEM the three variables calculated by Vertical Mapper are x, y, and z coordinates.

ISPM - Image Station Photogrammetric Manager

General photogrammetric data (parameters) of the study were introduced were introduced by the use of this software. Specifically, the following took place:

- Determination of parameters that involve flight info, image scale and capture info;
- Input of parameters that concern the orientation of each image.

ISDM - Image Station Digital Mensuration

This software was used for the measurements and the shots transport, among images of different geometry, and for the completion of the aero-triangulation. ISDM collected the photo-stables from the digital backgrounds (maps and DTM). In particular, the following took place:

- Relevant and absolute orientation;
- Alteration of the images' radiometry by dynamic alteration of the brightness and contrast, in order to be able to produce images of similar histogram.

ISSD- Image Station Stereo Display

This software was used in the MicroStation environment especially for the stereoscopic appearance and management of the images. Its basic function is based on the ImagePipeTM algorithm. The inserted images appear either through multiple stereoscopic windows, or through a window of uniform stereoscopic view of the whole stereo-model. The Image Station photogrammetric system offered the possibility of stereoscopic observation in "frame sequential", which is a technique used in the depiction of images with clarity, achieving a more relaxed stereoscopic observation and greater accuracy during the movement along the axis of the model's heights. The functions that were completed within ISSD were the following:

- 3D presentation of the whole model by the use of special equipment that comprises a transmitter and a pair of receiver-glasses;
- Overlapping of the vectorial elements that were digitised on the stereo-model's image in the GIS software.

ISDC – Image Station DTM Collection

This software was used for the semi-automatic correction of the digital terrain model (DTM) based on the known features like hypsometric points, abrupt topographic gradient changes and other geomorphological features. The original DTM occurred from the digitisation of topographic maps of scale 1:50 000. The changes and the DTM's update, either in contour lines, or in the form of triangle grid, were made in real time.

IRAS C

This software was used for the creation of Naxos' photo-mosaic using the aerial photos. This stage was preceded by the conversion of the aerial photos into ortho-aerial photos. It could possibly enable the deformation of the photo-mosaic and allow the correct observation and measurement of the area's geomorphological features.

Image Analyst
The processing of aerial photos took place through Image Analyst.

Image Station OrthoPro
This software was used to convert aerial photos into ortho-images, after they were first oriented through Image Analyst.

5.4 Scientific output
The development of erosion risk maps involves a number of stages, within which the most crucial are: the definition of the input and output variables, the calculation of those variables as well as the establishment of logical rules, the analysis and visualisation of the results. Most of the crucial steps to be accomplished need additional sub-steps. For example, one of the input variables is vulnerability. In order to extract vulnerability variables, many sub-parameters have to be taken into account and calculated. One of those concerns the discontinuities in the rocks.

In order to include the discontinuities in the rocks' vulnerability to erosion, 694 measurements were taken during fieldwork, which were mapped into GIS. Their orientation was estimated in the MapBasic software. The rodogram depicted in figure 17 was created out of discontinuity and tectonic lines. This variable was determined using the "Geoline Orientation Software" algorithm (Vassilopoulos 1999; Evelpidou *et al.* 2002), which calculates the azimuthal value of linear objects' direction, such as discontinuities. These directions were statistically analysed through rodograms, dividing all existed directions into 36 groups of a 10° range each. Therefore, the resultant rodogram was graphic depictions through rodograms (figure 16) of the distribution of the discontinuities' directions.

The erosion risk model was based on logical rules and concluded to the erosion risk map. As shown in the final erosion risk map (figure 18), the study area is regarded as of medium to high erosion risk. This map, which is derived from analytical methods, should not be considered as an application map, because it should be cross checked through field-work in order to correct the weight by which each parameter is influencing the model. For this reason extensive field-work took place and the model was reclassified in parts. All related factors, such as topography, morphology, geology, climatology, land use, and tectonic features have been combined to create erosion risk maps which show the areas that are vulnerable to erosion.

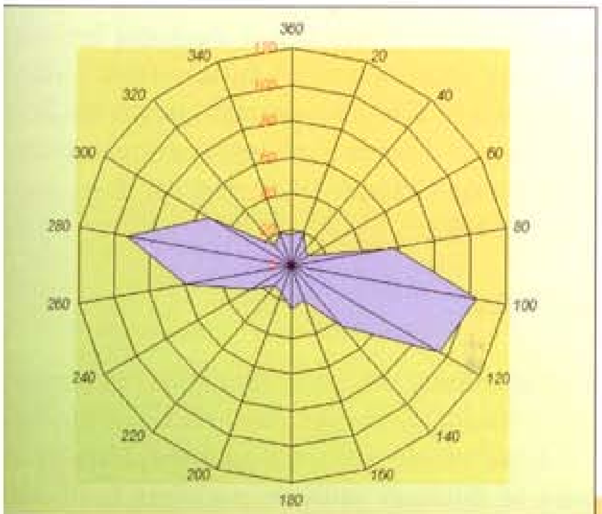


Figure 17: Rodogram of 694 directions of faults and discontinuities, measured during fieldwork

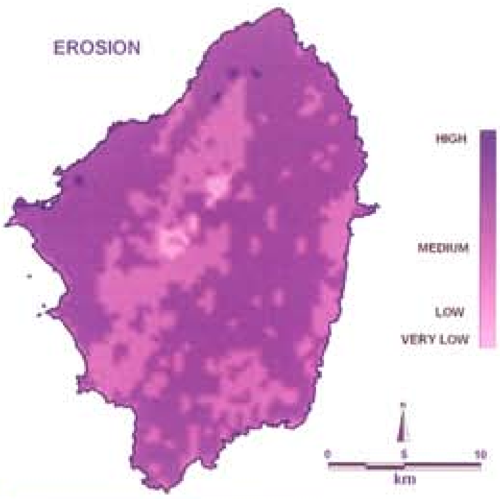


Figure 18: The erosion risk map of Naxos Island as it was derived through the aforementioned model

The results of the scientific analysis are the thematic maps showing the geographical distribution of the erosion risk classified in several risk classes. Figures 14, 15, 16 and 17 depict the parameters estimated by the use of a GIS and the final erosion risk map which was developed based on the interaction of the described parameters.

6. Formalisation of a GIS-Based Methodology

In this paper we have proposed formalisation in the context of the development of a GIS-based methodology. When such methodologies are developed, the primary goal is applicability. After the methodology has proven itself in practice, it can be applied in more sophisticated situations. In those cases, informal definitions and loosely defined systems and procedures are known to be inappropriate. Formal methods can complement traditional techniques, such as testing, and can help developers improve the degree of trustworthiness. Within this section we suggest only some of the possibilities of the approaches that could possibly be used for the formal descriptions and development of a GIS-based methodology.

The Unified Modelling Language (UML) is a modelling language known in software engineering and basically used to create abstract models of specific computer-based systems. It is developed as a graphical language for visualising, specifying, constructing, and documenting the components and functionalities of a planned software application. The abstract models are often presented in the form of a diagram. UML offers three kinds of diagrams that can be classified as follows:

- Behaviour diagrams. A type of diagram that depicts behavioural features of a system or business process. This includes activity, state machine, and use case diagrams as well as the four interaction diagrams;
- Interaction diagrams. A subset of behaviour diagrams which emphasise object interactions. This includes communication, interaction overview, sequence, and timing diagrams;
- Structure diagrams. A type of diagram that depicts the elements of a specification that is irrespective of time. This includes class, composite structure, component, deployment, object, and package diagrams.

The main approach is based on use cases. A use case is an amount of work as seen from the viewpoint of the user of the product. It expresses the behaviour of a system, the functional requirements, in a way that helps technical experts and non-technical people alike understand that behaviour. Use cases are a convenient way of identifying a user and a group of requirements that carry out a specific task of the user (Robertson and Robertson 1999). The term "use case" was introduced by Ivar Jacobson in 1986. Their value and power were clearly revealed by Object-Oriented programming (Bittner and Spence 2003). The motivation was to break the system into smaller units in order to conquer the complexity and largeness of modern systems. The technique was based on the conception that large systems should be partitioned into smaller pieces, according to the users' view of the system.

The UML is accepted by the Object Management Group (OMG) as the standard for modelling object oriented programs. Some critiques of this modelling say that it does not include semantics and sometimes suffers from ambiguities and incompleteness and ignores the human cognitive aspects of information capture (Simons and Graham 1999; van den Berg and Simons 1999).

Conclusions

Implementation of geoinformation technologies in landscape change research is not limited to the use of one software package. Usually a series of different software packages has been applied in various steps of the process. More attention should be paid to GIS as a methodology and to the possible changes it could provide in the workflow and analytical tasks. These technologies may change the researcher's tasks, processes, or even the workflows. Additionally, the value of modelling and its consequent impact on the results' quality is crucial for the interpretation and the analysis of a GIS output.

In this paper formalised GIS-based methodologies are suggested, in order to be able to exchange and use them in different case studies. These proposed formalisation methods are tested on a case of erosion on Naxos Island. Most steps have taken place with the use of self-developed algorithms within the GIS. However, the map derived from analytical methods should not be considered as a final map before it is cross checked through fieldwork, in order to correct the weight by which each parameter is influencing the model and thus calibrate it.

Additional implications of a GIS and the implementation of other information tools in the organisations and new research areas are the change of the processes and the organisation of the research tasks. At the same time, its implementation requires a new approach in the analysis of the selected research questions. Formalised methodologies could possibly reduce the work of the organisations that implement new technologies and analytical possibilities in their processes. Additional research is needed in the formal languages which could improve the formalisation techniques for GIS-based methodologies.

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