ΑΝΑΠΤΥΞΗ ΣΥΣΤΗΜΑΤΟΣ ΓΕΩΓΡΑΦΙΚΩΝ ΠΛΗΡΟΦΟΡΙΩΝ ΓΙΑ ΑΝΑΛΥΣΗ ΕΠΙΓΕΙΩΝ ΚΑΙ ΔΟΡΥΦΟΡΙΚΩΝ ΔΕΔΟΜΕΝΩΝ ΝΗΣΟΥ ΖΑΚΥΝΘΟΥ

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Περίληψη

Πλήθος ετερογενών δεδομένων σχετικών με τοπογραφία, γεωλογία, τεκτονική, εδαφική παραμόρφωση, σεισμολογία και δορυφορικές εικόνες από την Νήσο Ζάκυνθο συνδυάσθηκαν. Μια βάση δεδομένων σε Σύστημα Γεωγραφικών Πληροφοριών αναπτύχθηκε, θεματικά και συνθετικά επίπεδα καθώς και χάρτες παρήχθησαν, σε ένα κοινό χαρτογραφικό σύστημα (Ελληνικό Γεωδαιτικό Σύστημα Αναφοράς ΄87 / ΕΓΣΑ'87). Ένα Ψηφιακό Μοντέλο Αναγλύφου (ΨΜΑ), ακριβείας 30m, δημιουργήθηκε από δορυφορικές εικόνες ASTER, το οποίο απετέλεσε βάση για την παραγωγή θεματικών και συνθετικών επιπέδων αναλύσεως αναγλύφου (μορφολογικές κλίσεις και προσανατολισμό κλίσεων, επιφάνειες επιπέδωσης, μορφολογικές ασυνέχειες κ.ά.). Χάρτες οριζόντιας και κατακόρυφης εδαφικής παραμόρφωσης δημιουργήθηκαν από διαφορικές μετρήσεις GPS. Η βάση δεδομένων είναι δυνατόν να ενημερώνεται με νέα πληροφορία, ανάλογα με τις εκάστοτε ανάγκες, με σκοπό την ευκολότερη διεξαγωγή συμπερασμάτων.

DEVELOPMENT OF A GIS SYSTEM TO ANALYZE GROUND AND SATELLITE DATA OF ZAKYNTHOS ISLAND

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Abstract

A large amount of heterogeneous data relating to topography, geology, tectonic, ground deformation, seismology, satellite images of Zakynthos Island were compiled. A GIS Data Base was organised, and thematic and synthetic layers and maps were produced in a common projection system (Hellenic Geodetic Refference System'87 / HGRS'87). A 30m resolution Digital Elevation Model (DEM) was created based on ASTER images, as well as thematic and synthetic layers and maps of terrain analysis (slope and aspect maps, planation surfaces, morphological discontinuities etc.) were extracted from the DEM. Vertical and horizontal ground deformation maps were created using differential GPS measurements. The Data Base can be updated with new data and used for easy conclusion-extraction, depending on the current needs.

Λέξεις κλειδιά: Βάση δεδομένων ΣΓΠ, ΨΜΑ, DGPS, ASTER δεδομένα, Ανάλυση Αναγλύφου.

Key words: GIS Data Base, DEM, DGPS, ASTER data, Terrain Analysis.

1. Introduction

The broader region of Zakynthos Island comprises a seismotectonically complex area which plays an important role in the tectonic processes of Western Greece. This area is one of the most seismically active regions not only in Greece, but also in the whole Mediterranean area. This high seismicity level which characterizes the broader area occurs due to its position, as it situated between a subduction zone to the south and a collision zone to the north (Le Pichon et al., 1995; Papazachos and Kiratzi, 1996). The Eastern Mediterranean lithosphere, which is the front part of the African lithosphere, is subducted beneath the Aegean lithosphere, which is the front part of the Eurasian lithosphere, along the Hellenic Arc – Trench system. This subduction zone terminates against a major strike slip fault, the Cephallonia transform fault, which links this subduction boundary to the continental collision between the Apulia microplate and the Hellenic foreland (Sachpazi et al., 2000). Seismological data for this fault indicate right-lateral strike–slip focal mechanisms (Jackson and McKenzie, 1988) in agreement with geodetic data that clearly shows that the slip motion has a NNE–SSW direction (Jenny et al., 2004).

Considering all the above mentioned phenomena it is concluded that the broader area of Zakynthos is a geologically and seismotectonicaly very complex region, which may be considered as a key area for a better understanding of the processes related with the collision of the African and Eurasian plates. The regional crustal deformation along the entire Ionian Sea and Western Greece has been studied through repeat Differential Global Positioning System (DGPS) measurements (Kahle et al., 1995; Peter et al., 1998; Cocard et al., 1999).

However, additional monitoring of dense GPS networks in such an active area may yield useful information regarding local ground deformation and kinematics. For that reason, a local GPS network was installed in the island of Zakynthos in August 2005 by the University of Athens (Lagios et al., 2007). This network has been remeasured at the end of July 2006, almost one year after its establishment and the results of the processing of the GPS data can be used by a Geographical Information System to produce ground deformation maps. These data will be compiled with other data and various synthetic maps relating to ground displacements, geology, tectonic, terrain analysis etc, will be produced aiming to easy conclusion extraction.

2. GIS Data Base Development

A large amount of data (topographic, geodetic, geological, tectonic, seismological and satellite images) in various formats (vector, raster, ascii etc.), map projections (Greek HATT, UTM) and Datums (European 1950 and WGS'84) with different ellipsoids (Bessel and WGS'84), were incorporated. A GIS Data Base was organized aiming to the production of thematic and synthetic layers and maps, in a common projection system (Hellenic Geodetic Reference System 1987 / HGRS'87) using ArcGIS software (ESRI, 2005). Input and output data with their descriptive information are given in the tables 1-4.

Table 1. Data Base Schema

<table>
<tr><th colspan="3">Data Base</th></tr>
<tr><th>Input Data</th><th>Output Thematic & Synthetic Layers (Coverages & Grids)</th><th>Output Maps</th></tr>
<tr><td rowspan="2">Topography / Morphology (coastline, contour lines, elevation points, drainage network, 1:50000 scale maps of Hellenic Millitary Geographical Service - HMGS, 1976)</td><td>coast (arcs)
contours (arcs)
elevpnt (points)</td><td rowspan="2">DEM
Shaded relief
Map of terrain analysis</td></tr>
<tr><td>dem30 (DEM produced from ASTER images)
slope (morphological slopes % - polygons)
aspect, aspnt (aspect of morphological slopes – polygons and point respectively)
discontinuity (discontinuities of morphological slopes - arcs)
surfplanation (surface planation – polygons)</td></tr>
<tr><td>Geology (geological formations from 1:50000 scale Geological Map of Greece (Zakynthos sheet)), Institute of Geology and Mineral Exploration - I.G.M.E, 1985)</td><td>formations (polygons)</td><td>Geological Map</td></tr>
<tr><td>Tectonic (faults from the 1:100.000 Neotectonic Map of Greece-Zakynthos, Univ. of Athens, 1995)</td><td>faults (arcs)</td><td>Tectonic Map</td></tr>
<tr><td>GPS measurements (Aug2005-July2006):
• GPS stations
• Horizontal Displacement from GPS receivers illustrated as an arrow
• Vertical Displacement from GPS receivers (grid)
• Error of Horizontal Displacement illustrated as a circle</td><td>gpsp05a, gps06jscale (points)
gps05a06j (arcs)
v05a06j (grids)</td><td>Map of Horizontal & Vertical Deformation</td></tr>
<tr><td>Seismology (earthquake epicenters 1990-2007)</td><td>epicenter (points)</td><td>Seismological Map</td></tr>
</table>

Table 2. Descriptive Information of Thematic and Synthetic Layers related to Tectonic, Geology, Topography and Seismology.

Tectonic/Geology/ Topography/Seismology	Items	Description
tectonic	code	Unique number for each data
	name	The name of each fault or faulting zone
	zone	The name of each faulting zone in abbreviation
	activity	Characterization of each fault as active or possible active
	order	Classification of each fault as main or secondary
	visible	Characterization of each fault as visible or possible.
geology	formation	Classification of geological formation
	code	Unique number of each data
	zone	The name of each isopic zone
	age	The age of the formation
contours	elevation	elevation
elevpnt	elevation	elevation
epicenter	Year	the year of the earthquake
	Date	the date of the earthquake
	hr_min_sec	the time of the earthquake
	long_e, lat_n	the coordinates of the earthquake
	H	the depth of the earthquake
	M	the magnitude of the earthquake
	Codem	the epicenters are categorized related to M
	Codemh	the epicenters are categorized related to M and H

Table 3. Descriptive Information of GPS Layers

Specific Items of GPS Layers	Description
"easting_a", "northing_a", "easting_b", "northing_b"	Coordinates of GPS stations for each period (a: begin of vector/first measurement, b: end of vector/last measurement)
"ellip_h_a", "ellip_h_b"	Z coordinate of GPS station
"stdeast_a", "sd_east_b"	Standard deviation along easting coordinate
"sd_north_a", "sd_north_b"	Standard deviation along northing coordinate
"sd_h_a", "sd_h_b"	Standard deviation along height

Table 3.

Specific Items of GPS Layers	**Description**
"azimuth"	Horizontal displacement direction
"elldif_mm", "hightdif"	Horizontal and vertical deformation in mm
"stdevdifn" "stdevdife"	Standard deviation of horizontal displacement along X and Y axis
"stdevh_mm"	Standard deviation of horizontal displacement along Z axis
"xscale", "yscale"	"phseudo-coordinates" of the end of horizontal displacement arrow (they produced after real coordinates scaling for its representation on the map)
"stdevdifscale"	"phseudo-error" of horizontal displacement along X axis for its representation on the map (the error after scaling)
"value"	vertical displacement

Table 4. Descriptive Information of Morphological Layers

Morphological Layers	**Specific Items**	**Description**
dem30	value	elevation
slope	percent _slope	Classification of morphological slopes in categories
	slope-code	Unique number for each category of morphological slope
	code2	Unique number for specific categories of morphological slopes
aspect	aspect	Categories of angles for the calculation of the aspect of slopes
	aspect-code	Unique number for each category of aspect
discontinuity	lcode, rcode	Codes related to the right and left polygons that discontinuity is boundary
	lmedh, rmedh	The height of the right and left polygons
	newID	New ID of each discontinuity
	code	Unique number for each discontinuity
range	code	Unique number for each category of elevation zones
plansurf	*percent_slope*	Categories of slopes %
	slope-code	Unique number for each category of slope

3. Maps Creation

3.1. DGPS Measurements and Ground Deformation Maps

The Zakynthos network consists of 14 stations that were installed in August 2005 (Lagios et al., 2007). These stations are located on the main tectonic blocks and fault zones that could be recognized in the island and they are distributed accordingly for the study of the tectonic deformation. Generally, the stations are located at about the centre of the main tectonic blocks and are separated by 10 km or less. This spacing is sufficient for detailed monitoring of local and regional tectonic movements. The Zakynthos network was remeasured in July 2006 after the seismic activity that occurred offshore to the south of the island in April 2006.

Ground deformation map (Fig. 1) was created after combination of vertical and horizontal deformation layers (Table 1). Data Base organization with descriptive information in specific items is capable of helping the representation of the data (Table 3).

Horizontal deformation (in vector format), from GPS receivers, illustrated as arrows which indicate the direction of the displacement. The error of horizontal displacement illustrated as circle at the end of each arrow.

Vertical displacement (in grid format, applied IDW algorithm of ArcGIS) from GPS receivers, illustrated as a colour scale from blue (small deformation) to red (high deformation), At figure1, the ground deformation of Zakynthos during 2005-2006 can be observed. The ground deformation is overlaid on the shaded relief of the island for more realistic representation. The layer of faulting zones as well as other geological data can be combined with GPS data to produce synthetic maps and make the results extraction easier.

It is evident that a horizontal extension of the southern part of the island had occurred in the area around Laganas Bay (Fig. 1), which seems to be "opening": Its western part showed generally a westerly motion ranging from 15-20 mm, while its eastern part had magnitude of 26 mm towards the NNE. The central part of the island appears stable. The northern part, however, presents an inconsistent pattern with two stations (No 60 and 62) having directions to the SW, while the most northerly ones, No 61 and 63, have orientations to the NW and N with magnitudes of 24 mm and 5 mm, respectively.

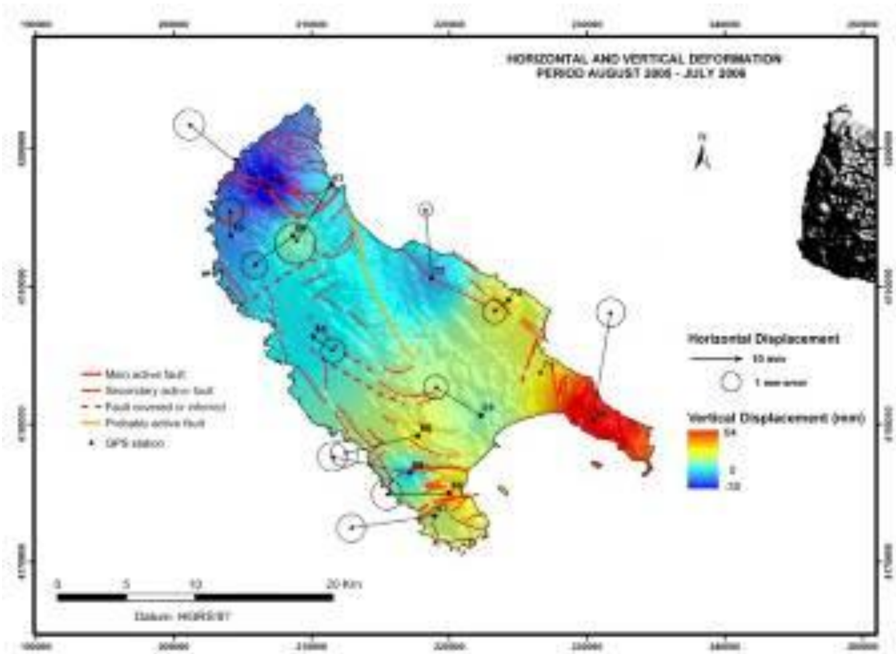

Figure 1. Horizontal and vertical deformation of Zakynthos Island (August 2005 to July 2006).

The vertical deformation is expressed with uplift mostly in the southern part bounding the area of Laganas Bay (Fig. 1), with values of 40 mm and 60 mm in the western and eastern parts, respectively. More than 60 mm occurred at station No 70. The extreme northern part (No 61 and 63) had subsided by 12-30 mm, while the section to its SE (No 60 and 62) was unchanged.

3.2. Geological and Tectonic Map

Geological and tectonic data were included in the GIS Data Base (Table 1&2). Geological and tectonic layers as well as maps were produced (Fig. 2). These layers were also used for synthetic maps and Data Base analysis.

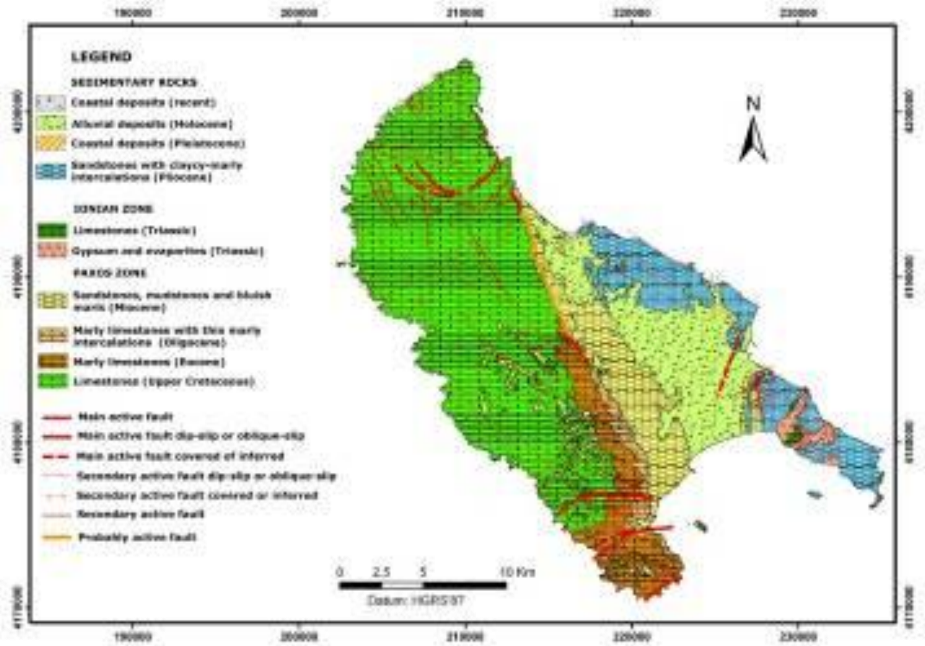

Figure 2. Geological map of Zakynthos Island. Alpine formation of Ionian zone (limestones, gypsum and evaporites of Triassic), Paxos Zone (sandstones, mudstones and bluish marls of Miocene, limestones of Upper Cretaceous to Miocene) covered the island.

3.3. Generation of Digital Elevation Model

ASTER is a high-resolution, multispectral/hyperspectral instrument onboard the TERRA spacecraft (http:// asterweb.jpl.nasa.gov). It takes data in 14 spectral bands in a variety of ground resolutions. (visible and near infrared (VNIR) at 15m, shortwave infrared (SWIR) at 30m and thermal infrared (TIR) at 90m.). For our purposes in DEM extraction the band 3 of the VNIR subsystem of an ASTER image (17/07/2001) will be used (Fig. 3). The band 3 includes two channels: a nadir (straight down) looking scene (3N) and a backward (aft-viewing along orbit, 27.6o off-nadir) looking scene (3B). These scenes consist of a stereo pair of images which a DEM can be extracted using specific software.

3.3.1.Data Processing

Georeference of Topographical Maps: At first, two topographical maps of Zakythos Island (Zakynthos & Volimai sheet, Topographical Map of Greece scale 1:50000 HMGS,

1976) were scanned and saved in tag image format (tif). The scanned maps were geo-referenced in the "Hellenic Geodetic Reference System'87" using ArcGIS software (ESRI, 2005). These maps will be used for GCPs selection.

Collection of TPs and GCPs: The DEM was produced using Geomatica OrthoEngine of PCI software. Tie points (TPs) are used to register the two images together (Fig. 3). A minimum of 9 points, evenly spaced around the image are required. Ground control points (GCPs) are used to bind the two images to a coordinate system and provide elevation data. The GCPs were collected using the geo-referenced topographical maps. Usually 6-8 GCPs are required for each image. After the GCPs and TPs collection, the two images are correlated together and the DEM can be extracted. A number of 14 TPs was collected with RMS error from 0.034 to 0.38 pixels. A number of 12 GCPs was also collected. Three of them were assigned as CPs (check points) and they were not used during processing. The RMS error was 0.76 and 0.83 pixels for 3N and 3B image respectively. For a 30m resolution DEM the maximum acceptable RMS error is 2 pixels, thus the above RMS errors are considerate satisfactory.

Epipolar Creation and DEM Extraction: After the collection of the TPs and GCPs the epipolar images (stereo pair) were created. These images were used for the DEM extraction during processing.

Dem Editing and Geo-coding: Generally the extracted Dem is acceptable, but requires further editing to correct holes of failed values (usually because of clouds and their shadows), that were created after automatic DEM extraction. Areas with failed values and the shoreline were corrected appropriately. Finally a DEM of 30m resolution was produced (Fig. 4) This DEM was evaluated using topographical maps and GPS measurements.

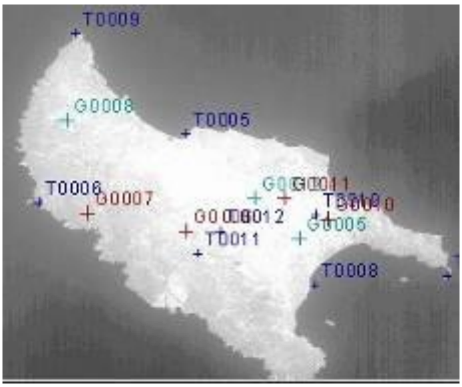

Figure 3. The 3B band of ASTER image of Zakynthos Island that was used for DEM extraction together with 3N band. The GCPs, TPs and CPs are overlaid to the image.

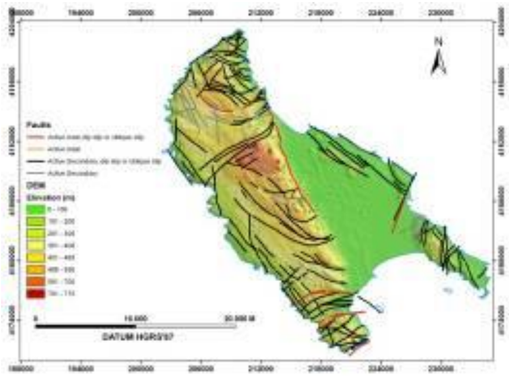

Figure 4. Shaded relief of Zakynthos Island (azimuth 45^0, altidute 45^0) based on 30m resolution DEM extracted from ASTER images. Faults are overlaid to the shaded relief.

3.4. Terrain Analysis Maps

Terrain analysis of a region is the base feature for each geo-environmental study (management of geo-environmental problems-natural hazards, large public constructions, waste-disposal areas, land use, studies regarding geodynamics, hydrogeology, geophysics etc.). At the present study, the specific software "PROANA" (Vassilopoulou, 1999; Vassilopoulou, 2001) was used and the following maps were created based on the above DEM.

Shaded Relief: These models are useful for our work. Draping thematic maps (geological, tectonic, ground deformation etc.) over the DEM, were produced more realistic images (Fig. 1, 4). These images were important for field work (DGPS measurements identification), as well as in the laboratory relating to other data.

Map of Morphological Slopes: It represents the slopes of the terrain classified in regions, together with the aspect of the slopes (Fig. 5). This map was compiled of slope and aspect layers after further processing. The slopes at the region of Zakynthos Island were classified in categories: 0-5%, 5–15%, 15-30%, 30–45%, 45-60%, slopes >60%. The angles of aspect were categorized by 450 and were transformed in to ArcGIS format.

Range Map: The study area was divided in categories of 30 meters elevation zones. These zones were contained in the range-polygon layer. The range-layer is useful for morphological discontinuities creation.

Map of Planation Surfaces: The planation surfaces are regions of the terrain where their slope take values from 0-15%. At the present study, the planation surfaces are classified in: 0-1%, 1-5%, 5-10%, 10-15%. Various parameters must be calculated and analyzed. The final layer of the planation surfaces is a compilation of the thematic layers of range, geology, and aspect. The planation surfaces are classified as depositional and erosional function of their slope direction and categorized with respect to their slope.

Map of Morphological Discontinuities of Slopes: It represents the differences in slope more than 10%. The morphological discontinuities are boundaries of polygons with specific characteristics in the layer of the slopes. This layer is a compilation of thematic layers of aspect, slope and range. Further processing conduct to the final thematic layer of the morphological discontinuities.

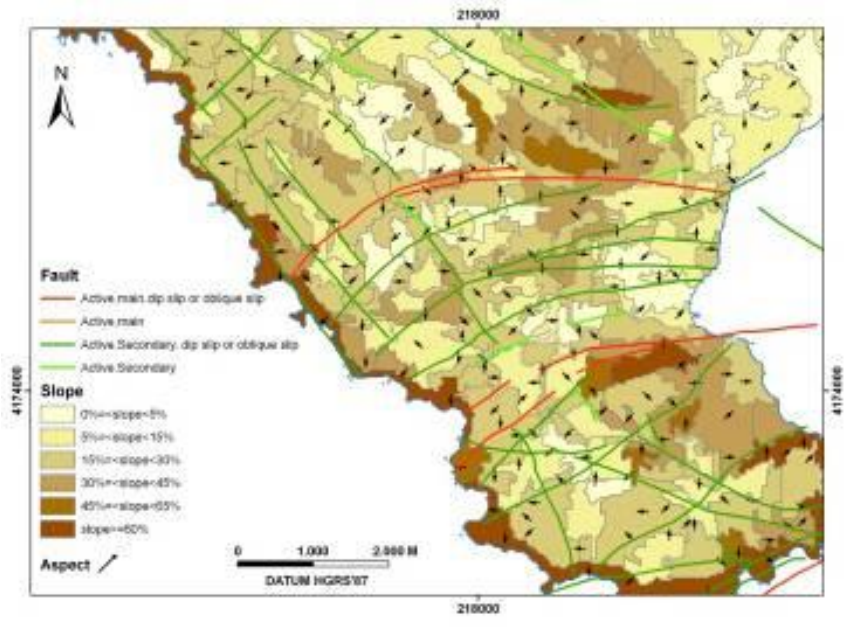

Figure 5. Morphological slopes of the NW part of Zakynthos Island. The slopes are represented in a color scale from light yellow (small slopes) to dark brown (high slopes). The aspect of slopes is illustrated as arrows. The layer of faults is overlaid to the morphological slopes.

4. Conclusion

A large amount of different type of data was processed, a GIS Data Base was organised and the following aspects were accomplished:

A 30m resolution Digital Elevation Model from ASTER images was created.

Various thematic and synthetic layers and maps related to the geology, tectonics, topography (DEM), geomorphology (slope and aspect maps, maps of morphological discontinuities, planation surfaces etc.), seismology and ground deformation using differential GPS measurements were produced in a common projection system.

The Data Base management and analysis solved particular problems related to the study.

The GIS Data Base can be constantly updated, and a decision making system can be created in the future for regional planning, management of geo-environmental problems and natural hazards, large public constructions, waste-disposal areas, land use, studies regarding geodynamics, geophysics etc.

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