Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Evaluation of Landslide Hazard Assessment Models at Regional Scale – *(SciNet NatHazPrev Project)*

Democritus University of Thrace (P1)

Department of Civil Engineering

Geotechnical Division

- **Scientific Staff:**
  - Dr Nikolaos Klimis, Associate Professor, Civil Engineering Dept. DUTh
  - Dr Ioannis Markou, Assistant Professor, Civil Engineering Dept. DUTh
  - Dr Stylianos Skias, Assistant Professor, Civil Engineering Dept. DUTh

- **Collaborating Scientific Staff:**
  - Dr Konstantia Makra, Senior Researcher ITSAK-EPPO
  - Dr Manos Rovithis, Researcher ITSAK-EPPO

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Activity 1.7:

Evaluation of existing Landslide Hazard assessment models in terms of scientific soundness, data demands, results credibility

Activity 1.11:

Development / Modification / Adaptation of existing models used to assess landslide hazard, based on local conditions.

Key parameters:

- **Successful assessment of the areas prone to slide**
- **Data to be provided**
- **Complexity of the model**

Scale: **Regional (1:250,000 to 1:25,000)**

1. Landslide Susceptibility (static conditions) *according to FEMA method*

1. Geology (lithology per geologic group)
2. Slope angle
3. Water table

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Table 1. Landslide susceptibility of geologic groups under static conditions (HazUS MH, Chapter 4 – PESH.) – FEMA method

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, $\phi' = 35^{o}$)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, $\phi' = 35^{o}$)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 $\phi' = 20^{o}$)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, $\phi' = 35^{o}$)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, $\phi' = 35^{o}$)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 $\phi' = 20^{o}$)	VII	IX	X	X	X	X

□Correspondence at a susceptibility category of Table 1, is based on a triple criterion control:

- **classification of geologic group**
- **slope angle**
- **hydraulic conditions**

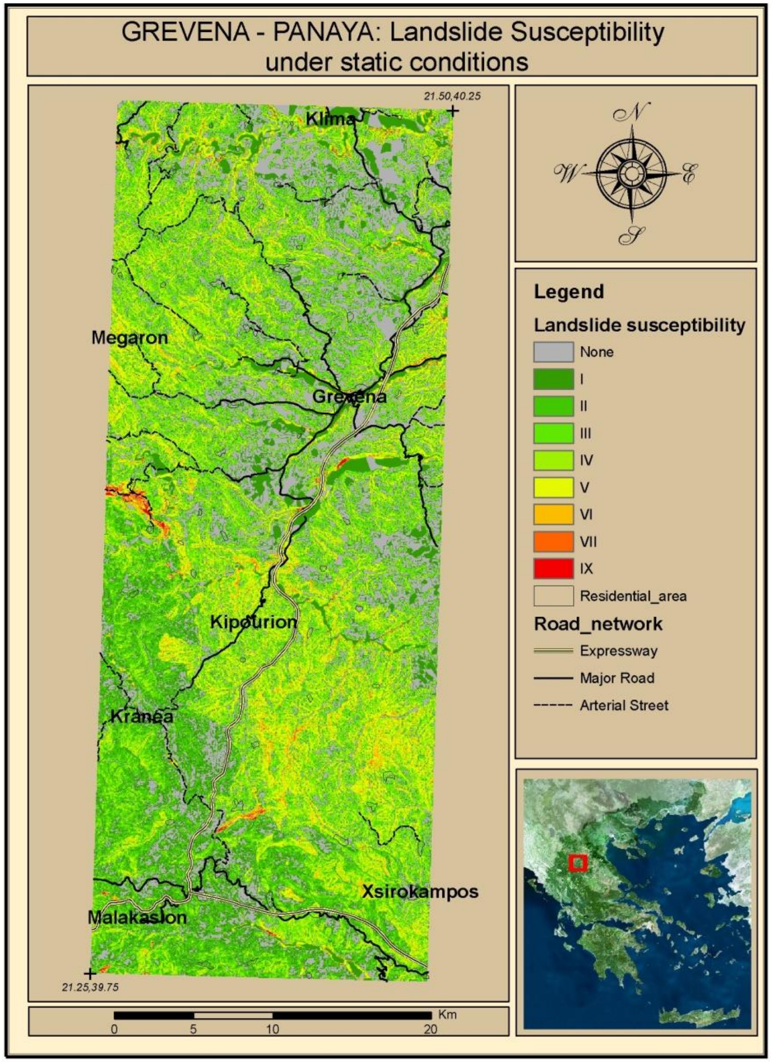
□Arbitrary scale from **I to X level**, the former (I) being the less susceptible and the latter (X) being the most susceptible

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.



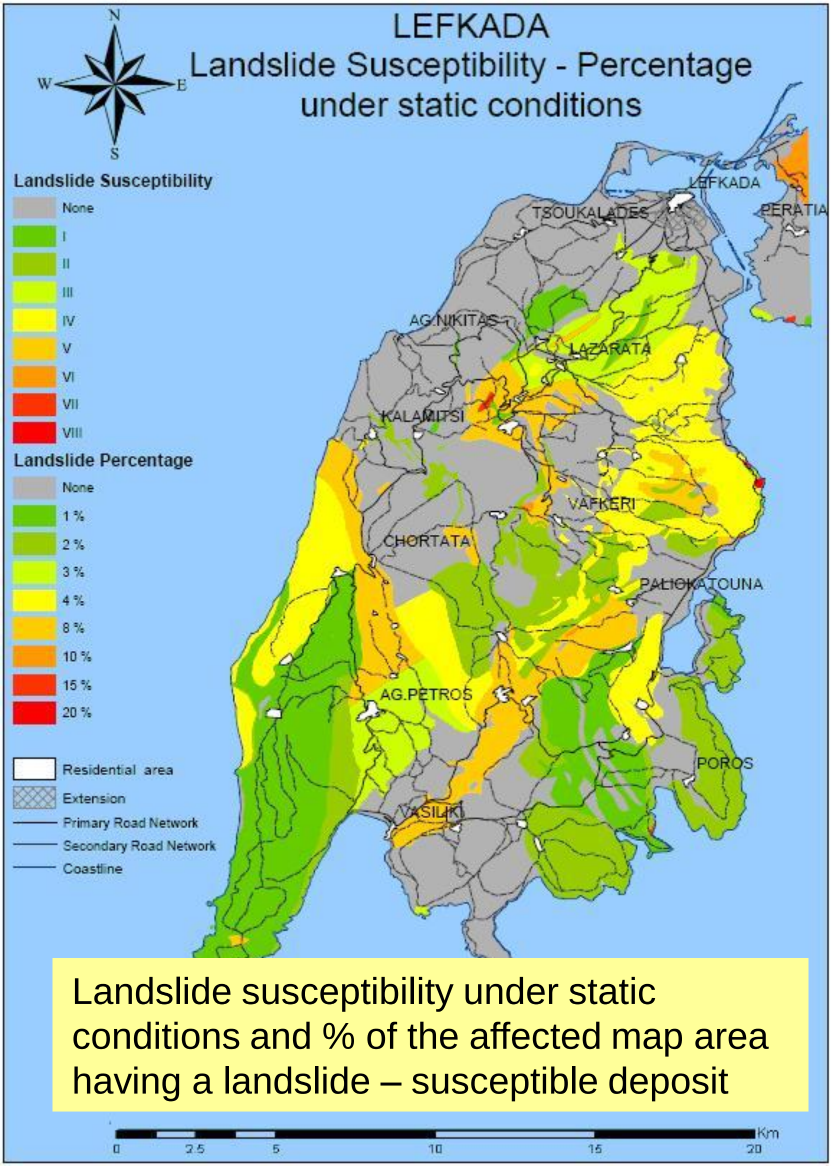
Programme INTERREG IIIB ARCHIMED ARCHIPELAGO MEDITERRANEO

Development of an Information System for Natural Risk Management in the Mediterranean (SyNaRMa Project, ITSAK)

Landslide susceptibility under static conditions according to FEMA method (based on geologic group and slope angle)

That was a successful example!

Scale 1:50,000



Landslide susceptibility under static conditions and % of the affected map area having a landslide – susceptible deposit

Landslide susceptibility under static conditions (based on geologic group and slope angle and hydraulic conditions)

That was NOT a successful example!

The west part of the island, even though dominated, along the coastline, by mountains with high and rather steep natural slopes, **landslide susceptibility is practical null or very low**, whereas the flat or smoothed eastern part of the island, dominated by alluvial deposits, presents higher susceptibility.

The reasons for this “paradox”?

- susceptibility based on natural slopes, whilst failures occurred mainly in cut slopes and downstream road embankment slopes
- incompleteness of the model

Scale 1:50,000

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Table 1 Examples of hazard descriptors for dealing with potential landslides at different scales of work

Scale of work	Runout	I(M)/F[a]	Hazard descriptor
National <1:250,000	Not included	Not considered	No. of landslides/ administrative unit/year
Regional 1:250,000–1:25,000	Usually not included	Often a fixed (constant) magnitude value	No. of landslides/ km^2/year
Local 1:25,000–1:5,000	Included	Spatially distributed magnitude (intensity)	Annual probability of occurrence (or return period) of a given magnitude or intensity
Site-specific >1:5,000	Included	Spatially distributed intensity	Annual probability of occurrence (or return period) of a given intensity

[a] Intensity (magnitude)/frequency

The current practice in Europe (Corominas et al., 2010) shows that the scale of the **landslide zoning maps** required by state or local authorities **varies significantly from country to country**, depending on ***the coverage, input data and methods used, as well as, the information provided (qualitative or quantitative)***

Typical areas to be examined in **regional scale** usually in early phases of regional development projects or for engineers evaluating possible constraints due to ground instabilities / failures during large engineering projects.

Corominas et al., 2013; based on SafeLand project

Susceptibility and Hazard maps are usually based on the following assumptions:

- ***homogeneous geological conditions***
- ***all slopes have the same probability of failure***
- ***exact location of slope failure NOT required***
- ***all landslides are of similar size***
- ***runout distance is NOT calculated; NOR spatial distribution and intensity***

This could be modified! HOW??

By introducing STRUCTURAL information

Predisposing factors play an important role in **landslide susceptibility and hazard analysis**:

- ***topographic information*** *and its derivatives (need for high-resolution DEMs)*
- ***geologic maps*** *focusing traditionally into lithological & stratigraphical subdivision should be converted into an engineering geological classification with emphasis on Quaternary sediments and rock texture/structure & rock mass strength*
- ***structural information*** *is important for landslide hazard assessments; attempts to incorporate dip & dip direction based on field measurements depend strongly on the number of measurements and complexity of structure*
- ***soil properties*** *in the use of physically based slope stability models for LHA (Landslide Hazard Assessment) are key parameters, especially for shallow depth failures. Soil depth, defined as the depth from the surface to a consolidated material*
- *spatial variability is also a crucial parameter, often ignored in landslide modelling*
- *Soil thickness can be modeled throughout physical based methods that model rates of weathering, denudation and accumulation*

• **Physically based landslide susceptibility** assessment methods are based on the modeling of slope failure processes

• Applicable over large areas if geological & geomorhological conditions are fairly homogeneous and landslide types relatively simple

• Applicable to areas with **incomplete landslide inventories**

• Most of them apply the **infinite slope model**, therefore they are applicable in the case of **shallow landslides**

• They account for different triggering parameters: **rainfall** and transcient groundwater response or to the effects of **earthquake excitation**

Corominas et al., 2013

Main advantages:

- They can be easily implemented in GIS framework
- Results are more concrete & consistent compared to other approaches
- Higher predictive capability and most suitable to quantify the influence of individual parameters contributing to shallow landslide initiation
- Based on slope stability models, they allow the calculation of quantitative values of stability (safety factor, probability of failure)

Main drawbacks:

- Parameterisation can be a difficult task; access to critical parameters (soil depths, transcient slope hydrological processes & temporal changes in hydraulic properties
- Degree of simplification encountered / need for large amounts of reliable input data

Corominas et al., 2013

2. Landslide Susceptibility (seismic conditions)

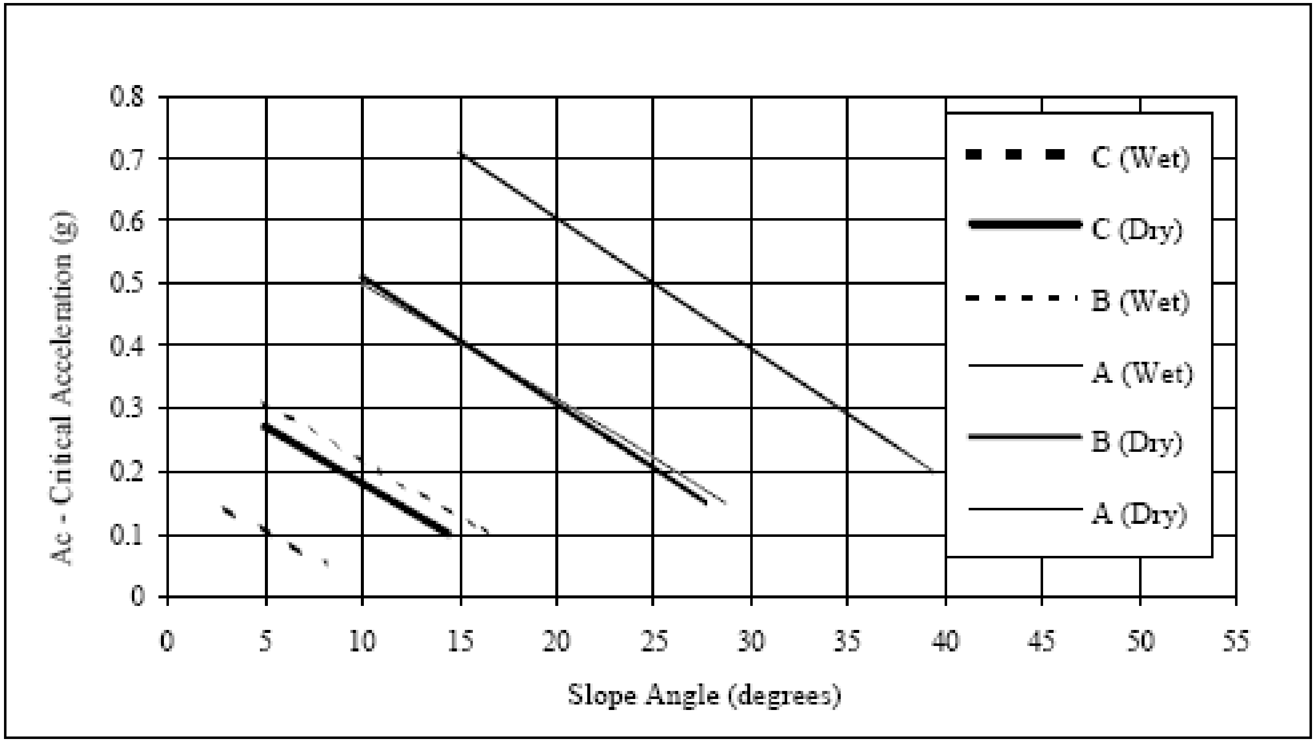
according to FEMA method

1. **Geology (lithology per geologic group)**
2. **Slope angle**
3. **Water table**

AND

4. **Critical Acceleration**

Critical acceleration (a_C), is a crucial parameter that is added to the aforementioned, being a complex function of slope, geology, steepness, groundwater table, type of landsliding and history of previous slope performance. The relationship of Wilson and Keefer (1985) is utilized in the method adopted herein.



Critical Acceleration as a Function of Geologic Group and Slope Angle (Wilson and Keefer, 1985).

Lower Bounds for Slope Angles and Critical Accelerations for Landsliding Susceptibility

Group	Slope Angle, degrees		Critical Acceleration (g)	
	Dry Conditions	Wet Conditions	Dry Conditions	Wet Conditions
A	15	10	0.20	0.15
B	10	5	0.15	0.10
C	5	3	0.10	0.05

Critical Accelerations (a_c) for Susceptibility Categories

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Critical Accelerations (g)	None	0.60	0.50	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05

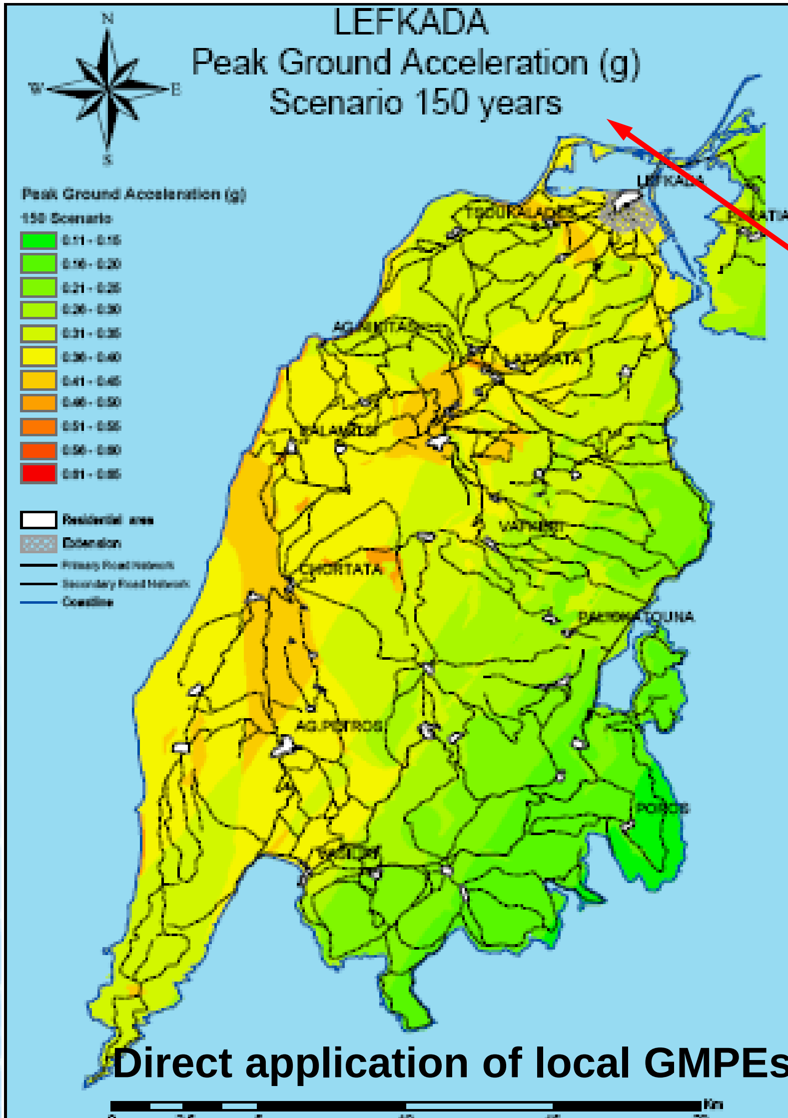
Percentage of Map Area Having a Landslide-Susceptible Deposit

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Map Area	0.00	0.01	0.02	0.03	0.05	0.08	0.10	0.15	0.20	0.25	0.30

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

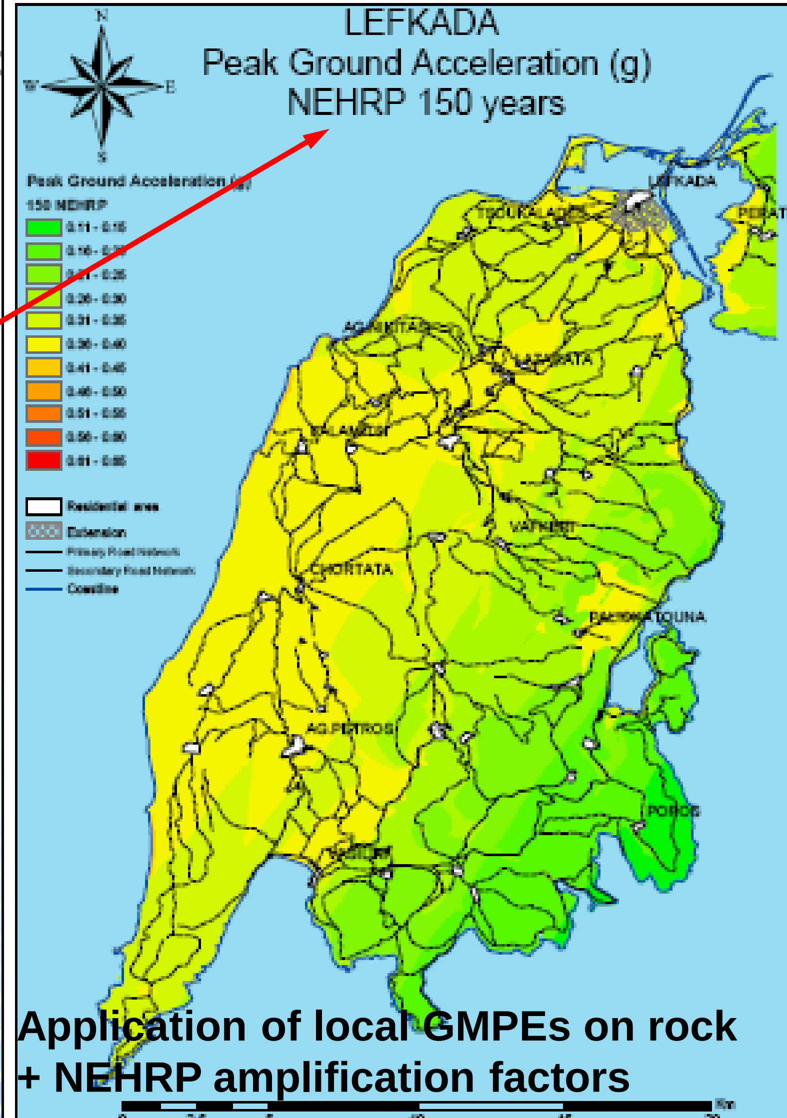
Black Sea CROSS BORDER COOPERATION



Direct application of local GMPEs

rders. Comm

PGA spatial distribution from LEFKADA island earthquake M6.2, 14-8-2003



Application of local GMPEs on rock + NEHRP amplification factors

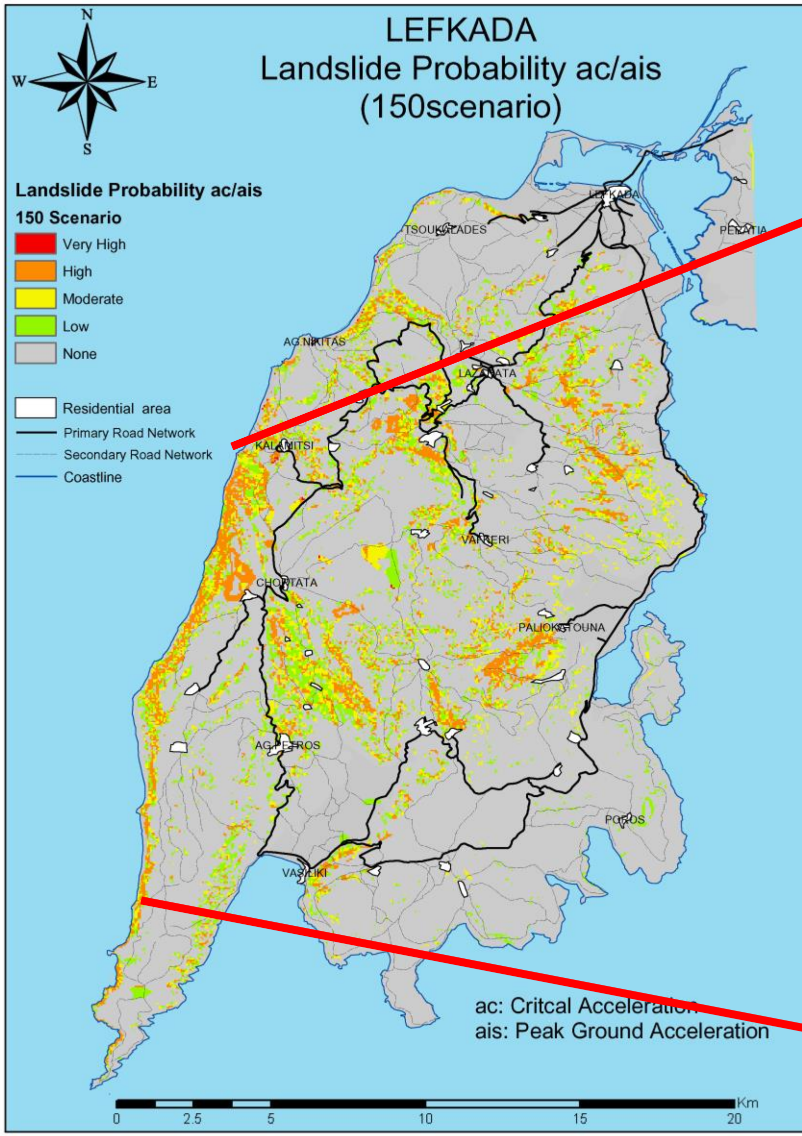
“Shallow” landslides susceptibility under seismic conditions

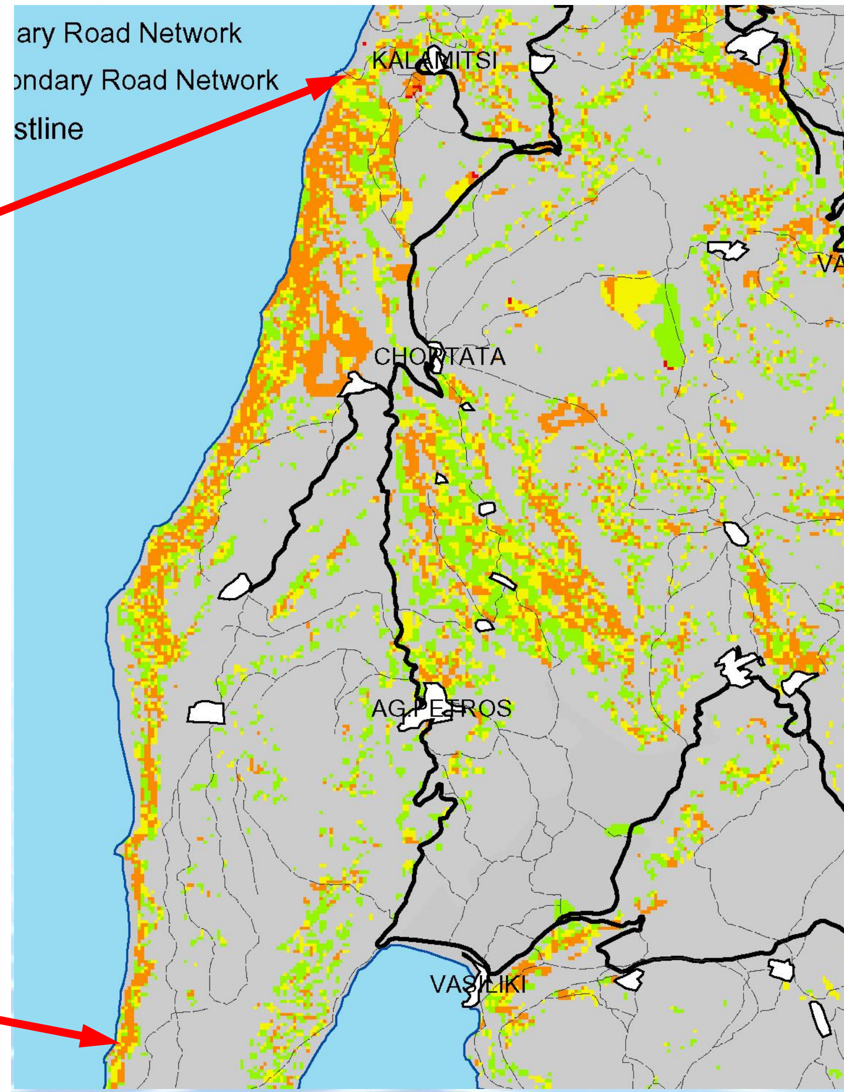
“Shallow” landslide susceptibility to earthquake-induced displacements, as specified by the index Ac/PGA for a mean return period of a seismic event or a a discrete seismic event (M6.2, 2003; Lefkada island)

On what criterion?

Index A_C/PGA and a “subjective” categorization

- **Very high: < 0.3**
- **High: 0.3 – 0.6**
- **Moderate: 0.6 – 0.8**
- **Low: 0.8 – 1.0**
- **Very Low: 1.0 – 3.0**
- **None: > 3.0**





smic
s, as
of 14
on the
EQ,

3. Landslide Hazard Assessment

(*under static* / hydraulic *and seismic conditions*)

Three (3) approaches for landslide hazard assessment were tested:

- HazUS method proposed by FEMA adapted to Hellenic data **(triggering: earthquake)**,
- Newmark modified method **(triggering: earthquake),** and
- the static factor of safety F_S computation method **(triggering: static/hydraulic conditions**).

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

3. Landslide Hazard (seismic conditions) *according to FEMA method (a)*

Assessment of Permanent Ground Displacements (PGD) of "shallow" landslides

$$E[PGD] = E[d/A_{is}]*A_{is}*n$$

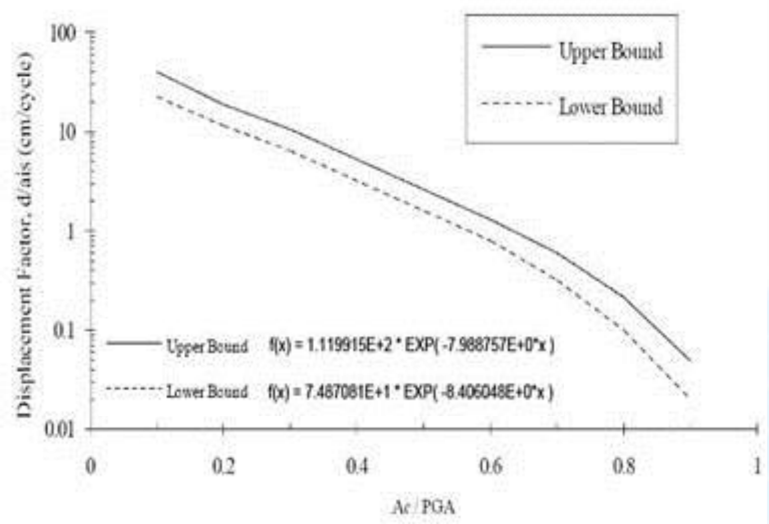
A_{is}: induced acceleration (g) – same with PGA

n: number of cycles

$E[d/A_{is}]$: expected displacement factor

$$n = 0.3419M_w^3 - 5.5214M_w^2 + 33.6154M_w - 70.7692$$

E[d/Ais]:



A_C / PGA

Local GMPEs (Skarlatoudis et al., 2003)

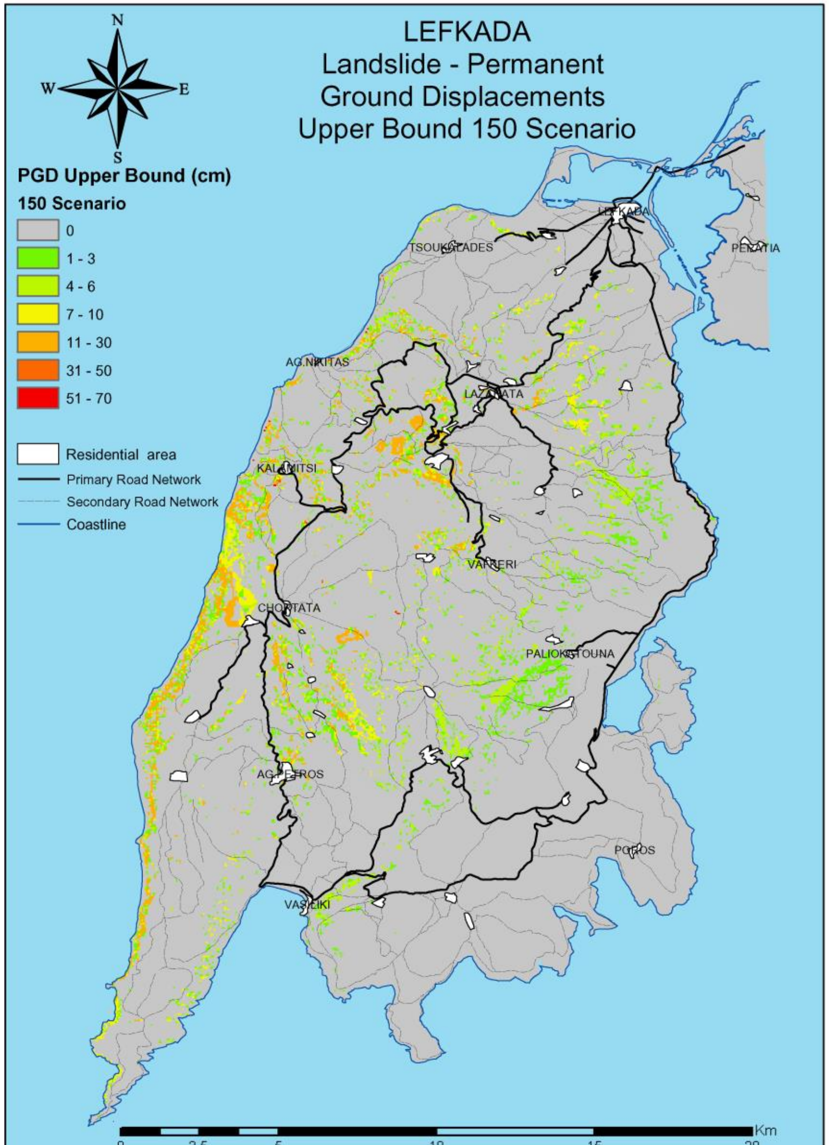
$$\log PGA = 1.07 + 0.45M - 1.35 \times \ln(R + 6) + 0.09F + 0.06S \pm 0.286$$

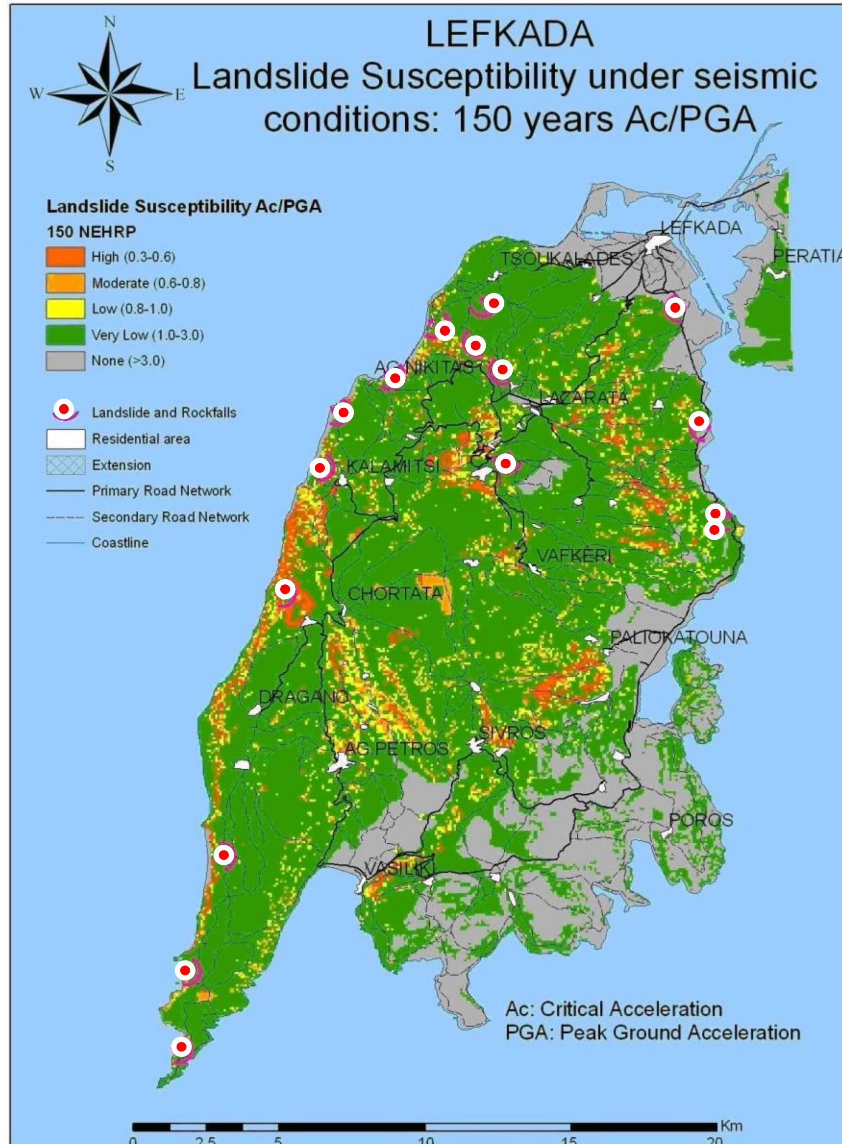
$$\log PGA = 0.86 + 0.45M - 1.27 \times \ln(R^2 + h^2)^{\frac{1}{2}} + 0.10F + 0.06S \pm 0.286$$

Project funded by the EUROPEAN UNION

ciNet NatHaz

Black Sea CROSS BORDER COOPERATION





Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

3. Landslide Hazard (seismic conditions)

according to modified Newmark method (b)

$\log D_n = 1.521 \log I_o - 1.993 \log A_C - 1.546$ *For slopes >10º*

D_n : Newmark displacements (cm)

I_o : Arias Intensity (m/sec)

A_C : critical acceleration

$$I_0 = \frac{\pi}{2g}\int_0^{\infty}\left[a(t)\right]^2 dt$$

- I_o *Arias Intensity (1970)*,
- g ground acceleration
- a(t) time series acceleration

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

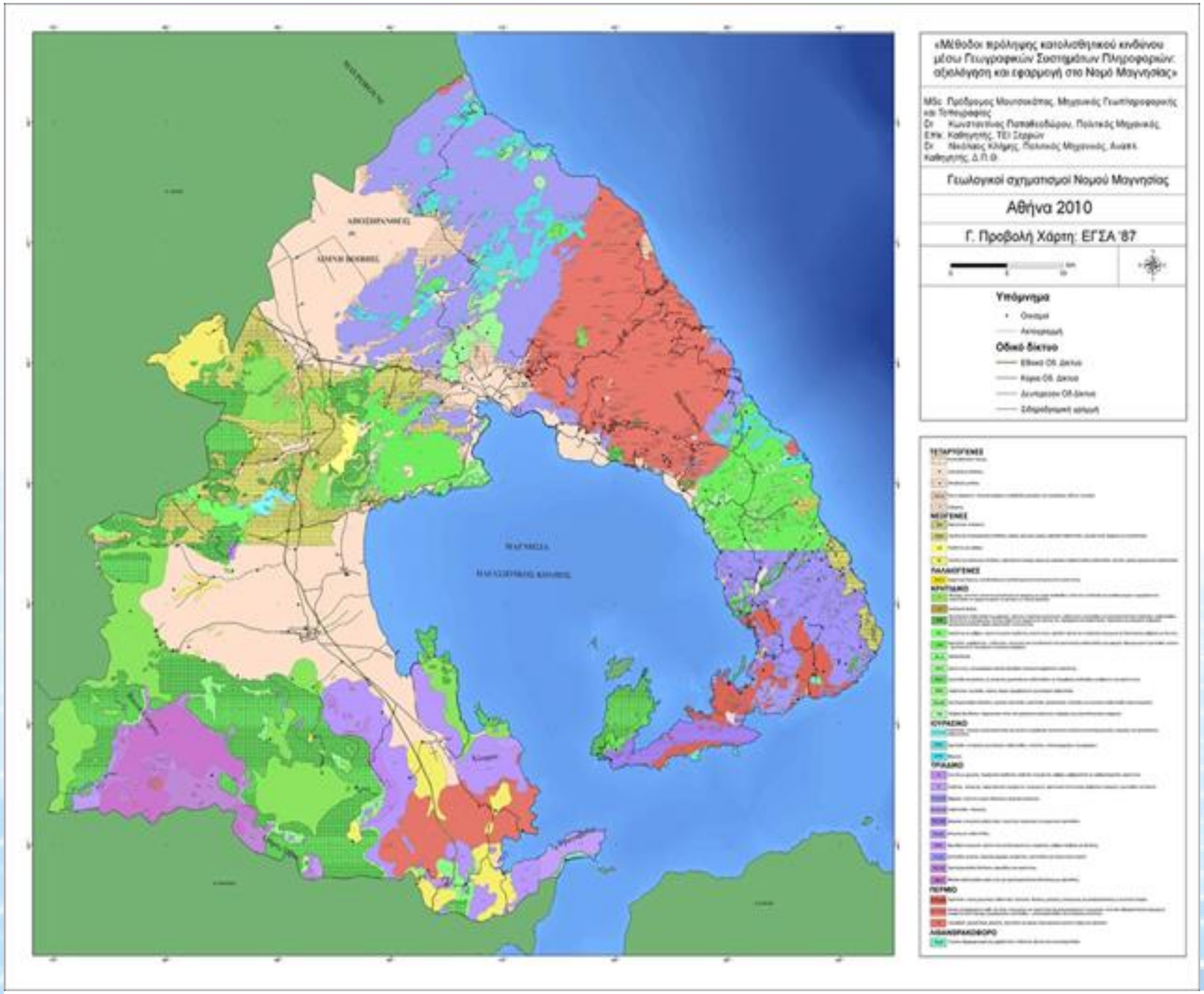


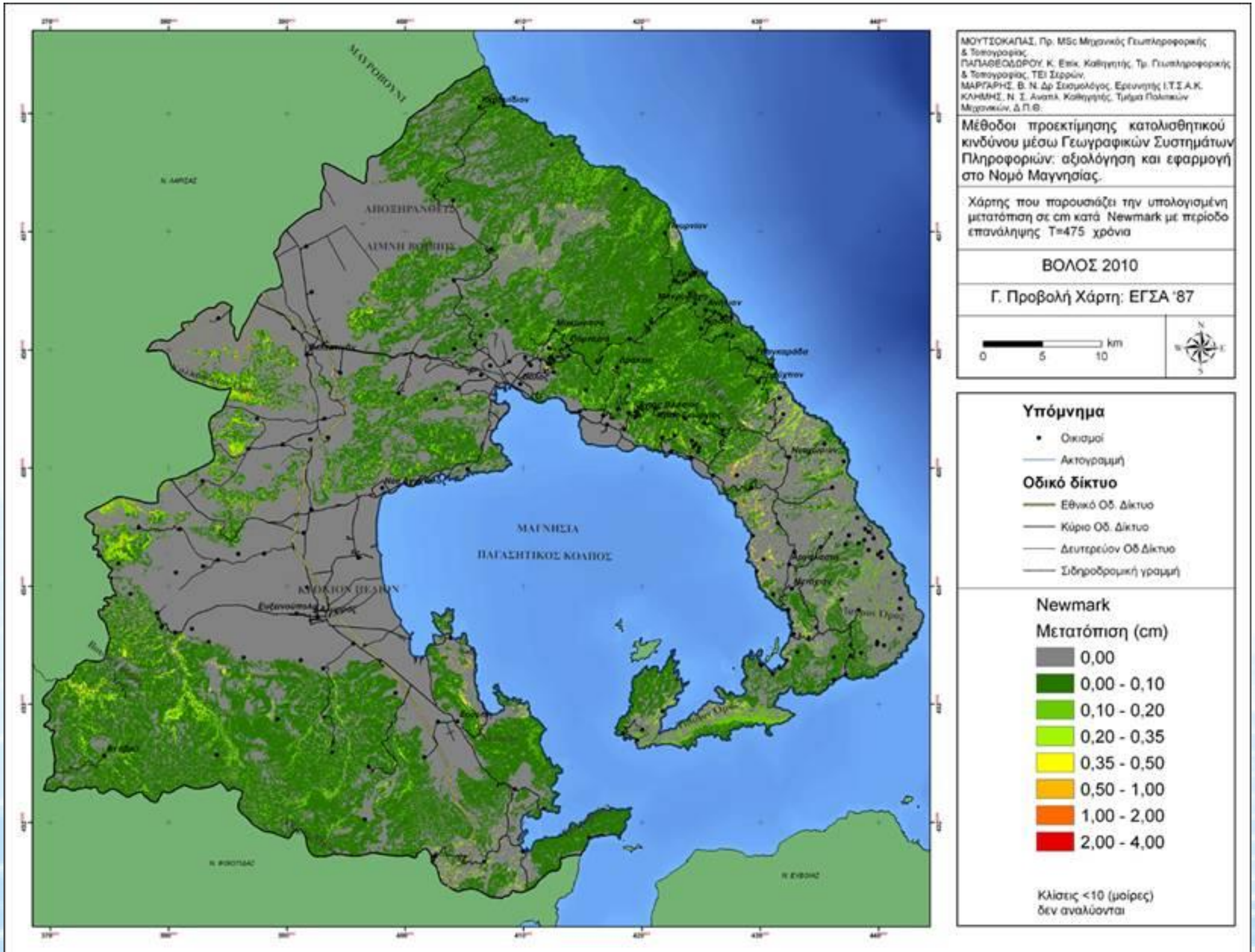
Figure 1. Geologic map of the Prefecture of Magnesia

Landslide hazard estimation methods using GIS: method evaluation and implementation in Magnesia prefecture

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION



Thematic Map

Scale: 1:50,000

Newmark displacements (cm)

3. Landslide Hazard (static / hydraulic conditions)

according to the safety factor method (c)

Factor of Safety Assessment:

$$FS = \frac{c'}{\gamma t \sin a} + \frac{\tan\varphi'}{\tan\alpha} - \frac{m\gamma_w \tan\varphi'}{\gamma\tan\alpha}$$

ϕ': effective angle of friction of geomaterial (^{0})

c’: effective cohesion of geomaterial (kPa),

γ: specific weight (kN/m^3),

a: slope angle (Deg),

γ_w: specific weight of th water (kN/m^3),

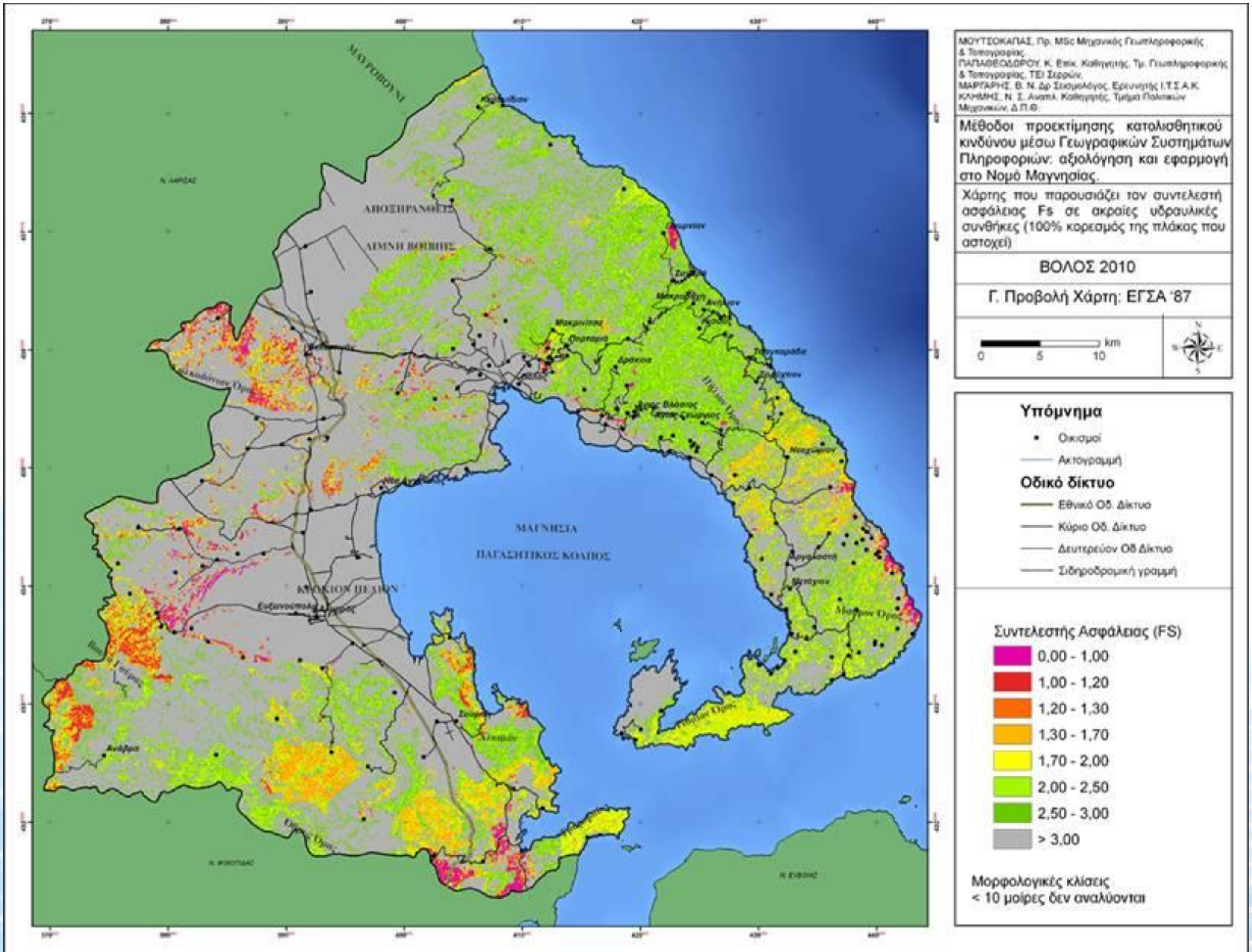
t: normal thickness of the failure slab (m)

m: percentage of the water saturated failure slab (%)

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION



Thematic Map

Scale: 1:50,000

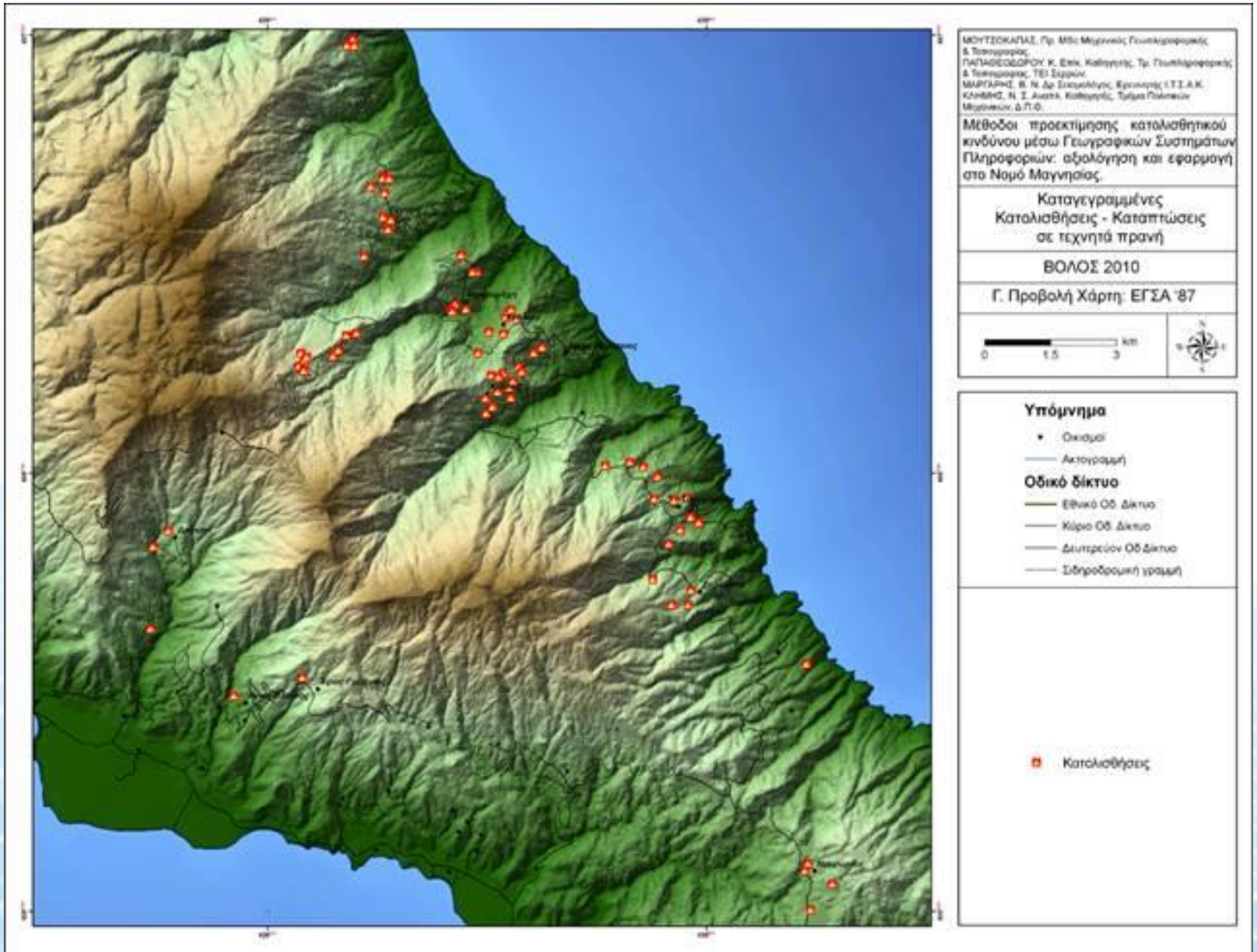
Safety Factor

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.



Landslides on cut slopes (v:h=2:1)

Scale: 1:50,000

Magnesia Prefecture

Project funded by the EUROPEAN UNION

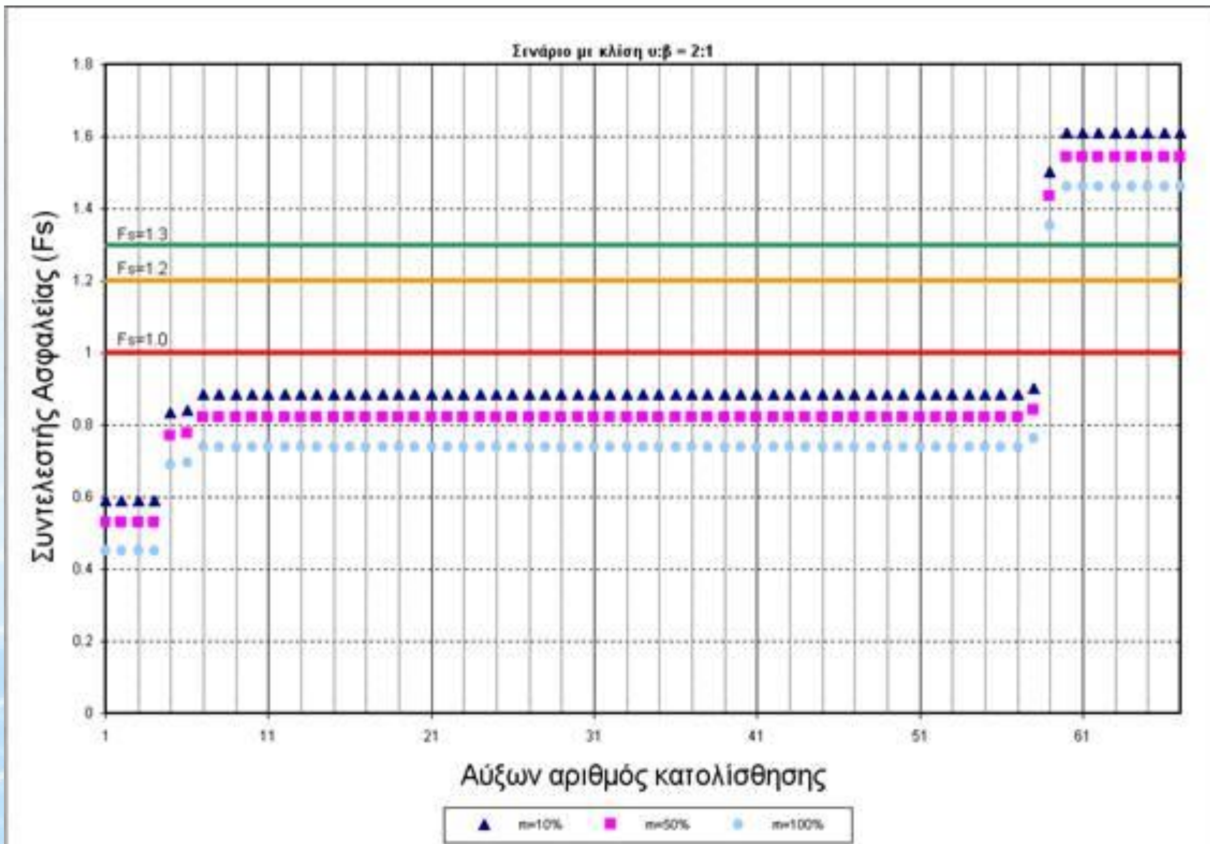
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Landslide Hazard (static / hydraulic conditions) *according to the safety factor method (c) in 67 locations where landslides occurred in cut slopes (vertical:horizontal = 2:1)*

The above method, albeit crude, reached a percentage of almost 85% success.

Parametric investigation regarding saturation % of the sliding slab **(m)**.



Slope-normal thickness of the failure slab (t) correlated to the slope angle (º).

Μορφολογική κλίση (º)	Πάχος πλάκας (t)
90º – 80º	t=0.0m
80º – 70º	t=1.0m
70º – 60º	t=1.5m
60º – 50º	t=2.0m
50º – 40º	t=2,5m
40º – 30º	t=4,0m
30º – 0º	t=10m

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility Regional Scale 1:250,000 to 1:25,000 *(static & seismic conditions)*:

1. ***FEMA method (for static conditions: geologic maps + topography maps + hydraulic conditions) BUT needs improvement (introducing structure of soils/rocks: dip & dip direction of bedding, schistosity, interface of weathered zone and rockmass or soil over rockmass)***

2. ***FEMA method (for seismic conditions: geologic maps + topography maps + hydraulic conditions) + Critical Acceleration: index A_C / PGA seems to work fine with local GMPEs and "shallow" landslides***

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Hazard Assessment Regional Scale 1:250,000 to 1:25,000 *(static & seismic conditions)*:

1. ***Factor of Safety method (for static conditions: geologic maps + topography maps + hydraulic conditions (% of sliding slab saturation) + geotechnical parameters (φ', c') + sliding slab normal thickness) seems to work fine for "shallow" landslides, BUT needs improvement (regarding assessment of sliding slab thickness)***

2. ***FEMA method (for seismic conditions: geologic maps + topography maps + hydraulic conditions) + Critical Acceleration: index A_C / PGA resulting in assessment of Permanent Ground Displacements seems to work fine with local GMPEs and "shallow" landslides***

3. ***Modified Newmark method (for seismic conditions: parameter of Arias Intensity NOT easy to be obtained)***

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Thank you so much for your attention and patience