



## **HAZARD MAPPING OF EARTHQUAKE TRIGGERED LANDSLIDES**

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### **SUMMARY**

Landslides are among the most common earthquake induced secondary effects and are causing huge damage to settlements, infrastructure and human life worldwide.

A time and cost effective method to identify high risk and landslide prone areas is presented here, based on the combination of remote sensing data and geologic, tectonic information. Due to the availability of remote sensing data the worldwide transferability of the method is possible. Remote sensing data can help to assess a better understanding of processes triggering landslides. Emphasis was put on the seismicity of concerned areas. Structural features visible on satellite imageries area were mapped in order to investigate the tectonic setting and to detect surface traces of fracture and fault zones. The detection of active, neotectonic features and unknown fault segments and structures is of high importance as fault segments, their bends and intersection are more apt to concentrate stress and amplify seismic shock and, thus, enhance landslide risk. The results from remote sensing analysis can be further integrated in a GIS-based model for landslide susceptibility mapping. Historical earthquakes as well as the actual tectonic situation influencing the damage intensity were integrated in the model.

The research presented here was part of the OASYS (Integrated Optimization of Landslide Alert Systems, EVG1-2001-00061) research project that considered the support provided by spatial databases for the delineation of potential natural hazard sites in different test areas. The goal of the project was to develop a small scale approach combining analysis of optical (LANDSAT ETM) and SAR intensity (ERS-1/2) remote sensing data with results from differential SAR interferometry in a GIS environment to assess the potential for landslide hazard on a regional basis. In this paper the methodology for hazard mapping of earthquake triggered landslides is presented together with a case study concerning the Printopa landslide in Greece.

### **1. INTRODUCTION**

The OASYS project was research project funded within the 5<sup>th</sup> Framework Programme of the European Community within the 'Energy, Environment and Sustainable Development Programme' (1998-2002). It started in January 2003 with a duration of 38 months. The following partners contributed to the project:

**Table 1: Contributing partners**

<b>Coordinator</b>	<b>Country</b>	<b>Acronym</b>
VCE Holding GmbH	AT	VCE
<b>Partner</b>	<b>Country</b>	<b>Acronym</b>

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Institute of Geodesy and Photogrammetry, Technical University of Braunschweig	D	TUBS
Institute of Geodesy and Geophysics, Technical University Vienna	A	TUW
Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences	HU	GGRI
Bureau of Applied Geoscientific Remote Sensing	D	BAGF
Geodata Meßtechnik GmbH	A	GEODATA
Bureau of Investigation and Survey	CN	BIS
Hungarian Ministry of Interior	HU	HMI
Egnatia Odos S.A.	EL	EGNATIA
Università degli Studi di Modena e Reggio Emilia	I	UNIMO
Wuhan Technical University of Surveying and Mapping	CN	WTUSM
The Laboratory of Geodesy, University of Thessaloniki	EL	UNITHES

<b>Contributing Participants</b>		
Sabba Stefanescu" - Institute of Geodynamics,. Romanian Academy	RO	GEODIN
Institute of Mechanics, Chinese Academy of Science	CN	IMECH

The objectives of the OASYS project had been the development of observation methods that allow

- the detection of potential landslides
- the efficient and continuous observation of critical areas
- the derivation of real time information about actual risks.

Test sites are located in China, Greece, Hungary, Germany, and Italy. For spatial optimization of the alert systems a multi scale approach was applied, which helped to reduce the areas that have to be observed step by step. On a regional scale the areas of active and potential landslides had been determined by an integration of remote sensing data (satellite data, aerial photographs), geological and topographic maps and data of historical landslides.

In those areas a coarse observation network (mainly GPS) was installed in order to localize active zones more precisely. The observation network was optimized in additional refinement steps. This was performed by the application of methods like high precision remote sensing and interferometric SAR (data of e.g. ERS-2, ENVISAT, IKONOS) as well as continuous survey by robotic systems and high precision hydrostatic leveling systems. An algorithm for detection of the taking-off domains has been developed based on the previous deformation analysis. After the detection of the block boundaries the observation was done on local scale by geotechnical monitoring.

## 1. OBJECTIVES OF OASYS

The basic idea of OASYS was that only a multidisciplinary approach including e.g. geology, geodesy, geotechnics, geomorphology can yield a reliable and effective monitoring and alert system. To combine all this information, one of the basic principles within the OASYS project was the multi-scale observation concept that was able to reduce the landslide prone areas step by step.

The multi-scale concept builds the frame for the work carried out in the OASYS project and includes all approaches. Therefore it is used for the technical summary of the project results below.

The main objective of OASYS was to develop a multi-scale observation concept that would be able to reduce landslide hazard by using a multidisciplinary approach which takes into consideration geology, geodesy, geotechnics and geomorphology and leads to the development of an effective monitoring and alert system. Following, the steps of this approach are described.

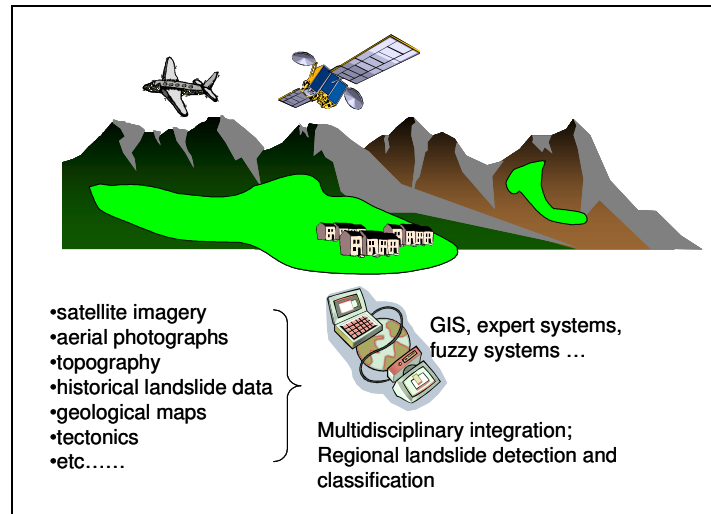
### 1.1 Multi-Scale Observation Concept

In principle the multi-scale observation concept consists of four major steps from small scale to large scale.

- **1<sup>st</sup> step: Detection of landslides and high-risk areas (Small-scale monitoring)**

As first step in the multi-scale approach the identification of historical and potential landslides and the major contributing factors is essential. The delineation of high-risk areas in the different test areas is the goal of

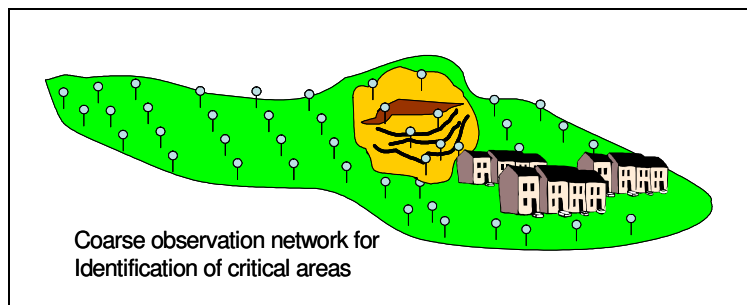
this step by means of a small scale approach combining analysis of optical (LANDSAT ETM) and SAR intensity (ERS-1/2) remote sensing data with results from differential SAR interferometry in a GIS environment in order to assess the potential for landslide hazard on a regional basis.



**Figure 1: Small (regional) scale (1<sup>st</sup> step in the multi-scale observation)**

- **2<sup>nd</sup> step: Detection of taking-off domains**

As soon as the potentially moving areas are identified in step 1, the regional geodetic monitoring network can be installed. Based on this monitoring information the taking-off domains should be identified. The goal was to develop an advanced deformation analysis algorithm based on improved geometrical as well as on topographical, hydrological and meteorological information in order to improve the detection of taking-off domains.



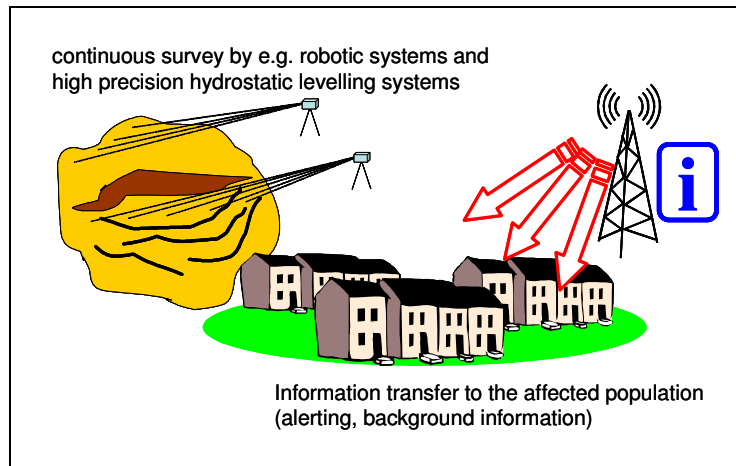
**Figure 2: Coarse local scale (2<sup>nd</sup> step in the multi-scale observation)**

- **3<sup>rd</sup> step: High precision permanent measurements in the taking off domain**

As soon as the block boundaries have been identified in step 2, the geotechnical sensors can be installed. The geotechnical sensors like inclinometers, piezometers, extensometers, tiltmeters etc. are high precision instruments used for a permanent monitoring in real-time. These instruments should be used to get additional geometric information about the deformations in the taking-off domain. The goal was to develop a multi-sensor system that will be continuously in operation and can therefore support a real time alert system.

- **4<sup>th</sup> step: Development of an alert system**

The final step is the development of an alert system. The aim was to develop a risk management concept that can be used in a decision support process and the development of automated data analysis methodologies for an alert system.



**Figure 3: Fine local scale (3<sup>rd</sup> and 4<sup>th</sup> step in the multi-scale observation)**

## 1.2 Landslide Hazard Analysis

The seismicity as triggering factor was taken into consideration as a major subject in the small-scale investigations. The remote sensing contribution was planned for providing an overview of potential further risk sites and for a better understanding of processes triggering landslides.

A multi-scale, interdisciplinary approach was applied in this study, which helped to reduce the areas that had been observed step by step. On a regional scale the areas of active and potential landslides had been determined by an integration of remote sensing data (satellite data, aerial photographs), geological and topographic maps and data of historical landslides. An existing database was used to generate landslide hazard zonation maps.

The main contribution of remote sensing data is to provide the morphological, land use, and geological detail to assist in determining how the landslide failed and what caused the failure. In other words, remote sensing data can be used to map factors that are related to the occurrence of landslides, such as lithology, faults, slope, vegetation and land use. Where failure could occur can be addressed in a more regional geographic information system (GIS) analysis as a necessary first step in risk analysis. This is because the factors contributing to slope failure at a specific site are generally complex and difficult to assess with confidence.

Remote sensing data can be used to map factors that are related to the occurrence of landslides, such as lithology, faults, slope, vegetation and land use.

The factors contributing to an increase of the shear stress include:

- removal of lateral and underlying support (erosion, previous slides, road cuts and quarries)
- increase of load (weight of rain/snow/ash, fills, vegetation)
- increase of lateral pressures (hydraulic pressures, roots, crystallization, swelling of clay)
- transitory stresses (earthquakes, vibrations of trucks, machinery, blasting)
- regional tilting (geological movements)

GIS techniques are used for regional analysis and prediction. Several digital data sets were integrated for such analysis. These include an inventory of landslides; seismic records; large-scale geological mapping; extensive geotechnical data on rock properties; high-resolution digital elevation data, and suitable high-resolution remote sensing data. The outcome of the analysis was the production of hazard risk maps. However, the data used were available in different scale resolution and level of detail. For example, both space- and airborne remote sensing systems have resolutions that permit detailed geomorphologic mapping to be conducted. On the other hand, current landslide inventory maps are not standardized around the world. They are published at different scales with various levels of details. These maps usually include information on the classification of the landslide type, their location, as well as the geomorphic and slope characteristics and only in some cases active and dormant landslides are distinguished.

The essential steps to be followed in landslide hazard zonation are:

- Mapping the landslide distribution based on type, activity, dimensions, etc.
- Mapping and analyzing the most relevant terrain parameters related to the occurrence of landslides
- Assigning weights to the individual causative factors, the formulation of decision rules and the designation of landslide susceptibility class.

## 2. METHODS AND APPROACH

The aim was to investigate the potential of remote sensing and GIS techniques to improve the understanding of the subsurface conditions influencing damage intensity. The study was an attempt to integrate various data sets as LANDSAT ETM data and satellite radar data SRTM, aerial photographs, and seismotectonic data to obtain a general better understanding of processes influencing the damage intensity of stronger earthquakes, including primary and secondary effects as ground motion, liquefaction potential and landslide susceptibility, and to improve hazard maps. One focus was to investigate the use of satellite imageries for the detection of the tectonic pattern and of earthquake induced faults and fracture patterns at the earth's surface. This information about seismicity and seismotectonic had been used in the identification of high risk areas for landslides.

### 2.1 Detection of Landslides and High-Risk Areas (Small Scale Monitoring)

The detection of landslides and high-risk areas (Small-scale monitoring) is the first step in the multi-scale concept. The delineation of high-risk areas in the different test areas is the goal of this step. A time and cost effective way to identify landslide prone areas is the interpretation and analysis of remote sensing data and the further use in GIS (Geographical Information System) based modeling. The approaches summarized in this chapter have been used for providing an overview of potential further risk at the test sites and for a better understanding of processes triggering landslides.

In this chapter the following approaches are described:

- GIS integrated geologic evaluations of remote sensing data
- InSAR interferometry
- GIS-based landslide susceptibility assessment.

#### 2.1.1 *GIS Integrated Geologic Evaluations of Remote-Sensing Data*

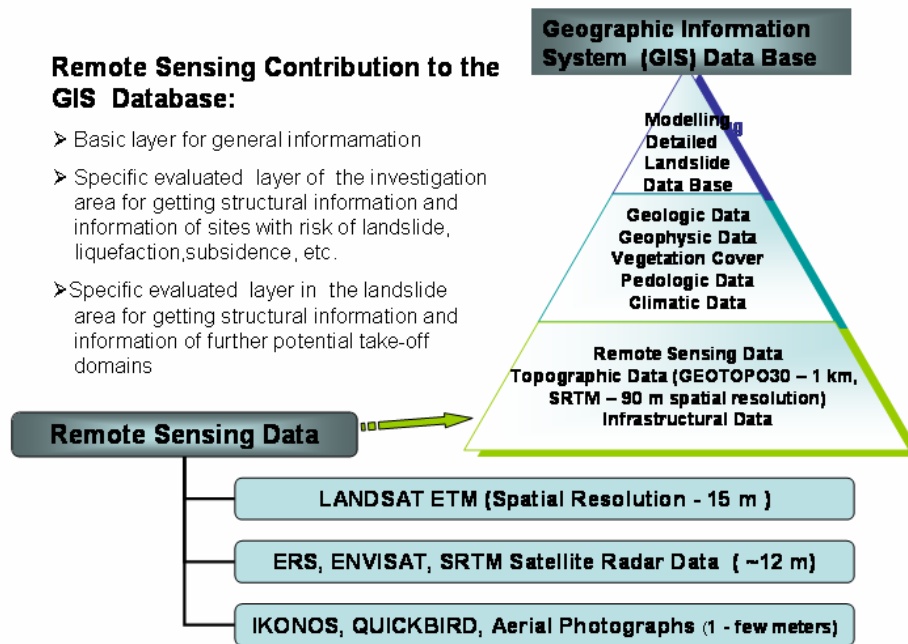
In the scope of the OASYS project remote sensing data with high spatial resolution were used for producing landslide inventory maps and for mapping factors related to the occurrence of landslides such as surface morphology, structural and lithological properties, land cover, and temporal changes of these factors. High resolution satellite data were used complementary to aerial photography or as substitute if no recent air photos were available. Regional physiography, geologic structure, and most landforms as well as land use and distribution of vegetation were evident on the satellite imagery. These features in conjunction with the tonal patterns present on the imagery provided information regarding the type of surface materials. However, at the small scale of satellite imagery, only larger landslides can be identified directly.

##### 2.1.1.1 *Evaluation of Maps and Other Data*

The comparative analysis of remote sensing data with available geoscientific data and maps has been carried out as well as the evaluation of reference data. Available geological and geotechnical data were collected, interpreted and mapped. The additional information gained by the linkage and overlay of different data sets was examined and the relationship between these datasets was better demonstrated.

##### 2.1.1.2 *Evaluation of Remote Sensing-Data and Image Enhancement*

For the objectives of this study the following remote sensing data have been evaluated: LANDSAT ETM- Data (provided by ESA / EURIMAGE) and the University of Maryland / USA, satellite radar imageries (ERS-1, SLC1) ENVISAT and SRTM data. As a complementary tool Google Earth Software was used in order to benefit from the 3D imageries of the various investigation areas (<http://earth.google.com/>).



**Figure 4: GIS and Remote Sensing Approach**

### **2.1.1.3 LANDSAT ETM Data**

LANDSAT ETM satellite data can be a valuable tool for delineating geomorphological, structural, hydrologic or vegetation features relevant to the hazard zone mapping. Their applicability though, mainly relates to giving additional information for the hazard zone mapping or for results visualization. In optical data scarps of sliding processes can be identified as their boundaries are often sharp.

For enhancing the LANDSAT ETM data digital image processing procedures have been carried out. Various image tools delivered by ENVI Software/ CREASO were tested, for example, in order to find the best suited contrast stretching parameters. With digital image processing techniques maps can be generated to meet specific requirements considering risk mapping.

Oblique views were constructed to visualize the pattern of regional structures. The resulting image files were rotated to a variety of viewing directions to make better observations of the fault pattern.

### **2.1.1.4 ERS and ENVISAT Satellite Radar Data**

Many of the known faults and fracture zones are traced as linear features and linear arrangements of pixels on the radar imageries, especially on amplifications of the radar data up to a scale of 1:25.000. In order to improve the lineament mapping feasibilities of the ERS data it is necessary to switch between different scales as the manifestation of lineaments is dependent on the scale of observation and dimension involved. However, additional and comparative evaluations of LANDSAT images are important for an as complete as possible detection of the tectonic pattern by remote sensing methods. The available ERS and ENVISAT scenes were merged with the different LANDSAT ETM bands in order to combine the geologic information content of the data.

### **2.1.1.5 Digital Elevation Model (DEM) Data**

Compared with two-dimensional images like the available satellite pictures, digital elevation models have the advantage of representing the vertical extension of the earth's surface by giving height values for every pixel. With digital image processing techniques, customized perspective views can be generated to meet specific requirements considering risk mapping. The elevation information was derived from the signals reflected on the Earth's surface. Depending on the wavelength the radar signal penetrates the ground coverage and in some cases even the ground. For getting a geomorphologic overview SRTM data terrain parameters were extracted from a DEM as shaded relief, aspect and slope degree, minimum and maximum curvature or plan convexity maps using

ENVI and ArcMap software. Geomorphometric parameters provide information of the terrain morphology indicating geomorphologic features that might be related to landslide events.

The remote sensing data were used for generating an image based GIS from the different test sites. Based on the different map products derived from SRTM data linear morphologic features were mapped. These linear anomalies of morphologic units as abrupt linear changes in the drainage pattern, slope orientation and curvature or linear scarps help to detect structural influence on slope failure, especially neotectonic movements in the subsurfaces. Surface-near neotectonic movements generally are well expressed by geomorphologic features.

### 2.1.1.6 Aerial Photographs

Available aerial photographs were used as further additional tool for the detection of areas prone to slope failure in order to profit from the high spatial resolution of a few meters. Especially for smaller landslides aerial photographs provide an important source of information.

The aerial photographs were contrast stretched and colour coded using ENVI and ArcView GIS. Limitations and obstacles of the potential support from earth observation techniques were considered carefully.

### 2.1.1.7 Lineament Analysis

The technique of digital image enhancement was followed by visual interpretation of the data in an interactive manner. Aim of this study was to investigate the use of satellite imageries and inferred products to detect linear or curvilinear features in order to find traces of possible slope failure. Lineament analysis provides important clues for delineation areas prone to landslides, especially a more precise localization of areas with a relatively higher risk of slope failure. Combining lineament maps for example with slope degree maps based on digital terrain data helps to delineate areas with a higher risk of landslides.

Lineaments often represent the surface expression of faults, fractures or lithologic discontinuities (Figure 5) and are expressed as scarps, linear valleys, narrow depressions, linear zones of abundant watering, drainage network, peculiar vegetation, landscape and geologic anomalies.

The detectability of lineaments is scale-dependent. Therefore the visual, PC based, lineament analysis has been carried out using different scales as 1:200000 up to 1:10000. Over long distances extended lineaments are often better visible on imageries at scales of 1:100000. Due to the large overview on satellite imageries geologic structures are better detectable than on large-scale aerial photographs. Amplifications of the scenes clearly show the linear arrangement of image elements (pixels) and linear morphologic features as linear valleys, escarpments, etc. Lineament analysis based on satellite imageries, thus, contributes to a more detailed knowledge about faults and fracture systems that might be important for recent crustal movements.

Structural features visible on satellite imageries area were mapped in order to investigate the tectonic setting and to detect surface traces of fracture and fault zones. Special attention was focused on the detection of active, neotectonic features and to find and map not yet known fault segments and structures. Fault segments, their bends and intersection are more apt to concentrate stress and amplify seismic shock and, thus, enhance landslide risk.

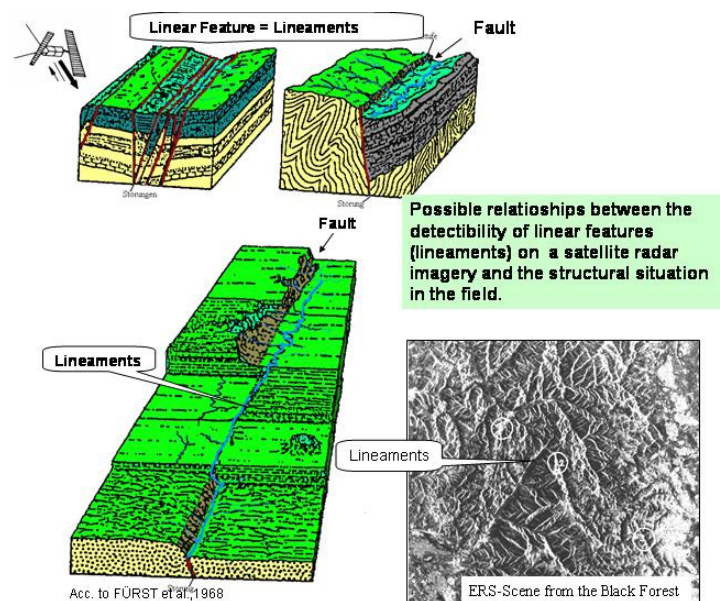


Figure 5: Lineament mapping based on morphology and drainage pattern

Analysis of the present-day displacement /deformation fields by geodetic studies and radar interferometry was of high importance in this study. Therefore special attention was focused on precise mapping of traces of faults on satellite imageries, predominantly on areas with distinct expressed lineaments, as well as on areas with intersecting / overlapping lineaments in areas with risk of slope failure and on areas with unconsolidated sedimentary covers. In case of stronger earthquakes fault zones could cause constructive interference of multiple reflections of seismic waves at the boundaries between fault zones and surrounding rocks and, thus, amplify earthquake shock or the potential of earthquake induced secondary effects as landslides.

Areas with intersecting probable fault and fracture zones were delineated as potential higher risk sites. The following linear and curvilinear features were identified:

- Lineaments
- Probable fault zones
- Structural features
- Probable traces of compression due to collision.

### **2.1.2 SAR Interferometry**

Remote sensing data and their archives give the possibility to have a look back into the past and on the other hand the ongoing and future satellite missions serve as a base for the detection and monitoring of earth surface processes. For the recognition of surface movements one has decided to investigate the capability of InSAR for these purposes.

The use of Synthetic Aperture Radar Interferometry (InSAR) for the detection and monitoring of earth surface processes is meanwhile an established method. However, this approach has only significant success if the observed area fulfils specific requirements, like sufficient backscattering, flat slope gradients or very slow change of vegetation.

The main objective of using InSAR was the detection of landslides and landslide prone areas. A spin-off product of the SAR processing was the local improvement of existing digital elevation model (DEM). These improved DEMs could serve as important input data for further GIS modeling.

### **2.1.3 GIS-based Landslide Susceptibility Assessment**

In OASYS the task was to build a GIS-based hazard information system including also the results from the remote sensing analyses. As a first step towards a landslide hazard information system the landslide susceptibility must be assessed. According to the generally recognized definition of Varnes (1984) the susceptibility is the probability of occurrence within a specified period of time and within a given area of a potentially damaging failure, which is in this case a landslide. In OASYS a GIS-based susceptibility assessment has been carried out integrating also the results from the geologic evaluations of the remote sensing data. The result was a landslide susceptibility map which is further integrated with other environmental, infrastructure, administrative and other data in order to estimate the landslide risk.

Because of the variety of factors contributing to mass movements, huge data volumes have to be processed and analysed, hence the application of geo-information systems (GIS) can hardly be dismissed. The application of GIS for the data capture and creation of natural hazards inventories is standard and indispensable. Apart from the pure data collection and processing function of GIS, there is a huge number of spatial analysis methodologies and the possibility to implement statistical and numerical models (map algebra) that allow manifold approaches for the assessment of natural hazards. The capabilities of GIS reach further, from monitoring of identified risk areas to preparation of the emergency planning (like logistic planning of rescue operations).

## **3. TEST SITE REPORT FOR PRINTOPA**

In the scope of the OASYS project the Printopa landslide (Greece) was selected for detailed investigations. The local site that is proposed for detailed study (Printopa) is situated near river Arachthos to Peristeri village.

According to local information ground instabilities in various parts of this area have been a problem for local roads and residencies for many years. The geomorphology of the area indicates that there have been in the past landslides of significant extent and this is also confirmed by the available geological data.

The problems in the test site are basically the combination of factors such as the mountainous terrain, the presence of the flysch formation (prone to instability), the adverse geotectonic conditions (faults, folds etc) and the adverse meteorological conditions. The factors that influence the occurrence of landslides are geomorphology (mountainous and hilly terrain), geology (presence of flysch formation, weathering effects, presence of fractures, faults, folds etc), geotechnics (presence of weak materials of low engineering properties, etc) and hydrology (high rainfall, groundwater, permeability contrasts, springs etc).



Fault segments and areas of fault intersections (arrows, Figure 7) are the most probable sites of stress concentration and creation of stronger earthquake shock. The highest risk must be anticipated in junctions of differently oriented ruptures, especially where they overlap each other. Unconsolidated sedimentary covers within the river sediments and the basin of Ioannina, especially when wet, could amplify earthquake shock. Arrows are indicating zones of lineament intersection and concentration, the black arrow a probable seismic reflector zone.

Assuming that the lineaments derived by visual interpretation of the LANDSAT imagery correspond to fault and fracture zones, these areas with intersecting lineaments can be considered as being more exposed to earthquake shock and, as consequence, to relative higher damage due to amplification of guided seismic waves along crossing fault zones. Fault segments, areas of fault intersections are the most probable sites of stress concentration and, thus, influencing slope instability.

#### 4. CONCLUDING REMARKS

LANDSAT and ERS imageries were used to create maps within a "Landslide Hazard Information System" as important layers in a GIS data base in order to perform user-defined computations of landslide hazard maps. Satellite imageries are of high importance and value concerning the detection and mapping of areas prone to landslide damage in the Greek test site. The detailed lineament analysis of LANDSAT ETM and radar imageries can contribute to a better knowledge about the tectonic setting in the environment of the Printopa test site.

Lineament analysis based on LANDSAT ETM and radar imageries can help to delineate those local fracture systems and faults that might influence seismic wave propagation in this earthquake prone area and, thus, influence the intensity of seismic shock as larger outcropping faults can cause for example a reduction of seismic velocities or multiple reflections amplifying vibration intensity and duration. Lineament analysis helps to detect relationships between active faults, neotectonic movements, morphology and the landslide occurrence.

Erosional processes and movements of slopes are structurally controlled by surfaces of planes of weakness, such as faults, joints and bedding planes. The identification of areas with close spacing of faults and joints, especially where they overlap, enables the finding of evidence of possible continued mass movements. The use of remote sensing to detect linear or curvi-linear features in order to find traces of possible slope failure is obvious. Lineament analysis provides important clues for delineation areas prone to landslides, especially a more precise localization of areas with a relatively higher risk of slope failure.

#### 5. REFERENCES

- Fiedler, F. (2001), Hrsg.: Naturkatastrophen in Mittelgebirgsregionen, Verlag für Wissenschaft und Forschung GmbH, VWF, Berlin
- Gupta, R. P. (1991): Remote Sensing Geology.- Springer-Verlag, Berlin - Heidelberg, New York
- Li, Y.-G. et al.(1994): Seismic guided waves trapped in the fault zone of the Landers, California, earthquake of 1992.- Journ.of Geophysical Research, Vol.99, B 6, 11,705- 11,722, June 10, 1994
- NPA Group, Crockham Park, Edenbridge, Kent, TN8 6SR, UK, Tel: +44( 0) 1732 865023, Fax: +44( 0) 1732 866521, Website: [http:// www. npagroup. Com](http://www.npagroup.com)
- OASYS Integrated Optimization of Landslide Alert Systems, Contract N°: EVG1-CT2002-00061, Deliverable D4.2, Report on the Observation System and on the Continuous Data Acquisition and Data Analysis, July 2004
- Pastor, M., Fernandez Merodo, J.A., Mira, P., Herreros, M., Gonzalez, E., Hadad, B., Quecedo, M., Benito, B. (2004), Modelling catastrophic landslides triggered by earthquakes, *Geophysical Research Abstracts*, Vol. 6, 07661, 2004
- Ponte, S.(1997): ERS Tandem Data for Earthquake Prediction Preliminary Results.- Proc.3rd ERS Symp.on Space at the Service of our Environment, Florence, Italy, ESASP- 414, 499-506
- Theilen-Willige, B.(1999): Erfassung der Erdbebengefährdung im Bodenseegebiet.- Abschlußbericht des Teilprojektes 4 im Projekt "Erstellung beispielhafter X-SAR Endprodukte" XEP für das Deutsche Zentrum für Luft- und Raumfahrt (DLR), DFD,Oberpfaffenhofen, PT-BEO FKZ 03EE 9714, Oktober 1999
- Theilen-Willige, B. (2001): Beitrag der Fernerkundung zur Erdbebenvorsorge - Fernerkundungsmethoden bei der Erfassung von durch Erdbeben und durch Erdbebenfolgeschäden gefährdeten Bereichen. - Beitrag zur Buchpublikation:
- Stucchi, M., Galadini, F. & Monachesi, G.(1999): The earthquakes of September/October 1997 in the frame of tectonics and long-term seismicity of the Umbria-Marche (Central Italy) Apennines.
- U.S. Geological Survey: <http://geography.about.com/library/misc/blcenturyworst.htm>