GIS Applications for Natural Hazard Zonation:

the Role of ITC in Addressing the Training Needs

C. J. van Westen

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By:

Dr. C.J. van Westen
International Institute for Aerospace Surveys and Earth Sciences, ITC
P.O. Box 6, 7500 AA Enschede, The Netherlands.
Tel: +31 53 4874263, fax: +31 53 4874336, e-mail: Westen@itc.nl

Abstract
The International Institute for Aerospace Survey and Earth Sciences, Enschede, is the largest institute for international higher education in the Netherlands. Its main objective is to assist developing countries in human resources development in areospace surveys, Remote Sensing applications, the establishment of geoinformation systems and the management of geoinformation. To this end, ITC concentrates on three activities: education/training, research and advisory services.
As one of its fields of specialization, the application of GIS and Remote Sensing in natural hazard zonation is carried out on a number of topics in a number of different countries, such as landslides (Colombia, Nepal), volcanic eruptions (Philippines), flooding (Bangladesh), earthquakes (Colombia) and spontaneous coal combustion (China). Research is carried out on the development of new technologies, such as the use of radar interferometry for monitoring landslides and subsidence, or the use of very high resolution multi sensor data for the detection of landmines.
However, most of the effort of ITC in this field is towards the application of existing technology in order to transfer this knowledge to persons working on disaster management in developing countries. For this purpose training packages are created and workshops are given in various countries. One of these training packages, dealing with the use of GIS in landslide hazard zonation will be highlighted.
Recently, ITC has become the executive secretariat of the UNESCO Coordination Programme for Disaster Reduction through Sustainable Development (CPDRSD). The main objective of this programme is to strengthen the capability of developing countries of mitigating natural disasters in these countries.

1. International Institute for Aerospace Surveys and Earth Sciences
To achieve an appropriate balance between the development of natural resources and maintaining an optimal natural environment, we need detailed and reliable geoinformation and geoinformation management tools. At the International Institute for Aerospace Survey and Earth Sciences (ITC), knowledge of geoinformation management is amply available, and continually being developed and extended. By means of education, research and consulting, ITC contributes to capacity-building in the developing world. Much attention is given to the transfer of technologies to organizations in developing countries.
'Geoinformation management', 'worldwide' and 'innovative' are the key words. ITC concentrates on earth observation, the generation of spatial information and on the development of data integration methods. Tools are provided that can support the processes of planning and decision making for sustainable development and the alleviation of poverty in developing countries.
ITC, established in 1950, is the largest institute for international higher education in the Netherlands. More than 11,500 students from over 150 countries have already followed courses at the Institute. ITC's courses are modular in structure to enable a multidisciplinary approach to geoinformatics, land resource surveys, urban sciences and earth resources surveys. The educational programme offers more than 40 specialization courses, leading to PhD and MSc degrees and postgraduate and technologist diplomas. The programme is intended primarily for mid-career professionals and scientists from developing countries.
The teaching staff at ITC includes international experts in fields such as photogrammetry, cartography, cadastre, computer science, management of geoinformation technology, forestry, urbanization, agriculture, vegetation science, soil science, social sciences, geography, geomorphology, geology, geophysics and mineral exploration. The teaching language is English.
ITC carries out interdisciplinary and problem-oriented research that focuses on strengthening organizations involved in survey, management and planning for sustainable development.

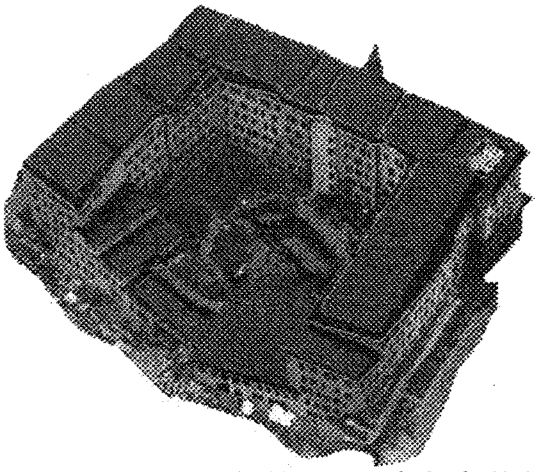

Figure 1: The new ITC building in Enschede, the Netherlands.

ITC's expertise in the application of geoinformation is also relflected in the development of GIS software: ILWIS. ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with image processing capabilities.
Surrounding the ILWIS software a large amount of training material has been developed over the years, on a basic as well as on advanced level. An example of this is the ILWIS Applications Guide (Van Westen, 1997), which contains discipline oriented case studies, and is intended for those who want to know how ILWIS 2.1 can be used for specific problems in various disciplines.
The ILWIS Applications Guide can be used both by persons on an individual basis, as well as in a course environment. Many of the case studies presented in this book are used in courses given at ITC, as well as abroad. The training material is also available on the ITC Website. The ILWIS Applications Guide consists of 25 case studies, arranged more or less according to the disciplines, reflected by the ITC departmental structure.

- **Applications in Earth Sciences**. Chapters 1 to 15 all relate to earth science topics:
    - *Applied Geomorphology and Natural hazards*. Chapters 1 to 7 deal with problems concerning natural hazard, such as flood hazards, cyclone hazards, volcanic hazards, landslide hazards, and seismic hazards.
    - *Engineering Geology*. Chapter 8 shows how to create an engineering geological data base for a mountainous area with a scarcity of borehole data.
    - *Surface hydrology*. Chapters 9 to 12 deal with hydrological problems related to irrigation, determination of peak runoff, and erosion modelling.
    - *Hydro-geology*. Chapter 13 explains a method for the evaluation of aquifer vulnerability to pollution.
    - *Geology*. Chapters 14 and 15 deal with the use of satellite images in geological surveys.
- **Applications in Environmental Management**. Chapters 16 to 18 relate to multi-disciplinary environmental problems.
    - *Neighborhood modelling*. Chapter 16 and 17 deal with the use of neighborhood modelling in GIS for specific environmental problems.
    - *Data combination*. In chapter 18 a number of methods are shown to combine multi-disciplinary data for the selection of a waste disposal site.
- **Applications in Land Resource and Urban Surveys**. Chapters 19 to 24 are concerning problems related to land resources analysis and urban studies.
    - *Urban Surveys*. Chapters 19 to 21 cover the suitability analysis of urban expansion and the monitoring of this expansion.
    - *Land use planning*. Chapter 22 is concerned with the analysis of fuelwood demand.
    - *Soil Surveys*. Chapters 23 and 24 are about soil erosion analysis.
- **Cartographic applications**. The last chapter (25) shows how ILWIS can be used in the preparation of a layer tinted map.

2. Development of training material on natural hazard assessment: GISSIZ.

One of the specialization fields of ITC is the study of natural hazards. The occurrence of Natural Hazards is a serious constraint on economic development, particularly in developing countries, where the economic loss due to the impact of natural hazards often makes the difference between economic growth and stagnation. On the other hand practice has shown that adequate hazard mitigation is possible.

In the field of natural hazards, the application of GIS and Remote Sensing in natural hazard zonation is carried out on a number of topics in a number of different countries, such as landslides (Colombia, Nepal), volcanic eruptions (Philippines), flooding (Bangladesh), earthquakes (Colombia) and spontaneous coal combustion (China). In this paper only the topics of landslides and coal fires are illustrated.

Slope instability hazard zonation is defined as the mapping of areas with an equal probability of occurrence of landslides within a specified period of time. Slope instability hazard assessment is based on the analysis of the terrain conditions at sites where slope failures occurred in the past. For the analysis of the causative factors the application of geographic information systems (GIS) is an essential tool in the data analysis and the subsequent hazard assessment.

When making use of GIS techniques, the following methodological approaches can be differentiated (van Westen, 1993):

- heuristic qualitative approach, particularly suited for small-scale regional surveys. The scale of such surveys is in the order of 1:100.000 to 1:250.000. They are used mostly by regional planning agencies.
- statistical quantitative approaches for medium scale surveys. These are in the range of 1:25.000-1:50.000, and are used by consulting firms or planning agencies for the preliminary planning of infrastructural works, such as the definition of road corridors. The methods at this scale can be subdifferentiated as follows:
  - data driven multivariate statistical analysis
  - experience driven bivariate statistical analysis
  - predictive modelling through the application of probability and favourability functions
- deterministic approach for detailed studies at large scale (1:2.000 - 1:10.000), without entering at the level of the engineering geological site investigation. Such small scale studies are used by consulting firms or local planning agencies for the detailed planning of infrastructural works.

All three methodologies require a good idea on the spatial distribution of landslides as the essential element for the analysis. The professional expertise, leading to a classification, is essential. Historic databases are most useful for this work. However, most of the landslide distribution mapping will be obtained by aerial photo interpretation, and image processing.

To assist earth scientist in the creation of landslide hazard maps that can be used for planning, ITC has developed a training package on the use of Geographic Information Systems for Slope Instability Zonation (GISSIZ). The first version of this package was released in 1993, as a contribution to the UNESCO-IUGS GARS project (Geologic Application of Remote Sensing) and included a version of a DOS based GIS system (ILWIS). Several hundreds of copies of this package have been distributed worldwide, and workshops were given with the package in Colombia, Costa Rica, Argentina, India, Nepal and the Netherlands.

Now the package has been adapted for the ILWIS for Windows software, and has been considerably extended.

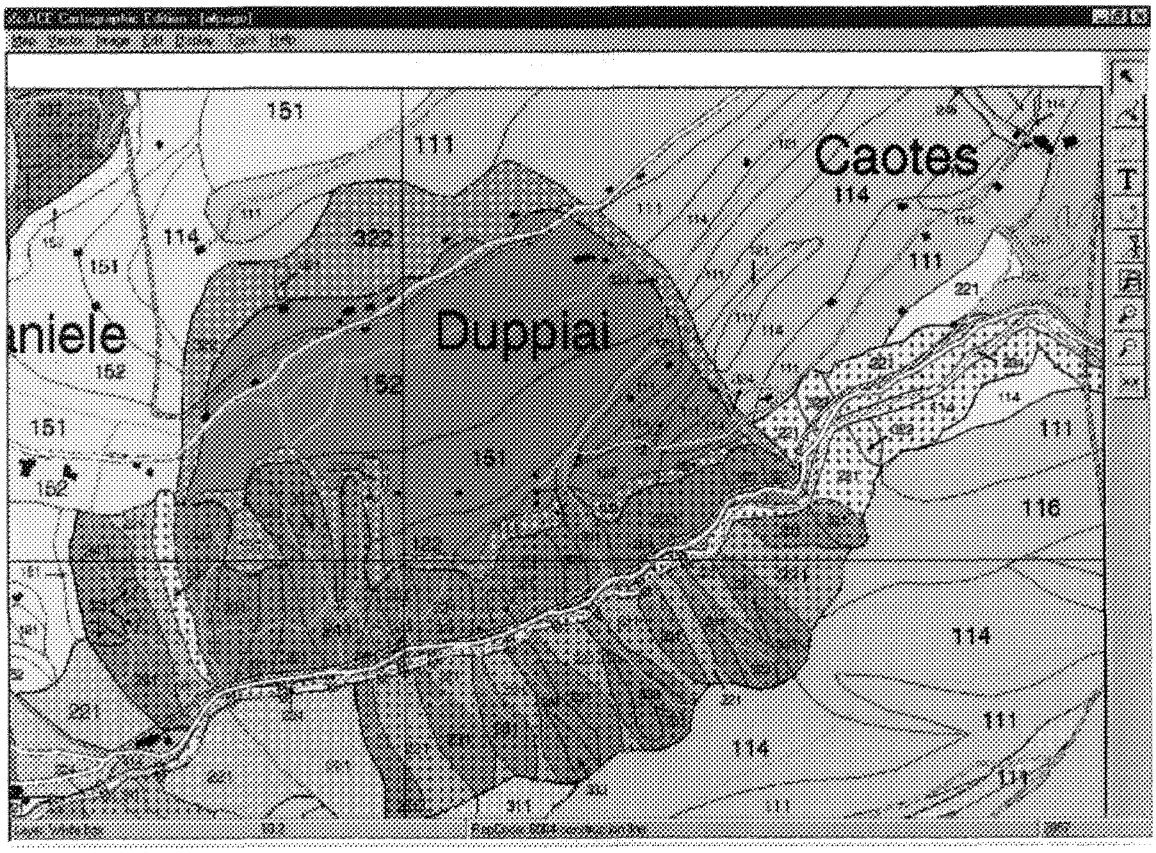

Figure 2: Fragment of a detailed (1:5000 scale) geomorphological hazard map of an area in the Italian Dolomites. The information is stored in a complex GIS data base.

The training package now contains the following topics:

- Introduction to hazard, vulnerability and risk,
- Landslide hazard: overview of methods, scales, objectives, and data needed
- Factors involved in slope stability,
- Application of Image Processing in landslide mapping,
- Landslide interpretation using Remote Sensing data,
- Fieldwork setup for landslide studies,
- Application of GIS in landslide hazard mapping:
  - Regional scale landslide hazard assessment
    - Terrain mapping unit approach
    - landslide density analysis
  - Medium scale landslide hazard analysis
    - Fuzzy logic
    - Statistical approach
  - Large scale landslide hazard analysis
    - deterministic approach
- Requirements for landslide hazard maps, cartographic production

The training package is planned to be finished by November 1997, and will be used on several workshops.

3. Investigation at ITC: the coal fire monitoring system

Apart from the training and the development of training packages, ITC is also involved in a number of research projects dealing with natural hazards. One of the largest of these projects deals with underground and surface coal fires, which are a serious problem in many coal producing countries. Combustion can occur either within the coal seams themselves or in piles of stored or waste coal at the surface. Although coal fires occur in many countries (USA, Australia, Germany, Spain, Poland, Czech Republic, India, Pakistan, Indonesia, Venezuela, etc.), the problem in China is much larger. China is world's largest coal producer, consumer and exporter. It produces some 1.400 million tons of coal per year, and exports approximately 23 million tons. An estimated 100 to 200 million tons of coal anually are lost by underground coalfires (Van Genderen and Haiyan, 1997). Coal fires cause serious environmental degradation, e.g. forest fires, destruction of grassland, soil degradation, and reduced agricultural productivity. Spontaneous combustion causes loss of life of coal miners, tens are killed anually by the fires. Underground coalfires generate land subsidence and surface cracks through which oxygen enters which causes more burning. The area affected by underground coal fires extends 5,000 km east-west and 750 km north-south in Northern China (see figure 3).

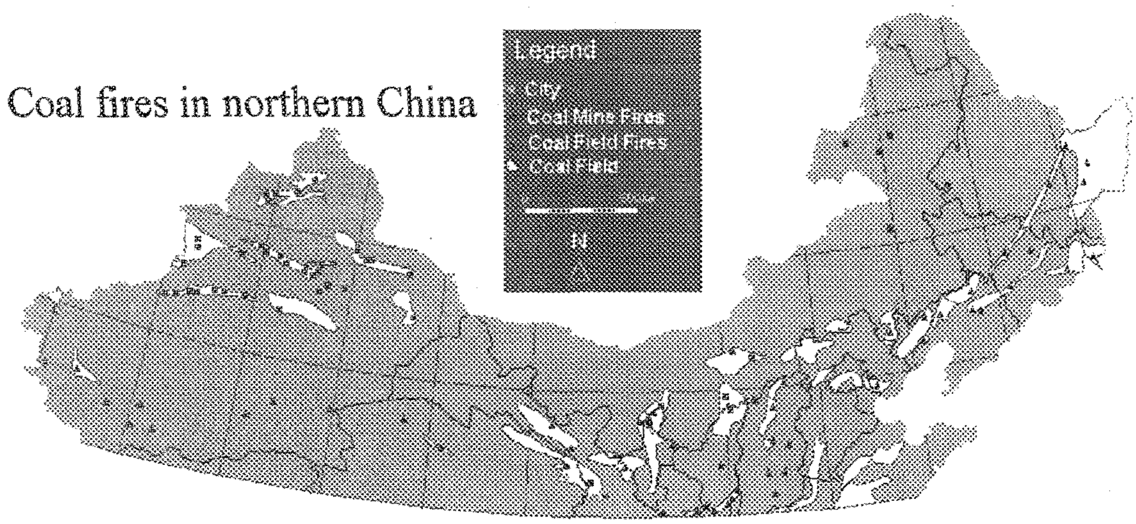

Figure 3: Distribution of coal fields and coal fires in the North of China.

Besides loss of revenues, the coal fires are one of the largest contributors to CO2 emissions. In 1992 the CO2 emission was estimated to be 2-3% of the world's total. Both large underground coal fires occur under natural conditions, as well as in coal mining regions, caused by spontaneous combustion of coal seams. A large part of burnt rock from so-called paleo coal fires appears to be of Pleistocene age.

Remote Sensing has proven to be a reliable technology to detect both surface and underground coal fires. A combination of satellite based sensors and airborne sensors are required to unambiguously detect and locate coal fires. By doing such remote sensing based detection on a regular basis, new fires can be detected at an early stage, when they are easier/cheaper to put out. Also, such routine monitoring is very efficient for evaluating the effectiveness of the fire fighting techniques being employed, and which can be remedied/changed as a result.

Thermal infrared data from satellites, especially from the Landsat-5 channel have been proven to be very useful. In mountain areas,. The detection of underground coal fires is limited by the non-uniform solar heating of the terrain. To remove these effects, a DEM was used for modeling the solar incidence angle. Night-time TM data are more useful for detection, but are not routinely available. On the other hand, due to the low spatial resolution of the TM thermal data (120x120 m) the best night-time TM thermal data can not detect a coal fire less than 50 m even if they have high temperature anomalies. Thus airborne data for detailed detection are still needed.

For the full exploitation of the increasingly difficult multi-source remote sensing data, advanced analytical or mathematical data fusion techniques need to be developed.

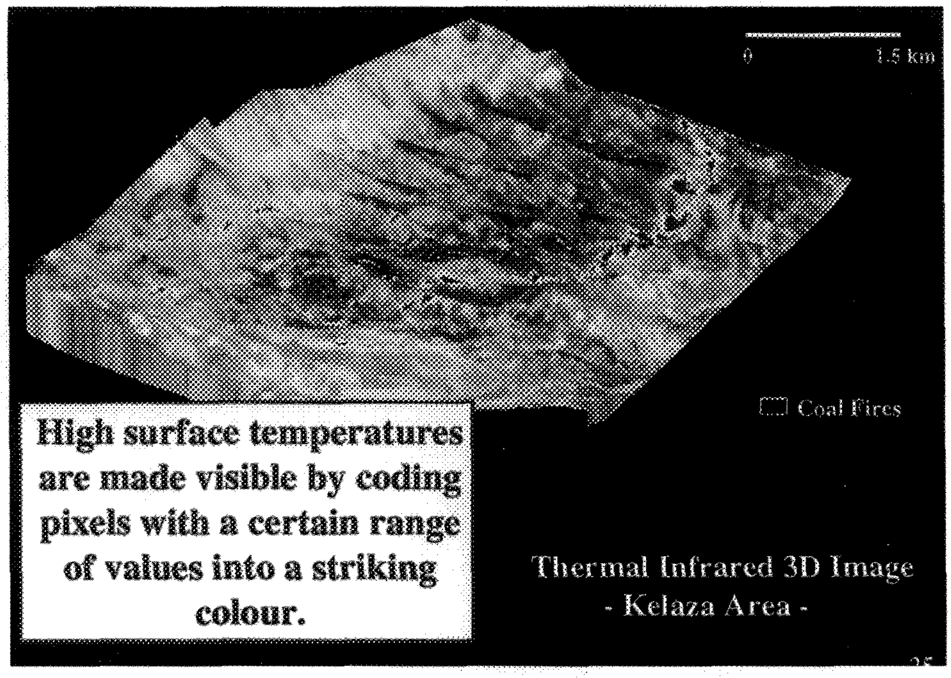

Figure 4: Thermal infrared image of a coal fire area in northern China, shown in 3-D. High surface temperatures are made visible by coding pixels with a certain range of values into a striking colour.

4. A new project: landmine detection using remote sensing

Another recent project on the application of remote sensing to, in this case, human-hazards, deals with the detection of landmines. There are tens of millions of landmines hidden in many countries around the World, especially in Developing Countries. For example, over one million land mines are known to exist in Angola, and some 9 to 15 million others are still to be discovered. Their presence impedes reconstruction and rehabilitation programmes in these countries. Traditional methods of locating minefields and landmines consist of the use of sniffer dogs, use of metal detectors, and of manually probing. Such methods are dangerous and extremely slow and time consuming, in addition to only covering a few square metres at a time.

In order to speed up the demining operations, an international project was launched to evaluate the usefulness of detailed remote sensing images. In this project ITC cooperates with the following institutes: CAE Aviation (L), Earth Observation Sciences Ltd. (UK), Swedish Space Corporation - Satellitbild (S), Geograf (P), Aerodata (B), RECON Optical (UK), Eurosense (B), University of Brussels (B), Zeiss Eltro Optronic (D), Norwegian People's Aid (N), Renaissance asbl (B), I.G.I. Ltd. (D), and Aerosensing GmbH (D). The project is funded by the European Commission, Belgium, Germany, United Kingdom, Luxemburg, and Portugal, and has a total budget of 5 million US $. The project will review various minefield detection methods, prior to developing an airborne remote sensing method using multiple sensors simultaneously from a fixed-wing aircraft. All sensors and platforms are commercially available off-the shelf instruments. By means of a Computer Controlled Navigation System (CCNS), together with DGPS and INS, an image and data fusion processing and analysis approach is used to detect the minefields.

Optical, thermal IR and SAR sensors are used on board the same aircraft (a Short SKYVAN) at the same time. The method for detecting landmines will first be tested in a testsite in Belgium. If a sufficiently large percentage of landmines can be detected in the Belgium testsite, real minefields in Angola, in different climatic conditions will be studied in August/September 1998.

5. The UNESCO-coordination programme for disaster reduction through sustainable development (CPDRSD).

Apart from developing methods for hazard assessment, and the training in these methods, ITC is also actively involved in the incorporation of these methods in disaster management.

Recently, ITC has become the executive secretariat of the UNESCO Coordination Programme for Disaster Reduction through Sustainable Development (CPDRSD). The main objective of this programme is to strengthen the capability of developing countries of mitigating natural disasters in these countries.

To reach this objective, the programme intends to execute a series of Regional Action Programmes. These Regional Action Programmes are concentrating on the transfer of knowledge and methods of natural hazard assessment, and the establishment of networks of organizations responsible for disaster prevention. The programme is sponsored by UNESCO, the Netherlands government and the participating Netherlands Institutions (ITC, TUD and UU). Other prospective partners will be identified, and additional sponsors need to be found for the different Regional Action Programmes.

The Action Programmes aim specifically at strengthening the capability of individuals and organisations in these regions to contribute to:

- reduce the vulnerability of society and infrastructure by a development planning which is based on awareness and understanding of the potential dangers of natural phenomena such as landsliding, volcanic eruptions, earthquakes and flooding
- reduce the adverse effects of anthropogenic development in order to minimize disasters.
- The Coordination Programme will assist UNESCO to develop, formulate and coordinate Regional Action Programmes in the field of natural disaster reduction.
- The programme aims at presenting the state of the art and bringing together knowledge and expertise dedicated at disaster prevention in developing countries with respect to the above mentioned fields. An important aspect will be the increase of awareness with respect to disaster prevention, and to have this increased awareness reflected in land-use planning and decision support systems.
- A parallel aim of the Programme is to have a reference function. The output of projects carried out through the programme will be available for use (and this use will be actively promoted) in the developing countries concerned.
- The creation of a common basis of understanding between earth scientists and planners and decision makers in pilot projects in which hazard and risk zonation maps are prepared and are applied in the decision making process for sustainable development planning and implementation at a local, regional and national scale.

An important part of the Programme will also be the establishment of networks, the linking of expertise and exchange of experiences in the field of natural disaster reduction. The Coordination Programme aims at establishing and promoting different forms of 'South-South' cooperation. In the end the 'South-South' cooperations should be pre-dominant, with the Coordination Programme providing only a supporting role.

The Coordination Programme will initiate Regional Action Programmes in the following regions: Central America, south-east Asia, the Himalaya region and the Andes region. These regions are selected because regional organizations, local institutions and governments have expressed an active interest in disaster reduction initiatives, good relations exist between the partners in the Coordination Programme and institutions in these regions and the type of natural disasters occurring is relevant both in terms of the expertise that can be offered and in terms of spin-off effects for the region.

The Regional Action Programmes aim at achieving a reduction of natural disasters through adequate development planning for particular regions with roughly similar conditions as regards the occurrence of natural disasters and the capacity for disaster prevention. Through a series of activities the overall capability to prevent and deal with natural disasters by geohazard zonation will be enhanced and the interaction between the different actors working in the disaster reduction field in the region will be strengthened. One of the most essential of these activities is the implementation of Pilot Projects. In these Pilot Project also local authorities and decision makers will be closely involved.

The Pilot Projects are implemented in the framework of Regional Action Programmes in particular countries in the region with favorable conditions for training of experts and investigating and testing methodologies supporting disaster prevention, such as geohazard zonation methods, for the relevant types of natural disasters. The outcome of these activities, like developed geohazard zonation methodologies, will be used as input for and incorporated in a decision support system for current and future land-use planning. The results and experiences of the Pilot Projects will be used at the regional level to achieve an increase in the awareness of and capacity for natural disaster reduction in the other countries participating in the Action Programme.

Acknowledgements

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