ASSESSING VULNERABILITY IN ISTANBUL: AN EXAMPLE TO SUPPORT DISASTER MANAGEMENT WITH REMOTE SENSING AT DLR-ZKI

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Abstract

This paper demonstrates the potential of remote sensing for support of disaster management in the disaster preparedness as well as in the disaster response with a focus on vulnerability assessment in Istanbul. With the focus on the megacity Istanbul the capabilities of remote sensing to assess vulnerability are presented. Explosive population growth, uncontrolled urban sprawl, housing at hazardous areas or bad building materials in combination with a significant risk of a major earthquake present acute danger to the population. Substantial and up-to-date data, area-wide data are premise of an effective crisis management. Furthermore, assessing vulnerabilities of the megacity are fundamental to enabling counteractive measures before an expected earthquake disaster as well as preparing for the post-earthquake response. This paper presents not only an overview of the capabilities of remote sensing to assess indicators of vulnerability, but shows also examples what remote sensing can contribute as a source of information in an acute emergency, crisis or disaster situation.

I. Introduction

The year 2005 forcefully demonstrated mankind's vulnerability in the face of the powers of nature. Satellite systems and image analysis techniques have developed in the last years to an extent where civil and commercial earth observation instruments can contribute significantly to support the management of natural disasters as well as humanitarian crisis situations both before and after a disaster strikes.

As an example the capabilities of remote sensing to assess vulnerability is shown for the megacity Istanbul. Highly-structured urban areas are a complex entity of unequal location factors. Especially megacities in developing countries are growing rapidly, not only in terms of population but also in terms of economic importance. The knowledge of current area-wide spatial information is needed in order to make decisions concerning vulnerability assessment, planning or management.

RASHED ET AL. (2003) described "urban vulnerability to natural hazards such as earthquakes is a function of human behaviour. It describes the degree to which socioeconomic systems and physical assets in urban areas are either susceptible or resilient to the impact of natural hazards". BLAIKIE (1994) defines vulnerability as being prone to or susceptible to damage or injury. In the World Vulnerability Report (2003) by ZENEB about 50 different indicators of vulnerability were shown. Thus, vulnerability is a complex coaction between natural exposure, physical exposure, social exposure, economic exposure and political exposure.

This paper presents an overview of the capabilities of remote sensing to assess in particular physical vulnerability indicators. From the original satellite image a classification of land cover and a spatial allocation of different physical vulnerability indicators within the city are presented as well as a derivation of the population density as an example for the inference of a socio-economic parameter. It focuses on spatial products necessary for the detection of highly exposed areas to react on the natural hazard in the pre- and post disaster phase.

In addition to the disaster preparedness, satellite imagery can serve as a source of information in acute emergency, crisis or disaster situation. Having recognized this need, the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) established a service called "Center for Satellite Based Crisis Information" (ZKI) for linking its comprehensive operational remote sensing data handling and analysis capacities with national and international civil protection, humanitarian relief actors and political decision makers. ZKI's function is the rapid acquisition, processing and analysis of satellite data and the provision of satellite-based information products on natural and environmental disasters, for humanitarian relief activities, as well as in the context of civil security. The analyses are tailored to meet the specific requirements of national and international political bodies as well as humanitarian relief organizations.

II. Data and test site Istanbul

For a sufficient assessment of location factors within heterogeneous city structures high spatial resolution satellite images are necessary. IKONOS images feature a geometric and radiometric quality of 1-m panchromatic, 4-m multispectral and 1-m pan-sharpened imagery. For this study an IKONOS imagery taken on December 20th 2003 from the centre of Istanbul (quarter of Üsküdar) has been used as test site. Istanbul as a highly dynamic and rapidly developing megacity, located on the transition area between Asia and Europe with its estimated 14 million people, lives through enormous demographic, cultural and economic changes.

II. Methodology overview and application products to assess vulnerability with remote sensing

1. Urban land cover classification

To analyse urban morphology or urban pattern characteristics, the original IKONOS imagery has to be classified. An object-oriented approach has been implemented. For this purpose the first step contains a reasonable segmentation of real world structures. The segmentation concept is that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships *(BAATZ ET AL. 2000)*. Additional to the spectral information the segments, representing significant real-world structures, contribute features like shape or neighbourhood to a more substantial information basis to classify urban land cover. Based on the generated objects a region-growing algorithm has been implemented for a very high fuzzy classification probability. This classification approach was predominantly based on shape features. The key-note for the adjustment of this classification algorithm contains the assumption that spatial segments like houses or roads correspond in any urban area. Thus, easy transferability for urban land cover classification can be achieved with a few adjustments due to different spectral values (TAUBENBÖCK, 2006). Figure 1 shows a basic land cover classification at the test site Üsküdar on the Anatolian side of Istanbul differentiation six different thematic classes.

Figure 1: IKONOS imagery of Üsküdar and a basic land cover classification

Thematic classes:

built-up areas **shadows** **lawn** **trees/brushes** **main roads** **water**

An accuracy assessment of the classification compared to a GIS-Layer of built-up areas resulted in a detection of 82% of the houses. A visual interpretation of figure 1 already highlights a spatial differentiation of structures, patterns, densities or location. This thematic land cover classification serves now as basis for a spatial derivation of different physical vulnerability indicators.

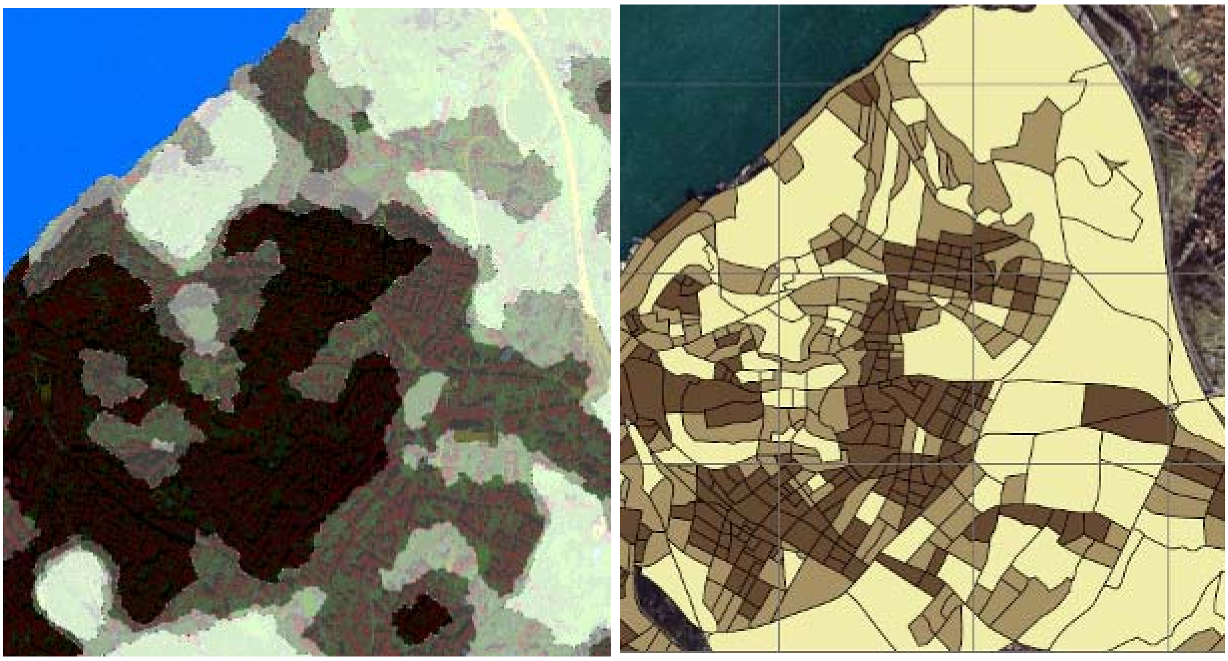
2. Physical vulnerability indicators derived from remote sensing

Remote sensing is capable to infer a number of physical vulnerability indicators directly. Based on the land cover classification five indicators have been used to allocate homogeneous zones within the urban area. The distinction of homogeneous zones within the complex urban morphology enables the spatial projection of standard parameters to assess location factors. To classify homogeneous zones the rules of grouping or zoning are, according to *ARNHEIM (1954)* and *WLODARCZYK (2005)*, based on similarities like size, orientation, location, shape, configuration, colour, material, texture and function. These might be the factors which facilitate the distinction. The city structuring in this paper has been computed by five different physical parameters derived from the land cover classification: Built-up density, Building alignment, Road width, Open spaces and Location (distance to major road).

Why are those indicators important for an assessment of the physical vulnerability of urban areas? The built-up density is a central indicator, because it provides information on the spatial concentration and distribution of infrastructure, housing areas and population. STEINNOCHER (2006) proved that population density is also proportional to built-up density. Therefore the built-up density is also basis for an indirect inference of the vulnerability indicator 'population density' and its distribution. A questionnaire in Üsküdar provided data on the residents per house, with what a spatial extrapolation indirectly derived an assessment of the population density and its spatial distribution. The spatial averaging resulted in 17.000 inhabitants per km² in highly dense built-up areas in Üsküdar, which matches the dimension of the population density gained from a census in 2000 in the whole quarter Üsküdar in

Istanbul that resulted in a population density of 12,837 inhabitants per km². The indicator 'open spaces' can function as firebreaks, refuge base, and disaster recovery bases. These open spaces serve also as safe havens or safe places or gathering in times of emergency. Tents can be pitched quickly to temporarily house victims of disasters. Figure 2 shows the two example indicators which describe vulnerability within the highly-structured urban area and its own distribution.

Figure 2: Building density and Open spaces accessibility



Built-up area: highly dense, dense, low dense, open space **Open spaces:** low vulnerability, medium vulnerability, high vulnerability

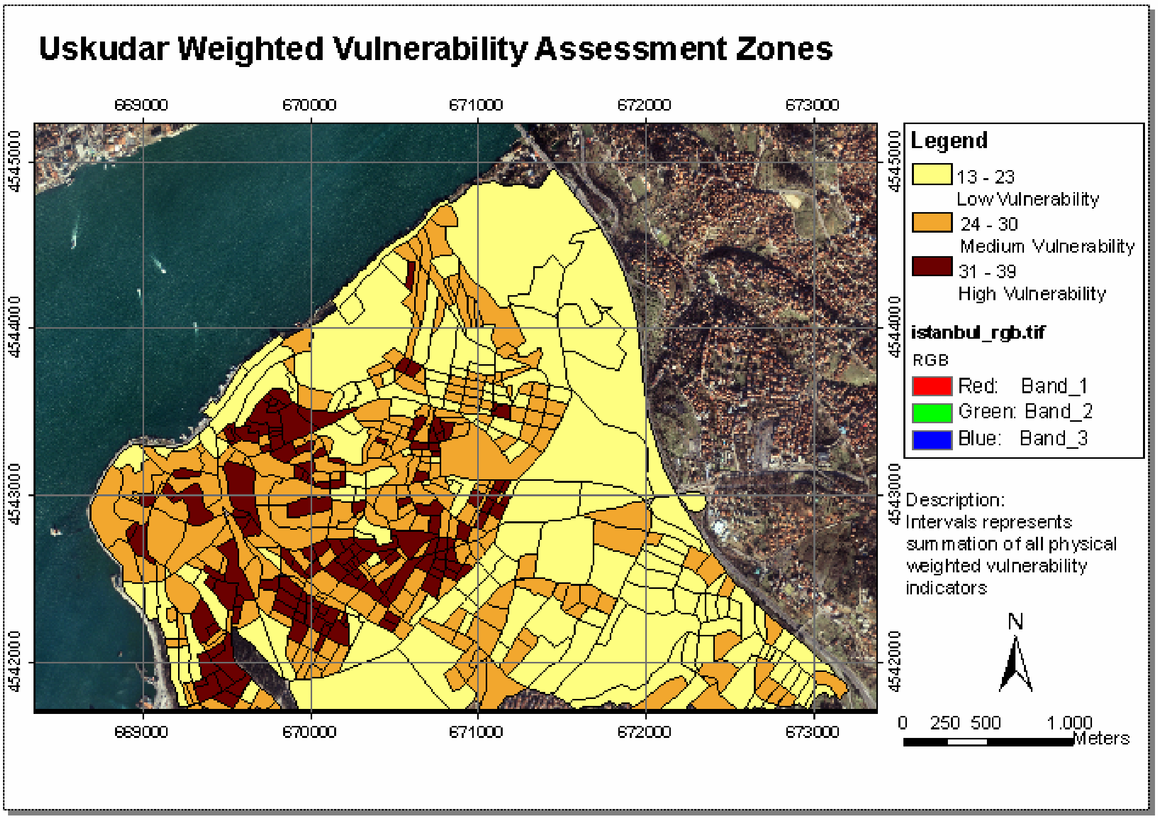
Further physical indicators used are the road width as well as the location (distance to major road), which give information on the accessibility and mobility in the post-disaster phase and are therefore important for supporting measures (ALEXANDER, 2000). The building alignment is an indicator assessing the structure within the agglomeration, evaluating organic, clustered or unplanned areas to well structured and planned alignments. This provides information on accessibility and bumping effects in case of the shaking of the buildings. In addition, a DEM (Digital Elevation Model) from the SRTM Radar Mission has been used to analyse the terrain situation to assess areas exposed to landslides or slope information to assess building ground stability.

Each physical vulnerability indicator results in one layer. First of all, each physical indicator has been levelled into three vulnerability groups, since each feature of physical indicators has a different level of contribution to the vulnerability. Thus, each of these features has been numbered according to their affect on the physical environment and their possible affect on the in case of an earthquake.

3. Vulnerability assessment based on physical parameters

The combination of the five different physical vulnerability indicators, the socio-economic indicator 'population density' as well as the indicator 'terrain situation' leads to an area-wide assessment of the city's exposure. For every spatial zone or unit, information of the described vulnerability indicators are stored in an attribute table and enable to compare, weight and sum the assessed vulnerability for a final vulnerability analysis map. Figure 3 shows the spatial distribution of three vulnerability levels computed from the weighted specific vulnerability indicators presented above. The result shows the vulnerability distribution within the highly-structured urbanised area of Üsküdar in Istanbul. Highly dense built-up areas, with its highest population concentration, narrow and complex road network or the long distance to open spaces show a higher vulnerability than planned and structured low dense built-up areas.

Figure 3: Vulnerability assessment zones



For every zone the parameters of the physical vulnerability indicators derived from solely remote sensing are known and contribute to an overall assessment of the urban area, firstly to identify highly endangered zones within the city, and secondly to identify counter measures in the pre-disaster phase. The spatial information are furthermore the basis for a fast and substantial crisis management in the post-disaster response.

IV. Satellite based crisis information at DLR

During the recent years there has been an increasing demand for up-to-date and precise spatial information on disaster and crisis situations in Europe and world-wide. The reasons for this development are manifold and can be seen in the increasing vulnerability of societies and infrastructure. Furthermore as a consequence of climate change weather patterns have been shifted to more extreme conditions. Having recognized this need, the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) established a service called "Center for Satellite Based Crisis Information" (ZKI) for linking its comprehensive operational remote sensing data handling and analysis capacities with national and international civil protection and humanitarian relief actors as well as with political decision makers.

In order to serve the full cycle from an emergency call through satellite tasking, data acquisition, analysis to map provision and interpretation a long chain of steps involving coordination of satellite commanding and data reception tasks as well as data ingestion, pre-processing, correction and analysis needs to be run through (Fig 4). Later on, the image data have to be interpreted in order to extract the required information and generate an appropriate mapping or reporting product. For this purpose algorithms for hot spot detection, vegetation analysis, generation of digital elevation models or for feature extraction are of great support for the image analyst. In many cases, however, these are not accurate or reliable enough for automated information extraction and thus also still a lot of visual interpretation and image fusion skills are required to generate fast and reliable information products and maps. Sometimes even maps or images are not the proper way of transporting the derived information. In these cases, reports or statistics are used to even better aggregate and communicate the satellite information, such as estimated number of affected people, area of land flooded, most severely hit areas, etc. During the past years it has also been shown, that training and consulting of the decision makers and field workers in the ministries, NGOs and other relief agencies plays a key role in proper understanding and accepting the space based information products as one information source for decision making or mission planning.

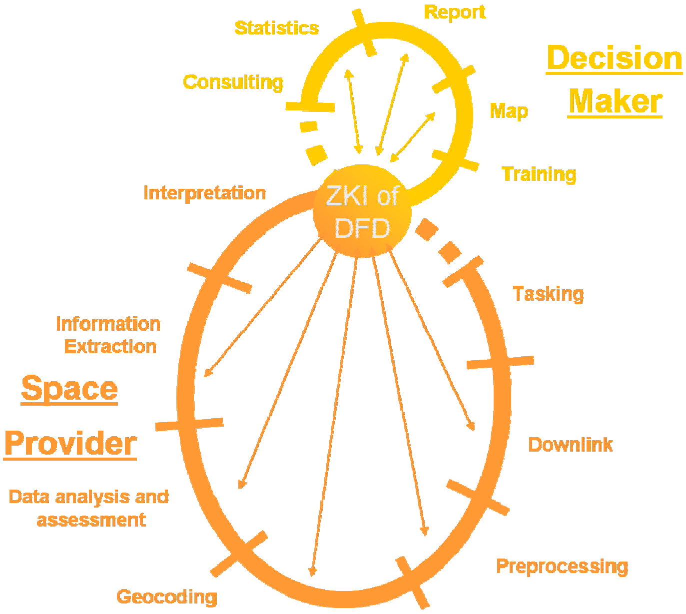


Figure 4: The ZKI Service cycle – providing satellite analysis for decision makers

International cooperation and interoperability of systems as well as fast and efficient communication among the civil satellite observation community provide the crucial key to satellite based disaster response capacities. Therefore the DLR is supporting the International Charter Space and Major Disasters, which was founded in 1999 by ESA and CNES. Since this time, it provided a crucial mechanism for globally coordinated disaster response by civilian governmental satellite operators and space agencies for natural and man made disasters. Over the years it has been joined by a number of space agencies operating satellite observation and communication assets from India, the U.S. as well as from Japan, UK and Argentine. The International Charter has been activated over 100 times so far, mainly for natural, but also technological disaster situations with an increasing rate.

In the last 2 years ZKI supported various international humanitarian relief teams in, amongst others, Southeast Asia (Tsunami), Portugal (fire hot-spots), Pakistan (earthquake), and the Philippines (landslide)

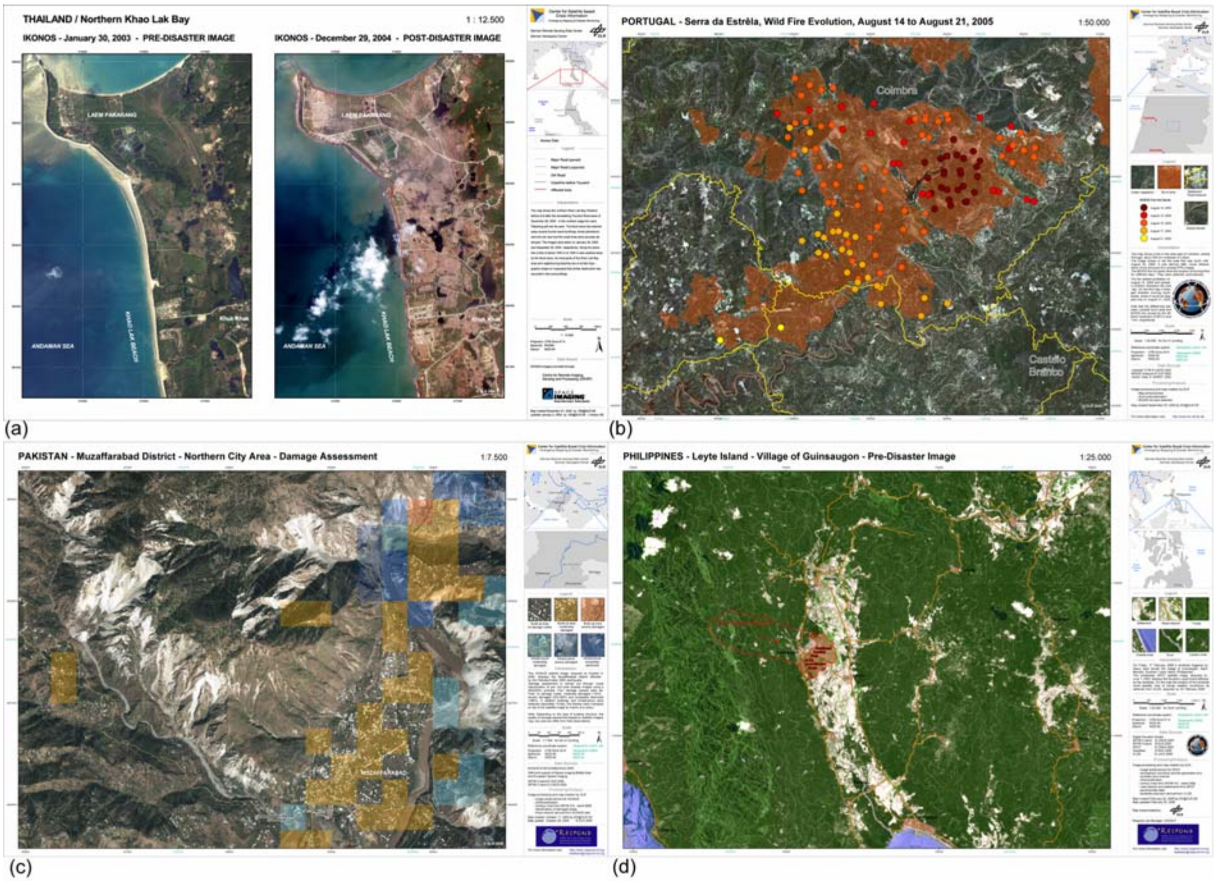


Figure 5: Examples of ZKI produced maps for disaster and crisis management support. (a) High resolution satellite map (from new and archived satellite imagery) of the northern Khao Lak Region, Thailand (1:12.500), (b) Satellite map of the Serra do Estrela, Portugal (1:50.000), (c) Damage assessment for Muzaffarabad District/Pakistan, northern city area (1:7.500), and (d) Satellite map of the Landslide affected area for Guinsaugon - Philippines (1:25.000).

Tsunami

In the early morning of Dec. 26th, 2004 a severe earthquake (30 km below sea level, magnitude 9) caused Tsunami flood waves in the Indian Ocean, which struck the coastal regions of Sumatra, Thailand, Sri Lanka and southern India. Due to the immense extent of the affected coastal areas, images from earth observing satellites have turned out to be a valuable support tool for international relief activities in the aftermath of the disaster.

In close cooperation with international partners such as UNOSAT, the Joint Research Centre (JRC) of the European Commission, Infoterra UK and SERTIT, ZKI had taken over responsibility for the acquisition of satellite data, the generation of image maps, and their dissemination to various relief organizations focusing on its activities on Sumatra and Thailand. Due to the scale of the damage medium (Landsat 7 ETM, SPOT, DMC) as well as very high resolution imagery (IKONOS, Quickbird) was used based on archived pre-disaster imagery and recent post-disaster satellite images. This combination allows easy and quantitative damage assessment by visual change detection (Fig. 5a).

This up-to-date mapping covering large areas enabled disaster managers to achieve an overview of the recent situation, to assess the damage, and to supply local logistic teams with reliable information. ZKI provided this service for the crisis reaction team of Germany's Federal Foreign Office (Auswärtiges Amt) and the joint federal situation and information center (GMLZ), the German technical relief agency (THW), the German Red Cross (DRK), Medicines Sans Frontiers (MSF) and many others including the press and the public.

Portugal

In the Mediterranean natural and human-induced wildfires are each summer a threat not only to the environment, but also to the local population. In the year 2005 after one of the most severe droughts over the Iberian Peninsula the wildfires were raging out of control across central and northern Portugal killing 15 people and destroying more than 150,000 hectares.

The worst-hit areas include the central region, where fires are threatening the outskirts of the third-largest city of Portugal, Coimbra. Wildfires were also continuing to burn in the northern districts of Viseu and Viana do Castelo. After a request of the Portuguese fire fighting service, the "Charter" was triggered and ZKI started to map the burnt area using SPOT, Landsat 7 ETM, DMC and IKONOS. In parallel the situation was monitored using the sensors NOAA-AVHRR 17 and MODIS Aqua and Terra for the detection of fire hotspots. This information was available few hours after the data acquisition in a ready-to-use GIS-format. This continuous monitoring allowed detailed tracing of the fire propagation, and was well received by the Portuguese civil protection (Fig. 5b).

Pakistan

A series of severe earthquakes (max. magnitude 7.6) struck the Kashmir region on Saturday, October 8, 2005. The epicenter was located on the India-Pakistan border, about 100 kilometers northeast of Islamabad, and Pakistani authorities reported casualties at some 49,700 dead and over 74,000 injured. On October 11 (2 days after the activation of the International Charter) DLR produced several detailed maps (1:7500) of a number of cities in the earthquake affected region, derived from very high resolution IKONOS imagery. Two weeks later for Muzaffarabad damage was assessed (Fig. 5c) by means of the grid cell analysis described above.

According to the users feedback the maps and layers (streets, damage, etc) yield vital information with respect to evacuation planning, general "pathfinding / tracking", to get a better overview and understanding of problems on site. In addition the maps proved very useful for negotiations about cooperation with other NGO and GO in the field.

Philippines

On Friday, 17 February 2006 a landslide triggered by heavy rains buried the village of Guinsaungon, Saint Bernard, Southern Leyte Island (Philippines). Most of the approximately 300 houses and the elementary school were fully covered by the mudslide, affecting the 1,411 village inhabitants (incl. 246 elementary school pupils and 7 teachers) at the time of the incident. A satellite map of the Landslide affected area using archive SPOT data for Guinsaugon - Philippines at a scale of 1:25.000 was produced a couple of days after the accident. At the same time the Advanced Land Observing Satellite (ALOS) imager from the Japanese Aerospace Exploration Agency (JAXA), launched on January 24th 2006, was the first optical sensor to successfully image the landslide partially (due to cloudy weather situations). The landslide mapping (Fig. 5d) shows the potential of the usage of a number of data sources (SPOT, SRTM, ALOS) for the benefit of humanitarian relief organizations.

V. Summary and conclusion

Remote sensing provides an area-wide assessment of vulnerability indicators to support the identification of highly exposed zones within the urban agglomeration. It has been shown that remote sensing is not only capable to derive physical vulnerability indicators directly, but also able to derive indirectly socio-economic parameters. The knowledge of the spatial distribution of vulnerability is the central information for counter measures in the pre-disaster phase as well as for crisis management in the post-disaster phase.

With the given examples it could be shown, that earth observation can successfully provide a beneficial support of disaster management, humanitarian relief and civil security. It was shown how satellite imagery can be acquired, assessed, processed and turned into information products for decision makers within hours. Nevertheless, there is still ample room for improvements and extensions of the services (faster delivery). Moreover, there are gaps between current state of the art automated feature extraction or automated map generation on the one hand side and real world, near real time requirements in actual disasters events on the other. Space technology today is still very complex and the different satellite systems require sophisticated processing techniques, which can not be handled by an individual relief organization for example. As a consequence it is of primary importance that the space technology and geoinformation sector provides easy to use and ready to access information solutions to the relief community.

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