Remote Sensing and GIS Methods for the Safety of Industrial Facilities and Infrastructure in Europe

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Motivation

Remote sensing technologies provide information in large areas. Technologies to properly exploit the information given in the images are desired to be used in subsequent risk management.

Main Results

A comprehensive set of tools has been developed to quantify a major number of parameters and established information on key performance indicators. These tools are introduced in the GIS based software platform developed by the IRIS project.
11 Introduction

Europe is experiencing an increasing number and impact of disasters due to natural hazards and technological accidents caused by a combination of changes in its physical, technological and human/social systems. Natural risks may interact with the risks coming from the industrial plants, especially from the high risk ones, giving rise to a negative synergism. In order to get an almost complete evaluation of the interactions between industrial settlements and environment, it is necessary to consider their double connection: the effects both of a natural event on the plant and of the plant itself on the surrounding environment. Therefore, information about features, like hydrogeological and geomorphologic factors, and suitable safety measures is needed. Industrial facilities and critical infrastructures, as well as individual production or service areas, are subject to different levels of risk from natural events.

The assessment of potential natural hazards is fundamental for planning purposes and risk preparedness, especially with regard to supervision and maintenance of industrial facilities and of extended lifelines. Areas at particular risk include networks, buildings, production, extracting and processing plants and non-electronic data records [Federal Ministry of the Interior, 2009]. Technical interdependencies between infrastructures have the potential for initiating widespread cascading effects of failure or loss of service. The clash of a climate change driven increase of flooding hazards such as storm surge and flash floods with explosive, uncontrolled urban sprawl and changing urban patterns constitutes a further increasing risk.

Industrial accidents triggered by natural events, such as e.g. earthquakes, floods, lightning etc., are referred to as “Natech” accidents. Natech accidents have occurred in relation to natural hazards and disasters and have resulted in the release of hazardous substances leading to fatalities, injuries, environmental pollution and economic losses [Krausmann et al., 2011]. One of the principal problems of most Natech accidents is the simultaneous occurrence of a natural disaster and a technological accident, both of which require simultaneous response efforts in a situation in which lifelines needed for disaster mitigation are likely to be unavailable. Natech risk differs from technological or natural risk as its multi-hazard nature requires an integrated approach to risk management. The catastrophic events in March 2011 in Japan have demonstrated this.

When natural hazards happen and affect cities, settlements and infrastructure, immediate and efficient actions are required which ensure the minimization of the damage and loss of human life [Savvaidis et al., 2012]. Proper mitigation of damages following disastrous events highly depends on the available information and the quick and proper assessment of the situation. Responding local and national authorities should be provided in advance with information and maps where the highest damages due to unfavourable, local site conditions in case of stronger earthquakes and earthquake-related secondary effects such as landslides, liquefaction, soil amplifications or compaction can be assumed. The better a pre-existing reference database of an area at risk is prepared and elaborated, the better a crisis-management can react in case of hazards and related secondary effects [Theilen-Willige et al., 2012]. Hence it is imperative to identify those areas most susceptible to different types of natural hazards as earthquakes, landslides, flooding or storms.
The ability to undertake this natural hazard assessment, monitoring and modelling can be improved to a considerable extent through the current advances in remote sensing and GIS technology. Geographic Information Systems (GIS) provide the appropriate platform for the registration and management of information on natural hazards and their impact on industrial facilities. Meanwhile disaster GeoInformationSystems (GIS) have been implemented in nearly all European countries, however, still with different standards and definitions, terminology, data bases and details, in spite of the on-going European INSPIRE activities. Therefore the compatibility of data and information is one of the major problems. The consideration of property rights of data is another obstacle for the international use and data exchange.

In case of larger accidents, changes often become visible by comparing a reference data base with most actual satellite imageries, that can be evaluated and, then, be part of decision processes. For example RapidEye – or Sentinel – satellite data can form an important part of such a reference data base before and after an event providing data within several hours.

Hence, the aim of this part of the IRIS-project was to elaborate an approach, in which Geographic Information Systems (GIS) used with integrated remote sensing data, contribute to the analysis and representation of information required for the geo-hazard assessment, that could cause industrial accidents and cascading, interfering effects affecting the safety of industrial facilities. Objective was the detection of areas susceptible to natural hazards and, thus, as a consequence, the susceptibility assessments of industrial facilities to these hazards according to a standardized, systematic and clearly arranged approach that can be used in any area due to the meanwhile standardized, open-source availability of the basic data input.

Causal or critical environmental factors influencing the disposition of industrial and infrastructural facilities to be affected by natural hazards and the potential damage intensity can be analysed interactively in a GIS database. The interactions and dependencies between the different causal factors can be visualized and weighted step by step in this GIS environment. Objective was to elaborate susceptibility maps for the detection of areas that are assumed to be more affected by natural hazards due to aggregation of causal/preparatory factors and merge these maps with data of industrial facilities. A further objective was the investigation of the question how the elaboration of a database for factors of local site conditions, which influence the damage potential of hazards, for example in case of earthquakes the shock intensities, could become part of a comprehensive industrial risk management system in the future.

Maps of European countries were created providing an overview of areas that are more susceptible to earthquake shock or flooding due to regional and local site conditions following the standardized workflow developed in the scope of the IRIS project. As demonstration example for this study the Vienna area in Austria was chosen.

The potential of social and economic losses due to earthquake events and secondary processes triggered by them, is increasing as well in Austria. Technical interdependencies between infrastructures have a potential in triggering widespread cascading effects of failure or loss of service. The Vienna area for example has more than two million inhabitants and sensitive infrastructure. Seismic hazard assessment and mitigation is therefore an important task [Hausmann et al., 2010].
11-2 Geomorphologic and Geotectonic Setting

Information of long-term information of geodynamic processes in the Eastern Alps and its environments (uplift, subsidence, horizontal movements) are a basic need for the maintenance of the buildings, infrastructure and industrial facilities in the Vienna area. As the geodynamic processes are linked with the morphologic development in the Vienna area, its morphometric properties have to be taken into account as well.

Vienna is situated at the western margin of the Vienna Basin, a pull-apart structure formed due to lateral extrusion between the Eastern Alps and the Western Carpathians. It developed during the Miocene and was reactivated in Pleistocene times [Beidinger et al., 2011]. The Vienna basin is surrounded by the Eastern Alps, the West Carpathians, and the western part of the Pannonian Basin. It strikes roughly southwest-northeast, is 200 km long and nearly 60 km wide. It extends from Gloggnitz (Lower Austria) in the SSW to Napajedl (Czech Republic) in the NNE [Harzhauser and Piller, 2004]. Major NE-striking fault systems of the Vienna Basin are related to the seismically active Vienna Basin Transfer Fault System (VBTF). The Vienna Basin fault system is a slow moving (1–2.5 mm/y) active sinistral fault extending from the Alps through the Vienna Basin into the Carpathians [Hinsch and Decker, 2010]. This is in good agreement with GPS data showing about 2 mm slip per year and precise levelling proving surface subsidence up to 1 mm/y. Three of these branch faults, which have at least been active through the Pleistocene, pass through the urban centre of Vienna. The landscape of large parts of the city of Vienna is dominated by Quaternary terraces of the Danube river.
Earthquakes in the Vienna Basin

The Vienna Basin is one of the main seismic active areas in Austria. During the 20th century 345 earthquakes in the Vienna Basin and adjacent areas in Styria could be felt, 17 earthquakes caused building damage [Hausmann et al., 2010; Meurers et al., 2004]. Most of the epicentres line up along the Vienna Basin Transfer Fault System (VBTF), see F.11-1. The region at the VBTF is in general characterized by moderate seismicity with almost medium sized earthquakes (Magnitude: ML 5.0–5.5). A stronger event, the Neulengbach earthquake, 1590 AD (ML about 6) was recorded in historic times [Hinsch and Decker, 2010]. The earthquake in the wider area of Neulengbach in 1590, about 30km northwest of Vienna, had an epicentral intensity of about 9, according to the analysis of historical documents [Lenhardt et al., 2007].

The available seismic hazard estimates for Austria were established on probabilistic and statistical analyses of historical earthquake data [Grünthal et al., 1998]. Such approaches assume that the future seismicity will be the same as past observed activity, implying higher earthquake probabilities in areas, where historical earthquakes occurred and lower probabilities for areas, where only few or small earthquakes occurred [Hinsch and Decker, 2010]. However, maps of active faults and computed seismic slip deficits indicate that previous hazard analyses for the surroundings of Vienna may both underestimate the probability of severe earthquakes and the maximum credible earthquake. The subsurface geologic structure of the Vienna basin has the potential to amplify and lengthen the duration of strong shaking in some places, such as in areas with surficial and shallow deposits of artificial fill and youngest, unconsolidated alluvium (Danube river deposits).

11-3-1 Local Site Conditions

Local site conditions play an important role when considering earthquake shaking and damage intensities and their local variations. The ground-shaking during an earthquake predominantly depends on several factors such as the magnitude, properties of fault plane solutions, the distance from the fault and local geologic conditions. An estimation of expected ground motion is fundamental for earthquake hazard assessment.

Generally, ground motion and damage are influenced by the magnitude of the earthquake, the distance from the seismic source to the site, and the local ground conditions [Atkinson, 2004]. Empirical attenuation relation, a practical way to estimate ground motion parameters, gives information about how these parameters depend on the above-mentioned source, path, and site effects. This, namely ground condition, must be considered, because the same earthquake recorded at the same distance may cause different damage according to ground conditions [Irikura et al., 2004]. The most intense shaking experienced during earthquakes generally occurs near the rupturing fault area, and decreases with distance away from the fault. Within a single earthquake event, however, the shaking at one site can easily be stronger than at another site, even when their distance from the ruptured fault is the same. Local geologic conditions are the cause of difference in shaking intensity, but often there is little certainty of the particular conditions in a spe-
cific area that are most responsible, and the degree to which they affect earthquake shaking. The variability in earthquake-induced damage is mainly determined by the local geologic and hydrogeologic conditions. These conditions, internally influence the amplitude, the frequency and duration of ground motion at a site. Groundwater level variations and associated saturation changes in sand layers within near-surface aquifers can influence local response spectra of the ground motion, through modification of shear-wave velocity. Changes of the groundwater level can also have a considerable influence upon the liquefaction potential of a region. Special attention is drawn to in-situ pore-water pressure responses in aquifers during earthquakes, to observe and explain the triggering mechanism of liquefaction [Hannich et al., 2006].

Previous earthquakes have indicated that the damage and loss of life are mostly concentrated in areas underlain by deposits of soft soil and high ground water tables as for example the Mexico City earthquake in 1985 [Steinwachs, 1988]. Soft soils amplify shear waves and, thus, amplify ground shaking. Wetlands have a higher damage potential during earthquakes due to longer and higher vibrations. The fundamental phenomenon responsible for the amplification of motion over soft sediments is the trapping of seismic waves due to the impedance contrast between sediments and underlying bedrock. When the structure is horizontally layered, this trapping affects body waves, which travel up and down in the surface layers. When the structure is a 2D or 3D structure, i.e., when lateral heterogeneities are present (such as thickness variations in sediment-filled valleys), this trapping also affects the surface waves, which develop on these heterogeneities. The interferences between these trapped waves lead to resonance patterns, the shape and the frequency of which are related with the geometrical and mechanical characteristics of the structure [Ehret and Hannich, 2004].

Traces of ancient river meanders with sediment depositions of different grain sizes as visible on a QuickBird satellite image scene
Factors as lithology (loose, unconsolidated sedimentary covers), faults, or steeper slopes (landslide susceptibility) or areas with higher groundwater tables were analysed in the Vienna area. Special attention was focussed on the detection of depressions filled with youngest sedimentary covers, wetlands, meanders, landslide areas and traces of sub-surface structures as these specific site conditions play an important role related to earthquake ground motion. F.11-2 and F.11-3 visualize the influence of varying ground conditions within ancient river meanders due to even small grain size and thickness variations of the layers, or height level differences.

Maps of seismic site conditions on regional scales require substantial investment in almost detailed geological and geotechnical data acquisition and interpretation. However, detailed macroseismic maps, that can help to detect local site conditions, are often covering only selected areas and based on different standards and scales. In many seismically active regions of the world, information about surficial geology and shear-wave velocity (VS) either, does not exist, varies dramatically in quality, varies spatially, or is not easily accessible.

There is a strong need to improve the systematic, standardized inventory of areas that are more susceptible to earthquake ground motions or to earthquake related secondary effects such as landslides, liquefaction, soil amplifications or compaction.
11-4 Methods

The hazard assessment derives places, which might be prone to higher earthquake damage during earthquakes. When searching for areas susceptible to soil amplification, liquefaction or compaction the so-called causative or preparatory geofactors have to be taken into account such as lithologic and hydrogeologic conditions and structural/tectonic conditions.

The existing data for this study include ASTER Global Digital Elevation Model (DEM)-data. To automatically identify the landform types that affect site conditions, the relief elements are grouped into terrain features. Terrain features can be described and categorized into simple topographic relief elements or morphometric units by parameterizing the DEM such as in height levels, slope gradients, and terrain curvature.

The prerequisite for natural hazard preparedness is the collection, georeferencing and storage of available maps and data in a GIS environment (F.11-4). GIS and related technologies can be used for monitoring and responding to disasters, as well as for planning community rebuilding or even for relocation in extreme cases. For disaster preparedness the almost detailed detection and documentation of settlements, infrastructure, industrial facilities, etc. that might be exposed to earthquake and other hazards, especially their different exposures to soil amplification, landslides or active tectonic processes is necessary. Thus, in the scope of this study spatial data layers come from various sources such as topographic maps and thematic maps (soil maps, geologic and hydrogeologic maps, land use etc.) and field survey were included and stored in a Geoinformation System (GIS) as

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**Elaboration of a basic GIS data base**

The prerequisite for natural hazard preparedness is the collection, georeferencing and storage of available maps and data in a GIS environment.

**Methods and Workflow for Data Mining**

F.11-4

**Digital Image Processing of Satellite Data**

- RGB
- NDWI-Wasser-Index for soil moisture detection
- NDVI-Vegetationindex for vegetation anomaly detection
- Principal component, classification
- Filter techniques (morphologic convolution)
- Change detection

**GIS Integrated Evaluation of Satellite Data**

- Deriving morphometric maps from DEM data
- Height level
- Slope gradient
- Curvature
- Drainage
- Lineament analysis
- Weighted Overlay

**Integration and Combination of Geodata**

- Integration of geophysical, geologic, geomorphologic and pedologic data
- Vegetation, land use, infrastructure

**LANDSAT-, RapidEye-, ASTER-, IKONOS-, etc. imageries and aerial images**

**Morphometric maps**

**GIS integrated data mining**
well as documents of past hazards such as landslides or flooding events. Using web-services of the actual land use information was derived from evaluations and classifications of the available LANDSAT, ASTER and Google Earth data, in addition to available open-source data such as open-street-map, Google Earth and ESRI-geodata. The workflow for the GIS data base creation is described in F.11-4. An important aspect was the availability of satellite data in order to create a most current, high spatial resolution GIS integrated reference database, aiming at visualizing critical points and areas and providing information about damage in case of emergency due to natural hazards as fast as possible, as the civil protection units need this information for their management.

11-4-1 Land Use Assessment

Some data layers, such as land use and forests, are dynamic in nature and need to be updated frequently. For risk assessment and mapping at a regional scale, information about the land use and building stock distribution in the Vienna area was derived from high resolution QuickBird satellite data, aerial images and from available information such as of the Vienna City Map (access: www.wien.gv.at/stadtplan). Data for hospitals and health centres, schools, governmental buildings, police, fire stations and industrial buildings were stored in the GIS data base (F.11-5). The tools of ArcScene/ESRI were used to exaggerate the artificial height (extrusion tools) of industrial and commercial facilities, mapped based on QuickBird-imageries, and derived from the city map of Vienna as well as from open-street-map data.
11-4-2 Evaluations of Digital Elevation Model Data (DEM) for the Extraction of Causal Factors

The GIS integrated geodata were used as well to visualize causal/preparatory factors related to the occurrence of higher earthquake shock and earthquake induced secondary effects such as lithology (loose, unconsolidated sedimentary covers), faults, or steeper slopes (landslide susceptibility) or areas with higher groundwater tables. Information of QuickBird-images were merged with actual city maps or open-source data for getting information on the functions of the different land use types and buildings. Maps of hazard-prone areas such as flood maps were superimposed on the land use maps, especially merged with available data of industrial, commercial and infrastructural facilities.

The factors influencing the occurrence, type and intensity of earthquake induced secondary effects that can be separated into causal and triggering. The causal factors determine the initial favourable conditions for the occurrence, while the triggering factors such as high precipitation rates principally determine the timing. Causal factors are, among others, the slope gradient, curvature, lithology and groundwater table level. The triggering mechanisms are quite unpredictable, as they vary in time. However, some of the causal factors can be integrated as layers into a GIS.

The influence of causal factors on earthquake ground motion is not equally important in the analysis. It varies according to the specific local settings (surface geology, structure) or according to the distance of the earthquake source. The percentage of influence of one factor also changes in consideration of seasonal and climatic factors. In very hot and dry seasons the risk of liquefaction and landslides is generally lower than in wet seasons with high precipitation.

Depressions filled with youngest sedimentary covers, wetlands and meanders, landslide areas and traces of sub-surface structures play an important role related to earthquake ground motion. Those areas are considered to be more susceptible to soil amplification wherein the following causal factors are summarizing and aggregating their effects: lowest height level of the terrain combined with relatively high groundwater tables, flat morphology with low slope gradients and no curvature, loose sedimentary covers within a basin topography or within flat areas. Deriving morphometric properties of a terrain from Digital Elevation Model (DEM) data such as the minimum curvature or lowest slope gradient and the lowest local height level helps to detect flat accumulation zones: areas with almost recent, unconsolidated sediments, generally being prone to relatively higher earthquake shock and to secondary effects as liquefaction or compaction.

Some of the causal factors were determined systematically then: From slope gradient maps those areas with the steepest slopes, and from curvature maps the areas with the highest curvature were extracted as these are more susceptible to landslides. Height level maps helped to search for topographic depressions covered by almost recently formed sediments, usually linked with higher groundwater tables. Flat areas with no curvatures of the terrain and low to no slope gradients and the lowest areas were extracted. In case of stronger earthquakes those areas often show the highest earthquake damage intensities (F.11-6).

Some of the causal factors can be determined systematically from SRTM and ASTER DEM data such as
Methods 11-4

Hydrogeology

Curvature
Height Levels
Slope Gradient

Selection and extraction of attributes for the detection of causal factors influencing local site conditions using ArcGIS and ENVI software.

- Minimum curvature > 250 (calculation in ENVI-software providing information upon flat, broader valleys, basins and depressions with younger sedimentary covers and higher groundwater tables, resulting in a grey-tone image with values between 0 and 255); curvature calculation in ArcMap using the Spatial Analyst-Surface-tools by extracting then areas with curvature = 0 which correspond to flat areas.
- The lowest local height levels are indicating areas with relatively higher groundwater tables.
- Flow accumulation > 1, highest flow-accumulations, providing information about areas with higher surface water-flow input.

The morphometric maps derived from DEM data were combined and merged with lithologic and seismotectonic information as layer in the GIS data base.

- Quaternary sediment distributions and faults derived from geologic maps.
- Lineaments derived visually from LANDSAT ETM+ and RapidEye imageries.
- Earthquake data downloaded from International Earthquake Centres (International Seismological Centre – ISC, US Geological Survey – USGS, etc.).
- Vs30-IDW-interpolation (data from USGS).
- Shake maps, macroseismic observation records and further available data.

The different factors were converted into ESRI-GRID-integer format and summarized/aggregated and weighted in per cent in the weighted overlay-tool of ArcGIS according

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Extraction of causal factors and their aggregation in a weighted overlay approach F.11-6

![Diagram showing extraction of causal factors](image-url)
to their estimated influence on the local specific conditions. For example, as a stronger earthquake during a wet season will probably cause more secondary effects than during a dry season, the percentage of the weight of the different factors has to be adjusted to seasonal effects and to the local geomorphologic and geologic settings.

The integration of different factors in a GIS environment using weighting procedures serves as one of the key objectives in the GIS application in the frame of this study. The weighted overlay method takes into consideration the relative importance of the parameters and the classes belonging to each parameter (ESRI, online support in ArcGIS).

The application of a weight-linear-combination in susceptibility assessment has been identified as a semi-quantitative method, involving both expert evaluation and the idea of ranking and weighting factors. The basic pre-requisite for the use of weighting tools of GIS is the determination of weights and rating values representing the relative importance of factors and their categories. The efficacy of the weighted overlay-method lies

**Workflow for the weighted overlay approach aggregating factors with influence on local site conditions**

**WOSAD – Weighted Overlay for Soil Amplification Detection – a Standardized Approach**

- Lithologic and seismotectonic information in a GIS data base as
- Quaternary sediment distributions and faults derived from geologic maps
- Lineaments derived from LANDSAT ETM imageries
- Earthquake data (ISC, USGS, EMSC, GFZ, etc.) downloaded from International Earthquake Centres
- Vs30-IDW-interpolation (data from USGS)
- Shake maps and
- Further available information

**Select a basemap**

<table>
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<th>Imagery with labels</th>
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</thead>
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<td>Light grey canvas</td>
</tr>
<tr>
<td>National geographic</td>
<td>Oceans</td>
<td>OpenStreet Map</td>
</tr>
<tr>
<td>Bing maps aerial</td>
<td>Bing maps hybrid</td>
<td>Bing maps road</td>
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</tbody>
</table>

Open-source information provided by ESRI, OpenStreet-Map, etc.
in the fact that human judgements can be incorporated in the analysis. The weights and ratings are determined using the expert’s subjective knowledge. The method starts by assigning an arbitrary weight to the most important criterion (highest percentage), as well as to the least important attribute according to the relative importance of parameters. The sum over all the causal factors/layers that can be included into GIS provides some information about the susceptibility to the amplification of seismic signals. This susceptibility is calculated by adding every layer, as described below, to a weighted influence and summing all layers. After weighing (in percent) the factors according to their probable influence on ground shaking, susceptibility maps can be elaborated, where those areas are considered as being more susceptible to higher earthquake shock intensities, where “negative” causal factors occur aggregated and are interfering with each other. The resulting maps are divided into susceptibility classes. The susceptibility to soil amplification is classified by values from 0 to 6, where the value 6 stands for the strongest, assumed susceptibility to soil amplification due to the aggregation of causal factors. The approach mentioned above is described as the Weighted-Overlay for Soil Amplification Detection (WOSAD) approach using ArcGIS and ENVI-software (F.11-6, F.11-7).

Comparing the results of the weighted overlay-calculations with geologic maps, there is a clearly visible coincidence of areas with higher susceptibility values and the outcrop of unconsolidated, quaternary sediments in broader valleys and depressions.

Whenever an earthquake happens, it can now be better derived where the “islands” of higher ground shaking are most likely to occur in the affected areas by adding the specific information of the earthquake to the susceptibility map using the WOSAD-weighted overlay-approach. The approach hereby presented is proposed to serve as a first basic data stock for getting a perception of potential sites susceptible to higher earthquake ground motion, including in the next steps the integration of further, available data such as movements along active faults, focal planes, 3D structure, lithologic properties and thickness of lithologic units or shear wave velocities. The analysis method and integration rules can be easily modified in the open GIS architecture as soon as additional information becomes available. The limitation of the approach, however, lies in the constricted accuracy of the SRTM and ASTER DEM data sets of up to several metres. At least, it is suited to obtain a first basic overview on the susceptible areas and hazard perspectives according to a standardized approach. This might be of interest especially for countries with low financial resources where such maps are still unavailable. The information of the industrial/commercial facilities were overlaid in ArcGIS with the results of the WOSAD approach (F.11-8). Thus, those facilities were visualized that are situated in potentially endangered areas in case of stronger earthquakes.

11-4-3 Digital Image Processing and Evaluations of Satellite Imageries

To deliver information about a disaster in near real time is vital to save lives of people involved and to prepare measurements. High resolution satellite data are needed for this purpose, however, most of them are available with a time delay. An important aspect is the delivery of satellite data for both, for creating a most actual, high spatial resolution, GIS integrated reference data base visualizing critical points and areas, and for providing
Overlay of industrial/commercial units with the results of the WOSAD approach indicating industrial/commercial facilities situated in areas assumed to have the highest susceptibility to soil amplification in red.

Weighted overlay of causal, morphometric factors based on ASTER DEM data.
information of damages in case of emergency due to an accident in an industrial plant or due to natural hazards as fast as possible, as the civil protection units need the information for their management.

For a better overview of seasonal influences on earthquake ground motion and on secondary effects multi-temporal analysis of different satellite data and aerial images were carried out, in combination with evaluations of geotechnical data, climatic data, long-term soil moisture and groundwater table measurements and data of vegetation status. Digital image processing tools for the different satellite data providing the best results for this purpose were investigated. Based on multispectral satellite data combinations of different RGB combinations of the spectral bands were tested. Low pass and high pass filters and directional variations were used for the detection of subtle surface structures such as meanders or landslides. The visibility of linear features in the images that might be related to sub-surface structures was enhanced. Lineament analysis based on LANDSAT imageries or DEM derived morphometric maps such as hillshade or slope maps helped to detect possible fault and fracture zones in the subsurface. Merging the “morphologic” image products derived from “Morphologic Convolution” image processing in ENVI software with the RGB-satellite imageries, the evaluation feasibilities were improved. Tectonic features (GBA, Vienna) were included to focus on the potential influence of sub-surface structures on seismic wave propagation and on their important role for horizontal and vertical movements, especially for subsidence in the Mitterndorf-Graben-area. Earthquake damage can be amplified by guided seismic waves along fault zones. Seismic waves travel-
ling in the subsurface might be refracted at sharply outlined discontinuities as faults, and, thus, arrive at a summation effect that influences the damage intensity. Fault segments, their bends and intersection are more apt to concentrate stress and amplify seismic shock and, thus, provide an assumption where summation effects can be expected.

11-4-4 Evaluations of Shear Wave Velocity Data

In order to provide a first-approximation of local site conditions, an approach was developed to characterize potential ground motions on the basis of known correlations between variations in shear-wave velocity and topographically distinctive landforms by applying geomorphometry, a quantitative description of landforms based on DEMs [Wald and Allen, 2007; Yong et al., 2008]. Hereby, Vs30-measurements (the average shear-velocity down to 30 m) are correlated against topographic slope. These authors also compared topographic slope-based Vs30 maps to existing site condition maps based on geology and observed Vs30 measurements, where they were available, and found favourable results. Thus, for getting a first impression of shear velocities in the Vienna area, the estimated Vs30-data provided by USGS were used. The Vs30-data were converted into point-shapefiles, serving as a base for interpolations. From the interpolated Vs30 contour lines the values below 300 m/sec were extracted as lower Vs30-values are correlated in their position with unconsolidated Quaternary sediments, what is assumed to contribute to higher earthquake damage. The resulting interpolation contour-lines were merged with other geodata such as geologic, geophysical and hydrogeologic maps as for example provided by GBA Online. The Vs30-interpolation results were combined as well with the weighted overlay results (F.11-9).
11-5 GIS Integrated Evaluations of Remote Sensing and Different Geo-Data

According to the described methods the WOSAD approach was investigated based on SRTM- and ASTER DEM data providing an overview of areas with aggregation of causal factors in the Vienna area, where the susceptibility to damages can be assumed to be higher in case of stronger earthquakes due to local site conditions.

11-5-1 Results of the WOSAD Approach

The overlay of industrial/commercial facilities with the results of the WOSAD approach contributes to the detection of those facilities that might be exposed to higher soil amplification due to the aggregation of causal factors (F.11-9). However, whether these facilities are exposed in fact to higher damages in case of stronger earthquakes, depends on factors such as the building construction type, function, the age, or the used material. Therefore an almost detailed inventory of building properties is required. Based on the developments of the MaeViz-software in the United States and an innovative disaster management platform, the software EQvis was created in the scope of the EU-funded IRIS-project by VCE allowing quick reactions in case of disasters as well as simulations for the improvement of disaster preparedness. Simulation and visualization can be performed on the EQvis platform. By introducing various hazard scenarios the response of the infrastructure can be computed (F.11-10).

3D perspective view of the weighted overlay results combined with the QuickBird-scene and estimated Vs30-data < 300 m/sec (USGS)

Perspective 3D-view of Vienna based on a QuickBird-scene merged with ASTER DEM data, the results of the weighted overlay-calculations and estimated Vs30-contour lines < 300 m/sec

WOSAD results

<table>
<thead>
<tr>
<th>Gridcode</th>
<th>Susceptibility to soil amplification due to the aggregation of causal factors</th>
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<tbody>
<tr>
<td>1</td>
<td>Contour-Vs30 &lt; 180</td>
</tr>
<tr>
<td>2</td>
<td>180–200</td>
</tr>
<tr>
<td>3</td>
<td>201–220</td>
</tr>
<tr>
<td>4</td>
<td>221–240</td>
</tr>
<tr>
<td>5</td>
<td>241–270</td>
</tr>
<tr>
<td>6</td>
<td>271–300</td>
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</table>
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WOSAD results presented in 3D views using ArcScene-tools

Use of Google Earth for visualization of areas with assumed higher susceptibility to soil amplification due to the aggregation of causal factors
When combining the results of the weighted overlay-approach (summarizing factors with influence on earthquake shock), and the estimated shear wave velocities (Vs30), a better understanding and visualization of differences and "islands" of higher earthquake damage and potentially affected areas can be achieved. There is a clearly visible coincidence of areas with lower Vs30-values such as assumed Vs30 < 200 m/sec, and areas with higher susceptibility to soil amplification due to the aggregation of factors influencing the specific local site conditions as well as a distinct correlation with areas covered by unconsolidated, Quaternary sediments. The Vs30-values < 300 m/sec were confirmed by field measurements during the SEISMID-project (SEISMID – Seismic system identification for the Vienna Basin-Project, 2007–2011 [VCE, 2011]).

Infrastructural data and weighted overlay results were merged with QuickBird satellite data (F.11-12). The visualization of the susceptibility to soil amplification in the Vienna area was enhanced by 3D perspective views (F.11-13). The 3D-perspective views clearly show where industrial facilities are underlain by so far known sub-surface structures and where these facilities are built in areas with relatively higher susceptibility to soil amplification in case of stronger earthquakes. These data were converted into .kmz-format for being displayed in Google Earth. The weighted overlay results were presented in Google Earth, combined then with the detailed 3D views of the buildings (F.11-14).

11-5-2 Neotectonic Movements

The analysis of the drainage pattern can help to detect the location of active structures [Yang et al., 2007]. Meanders typically develop under conditions of limited bed-loads, fine-grained sediments and low river-bed gradient [Burnett and Schumm, 1983]. Even little uplifting or subsiding can change the network of rivers. The Marchfeld-area
north of Vienna and the Little Hungarian Plain are characterized by meandering rivers with relatively low surface slope and river gradient, but high river sinuosity. The Danube river area has slightly tilted terraces with river meanders and many tributaries developed on its surface. QuickBird and LANDSAT ETM imageries allow the detailed mapping of these rivers and meanders. A distinct relationship between active tectonics, topographic evolution and drainage pattern development can be observed. When combining and comparing the traces of meanders with geodetic measurements, it becomes obvious that the occurrence and density of meanders coincides with areas of subsidence. Negative, vertical movements as measured by precise geodetic measurements of height differences are prevailing and concentrated in the Danube river [Szeidovitz and Gibrovski, 2004]. There is a clearly visible spatial coincidence between subsidence areas and meander development. The result of the weighted overlay of morphometric properties (height level <150 m, slope gradient <10°, curvature = 0, drop raster <100000) shows as well a coincidence between these morphometric properties and subsidence areas. As vertical and horizontal movements are influencing the long-term stability of infrastructural facilities such as piping, sewage, railroads and roads, especially in the transition zones between uplift and subsidence, an inventory of infrastructural facilities situated in those “critical” areas is necessary (F.11-15).

11-6 Conclusions

RS and GIS data and results can be combined with updateable and dynamic scenarios for earthquakes in the geo-databases of a GIS, assisting the procedure of preparedness and increasing the organization and effectiveness of response activities. GIS integrated evaluations of different satellite data can contribute considerably to the detection of subsurface structures in Eastern Austria and those areas that are assumed to be prone to relatively higher earthquake ground motion due to the aggregation of preparatory factors. This supports the monitoring of infrastructural facilities. Finally, WebGIS components can be used for the collection and analysis of real damage to the built environment in case of stronger earthquakes and related secondary effects, thus, providing valuable information on the behaviour of buildings and the cost of repair and re-habilitation procedures.

References


Earthquake Data

European Mediterranean Seismological Centre – EMSC:
www.emsc-csem.org/Earthquake/earthquake.php?id=107436

International Seismological Centre – ISC:
www.isc.ac.uk/help/search/custom/maptool.html

US Geological Survey – USGS:
http://earthquake.usgs.gov/earthquakes/eqarchives/eqpic/
http://earthquake.usgs.gov/hazards/apps/vs30/

Central Institute for Meteorology and Geodynamics – ZAMG:
www.zamg.ac.at/erdbeben/jahrbuch/?ts=1322646001

GIS-Data

OpenStreetMap:
http://download.geofabrik.de/osm/europe/

Land Use:
www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/siedlungsentwicklung/realnutzungskartierung.html

Satellite Data

ASTER DGDEM:
www.gdem.aster.ersdac.or.jp/search.jsp

SRTM DEM:
http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

LANDSAT:
http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp
http://earthexplorer.usgs.gov/

Geologic Data

Geologische Bundesanstalt in Vienna (GBA):
www.geologie.ac.at
http://geomap.geolba.ac.at/MASS/intro_start1.cfm