Chapter XXII

Development of a Decision Support Tool for Technological Risk Management with Remote Sensing and GIS

Nektarios Chrysoulakis, Foundation for Research & Technology - Hellas, Greece

Poulicos Prastacos, Foundation for Research & Technology - Hellas, Greece

Constantinos Cartalis, University of Athens, Greece

Abstract

In this study, a GIS based decision support tool is proposed for the support of technological risk management by integrating moderate and high spatial resolution satellite imagery with in-situ vector data. The Advanced Very High Resolution Radiometer (AVHRR) on board the NOAA satellites has been used for the detection of fire as well as for the detection and
monitoring of plumes caused by major technological accidents. The Thematic Mapper (TM) on board the Landsat satellite has been used for the depiction of the urban areas and the main road network as well as for the estimation of the spatial distribution of vegetation in the study area. A major technological accident scenario was developed for the broader area of Athens (Greece) in order to present the functionality of the GIS tool for the support of decision making during the crisis, as well as for the assessment of the accident’s impact on the natural and human environment.

Introduction

Major technological accidents comprise great danger to the environment and public health. A number of accidents have taken place in recent years with serious costs in terms of human life as well as with considerable – and in many cases irreversible – damage to the natural environment. In many cases toxic substances or released airborne material develop into plumes which may reach high concentrations at ground level and pose dangers to the human and natural environment. Damages may thus occur both as an immediate and direct consequence of the accident, and subsequently during propagation and dispersion of the resulting plume. Exhaustive consideration is usually given to the immediate ground-level effects in close vicinity to the installation; however, it should be mentioned that in several cases, only limited effort was given to examining the impacts of the plume in the wider geographic area during the course of the hours or days following the accident. Technological accidents can be characterized by a number of different events and processes, including spillage or sudden release of materials, fire, or explosion. Airborne releases usually develop in plumes, which can thereafter be monitored either due to their optical depth or their temperature difference from the ambient air. The emission of toxic gases and formation of carbon particles which can carry toxic material absorbed onto their surface as well as obscuring vision both present hazards in a fire situation.

A number of experiments (Atkinson et al., 1994; Bartelds et al., 1993; Cozzani et al., 1996; Davie & Nolan, 1993; Grant & Drysdale, 1994; Lang, 1993; Marliere, 1996; Martins & Borrego, 1994; Martins et al., 1996; Miles & Cox 1994; Porter et al., 1996) involving fires in warehouses and awareness of the hazards of plumes in a fire situation have been oriented towards the definition of the properties and of the amount of the plume particulates generated by different materials, including pesticides, under varying fire conditions. Various numerical models and software packages have been developed for the simulation of the
conditions and the process of technological accidents (Andronopoulos et al., 1994; Cleaver et al., 1995; Hanna et al., 1993; Khan & Abbasi, 1999; Kukkonen et al., 1994; Webber et al., 1993).

In this study, the design and implementation of a technological risk management decision support tool (DST) is presented. It is based on the detection and space-time monitoring of the produced plumes by integrating moderate and high spatial resolution satellite imagery with vector data in a GIS platform capable of supporting technological risk management. A major technological accident scenario for the broader area of Athens was developed by adjusting Advanced Very High Resolution Radiometer (AVHRR) images that were acquired during the massive explosion in a fireworks factory in Enschede (The Netherlands) on May 13, 2000. This scenario was used to present the functionality of the developed DST for the support of decision making during the crisis, as well as for the assessment of the accident’s impact on the natural and human environment.

**Fire and Plume Detection Methodology**

The methodology for the detection of fires caused by major technological accidents with the use of AVHRR imagery has been presented in a past study (Chrysoulakis & Cartalis, 2000). The detection algorithm has the advantages of multispectral analysis and provides valuable results for the detection of fires caused by technological accidents. In practice, the pseudochannel image of brightness temperature difference between AVHRR channels 3 (3.55 - 3.93 µm) and 4 (10.5 - 11.3 µm) is created and filtered for clouds by applying a cloud-masking algorithm which is based on the combination of AVHRR channels 1 (0.58 - 0.68 µm) and 5 (11.5 - 12.5 µm). In this filtered image, pixels with brightness values greater than an experimental derived temperature threshold correspond to fires produced by major technological accidents. The fire detection algorithm has been programmed as a stand-alone application for the automatic detection of fires caused by major technological accidents with use of AVHRR imagery (Chrysoulakis & Cartalis, 2003a).

The methodology for the automatic detection and monitoring of plumes caused by major technological accidents with the use of AVHRR multispectral imagery has also been presented in a previous study (Chrysoulakis & Cartalis, 2003b). A two-dimensional feature space image is used in order to discriminate pixels that contain plumes from those that may contain clouds or the underlying surface. The two-dimensional feature space is generated by combining AVHRR channels 1, 2 (0.72-1.10 µm) and 5.
Both methodologies have been evaluated on the basis of past technological accidents (Thessaloniki, February 24, 1986; Lyon, June 2, 1987; Genoa, April 13, 1991; Enschede, May 13, 2000). AVHRR images acquired over the broader area of the Netherlands on May 13, 2000 (14.44 UTC and 17.20 UTC) were used for the development of a major technological accident scenario in this study. This date refers to the massive explosion in a fireworks factory in the town of Enschede. The fire was detected by applying the aforementioned fire detection algorithm to the AVHRR images; whereas, in order to simplify the scenario, AVHRR channel 2 images were used for monitoring the plumes.

Design and Application of a GIS Based Tool for Support of Technological Risk Management

The main factors that need to be covered in the course of preparing an emergency plan for major industrial accidents range from the definition of land use/cover and the potentially exposed population to the rate and direction of propagation of the plume. Satellite data are the main information source in the proposed system. The fire and plume detection algorithms are applied to AVHRR imagery. If both results are positive (this means that an industrial fire and a plume have been detected in the same area), the system will classify the corresponded pixels as “potential incident pixels”. Since the AVHRR images are geometrically corrected, the coordination of these pixels is automatically stored in the system. The areas in which a technological accident is most likely to occur (industrial installations, warehouses of toxic substances, offshore installations, petroleum products storage sites, ports, airports, etc.) were mapped with the use of high spatial resolution satellite imagery (Landsat TM) in combination with other sources of information (CORINE land cover data, land use maps, etc.). These areas were classified as “possible areas of occurrence”. Therefore, the developed DST examines whether the detected “potential incident pixels” are located within any possible area of occurrence. A positive result will verify the occurrence of a technological accident and will comprise an “alarm” for the system. This alarm sets off the plume monitoring modules as well as the modules used by the system for the estimation of the population at risk. The latter combine the high spatial resolution satellite derived information (urban areas, road network) with in-situ derived vector data (spatial distribution of population in the vicinity of the incident).

About half of the population of Greece is concentrated in Athens. A lot of refineries, chemical industries and warehouses are located in the broader region
of Athens and especially within the industrial zone of “Thriasio Pedio,” about 15 km NW from the centre of the city. For the application of the proposed GIS tool, taking into account that the prevailing winds in the area of concern are from the N – NW directions, a major technological accident scenario for a refinery installation at Thriasio Pedio was generated. In the past, similar accidents took place in this area (i.e., Petrola refinery, February 1, 1992), but for the application of the GIS tool in this study, real plumes depicted on AVHRR imagery were needed. For this reason, the available AVHRR data of May 13, 2000, were used (major technological accident in Enschede). Rectangular portions (50x30 km), around the pixels corresponded to plumes, and were extracted from these AVHRR images and adjusted to the broader area of Athens. High spatial resolution satellite imagery and in-situ vector data have been also used. More specifically, for the development and implementation of the scenario the following data were integrated:

(a) **NOAA/AVHRR images (May 13, 2000, at 14.44 UTC and 17.20 UTC).** The fire detection algorithm was applied to these images in order to detect the pixels corresponding to the accident site in Enschede. Since pixels corresponding to the fire caused by this accident were detected, AVHRR images were adjusted to the area of Athens by adapting these pixels to the position of the refinery at the Thriasio Pedio. A transverse Mercator projection was applied (Projection System: Hellenic Geodetic Reference System 87 - HGRS87; Reference Ellipsoid: GRS80). Figure 1 presents the position of the plume at 14.44 and 17.20 UTC (AVHRR channel 2).

(b) **Landsat TM image (April 26, 1994).** Ground Control Points (GCPs) were used for the geometric correction of this image and for its projection to the HGRS87 system. The TM image was used for the depiction of urban areas and of the main road network, as well as for the depiction of the industrial zones in combination with land use maps. It was also used for the estimation of the state of the environment in the area of concern.

(c) **CORINE Land Cover data and land use maps.** These data were used in combination with Landsat TM imagery for the depiction of areas in which a technological accident is most likely to occur (possible areas of occurrence).

(d) **30m contours were used for the production of a Digital Elevation Model (DEM) for the broader area of Athens.** This DEM is used to feed the dispersion models with topographic information, as well as to produce 3D views of the landscape with the combined use of Landsat TM imagery.

(e) **Vectors of the main and secondary road networks for the broader area of Athens.** The integration of these vectors with the Landsat TM image has the potential to support either the development of emergency plans for the area of concern, or the decision making during the crisis mitigation phase.
Vectors of the spatial distribution of population for the broader area of Athens. These vectors were used by the GIS tool in order to support the decision making during the crisis mitigation phase, especially regarding the evacuation of urban areas to avoid plumes. The system has the capability to combine these vectors with the satellite derived information in order to estimate the population at risk.

Results

The red polygons correspond to the possible areas of occurrence in Figure 2. These areas have been superimposed on a pseudocoloured composition (RGB: 3-2-1) of TM channels 1, 2 and 3. The DST examines whether the detected “potential incident pixels” are located within any possible area of occurrence. According to the scenario used in this study, the area represented by the detected “potential incident pixels” (yellow polygon) is located within a possible area of occurrence.

Figure 3 presents the physical and artificial characteristics of the area located around the accident site. Three sources of information have been used: a) NOAA/AVHRR imagery for the detection of the exact position of the technological accident (yellow polygon); b) Landsat TM imagery for the monitoring of the area located around the accident site; c) vectors of the main and secondary road network. This type of visualization is used in the developed GIS tool to inform about the accessibility of the area of interest, as well as to depict the
artificial characteristics, which may be used during the crisis mitigation phase (i.e., airports).

Figure 4 presents a product of the “monitoring module” of the proposed DST. The selected GIS layers present: (a) the urban areas (Landsat TM pseudocoloured image 3-2-1); (b) the spatial distribution of vegetation, in green tones (Landsat TM, NDVI); (c) the position of the accident site, within the red polygon (from NOAA/AVHRR channels 3 and 4); (d) the position of the plume at 14.44 UTC, within the black polygon (from NOAA/AVHRR channel 2); (e) the position of the plume at 17.20 UTC, within the blue polygon (from NOAA/AVHRR channel 2).

This product may be used for the monitoring of urban and natural disaster areas as well as for the location of areas where high ground level concentrations of toxic substances are expected. It can be also used for the estimation of the horizontal propagation velocity of the produced plume. For the scenario used in this study, the analysis of this product indicated that the mean plume propagation velocity along the main propagation direction (NW to SE) was about 3.5 Km/h, whereas its mean diffusion velocity in a perpendicular direction was about 0.8 Km/h. Therefore, this product has the potential to offer valuable information to the decision making authorities, either during the crisis mitigation phase, or during
a post-crisis assessment. However, for the estimation of the population at risk during the propagation of the toxic plume, the spatial distribution of population was needed.

Figure 5 presents the final product of the “population distribution module” of the GIS tool. The selected GIS layers present: (a) the position of the accident site (within the yellow polygon); (b) the spatial distribution of population between 5 and 10 Km (blue circles) from the accident site; (c) the position of the plume at 14.44 UTC (green polygon); (d) the position of the plume at 17.20 UTC (red polygon); (e) the urban web and the physical and artificial characteristics of the broader area. The population distribution module has been designed for the automatic estimation of the population at risk. In terms of the scenario used in this study, the number of potentially affected inhabitants at the area within a circle centred at the accident site with 5 km radius was found to be at the order of magnitude of 15,000 persons, whereas the number of potentially affected inhabitants at the area between 5 and 10 Km from the accident site was found to be at the order of magnitude of 300,000 persons. Therefore, the integration of the spatial distribution of population with moderate spatial resolution satellite data has the potential to estimate the population at risk during the dispersion of a toxic plume, as well as to support (in combination with other elements of the proposed

Figure 3. Physical and artificial characteristics of the area located around the accident site are presented (The road network has been superimposed.)
Figure 4. Integration of Landsat, NOAA, CORINE and in-situ data for the monitoring of the urban areas, of the spatial distribution of vegetation, of the position of the accident site, of the position of the produced plume at 14.44 and 17.20 UTC

Figure 5. Estimation of population at risk during the propagation of toxic plumes over the city of Athens
DST such as the road network) the decision making regarding evacuation of the disaster area.

Conclusions

In this study, a GIS based tool was designed for the support of technological risk management. It has the advantages of the detection and space-time monitoring of the plumes by integrating moderate and high spatial resolution satellite imagery with vector data in order to estimate the population at risk during an emergency, as well as to support the assessment of the impacts of these plumes on the local environment. A major technological accident scenario was developed to present the functionality of the GIS based tool for the support of decision making during a crisis, as well as for the support of the assessment of the accident’s impact on the natural and human environments.

During the crisis phase, the proposed tool has the potential:
(a) to support dispersion models and to verify their results;
(b) to describe and map the characteristics of the natural environment and the population, thereby providing a means to assess the environmental and health impacts of the plume;
(c) to help identify at-risk populations and environments which may need special protection;
(d) to support the coordination among involved parties as well as the decision making regarding the evacuation of urban areas to avoid plumes.

During the post-crisis assessment phase, it has the potential:
(a) to thematically map disaster areas;
(b) to support the assessment of the impacts on the local (anthropogenic and natural) environments;
(c) to help design and plan follow-up strategies to deal with the consequences of accidents.

The main advantage of the proposed DST is its wide area coverage with very good spatial and temporal resolution. The main disadvantages are:
(a) It is able to detect the technological accidents that cause fires and/or explosions, whereas incidents such as the release of dangerous substances cannot be detected.
(b) The observation of a given area with the use of AVHRR is not accomplished on a continuous basis, because NOAA are polar orbiting satellites.

References


