Journal of Environmental Informatics 17(2) 83-90 (2011)

Journal of Environmental Informatics

www.iseis.org/jei

GIS Development for Environmental Hazard Management Based on Gridding Management

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Received 7 May 2010; revised 1 January 2010; accepted 18 January 2011; published online 12 June 2011

ABSTRACT. Due to the economic growth in China in recent years, the frequency of sudden environmental events has increased. As a result, Environmental Hazard Management (EHM) becomes important when mitigating such events. Geographic Information System (GIS) has been widely used for EHM both domestic and abroad, and while the studies usually focus on how to develop GIS, there has been little research on the linkage between GIS and EHM. In this paper, we propose GIS development for EHM based on Gridding Management (GM), i.e. the integration of EHM and GIS through GM. First, we will introduce the principles of GM for EHM, followed by the procedures of system development. Based on these principles, a prototype of GIS for EHM is developed for a highly urbanized district of Shanghai in which the management area is divided into appropriate grids. Each grid is supervised by a specific person, and all environmental hazard sources, sensitive objects, and other resources and information are coded geographically. After these steps, grid querying is implemented. Through a hypothetical scenario, the effectiveness of this methodology is tested and can help avoid some phenomena in traditional EHM, including separation of corporate and government EHM, neglecting surroundings information, overlaps or blind areas, no supervision or assessment, and no permanent mechanisms. We think this study is a useful probe into effective linkage between GIS and EHM.

Keywords: environmental hazard management, geographic information system, gridding management, emergency plan, risk management

1. Introduction

With the economic development in recent years, China has entered a period of sudden environmental events occurring at a high frequency (Zhou, 2006). The production, storage, transportation, and usage of various hazardous materials are increasing, which poses great danger upon the society. Statistics for industrialized countries show that cases with effective environmental hazard management systems can reduce losses due to environmental accidents by 94% in contrast with cases without such ones (Chen et al., 2006). Therefore, reasonable emergency mechanisms need to be established to control potential environmental hazard (EH) events, and fundamental research on the environmental hazard management (EHM) methodology is essential. The key issues of EHM include, but are not limited to, surveying and differentiating the EH sources, capturing the information of surroundings, establishing management information systems, and studying the methodology of EHM.

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ISSN: 1726-2135 print/1684-8799 online
 doi:10.3808/jei.201100190

Various EHM systems have been developed with a variety of technologies, especially geographic information system (GIS) (Assilzadeh and Gao, 2009; Bradaric et al., 2008; Conover et al., 2006). A specific advantage of GIS consists in its ability to integrate information from a range of sources and to present the results in map form. As a powerful spatial analysis tool, GIS has been widely used in many fields of EHM, such as risk analysis (Lahr and Kooistra, 2010; Lovett et al., 1997), mapping the spatial distributions of hazardous sites (Bolin et al., 2002), predicting harmful algal bloom (Shuhaibar and Riffat, 2008), oil spill analysis (Audu and Ehiorobo, 2009; Keramitsoglou et al., 2003), toxic chemical releases (Nadal et al., 2008; Nadal et al., 2006), and toxic metal transport (Gruiz et al., 2008). GIS can also become a basis of a decision support system or an emergency response system (Yu et al., 2009; Bacon et al., 2008; Ochola et al., 2004).

Two major issues exist in traditional GIS for EHM. One is effective integration of GIS and EHM. This is usually overlooked because most work focuses on the development of GIS and causes disconnection between GIS management and administration management. The other issue is the integration and extraction of valuable information, e.g., how to capture surroundings information related to EH sources. Because of the two inner issues, there are some exterior phenomena in current GIS for EHM in China, such as separation of corporate and government EHM, neglecting surroundings information management in the EHM, passive management, and existing blind areas or overlapping of management.

In recent years, a new kind of urban management mode called Gridding Management (GM) has been developed in China. At the Microsoft Mobile & Embedded Devices Developer Conference 2005, Gates (2005) introduced the case of Beijing's East District government and praised this kind of urban management mode as a "great example". Although GM has been used in urban management and has succeeded, further research is necessary to transplant this technology into the EHM domain, such as the feasibility and validity of this technology in EHM through examples, the main procedures of EHM GIS development, and the aspects needed to be modified when using this technology in EHM. The goal of this paper is to study the methodology for developing EHM systems using GM.

The rest of this paper is organized as follows. Section 2 begins by introducing the principles of GM in EHM. Then, procedures of system development are introduced, including grid partitioning, structure designing, database establishment of EH and grid information querying. In Section 3, as the result of this research, a developed prototype system for a highly urbanized district of Shanghai, China is introduced and its application is demonstrated by a hypothetical case. Section 4 presents our discussion, where we analyze the effectiveness of this methodology. The last section is summary and conclusions.

2. Methodology

We present a general methodology for developing EHM systems based on GM in this section. A prototype system is used as an illustrative example.

2.1. Urban Gridding Management

Urban Gridding Management, which was first developed by the local government of the East District in Beijing, has spread around China as a modern urban management mode (Chen, 2005; Yan, 2006). The two elements of Urban Gridding Management are components and events. Many technologies have been used in Urban Gridding Management such as gridding management method, city component management method, mobile communication technology, and an Urban Gridding Management GIS platform.

Urban Gridding Management is an innovative urban management mode. By establishing the management system and reconstructing the workflow of urban management, the transition from an expansive, blind, often delayed, campaign-filled method to a precise and efficient method can be realized. The failures of government, such as crossover of powers, can be avoided. The social management and public service function of government can be intensified.

GM can also be applied to other fields such as public security management, social welfare, community health care, etc. GM has been applied to Shanghai and other cities in China. Since EHM is an important aspect of urban management, GM can be applied to the development of GIS for EHM.

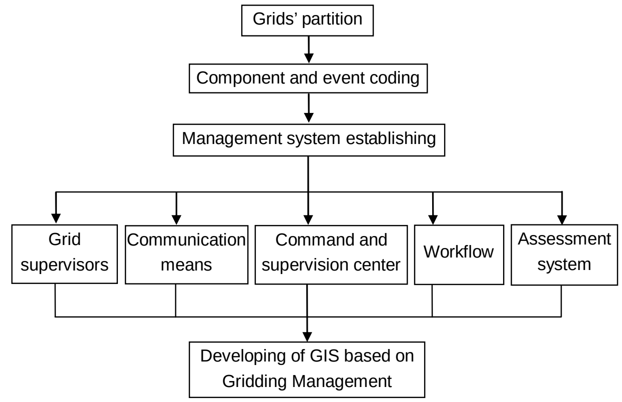


Figure 1. Technical framework of the developed EHM GIS based on GM.

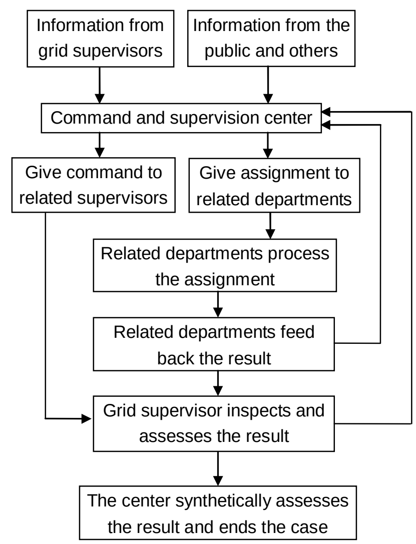


Figure 2. Workflow chart of the developed EHM GIS.

2.2. Principles of Gridding Management in EHM

Referencing the principles of GM, the study area is divided into grids with a specific size. Grids do not overlap, and the blind area of administration is eliminated. The environmental hazard sources, sensitive objects, and other related objects are coded geographically. Events are also coded and the querying according to grid is created. The EHM system includes grid supervisors, communication means, a command and supervision center, workflow, and an assessment system. Supervisors are assigned to all grids. A command and supervision center is established as the head of the EHM system. Communication means, workflow, and assessment system are also established simultaneously. Based on these, a GIS is developed, and the geographical information is connected with the relevant data. The technical framework is shown in Figure 1.

The management and supervision flow is regenerated accordingly. The command and supervision center receives the information not only from supervisors' active inspection, but also from the public, the media, and other ways. If information of an accident is not coming from the supervisors, the center can immediately send a related supervisor to the location to check the situation. The center can also command related departments to do maintenance and deal with events immediately. The processing of results can be inspected and assessed by the supervisor. The supervisors can be hired either by the government or enterprises, but each supervisor receives commands from the command and supervision center, and the center manages all related forces uniformly. This method ensures the contradiction between factory's self-inspection and government's inspection can be solved. The workflow chart is shown in Figure 2.

2.3. The Procedures of EHM GIS Development based on GM

By transplanting the gridding method into EHM, a prototype GIS system of one district in Shanghai is developed. The procedures of the system developments include grid partitioning, framework design of the system, and database establishment of EH and grid information querying.

According to the characteristics of EHM and the partition principles of Urban Gridding Management, the principles of EHM grid partitioning include 1) all areas should be covered, and overlapping should not occur; 2) one grid managed by different administrations should be avoided; 3) fully considering the spatial extent of environmental pollution as EH sources leak; 4) partitioning should be in accordance with street, courtyard, public greenbelt, square, bridge, river, mountain, lake, and other natural geographical layouts; 5) a grid border should not pass through a management object; 6) workload (usually referring to the number of management objects) in each grid should be approximate equal; 7) the type of land use in each grid should be homogeneous. The priorities of the seven principles above are in order of importance. When there are contradictions among the principles, anterior ones are accepted.

The framework of the system is shown in Figure 3. The system mainly includes map module, information management module, system management module, and other related decision support modules. What makes it different from traditional GIS is the grid querying. The querying and statistics functions of EH and the grid's information are realized in the information management module. Grid querying is in accordance with Geodatabase and EH database's tables. The basic map includes three types of layers: *Point layer*, *Line layer* and *Area layer*. The grid belongs to *Area layer* (named GRID_region).

Database establishment of EH and grid information querying is the last step. There are 13 tables in total in the database of EH: basic information of the enterprise, enterprise, EH material, storage mode, original source, usage, storing address, artificial person, industry, area, grid, risk of grid, and supervisor of grid. Different tables are connected each other with same fields. The relationships of these tables are shown in Figure 4.

The grid information is classified and saved into three tables: grid, risk of grid, and supervisor of grid. Table "Grid" includes the name of the grid, code of the grid, the supervisor, and the area. Table "risk of grid" includes the number of environmental hazard sources, the population, the number of sensitive objects, risk and sensitivity level, etc. Table "supervisor of grid" includes the information of the supervisor, such as name, gender, contact information, etc. Not only is there a focus on EH sources information, but also on the sensitive protection objects, population distribution, roadways, rivers, and other information.

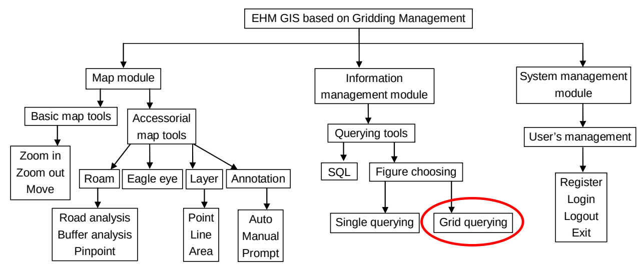


Figure 3. System structure design for the EHM GIS based on GM.

3. Results

As is apparent in the above description, a prototype system is developed. More than 100 environmental hazard source records, in which 13 are ranked top 100 in Shanghai, are included in it. The following is a demo scenario that shows this prototype system's information support function in the emergency response process after an EH sources leak. Figure 5 is the result of grid partitioning of the studied area. Figures 6 to 8 explain this system's interface and functions. Although the system runs in Chinese, here the key words are annotated in English to ensure the international readers' understanding of each figure.

3.1. Grid Partitioning of the Case Area

Located in the southwest area of Shanghai, the selected district covers an area of 370 km^2 with a population of 1.7 million. There are a number of heavily polluting industries and factories in this area.

According to the situation of the area and the principle of the grid partitioning, the studied area is divided into 25 grids (see Figure 5). These grids are further divided into 352 sub-grids according to the demand of EH management.

3.2. Hypothetical Scenario

The hypothetical scenario takes place in a chemical factory named "A". Because of an operation failure of a worker, a feeding pipe valve for a reaction tank breaks, and liquid pours out due to the high pressure. A significant amount of chemical raw materials leak out and create a dangerous work environment.

3.3. Application of the System

When the supervisor in this grid knows of the accident, he informs the command and supervision center immediately. The operator in the center finishes the following operations by using the EHM system:

1) Pinpoint the situation on the map. The operator runs the system, zooms to a suitable view, and pinpoints the grid acci-

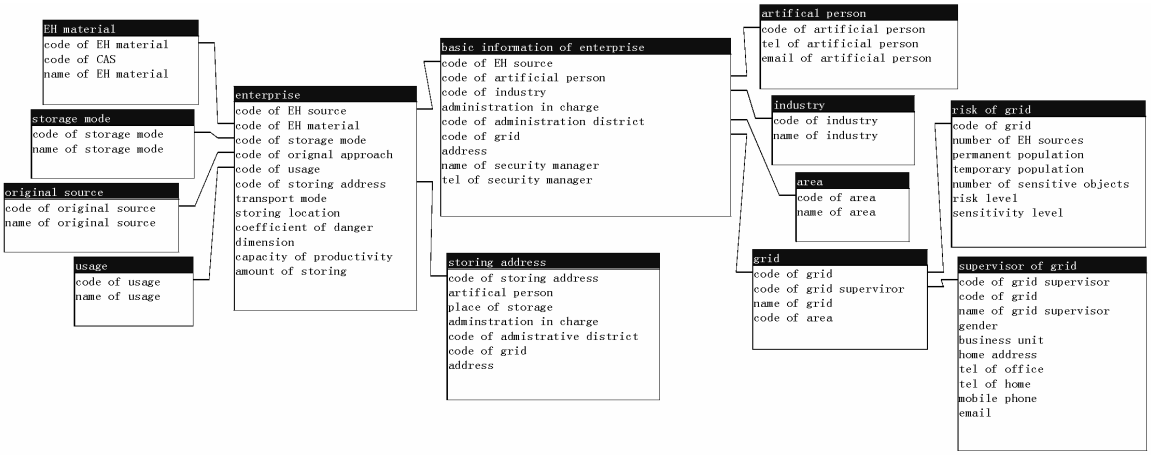


Figure 4. Relationships between grid information tables and other information tables in the developed EH database.

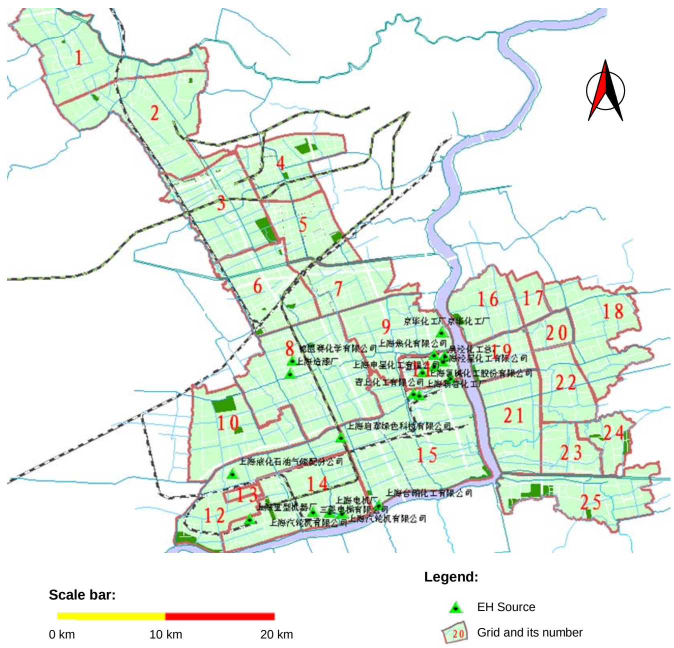


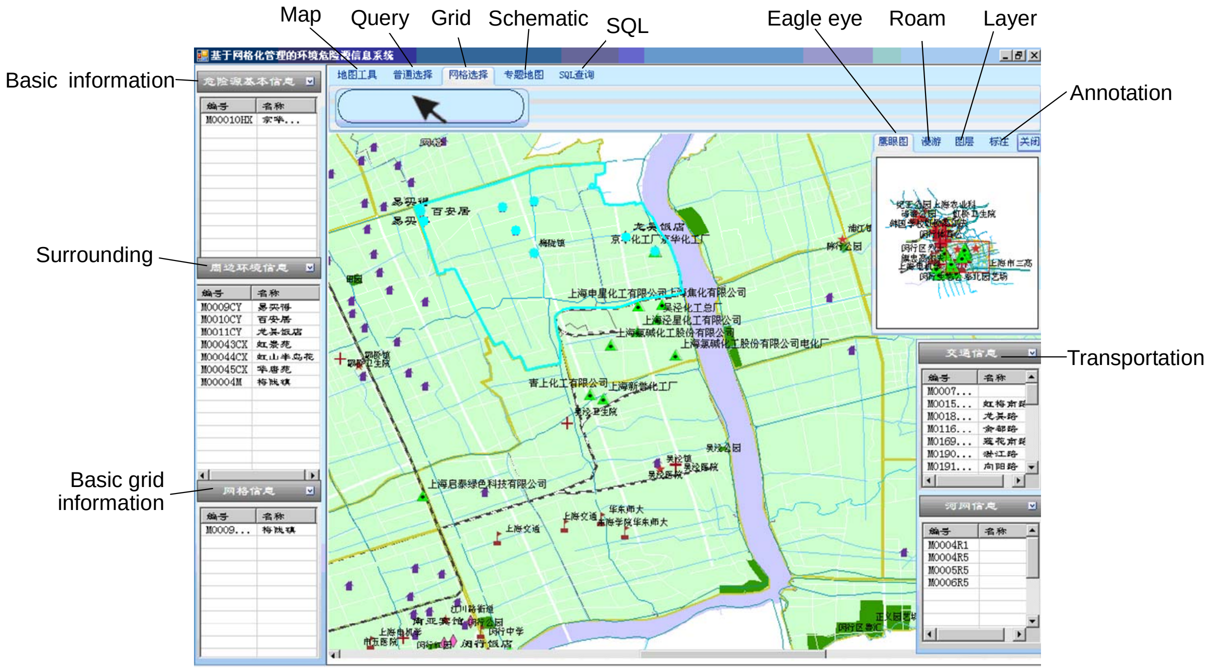
Figure 5. Schematic map of grid partitioning of the studied area.

dent using the grid-choosing tool. In this hypothetical case, the EH source name is A, the No. is M00010HX and the grid No. is M0009GRID. When the grid is chosen, the grid and the one EH source, seven sensitive protection objects, main roads, rivers, and other information are listed in the five tables on the two sides of the window (shown in Figure 6).

2) Query the basic enterprise information. The related enterprise table includes name, location, district, principal of security, charging department, artificial person's connecting information, etc. Users can contact the factory manager and the administration in charge by using this information.

3) Hazardous chemicals information querying. In order to understand the damage of the accident, we need to query the EH source's risk information and hazardous chemicals' information. The EH source's risk information table includes the chemical's name, position, deposited mode, reserves, and purpose. At the same time, we know that A's main chemical raw material is 1,2-dimethylbenzene according to the above query. An Instruction System that contains detailed information of the hazardous material is also included in this system. The items of detailed information include: the material's basic information, characteristics, description, stability, toxic and ecological information, operation and processes, control and prevention, storage and disposal, first aid method, transportation, and emergency process method. The hazard material information is shown in Figure 7.

4) Surroundings querying. The EH source risk information table provides decision support information for emergency processes in the field. However, sometimes the extent of the accident's impact can pass through the border of the factory and affect the people and objects outside that should be protected. It



Note: when the grid is chosen, all related information in the grid can be shown.
Figure 6. Sketch map of the grid which can show all related information.

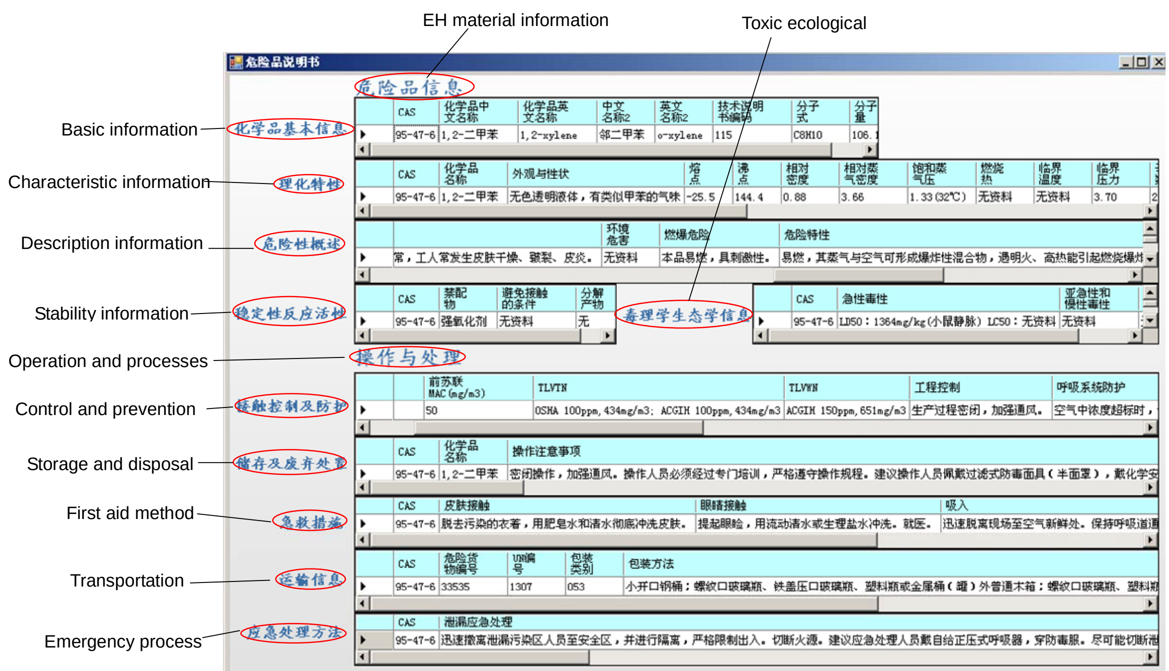


Figure 7. The Instruction System containing detailed information of hazardous material (e.g. 1, 2-dimenthylbenzene).

is necessary to protect the people, hospitals, marketplaces, and rivers, etc. that are outside the boundary. This system includes surroundings information within the grid so that it is convenient to do surroundings querying. By querying, it is apparent that there are in total seven sensitive protection objects in the grid in which the chemical factory is located, and the population in the grid is about 120,000. This information can help the decision maker to consider the level of precaution and the evacuation procedure. The results of the grid information querying, including basic enterprise information, EH source risk information, surroundings information, is shown in Figure 8.

Based on all of the information above, the command and supervision center gives commands to related departments to assist and handle the situation. After receiving feedback from

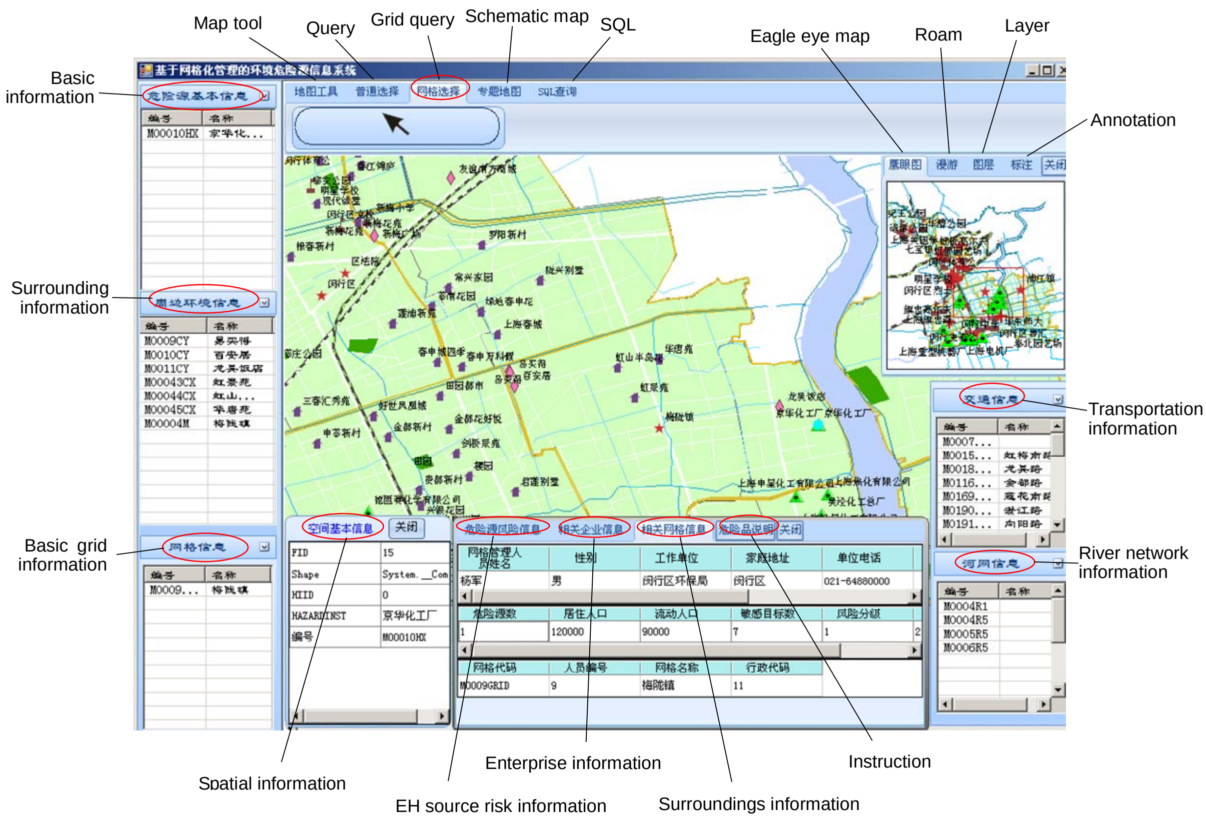


Figure 8. Demonstration of grid information querying (including EH source risk information, enterprise information, surrounding information, and instruction of the hazardous material).

the grid supervisor and others in the field, the center then decides whether to end the case or not.

4. Discussion

Through the description above, we argue that GM is aimed at problems that possibly exist in current GIS for EHM systems as stated in Introduction Section.

Firstly, separation of enterprises and government EHM can be avoided, because all grid supervisors receive commands from the command and supervision center, and this center orders and coordinates all related forces uniformly. EHM needs to integrate every kind of management resources including environmental protection departments, water authorities, fire departments, police departments, hospitals, enterprises, etc. GM is an effective method to integrate management resources.

Secondly, GM can effectively integrate and extract related information in the grid, such as EH sources, sensitive objects, and surrounding situations. Because surroundings information of the EH source is included in the grid, we can obtain it easily by using grid information querying. GM provides a new method of information organization. We can do statistical analysis and show surroundings information of the EH sources according to the grid. In this way, valuable support information for environmental emergency decisions can be provided, too.

Thirdly, aside from the public and the media, most information comes from the supervisors' active inspection, so it can be called active management. GM can also be used as precautionary management, since GM begins before the accident. One of the purposes of GM is to prevent the accident from occurring, thus it is in accordance with the EHM tenet. The system based on GM can initially query the risk from the unreasonable layout of the EH sources. As a result, the risk originating from the layout can be avoided if GM is used in urban planning, location selection of the factories, and regional environmental risk assessment.

Additionally, based on the principle of seamlessness during EHM grid partitioning, blind areas and grid overlapping can be eliminated. Besides advantages above, GM ensures effective supervision and assessment providing a new measure for supervision feedback and incentives, and this kind of communicating platform gives the technological support for both citizens and governments.

Considering all aspects of GM, it is a permanent management mechanism in terms of methodology. We believe if there is political will, it can be an important lasting tool. Currently, management reform and modernization is going in the direction of GM in China.

Compared with urban gridding management, several modifications of GM have been made in EHM. The grid scale is no longer limited to around 10,000 square meters. In downtown urban management, the number of components and events is enormous, so the area of each grid by one supervisor cannot be large. However, in EHM we can enlarge the scale because components and events related to EH are not abundant. Furthermore, Supervisors can use mobile transportation tools to perform inspections. In the case above, we established a two-level grid system: grid and sub-grid. The numbers of them are 25 and 352 respectively.

In Urban Gridding Management, command center and supervision center are individual of each other, but here they are combined into a single entity for higher efficiency of EHM. Special mobile communication tools are used in Urban Gridding Management, but it is not necessary in EHM where common mobile communication tools are enough. Furthermore, in Urban Gridding Management, all supervisors are hired by government, although they can be from different government departments. But in EHM, supervisors can be from both corporate entities and the government, for the reason that more professional knowledge is required in EHM, and most corporate entities should have hired people to do this kind of job which is supervised by government to ensure environmental security of both factories themselves and the public.

5. Summary and Conclusions

This paper discusses the incorporation of GM methodology into the GIS development for EHM. Through the demonstration of a prototype system in Shanghai, we know that GM in EHM is feasible. The main steps of developing the GIS for EHM based on GM include grid partitioning, component and event coding, system designing, and developing. Basic elements of the system include grid supervisors, communication tools, a command and supervision center, a workflow, and an assessment system.

In order to use GM in EHM, the following modifications are helpful when compared with urban management: 1) the grid scale needs to be adjusted in order to be suitable for EHM; 2) command center and supervision center can be combined into one; 3) common mobile communication tools can be used; and 4) supervisors can be from both corporate entities and government.

With the GM method, the administrative work of EHM and GIS can be integrated, and information of EH sources and surroundings can also be integrated and extracted effectively. Compared with traditional EHM, GM is an active management method. It can reduce long distance management, crossover of functions, ambiguity of responsibilities, and workers' disputes. Moreover, it can eliminate blind areas and overlapping of management. EHM is transformed from a broad to a precise method by using GM, which improves the applicability of EHM. GM can be applied to the prevention and disposal of environmental emergency accidents, and can provide valuable support information for the decision maker.

However, deficiencies still exist in GM in EHM. Primarily, detailed EH information of enterprises is required to be integrated into such an open system, and usually enterprises are reluctant to do so. Therefore political measures are needed to spread this technology in the EHM field. Currently, GM application in EHM is in its experimental period, and the validity of this method needs to be continually verified in practice. Specific situations in different regions should also be considered when using this method.

Acknowledgments. This work was supported by a grant from the National High-Tech Research and Development (863) Programme of China (No. 2007AA06A401), and the Foundation of Key Laboratory of Yangtze River Water Environment, Ministry of Education (Tongji University), China, (No. YRWEY 1010 and No. YRWEF08005).

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