Spatial Data Management and Analysis System for Flood Hazard Mitigation of Poyang Lake Watershed, China

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Abstract

Flood hazard Prevention and mitigation of Poyang Lake watershed is an emergent environmental problem because Poyang Lake watershed is one of the regions exposed most frequently to flood hazard in China. In order to meet the need of disaster reduction decision making of Poyang Lake watershed, Spatial Data Management and Analysis System of China Land Territory (not include islands in South Sea of China)for Flood Hazard Mitigation(short for SMAS-FHM) has been established making use of the methodology of spatial database technology based on Oracle9i&ArcSDE9. This paper, probes into designing and implementation of multi-resources and scales massive spatial database management system about flood hazard, and integral management between hazard thematic data and spatial data. Especially, a bitmap index adapted to primal TM/ETM+ image has been put forwards and realized to accelerate data search in the spatial database, which is turned out to be efficient and effective. Based on carrying out experiment, this paper has been also researched the key issues, including massive spatial data and flood hazard thematic data organization and storage, spatial index creating, spatial data searching, and flood hazard analysis models realizing and their effective organizing, such as flooding areas computing, 3-dimension flooding simulation, refuge location selection, refugee evacuation path analysis and relief material dispensing. Finally, important applications of SMAS-FHM in flood hazard mitigation have been also discussed for Poyang Lake watershed.

Keywords

Poyang Lake watershed, flood hazard, massive spatial database, bitmap index, decision making system, Geographic Information System (GIS)

I. INTRODUCTION

China is one of the countries in the world for the most various, frequent and serious loses in natural hazards, in which flood hazard is the most serious one. China is almost subjected to serious flood disaster hazard every year(Zhang, et al., 2002). Flood hazards have been led to massive loses not only in past years, but also at present and in future. Especially, frequency of flooding is gradually increased with the further deterioration of ecological environment. And it's a tendency that flood loses is increasingly more serious for the persistent and fast development of national economics, expanding of producing scale and deposition of social wealth. Thus, flood hazard mitigation is a systemic engineering, in which every course is related with the geographic features in geo-space, such as tempo-spatial distribution of flooding and path selected for refugee evacuation. Poyang Lake, which is the largest freshwater lake in China, located in the middle and lower reaches of Yangtze River. It's a seasonal lake in the lower topography (Wang, 2006).With applying the technology of geographic information system(GIS), we can obtain timely and precise information for flood hazard mitigation through monitoring flood disaster, computing flooding areas, evaluation of flood hazard. However, spatial data management and analysis is the kernel of GIS, which is guaranteed to predict and warn hazard, and to make decision. SMAS-FHM, which can integral manage and analyze spatial basic data, remote sensing data and flood hazard thematic data ,using Geodatabase object-relation model based on mature database software Oracle9 and spatial data engine ArcSDE9, tries to establish to accord with flood hazard mitigation management and decision making in China.

SMAS-FHM has confronted several key problems. Firstly, It's difficult to manage massive spatial data in SMAS-FHM, including DLG, DEM and DOM covered the whole regions of Poyang Lake watershed, in which, there are hundreds of TM/ETM+ images, including panchromatic, multi-spectral and infrared bands with the total of above 50GB.There are also hundreds of DLGs with the scale of 1 to 0.25million, including drainage and transportation network, boundary, residential areas, topography, land cover and so on. Besides, there are also MODIS images, IKONOS images, DLGs with the scale of 1 to 1 million DEMs , 1 to 4 million and 1 to 1 million ,and flood hazard thematic data, such as land use status, social economic static data ,preventing and controlling flood engineering distributing thematic map, drainage distribution map and so on. All the data are amount to hundreds of GBs. Multi-resolutions and resources data may be taken into consideration according to the request of different levels of hazard management, and carrying out the China environment and hazard small satellite group project. What's more, storage and management of TBs level of massive spatial data, and the

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responding speed of the database for hazard is also to be considered. It's incredible to manage so massive data using file storage system; therefore, spatial database is imperative.

Secondly, multi-resources data integration and management is another challenge. Source data in SMAS-FHM come widely, which is not characteristic of only multi- scales, temporal and resources, but also many forms such as vector, raster and image. However, efficient and uniform management for such complex data affect the integrated application capacity directly. We must consider the integration between spatial data and thematic data for flood hazard mitigation as well as multi-resources spatial data integration.

Realization and integration of application models for hazard mitigation is the third problem. Establishing this system is aimed to assist decision maker to make hazard mitigation decision that is usually based on certain models, such as flood hazard loses evaluation model and emergent responding to flood hazard model. The author tries to solve the problem in establishing SMAS-FHM.

II. MAIN FRAMEWORK OF SMAS-FHM

SMAS-FHM is built on 3 tiers Client/Server mode. Client runs the application program, while server database stores data. In order to reduce network runoff, ArcSDE is taken as a middleware configured at server, so as to share and interoperate avoiding the discrepancy for different operation systems and database systems. Application management system, developed with Microsoft Visual Basic and ESRI ArcObjects (ESRI, 2002) based on COM components, can manage spatial database through Internet/Intranet in server. The Server deals with the request from clients, executes spatial searching and data extracting, stores the data met the conditions into the server buffer, and then returns the results to the client applications(ESRI, 1999–2004). SMAS-FHM is composed of basic information subsystem, flood hazard management information subsystem, flood hazard analysis subsystem, hazard emergent decision responding subsystem(Figure1).

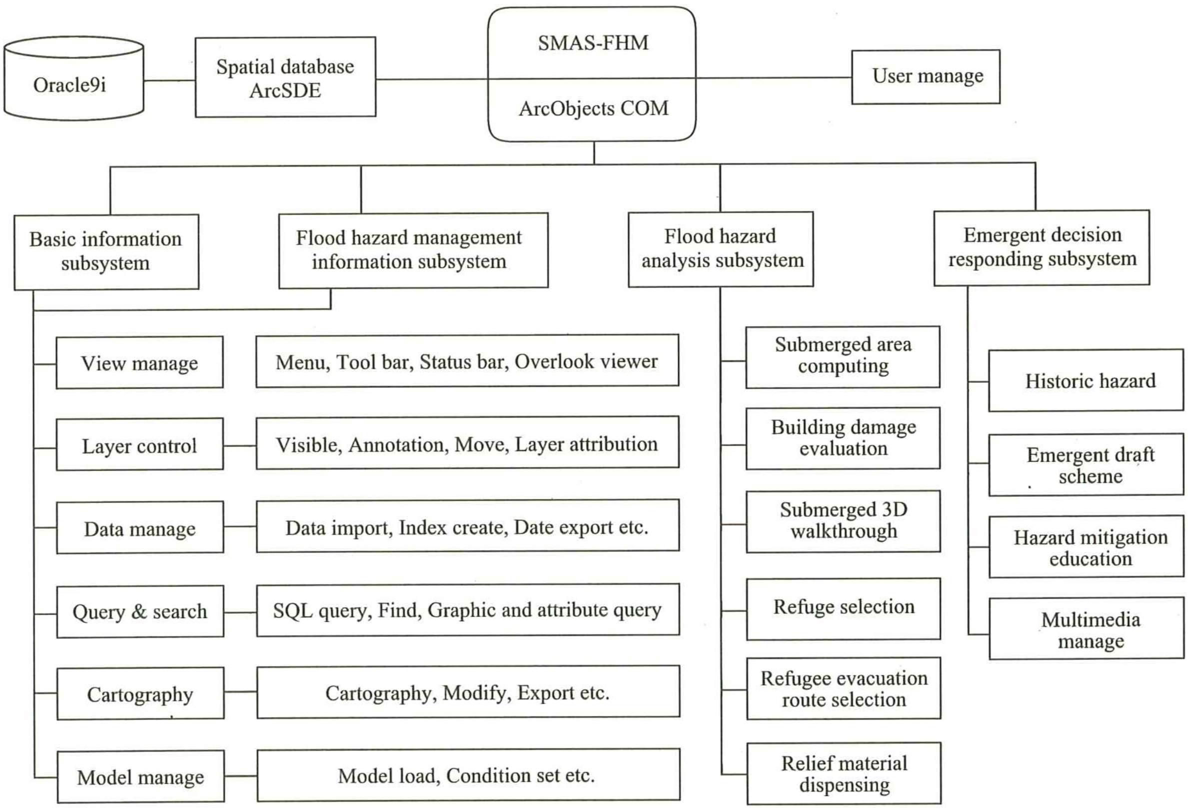

Figure 1. Structure of SMAS-FHM

A. Basic information subsystem and flood hazard management information subsystem

File and document management module supports map exporting, document printing, initial file configure and data loading from file or database. Data management module provides database connection, spatial data importing and exporting, spatial bitmap index creating, data searching. Viewer management module manages map browsing, overlook viewer, toolbar, and status bar. Data query module supports click querying, attribute table fuzzy or accurate querying, SQL querying, and spatial location querying. The querying results can be saved as text or web page (HTML), and exported for printing. Spatial measurement such as length, area and perimeter is utilized in the system. Overlapping and buffering analysis are also supplied in spatial analysis module. The cartography module can modify and print thematic map, such as flooding area distribution map, and refugee evacuation path map. The hazard document management module manages flood hazard reports; historical records emergent draft schemes and media reports.

B. Flood hazard analysis subsystem

Flood hazard analysis subsystem is mainly to solve flood hazard prevention problems, such as flooding submergence analysis, refugee evacuation path analysis, flooding areas computing ,and relief materials dispensing(Xu, et al.,2005; Feng, et al., 2004). Scientific and accurate forecast and evaluation flood hazard loses is an important mission in flood hazard prevention and mitigation, which is in favor of constituting draft scheme for hazard rescuing .To compute flooding areas precisely and quickly through spatial analysis of GIS is the premise of hazard loses evaluation and relief materials dispensing. This subsystem supports functions such as building flood submerged area analysis module, damage evaluation module, 3-dimension flooding demonstration module, refuge location selection module, refugee evacuation path analysis module, and relief materials dispensing module.

(i) Flood submerged area computing

In order to compute flood submerged area, we must know at least 2 parameters: DEM data and water level at that time in flooding area. This model is only to compute the area below the given water level according to the given DEM data taking static water as the premise. If precipitation and flood submergence are taken into consideration roundly, it's helpful to quickly make decision for flood prevention and mitigation. Firstly, submerged area is calculated and highlighted based on the input DEM data and water level, then input vector data for overlapping analysis, finally, symbolize the submerged area and output submergence thematic map.

We want to calculate submerged area, denoted by S_{SA}. Supposing 2-dimension data structure $h(i, j)$ denotes flood water level, $g(i, j)$ denotes topography elevation, all the connected area which submits to inequation $h(i, j)>g(i, j)$, makes up of the possible submerged area. We use '1' to denote submerged area, and '0' to denote unsubmerged area, then possible submerged area S_{PSA} shows all the grid area where topography elevation is lower than flood water level(Equation 1).

$$S_{PSA}=\begin{cases}0, h(i,j)<g(i,j)\\1, h(i,j)\geqslant g(i,j)\end{cases} \qquad (1)$$

S_{PSA} contains area where the actual elevation is lower than flood water level, but it is surrounded by higher parcels so as to be unsubmerged depression area called isolated island, which is denoted by S_H.

$$S_{SA}=S_{PSA}-S_H \qquad (2)$$

We can take methodology of plane connecting graph searching. Given an initial status $S_{SA}=S_R$, in which normal water level can be regarded as a special status of flooding area, the submerged area gradually expands until all the possible submerged areas are connected.

(ii) 3-dimension flooding walkthrough

This system can take DEM data as digital terrain surface model and high resolution remote sensing image as texture, overlapping vector feature and annotation to produce 3-dimension landscape visualization(Wu, 2006),so that it's intuitionistic to delineate flooding locale. Besides, users can also set topography exaggeration factor in the scene, and set different color for different evaluations, and query attributes. This module supplies two ways to fly the scene; one is to import an existed line feature file, while the other is to click the scene to form a polyline timely for walkthrough path (Figure 2). It can be applied in hazard mitigation propaganda and education, hazard prevention and monitoring, relief materials dispensing and decision making. It's also the foundation of path selection of refugee evacuation.

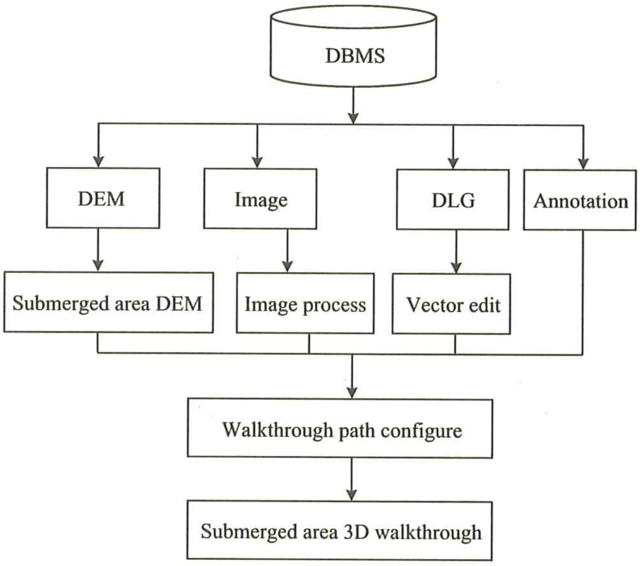

Figure 2. Flow chart of submerged area 3D walkthrough

(iii) Refuge location selection

In order to reduce flood hazard loses, to rescue refugee in time, and to supply refugee with basic survival condition and public services, selecting right resident location temporary to accommodate refugee is imperative. Therefore, the model deals with factors related to locating refugee temporary such as evaluation, topography, transportation capability and distance away from the flood and so on, so as to select right resident location for refugee using the spatial analysis in GIS, which can assist decision making.

Contraposing the specific object for refugee rescuing location selection, this model fully considers different factors and weights respectively, and then analyzes overlapping to obtain the reference for location selection using optimal location analysis method in GIS. The flow chart for the model are as follows (Figure 3).

C. Flood hazard emergent decision responding subsystem

Flood prevention emergent decision is an emergent response

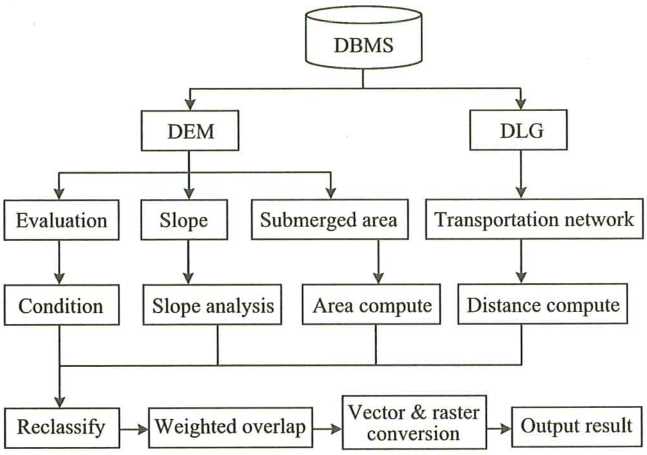

Figure 3. Flow chart of refuge location selection

to flood, which can enhance integrated command capability to cope with great hazard, and increase emergent rescuing speed. The aim is to minimize flood hazard loses to the least. The model uses flood hazard analysis subsystem fully considering social rescuing power such as police force, social economic power and historical hazard, to supply decision support for decision makers. Flood hazard emergent decision responding subsystem can produce refugee evacuation draft schemes, polices dispatching draft scheme, and public security education draft scheme. Basic functions to draft schemes such as modify, query, delete, are provided.

III. SYSTEM IMPLEMENTATION AND ITS KEY TECHNOLOGIES

A. Logical structure of database

In database, DLGs, DEMs and remote sensing images are stored by uniform geographic coordinate system avoiding span several geographic bandages. The flood hazard mitigation spatial database in SMAS-FHM has been divided into 13 tablespaces with 4 parts logically (Figure 4), including remote sensing image sub-database, DEM sub-database, DLG sub-database, and flood hazard mitigation thematic sub-database.

B. Spatial Index and data searching

Building spatial index of massive data is a key technological issue in spatial database(Gong, 2001; Liu, 1998). Spatial index usually organizes and stores data structure according to the spatial objects distribution characteristics(Gong, 2004).The aim of establishing spatial index mechanism is to save data access path and pointer, so it's convenient to locate spatial objects and operate spatial data. Spatial index is an efficient method to deal with spatial query.

In SMAS-FHM, ArcSDE builds grid spatial index to vector (Feature Class), listing all the object IDs of features spanning this index unit. Therefore, users can quickly query spatial features and search through spatial index. To raster dataset, ArcSDE stores data with Long Raw or BLOB data types to enhance continuous seamless mosaic function. Raster data are stored in business table, which is composed of bands metadata table, bands auxiliary information table and pixels table, etc.. Image pyramid has been built based on image partition and compress technologies to optimize speed of image display.

Especially, in order to avoid redundant data names comparing in database, an image index layer that is a feature class(Table 1) in fact, has been created to the primal TM/ETM+ image searching when data have been imported to the spatial database. Then we can build bitmap index to the fields which are with low cardinality(Wan, et al., 2006), otherwise, there will be large redundancy bits. And it can be solved by compressed encoding of the bitmap(Jinguk, et al., 2004; Zhou, et al., 2004). If field *F*, whose cardinality is m, is the index row of table *T*

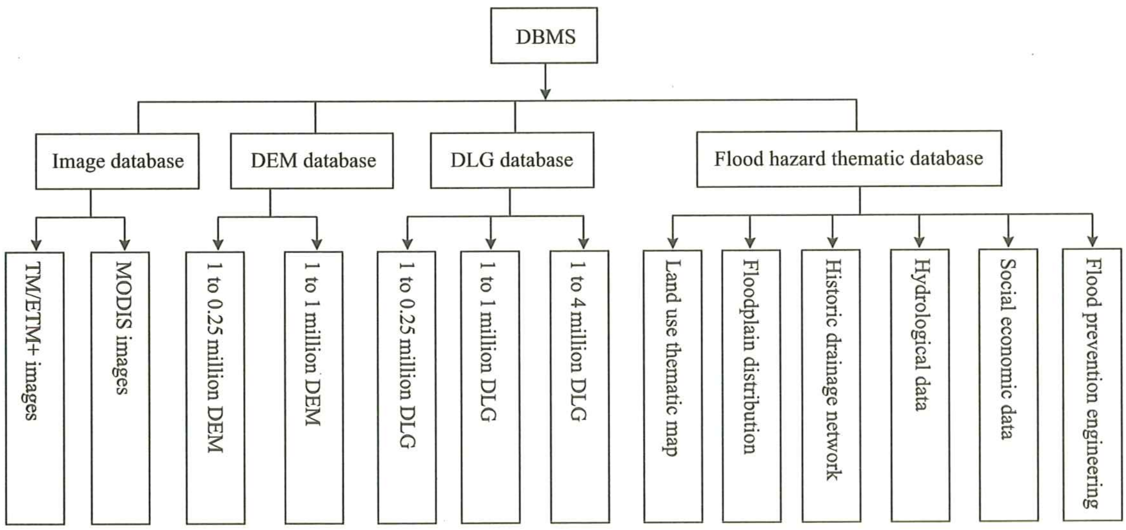

Figure 4. Logical structure of the database

Table 1. Part records in feature class of the index layer

OID	Shape	Row	Column	Year	Month	Name_RST
0	Polygon	121	41	2000	09	p121r41_7x000926
1	Polygon	122	40	2000	12	p122r40_7x001210
2	Polygon	120	41	1999	11	p120r41_7x991115
3	Polygon	120	40	1998	11	p120r40_7x981125
4	Polygon	122	42	1999	10	p122r42_7x991023
5	Polygon	121	42	2001	09	p121r42_7x010916
6	Polygon	122	41	2000	12	p122r41_7x001226
7	Polygon	120	42	1998	12	p120r42_7x981215
8	Polygon	121	40	1998	10	p121r40_7x981023

containing n records, the bitmap index of field F is a set with m vectors with the length of n. Each vector is corresponding with a possible value in field F. With the bit vector, the value in k^{th} bit denotes by '1', if the value in field F of the k^{th} record is corresponding with the index value, otherwise, it denotes by '0'. The field of this index layer is composed of OID, shape, column and row of image, year and month, and the name of the Raster Catalog (a data storage type by ESRI). Bitmap index of Field column and row may be built as Table 2 and 3 shows, so that complex data searching operation can be transform to logical AND and OR operation. Bitmap index of other fields can be also established with the same method. System may create a grid at the corresponding location in the index layer if the image exists, and store the image full name that can be formed through combination of fields in index layer. The image data can be obtained through the full name in database mapping into the physical address of this image, and then added to the display devise. The new index method quickens the speed of image searching and increases the effect of database. Bitmap index also provides data maintenance mechanism to insert, delete and update data in spatial database.

Table 2. Bitmap index of field row

Value	Bit Vector
120	001100010
121	100001001
122	010010100

Table 3. Bitmap index of field column

Value	Bit Vector
40	010100001
41	101000100
42	000011010

The spatial data searching interface has been developed in SMAS-FHM. District name, longitude and latitude, and tracking polygon can be input as the searching conditions. Then, searching results are returned and listed to the Listbox Control. Specially, being kept integrality of TM/ETM+ image data, they are stored directly without any conversion operates. Thus, they can be used for quantitative analysis, but they are not appropriate for displaying because of white and black visualization for single bands without fusion. In order to improve visual effects, three bands have been selected and fused, then delineated from red, green and blue channels, when displaying primal TM/ETM+ image data to a context devise. The NoData pixels are transparent to display. All these procedures are realized automatically by this system.

C. Integration of multi-resources and scales spatial data

Multi- scales spatial database can be established from multi-scales primal data existed in database or extracted multi-scales data from existed data(Gong, 2004). Because the problem of cartography generalization automatically is not solved completely, it's difficult to extract any scales data from a certain scale spatial database. The spatial database in SMAS-FHM takes the methodology of primal data scales controlling and levels attempering. Spatial data are set a displaying scale range, in which data are visible. There are 1 to 4 million, 1 to 1 million and 1to 0.25 million for a total of three levels of DLGs. With zooming in the map, 1 to 4 million topography information gradually reduces. In order to obtain detail information, larger scale 1 to 1 million data will be displayed instead of 1 to 4 million data. As the same, 1 to 0.25 million data will be presented for more detail and richer information with keeping zooming in to meet users' need.

Multi-resources data for vector, raster and DEM are stored in different sub-database with the same spatial reference. 250m resolution SPOT image and 90m TM/ETM+ image after resampled are used for background according to the different scales of topographic data. Besides, overlapping 1 to 1 million or 1 to 0.25 million DEM will give you actual real feelings.

D. Integration of flood hazard data and spatial data

Flood hazard data is mainly thematic attribute data. Because every fatal natural hazard takes place at a certain location called spatial characteristic, a corresponding relationship(Richard, et al., 1996) between spatial feature and location of the hazard will be built if flood hazard thematic data are integrated into spatial data. The SMAS-FHM integrates hazard data as a thematic layer through extending spatial data. A new field, which is used to save thematic data, will be added to original data. Therefore, when attribute and geometry querying, it's convenient a query attributing to spatial location, vice versa. This system manages multimedia such as videos and pictures with file management methodology, while the paths are saved with extended field in database. Thus, the relationship between flood hazard data and spatial data is built.

E. Models management

Model is a kind of simulation on process of decision making. Models of spatial decision making are stored and presented in three forms, namely, data, logistics, and programs(Wang, et al., 1999).Most models are structured models which are suitable to be stored as program. That is, model is a subprogram that has its own input and output. Figure 5 illustrates the

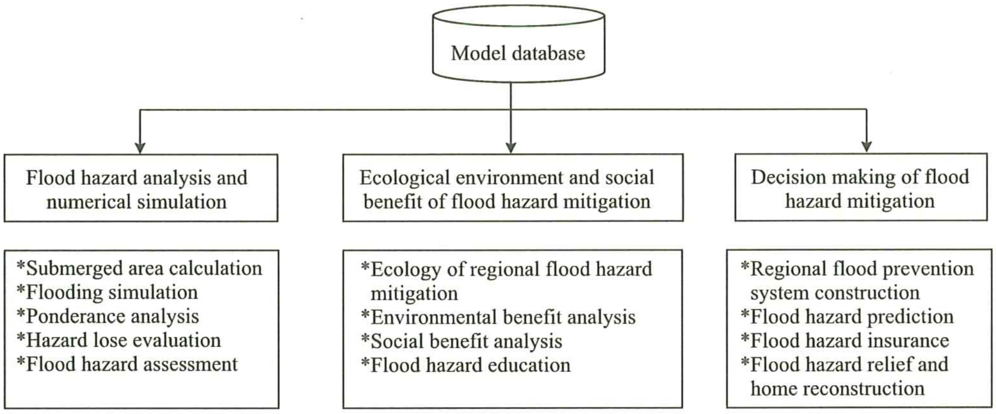

Figure 5. Components of model database

components of the model database, which is divided by their functions in SMAS-FHM.

Integration of models and system can be realized by source code, function, executable program, ActiveX, and model base and so on. The method of model base is readable, extendable and effective, however, there isn't completely model operation theory system, especially in generation models automatically or semi-automatically. Methodologies of source code and program have been taken in this system. Model with more inputs and outputs integrates by source code, while integrates by program with less human and computer interaction. For example, when the model of computing flood submerged area, needs DEM and water level two parameters, it is compiled into dynamic link library after having been debugged. Parameters have been input at different steps, and then referred to the program to integrate the models. Model database implements management operation to all models mentioned (Wei, et al., 1997), which are as follows: a)modeling dynamically; b)definition, establishment, storage, query and modify of model dictionary; c)interaction mechanism between models and data.

F. System implementation

SMAS-FHM reads XML configure file to initialize interface after user login validating. Initial workspace, initial displaying layers, and annotation field of layers can be set before the program running. System enters the main interface(Figure 6) after successfully configure. Main interface is composed of menu, tool bar, layer controller, overlook viewer, status bar and map viewer, which can be customized as individuals' favorite.

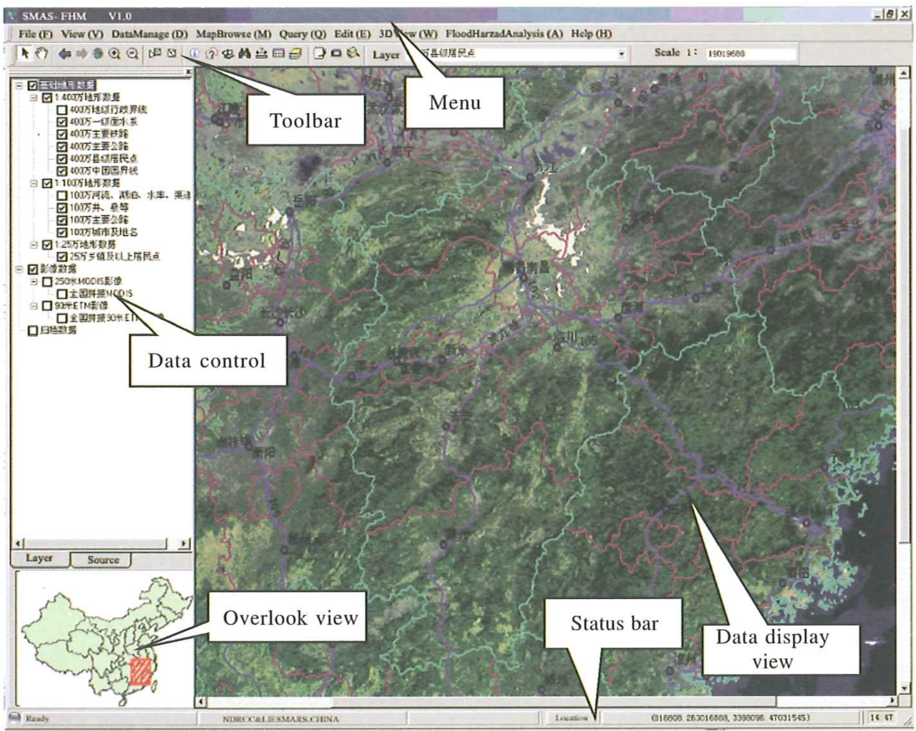

Figure 6. Main interface of SMAS-FHM

IV. APPLICATION OF THE SYSTEM

The purpose of spatial database management system designing and establishment is application(Chen, et al., 2000), and so is this system. SMAS-FHM doesn't only supports querying and searching directly and also supply more spatial analysis and statistics results based on spatial database which organizes massive spatial data and flood hazard thematic data, which is taken effect in hazard mitigation decision making.

A. Preventing and warning before hazard

Users can query historical data in database to get location where underwent great natural hazard, then predict the possible flood submerged area, flood intensity, flood risk level, and take corresponding possible measures to mitigate hazard , combining historical data and real-time data.

B. Evaluation and rescue in hazard

The SMAS-FHM provides interfaces for updating data, so that it can monitor the flooding quickly, compute flood submerged area, evaluate flood hazard loses and so on. Therefore, timely and accurate information of the flood hazard mitigation can be obtained. Users can acquire the hazard affected areas, flood hazard intensity, and flood hazard risk level via dynamically analyzing the historical data and real-time data. Finally, positive and efficient measures of rescuing can be taken, which will minimize flood hazard loses to the least. 3-dimension visualization will help with setting rescuing route, and supervise government to dispense relief material, which will reduce the number of death and injured.

Taking example for refugee evacuation route selection, when flooding, residents and possession evacuation is impacted by lots of complex and changeful factors, including levels of transportation network, population of refugee, maximum number accommodated by refuge, migration path, the damage of the road and so on. The grade of road plays an important role that whether evacuation can be successful. Combination of road level, passenger and the speed of vehicle is one of key factors for refugee evacuation route selection. The population must be taken into consideration because there is inevitable relationship between the population of refugee and the maximum number accommodated by refuge. Refugee evacuation route selection requires finding an optimal path between the flooding area and the refuge, which is the characteristic of time and space. The SMAS-FHM can compute the optimal refugee evacuation route by dynamically analyzing, based on the shortest time principle.

C. Management after hazard

The SMAS-FHM assists to pack up flood hazard history data, memorize hazard, analyze post-hazard loses and social economy, reconstruct, compile and manage of the post-hazard draft scheme, and educate in hazard prevention and defense.

V. CONCLUSION AND DISCUSSION

Flood disaster relief is a major research subject for realizing sustainable social development. Establishment of Spatial Data Management and Analysis System for Flood Hazard Mitigation of Poyang Lake Watershed(SMAS-FHM) is a systematic engineering, which is the foundation of flood hazard prevention and defense. The system has played a very important role in flood control and disaster mitigation in Jiangxi Province.

The system presented here includes GIS integrated with a database management system, which has incorporately stored multi-scale vector, raster, DEM data, integratively managed massive spatial data and flood hazard thematic data. Multi-sources and scales massive data seamless integration is a successful example here. Furthermore, this study pioneers to advance a bitmap index adapted to primal TM/ETM+ images, which are turned out to be effective and efficient. An experiment has been carried out based on ArcObjects. The framework of flood hazard mitigation system has been advanced, which technically supports hazard prevention before flood, rescuing in flood, and management and evaluation after flood. Models of them have been efficiently implemented and orderly organized in the system. Finally, important applications of SMAS-FHM in flood hazard mitigation have been also discussed for Poyang Lake watershed.

However, there remain a high degree of uncertainty in spatial and temporal modeling for flood hazard despite highly developed computer tools. This is mainly due to: 1) uncertainties in complex flood occurrence; 2) insufficient geotechnical data on regional scales and high resolution data; 3) difficult to obtain timely data. All these factors will affect the efficiency of flood hazard modeling, assessment, and management.

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