MINE ENVIRONMENTAL GIS: FRAMEWORK, KEY TECHNIQUES AND CASE STUDY

ID 048

Hairong ZHANG, Peijun DU, Fengjie GAO

China University of Mining and Technology
School of Environmental Science and Spatial Informatics
Xuzhou, Jiangsu, CHINA
cumt1234@163.com

ABSTRACT

The large-scale coal mining has caused serious environmental pollution and ecological damage in the coal mining areas in China. The serious conditions are listed as below: the geological disasters such as landslide, dilapidation, mud-rock flow and so on aroused by mining subsidence; the side effects such as land occupying, side sloping, filtrating and raised dust brought by the waste rock and gangue heap; the ruin of the water cycle system when the groundwater is drained and the waste water is discharged; the air and noise pollution during the coal mining and the transporting processes. Based on the characteristics of acquisition and management of environmental information in China as well as the theory and technology of environmental informatics and GIS, the Mine Environmental GIS (MEGIS) was studied and developed, and some key techniques were investigated. The objective of MEGIS is to manage, inquire and analyze environmental data and provide users with decision support for environmental protection. In the MEGIS, both the Point Mode and the Region Mode of the Gaussian Air Diffusion Model are used to simulate air pollution, and the water quality model is used to simulate the water pollution in 1-dimensional and 2-dimensional. The spatial discrete concentration points are used to build up Triangulated Irregular Network (TIN) which creates a new *iso*line or *iso*surface for environmental analysis in mining areas. Mining subsidence simulation and prediction model was used to analyze ground surface subsidence caused by mining. Using the proposed MEGIS it is much easier to update, manage and analyze environmental data, further to support environmental management decision-making.

Key words: Mining area; Environmental impacts; Mine Environmental GIS (MEGIS); Environmental Information Science (EIS).

INTRODUCTION

As a novel cross-disciplinary subject, Environmental Information Science (or Environmental Informatics) is developing rapidly along with the environmental informationization and the application of environmental modeling, GIS, environmental

Remote Sensing and the other information technology in environmental field. Once a single engineering direction— "environmental informationization" is now becoming a new discipline with cross theory and integrated technology [1-3]. In the international society, more and more research work about EIS has been done. In 2005, EIS was granted as one of the future research priorities by USGS [4]. In China, although achievements in theory research, technology development and application of EIS have grown tremendously, over all speaking, the research itself is still lack of systematicness, integrity, and comprehensiveness.

Due to the complexity of environment phenomena and processes, the high requirements of environmental computation and the rapid development of information technology, both government policymakers and mining industrial enterprises are now trying to connect environmental issues with the information and knowledge of society, economy and ecology. The Environment Information Science integrates a series of methods based on information technology, various environmental monitoring methods and mathematical models to achieve the goal of making environment protection plan with the capacity of risk prediction, public service and economic benefits. World-widely, the first Environmental Informatics Institute was set up in German Saarland State University for Applied Sciences (HTW) in 1987, and then the Environmental Informatics Institute Group continued to promote the research of EIS. The foundation of International Society for Environmental Information Sciences (ISEIS) attracted more attention of the international academic communities.

The environmental information management in China has been developed rapidly since the 1990's. Especially, as the construction of the governmental environmental management information system for central, provincial government to local government, the development of EIS was strongly promoted [5-6]. The environmental management information system includes traditional MIS-based Environmental Management Information System (EMIS) and GIS-based Environmental Geographic Information System (EGIS). The early researches are mainly concentrated on the EMIS. Along with ever grown applications of GIS in environmental field, the EGIS has become the first selection of environmental informationization [7-9].

The functions of the present environmental management information system used by province or local government departments include environmental data statistics, query and environmental information issue platform by network. The application of the environmental management information system delivers a good result in such as environment management, pollutant control, environment protection, environment analysis and assessment, etc. However, there are many weaknesses in the environmental management information system, such as insufficient integration with those independent analysis models (air, water, pollution and so on), the deficient synthesis of the static expression (for example, the records or outputs are lack of dynamic continuity), the difficulty of data sharing since the lack of standards, the limited capacities for decision-making supporting, etc. Therefore, it is necessary in the future research to improve the ability of information analyzing and disposing and enhance the level of system integration and data sharing.

The environmental information management and analysis has always been an important research field for GIS application since its origin in 1960s. The integrated management of spatial location and attribute information of various environmental features, phenomenon and process in GIS meets the requirements of environmental modeling, spatial analysis, optimal deployment and decision-making supporting, which makes GIS applied widely in environmental management [7-9]. The application of GIS in environmental field is transforming from earlier information management and thematic map-making to the integration of GIS and environmental models[9-10], the multimedia environmental information system based on 3S integration technology[11], GIS-based simulation of pollutant diffusion[12-14] and decision-making supporting system, etc. The research fields of GIS application in environment have been switched from general human habitat environment [15], regional ecological environment [16] to air-pollution, traffic environment, water environment and soil-pollution, etc.

The large-scale coal mining has caused serious environmental pollution and ecological damage in the coal mining areas in China. The serious conditions are listed as below: the geological disasters such as landslide, dilapidation, mud-rock flow and so on aroused by mining subsidence; the side effects such as land occupying, side sloping, filtrating and raised dust brought by the waste rock and gangue heap; the ruin of the water cycle system when the groundwater is drained and the waste water is discharged; the air and noise pollution during the coal mining and the transporting processes. Additionally, there are many pollution enterprises live on the coal in the mining region such as power plants, chemical industry, etc. So the environment of mining area has obvious complexity with such characters of destroyed landscape, polluted environment and contaminated ecology [17]. The impact of industrial pollution and ecological damage brought by the coal mining will not only slow down the economic development level in the mining area, but also poses a serious threat to the national economy.

The environment protection and recovery of mining area is obtaining more and more attention in China. However, the environmental management technology is still quite behind the demand and there is not even an EMIS in the mining area. Lots of monitoring data were wasted during the environment management and decision-making process. So it is urgent to improve the skill set and performance of environmental information system in the mining area to urge the rational resource exploitation and environment protection.

Based on the theories and technology of EIS and GIS, the structure and functions of the Mine Environmental Geographic Information System are presented. The MEGIS is well deployed in the Yanzhou (in east China) mining area as the object of this research project.

THE CONSTRUCTION OF MEGIS

The functions and the framework

The objective of the construction of MEGIS is to deploy the GIS technology to the environmental information management system in mining area. MEGIS integrates

environment data, environmental analysis models and spatial position to support spatial environment analysis, decision-making process and visualization expression. With the general characters of GIS, extra features as pollution detection and protection in the mining area is also embedded in the MEGIS.
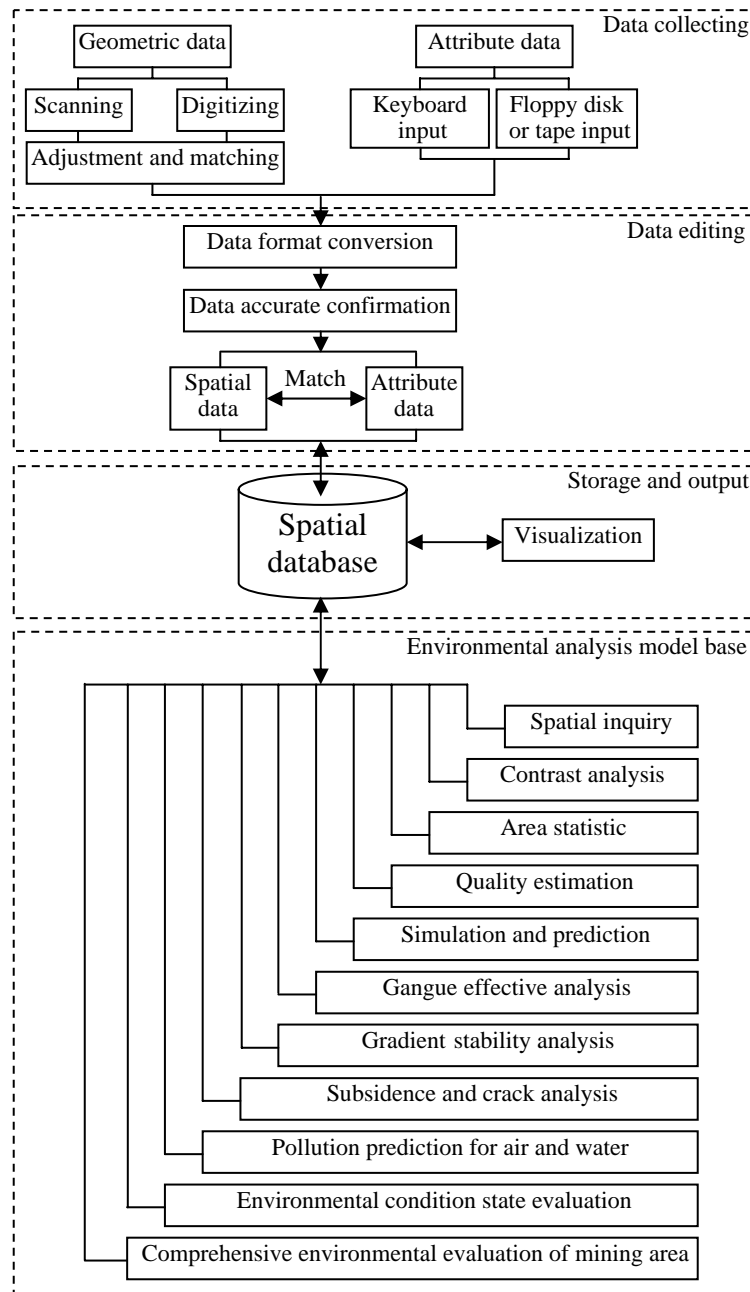
Figure 1.: The framework of the system.

The key functions of MEGIS are described as follow:

(1) The spatial data management module

The spatial data management functions as vehicle of data collecting, converting, data input and output that is to establish and maintain the spatial environment database. Two different types of data source involve in the mining area: paper maps/documents and electronic maps/documents (e.g. CAD maps and dynamic monitoring data). The former one refers to terrain maps, geological maps, mining maps, environmental monitoring maps that can be scanned and digitized; the latter one can be converted to required data format. After editing, all the data will be stored into spatial database.

(2) The environment analysis model library

The environment analysis model library integrates various environmental analysis models that are created for the mining area with GIS to quantitatively study the transference and transform rule of the pollutant, dimensional, forecast the change trend in the space-time of environmental condition, which makes the environment monitoring, analyzing, modeling and predicting conveniently and efficiently.

(3) The visualization module

The environment information and environmental analysis results can be visualized with various expression methods in GIS such as diagrams, charts, 2D or 3D graphs, especially thematic map generated by GIS is quite efficient to environmental visualization.

(4) The attribute data management

The system is equipped with the general capacities as MIS and organizes all types of data of the enterprises, including production data, management data, etc.

The development platform

In order to make full use of the advantages of GIS, the MEGIS is developed based on Component GIS. Currently, there are many GIS platforms and Com GIS products that can be used to develop GIS applications, such as MapGIS, GeoStar, SuperMap, GeoBeans, ArcGIS, GeoMedia, MapInfo, etc. The Supermap Objects was chosen to be the development platform because it provides sufficient GIS components as well as the SDX+ technology for database manipulation, its affordable price and it fulfills the function requirement of MEGIS. Concerning about the storage capacity, security issue, system maintenance, network communication and cost efficiency, we choose Microsoft SQL Server 2000 as the agent to manage all the spatial data and attribute data.

THE DESIGN AND CONSTRUCTION OF SPATIAL DATABASE

The data collection and entry

The coal mining area is a multi-purpose, intricate and dynamic system. Therefore, the environmental data involves massive geographical spatial data and attribute data, including natural earth surface data, underground excavation data and exploitation plan data. Moreover, the data system is also complicated. It consists of environmental monitoring

data, management reports, quality standards, economic data, population data, transportation data and the data from the geological exploration and mining engineering. Since the data comes from different data source and the format from different source is differentiated, thus this differentiation will result in precision deviation in the long time accumulation. To minimize this deviation and to deliver accurate result, it is necessary to assure the data quality while converting the format and inputting them into the system.

The database structure design

The database is one of the key issues upon the formatting of MEGIS. In MEGIS, the geometric data and attribute data are integrative managed in SDB. The spatial data can be abstracted into points, lines and regions according to different objects, including mining enterprises, residential areas, rivers, transportations, administrative boundaries, air pollution sits, subsidence pits, gangues, etc. In the SuperMap, data is organized with workspaces, data-sources, datasets and record-sets. Every layer is assigned to relevant dataset. The spatial data and the relative attributes data are stored in the same dataset. Thus the spatial data and attributes data are seamlessly integrated in the system. The data from the monitoring reports and statistics reports are stored in relation tables and linked with the corresponding spatial entity by keywords. The main contents of the spatial database are shown as Table 1.

Table 1.: The main contents of the SDB

Types	Items
Spatial database	administration map of the mining area, traffic map, settlement map, river map, monitoring points map, pollution source map, waste dump map, collapse pit map, vegetation map, notes map, thematic map of the spatial analysis, etc.
Attribute database	Environmental data, economic and society data, pollution standard, polices and regulations, basic industry data, pollution volume, monitoring data, pollution compensation and the facilities, etc.

THE ENVIRONMENTAL ANALYSIS MODEL LIBRARY

The relationship between GIS and environmental models

Being an important component of Environmental Information Science, the environmental analysis model is a powerful tool for environmental appraisement, analysis, prediction and decision-making process. Many environmental analysis models are built on mature achievements in EIS field research [9]. It has been demonstrated that some environmental analysis models are much more accurate and concise when they are used to describe environmental problems that bear obvious spatial characteristics, for example, the 2D and 3D water quality model, the air diffusion model and the pollutant migration model in the underground water. However, a common shortage occurs among above mentioned models

which is the incapability in spatial data operation, especially in the intuitional expression, due to lack of spatial analysis environment as GIS. For those who lack of specialty knowledge, it's tough to accept the system because spatial visualization expression is critical for the environmental analysis.

Compared with environmental analysis models, the GIS has the advantage of handling the expression job of the migration, diffusion, dynamic changes and reciprocal affection of the research objects in the spatial environment. Therefore, it can provide a series of spatial data manipulation criterion for the environment analysis models to improve the performance and accuracy of them. It's also found that, while dealing with complicated environment conditions or simulating intricate, dynamic environmental motion, current GIS in the industry has lack of processing power of prediction and other relative analysis capability.

Considering the advantage and disadvantage of both GIS and environmental analysis models, it's apparent to tell the complementary relationship of these two parties. While GIS provides spatial data manipulation power to the environmental analysis models, the environmental analysis models can help the GIS to avoid the obstacle of algorithm in return, thus the GIS could make full use of its abilities for spatial data management, analysis and visualization.

MEGIS is trying to build an innovative model based on the combination of GIS and the environmental analysis model. To integrate them together, the functionality of both parties would be highly improved and this will bring the Environmental Information Science into a brand-new stage.

The integration of GIS and environmental models

Since 1990s, more and more research has been pursued on the integration of GIS and environment models to resolve resource and environment issues such as meteorology, hydrology, water-resource, soil-erosion, desertization, environment monitoring and global changes, etc. Although certain progress has been achieved, the system and the implementation still need to be improved. Most research only takes GIS as the tool of input or output and the data was exchanged by data files between the GIS and environmental analysis model. The restriction lies in the relatively limited spatial data disposal ability and the confliction between the environment analysis models and the inherent function of GIS [18-19]. In MEGIS, the mathematical models are built in the GIS framework as the same as some researchers has done [20-23]. All the data and results are stored and managed in the spatial database.

The environment models in MEGIS

The problems in mining area mainly involve in the industrial pollution such as air pollution, water pollution and solid waste pollution aroused by coal exploitation and utilization and the ecological damage like gradient non-stabilization, crack of the surface, mining

subsidence, soil and water loss, and land erosion. The pollution possesses the characters of large pollution area, various pollution ingredient, serious pollution degree and awful pollution disposal, etc. So the functionality of analysis and forecast is the most important components of the system.
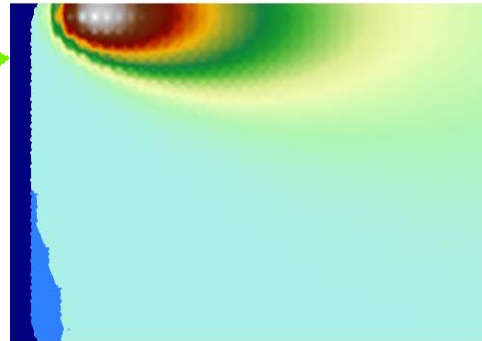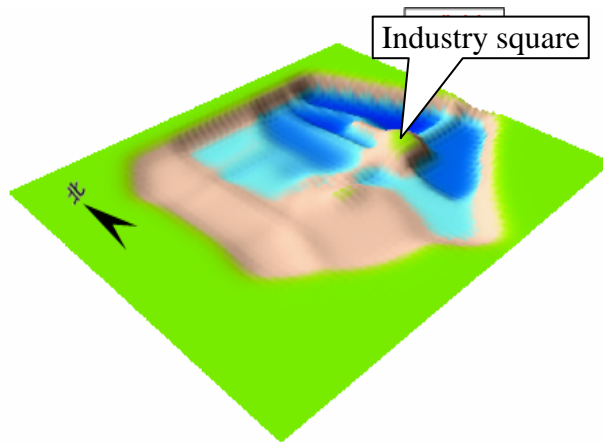
Industry square

Figure 2.: the subsidence simulation result   **Figure 3.** the diffusion simulation of SO$_2$

Table 2.: The environmental analysis models in the system.

Model type	Methods and parameters
The forecasting of the total volume of waste gas	Method: measured Parameters: dust, SO2, nitrogen oxides, hydrocarbons and co, etc.
The forecasting of the total volume of waste water	Method: measured Parameters: SS, sulfide, chemical oxygen demand, oil, phenol, fluoride, ammonia, mercury, cadmium, hexavalent chromium, lead, arsenic, cyanide, etc.
The profiteering of gas	Method: GUASS model Parameters: Source, the height of the chimney, vertical and horizontal diffusion coefficient, weather, the speed of wind, temperature, etc.
The profiteering of water	Method: One-dimensional, two-dimensional flow model proliferation Parameters: Source, vertical and horizontal diffusion coefficient, flow rate, water depth, time t, horizontal vertical distance x and y, etc.
The evaluating of environmental quality	Method: Grid statistics of Comprehensive Evaluation Parameters: Collapses, landslides, mud-rock flows, to the cracks in Waste, gas, soil erosion, air pollution, water pollution, soil contamination, etc.

The MEGIS integrated the mathematical environment models and the GIS to take full advantage of the environment models to analyze and forecast the environment condition, as well as make the best use of GIS to express the results in spatial dimensional. Considering

the peculiarity of pollution in mining area and the requirement of the environmental management, the total quantity forecasting models, pollutant diffusing models and tendency predicting models are integrated in MEGIS in the first stage, and more environmental models will be incorporated in the next stage (Tab.2). Fig.2 is the subsidence simulation result by the subsidence calculating model and Fig.3 is the diffusion simulation of SO_2 by the GAUSS model.

CONCLUSIONS

The Mine Environmental Geographic Information System is a novel cross-disciplinary research field. It is an important action for the enterprises to perform environment management with high-technology and an effective tool for the government to monitor and manage regional ecological environment. The purpose of MEGIS is to integrate spatial information and environmental attribute information in a visual background, and extend the thematic analysis capacities by integrating with environmental models. So the system can be used to monitor, simulate, analyze and forecast the environment effectively in mining areas with the help of powerful spatial data editing and processing capability provided by GIS. The MEGIS can provide comprehensive, timely, accurate and external information service and technology support for the environmental protection decision-making and planning. Our former studies have showed its liability, validity and superiorities and revealed its potential prospects. But it is a complex project to establish a powerful MEGIS and the research is still at the fledgling stage, so more profound research should be conducted in the near future, especially in such fields as environment modeling, environmental simulation, environmental data mining and intelligent information processing and decision-making support for environmental management based on GIS and MEGIS.

REFERENCES

[1] G. H. Huang and N. B. Chang. Perspectives of Environmental Informatics and Systems Analysis. Journal of Environmental Informatics, 2003, 1(1): 1-6.

[2] Zhang Aijun. Preliminary Study on Environment Information Science. Environmental Science Trends, 1998, (6): 25-27.

[3] Günther, O. Environmental information systems. Springer. 1998.

[4] USGS. Future Science Direction: Environmental Information Science Plan. http://www.usgs.gov/pubprod.

[5] Yan Haizhong, Yang Shuhua, Zhang Guangfei. The foundation of Environmental Information System. Science Publishing House, 2006.

[6] Xu Fuchun. The application and practice of Environment Information technology. Chemical Industry Publishing House, 2005.

[7] Li Xuxiang. The application of GIS in Environment Science and Engineering. Electronic Industry Publishing House, 2003.

[8] Wang Qiao, Zhang Hong, Li Xuwen. Environmental Geographical Information System. Science Publishing House, 2004.

[9] Li Bengang, Tao Shu. The application of GIS in Environment Models Research. Chinese Journal of Environmental Science, 1998, 19(2): 87-90.

[10] J.C.Hinton. GIS and Remote Sensing integration for environmental applications. *Int. J. of GIS*, 1996, 10(7): 877-890.

[11] Wang Hongwei, Cheng Shengtong. Technology of M-3S Integration and Its Application in Environmental Sciences. Chinese Journal of Environmental Sciences, 1998,19(2): 83-86.

[12] Zhao Biyun, He Bin, Zhu Faqing, etc. Study on Spatial Information System of Air Pollutant Dispersion, Research of Environmental Sciences, 1999,12(6):10-12.

[13] Hou Jixiong, Cheng Shengtong, Su Baolin, etc. Simulation of Vehicle Pollutants and Support of Geographic Information System. Urban Environment and Urban Ecology, 2000, 3(2):57-59.

[14] Li Bengang, Tao Shu, Lin Jianzhi. GIS based traffic noise prediction and planning system. Journal of Environmental Sciences, 2000, 20(1): 82-85.

[15] Wang Xiaodong, Mao Qizhi. Preliminary Study on Geographical Information Technology Applications in the Science of Human Settlements. Huazhong Architecture, 2000, 18(3): 20-22.

[16] Liu Haiyan. Application of GIS to Studies of Landscape Ecology. Journal of Geographical Sciences, 1995, 50(supplement).

[17] Du Peijun, Hu Zhaoling, Guo Dazhi. Study on Monitoring, Analysis, Adjustment and Treatment of Terrestrial Surface Evolution in Industrial and Mining Areas. Geography Publishing House. 2005.

[18] Bai Yanchen, Lixin, Feng Xuezhi. Spatial data analysis and models. Geographical Researches, 1999, 18(2): 185-190.

[19] Liu Xue, etc. Study on GIS-Based Modeling of Spatial Processes Simulation. Journal of Image and Graphics, 1999, 4(6):476-480.

[20] Chen Z, Huang G H, Chakma A. Integrated environmental risk assessment through a GIS-based decision-support system[A]. ESRI User Conference Proceedings. 1998, 769

[21] Pickett S L , Danison C. Air Quality Analysis Using ArcView GIS and CAL3QHC [A] . ESRI User Conference Proceedings, 2001.

[22] Liu Xue, Wang Xinglong, Wang Guangqian. GIS-Based 3-D Visualization of Debris Process Simulation. Advances in Water Sciences, 1999, 10 (4) : 388-392.

[23] Lin Nianfeng, Yang Jie. The Effect and Signification of GIS and EIS on the Research of Environmental Geology. Soil and Environmental Sciences, 2000, 9 (4) : 259 – 262.