A GIS-BASED ENVIRONMENTAL MANAGEMENT SYSTEM FOR OIL AND GAS INDUSTRY

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Abstract. *Highly intensified development of petrochemical industry may lead to environmental problems with complicated temporal and spatial dynamics that make traditional environmental analysis and management methods inadequate. In this work, we applied the technology of Geographic Information System (GIS) to develop an Environmental Management System (EMS), termed DQOFEMS, for the oil and gas industry. Essential services supplied by DQOFEMS are data management, data analysis and processing, environmental impact assessment (EIA) and the distribution of spatial visualization. The system utilizes capabilities of GIS, network and RDBMS to manage effectively spatial geographic data and environmental pollution discharge data. The system integrates environmental information with spatial geographic information to model environmental impacts with the aid of related environmental mathematical models. Moreover, data-mining is applied to analyze and process environmental data to discover valuable knowledge for supporting sustainable development planning. The DQOFEMS has been applied for environmental management in Daqing Oil Field, China with promising results.*

Keywords*: EMS; GIS; EIA; data management; data-mining; decision support*

1. Introduction

Highly intensified development of oil and industry may lead to serious environmental problems with complex temporal and spatial dynamics that make traditional environmental analysis and management methods inadequate. The solution to environmental pollution problems of the oil and gas industry is a major technological challenge that requires effective spatial management, spatial analysis and processing of environmental information, environmental impact assessment and decision support (Leknes, 2001; Salter and Ford, 2001; Sebastiani et al., 2001; Puppim de Oliveira, 2003). On the one hand, pollution discharge data are massive and diversified. They accumulate along the time so rapidly that makes usual database management system invalid. On the other hand, the pollution sources distribute spatially in geographic locations while their pollution discharge has temporal, continuous and dynamic characteristics. In addition, the realization of environmental impact assessment and decision support depends on the utilization of environmental models based on the analysis of local, social, economical, population and resource development (Curran et al., 2005).

The recent development of Geographic Information System (GIS) provides a powerful tool for meeting the challenge of environmental management in oil and gas industry (Polichtchouk, 1998). GIS has the capacity to manage, analyze and process spatially distributed environmental data. By integrating with environmental impact models and spatial distribution models, GIS can describe and visualize spatially environmental impact phenomena in one, two, or three dimensions (Li and Tao, 1998; Fedra, 1999; Wu, 2003).

In this work, we applied the Geographic Information System (GIS) to develop an Environmental Management System (EMS), DQOFEMS, for the oil and gas industry. Essential functionalities provided by DQOFEMS are the data management, data analysis and processing, environmental impact assessment (EIA), and the visualization of spatial distribution. The system utilizes capabilities of GIS, network and RDBMS to manage effectively spatial geographic data and environmental pollution discharge data. The system integrates environmental information with spatial geographic information to model environmental impacts with the aid of related environmental mathematic models. Moreover, data-mining is applied to analyze and process environmental data to discover valuable knowledge for supporting sustainable development planning. As a case study, DQOFEMS has been applied to environmental management in Daqing Oil Field, China with promising results.

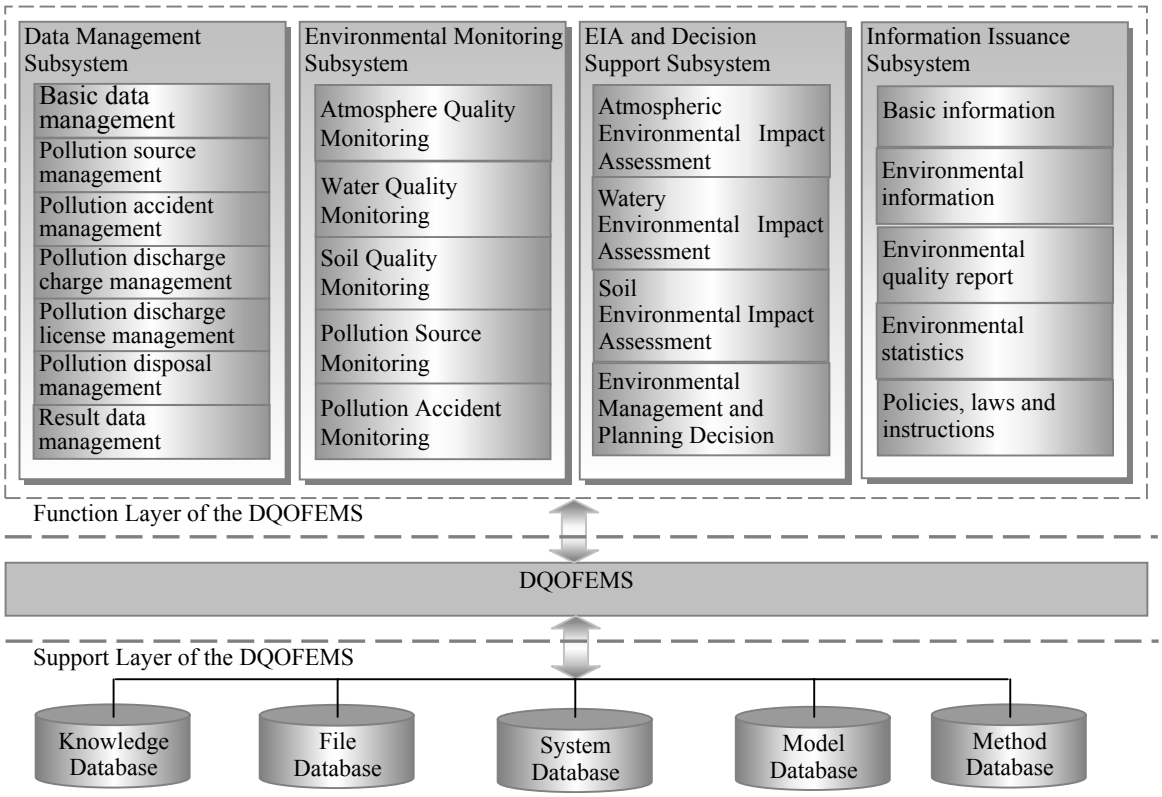

Fig.1 Functional Framework of DQOFEMS

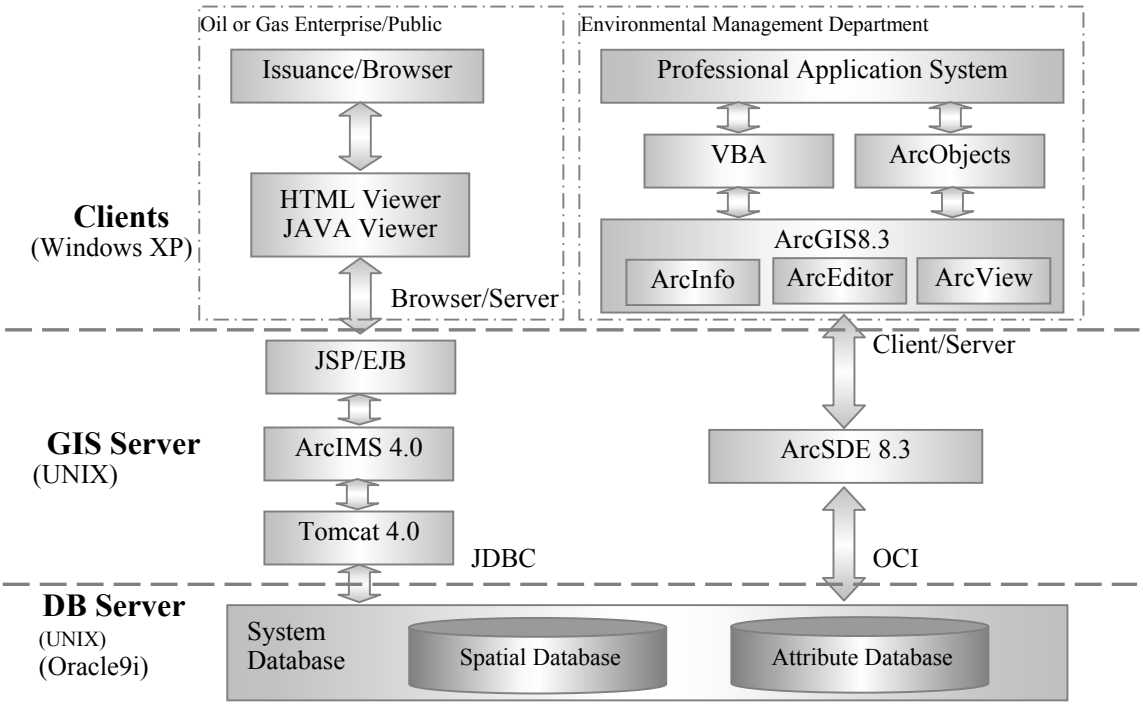

Fig.2 Technological Architecture of DQOFEMS

2. Functional Framework of DQOFEMS

The objective of DQOFEMS is to provide support for environmental management department by researching the relations between resources and environment to be used in the solution of environmental pollution problems, and in the planning of a harmonious sustainable development between the economy growth of oil and gas industry and the surrounding environment. With the general objective of sustainable development of economy, resources and environment, DQOFEMS aims to provide a strong function layer that consists of functions of data management, environmental monitoring, environmental impact assessment (EIA), decision support and related information issues. The realization of each function requires the support of related databases, including knowledge database, file database, model database, method database, and system database. The database layer is called the system support layer of the DQOFEMS. The functional framework of DQOFEMS is shown in Fig.1

3. Network Architecture

In the aspect of network architecture, the DQOFEMS adopts the combined net-system of Browser/Serve and Client/Server for the large scope of spatial geographic distributions of oil and gas industry and the long distance between each oil or gas enterprise (called pollution source in Fig.1) and environmental management department of oil field. Every pollution source gives related environmental information of production and pollution discharge to local environmental management department's DB Server by HTTP through Internet. Meanwhile, related inner users of local environmental management department gain the environmental information by TCP/IP through the inner intranet, and then analyze and process them to give results by the way of figure or image for the purpose of providing decision bases for environmental planners. On the other hand, related information is issued in Internet by local environmental management department while every pollution source and public get and browse them in Internet by different identifications. In the aspect of system software development, ArcGIS8.3 (ArcInfo, ArcEditor, ArcView) is applied (ESRI 2004; Liu and Liu 2002; Zhang et al. 2004), and the management of system database is realized by ArcSDE and Oracle9i. The c/s part of DQOFEMS' software is developed by ArcGIS based on ArcObjects and VBA while its b/s part is developed by ArcGIS based on ArcIMS and JAVA (JSP, EJB). Fig. 2 shows the network architecture of DQOFEMS in detail.

4. Data Management

4.1 Data collection

Modern construction of oil field is a multifunctional, comprehensive, and dynamic system. Therefore, except for environmental monitoring data and relevant report data, the DQOFEMS must consider economy, population, and resources. In general, data sources can be divided into five parts: basic map, background data, pollution discharge data, environmental management data, and environmental assessment data. The detail of data sources used to build the DQOFEMS is in Table 1.

Table1. Data Sources used to build the DQOFEMS

Basic Data Type	Data Themes
Map data	electronic map, relief map, surface construction map
Background Data	natural environment, economy, population, resources, enterprises
Pollution Discharge data	production data, pollution discharge data, pollution monitoring data,
Environmental Management Data	EIA of constructive project, ISO14000 authentication of industry, pollution accident, environmental compensation, data of sanitary product examination of enterprise, waste disposal, establishment for waste disposal, new project construction
Environmental Assessment Data	pollutant discharge criteria, rule and policy, environmental quality criteria; expert knowledge

4.2 Database Structure

Based on the analysis of data sources used to build the system, DQOFEMS adopts the combination of spatial database and attribute database to build the system database managed by Oracle9i. Spatial database comprises two parts, basic layer database and applied layer database, and the detail is in Fig.3. Attribute database is comprised of basic attribute database, special attribute database and result attribute database, and the detail is in Fig.4.

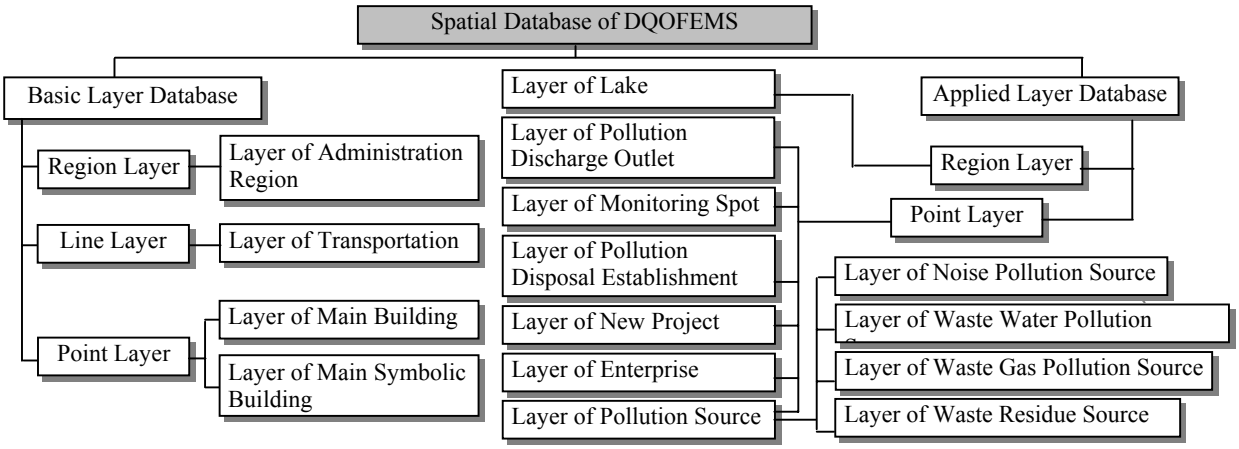

Fig.3 Construction of Spatial Database of DQOFEMS

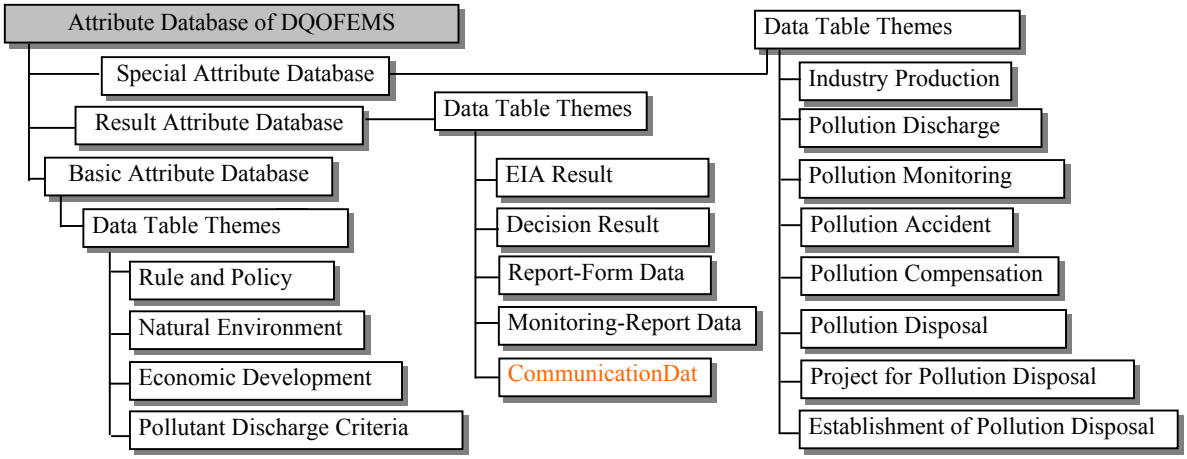

Fig.4 Construction of Attribute Database of DQOFEMS

Basic layer database and basic attribute database are applied to analyze and display spatially basic geography states and environmental background states for the further scientific research. Applied layer database and special attribute database serve in-depth study of oil field environment, such as calculation, analysis, simulation, and so on. And the storage of study results is performed by result attribute database under some certain rules of data storage.

5. Environmental Models

5.1 Pollution Discharge Gross Control Models

Environmental capabilities are defined by atmosphere and water states. Pollution discharge gross control models are applied to reasonably plan pollution discharge spots and define pollution discharge decreases. Moreover, taking policies of pollution disposal and charge as supports, pollution discharge declaration and license rules carry into effect and pollution discharge authority dealing puts into practice for ensuring better environmental quality.

5.2 Pollution Diffusion Models

In the aspect of gas waste pollution diffusion, overhead GUASS model is applied to analyze diffused characteristics of gas waste pollutants, find out their impacts on surroundings and predict pollution accidents. In water waste pollution diffusion, 2D water quality pollution diffusion model is applied to analyze different pollutants' diffusion characteristics and impacts on different waster systems and meanwhile predicting general states and change trends of water system pollution.

5.3 Pollution Trend Analysis Models

Monitoring values of all monitoring objects, including gas waste pollutants and water waste pollutants, are analyzed monthly, quarterly and yearly to define their change trends and pollution development states of regions by figure and graph.

5.4 Environmental Economic Models

Environmental economic models are applied to estimate input, output and general benefits of pollution disposal project establishment and ecological engineering, choose reasonable plans, and analyze land-using benefits and ecological benefits.

5.5 Environmental Quality and Impact Assessment

Based on statistic and analysis results of pollution discharge states and environmental impact states, the system outputs environmental impact assessment reports and quality graphics to analyze feasibility of engineering project and scientific research, choose addresses and amend reasonably constructed plans for new constructing projects integrated with environmental quality states.

6. Spatial Data Mining (SDM) and Decision Support

The DQOFEMS applies the embedded model of SDM technologies integrating with GIS to analyze and process environmental data in order to discover valuable and hinted knowledge. Meanwhile, it provides decision support for environmental planners to realize the sustainable development planning (Di, 2001). The embedded model not only makes the best out of spatial analysis capabilities of GIS but also achieves the integration SDM with spatial analysis capabilities of GIS. On the one hand, SDM technology fuses and analyzes GIS data On the other hand, results produced by SDM are shown in GIS interface by spatial visualization. Fig.5 shows the flow of spatial data mining and decision support.

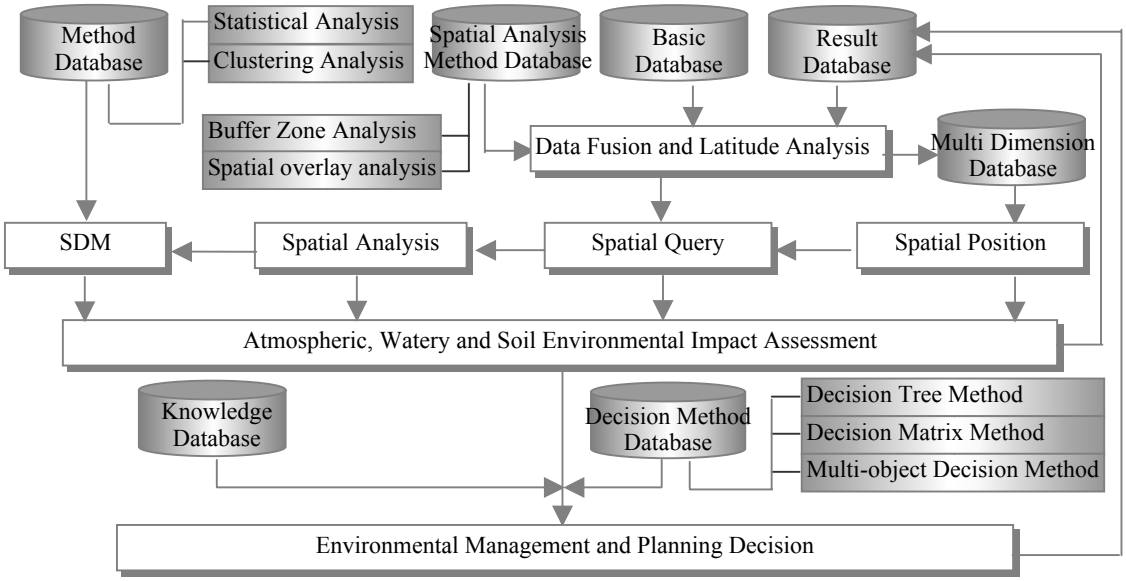

Fig.5 Flow of Spatial Data Mining and Decision Support

The system utilizes capabilities of SDM methods integrated with Spatial Analysis methods to discover hidden rules and relations among urban environment, population, economy and resources. Decision methods are applied by the UEMS to make environmental management and planning decisions. In SDM methods, statistic analysis method is applied to study and predict pollution discharge states of every pollution source by analyzing and processing historical discharge data of every pollution discharge, and gray clustering analysis method is applied to impact atmospheric and watery current quality and predict atmospheric and watery quality states in the future. Decision making is achieved by decision tree method, decision matrix method and multi-object decision method. Decision tree method is applied to find optimum plans for given regions, decision matrix method is applied to solve optimum distribution problems of natural resources like mineral resources and soil resources, and the multi-object decision method is applied to make or amend

plans for scientific researches and engineering projects based on the general consideration of relations among resources consume, economic benefits and environmental impacts.

7. Applications of DQOFEMS in Daqing Oil Field, China

DQOFEMS has been applied for spatial management and assistant decision means for environmental management and planning department of Daqing Oil Field, China. Daqing Oil Field has a large scope of 4415.8 square kilometers and more than 52 thousand oil wells. Some data sources come from monitoring data and related report data of Daqing oil field construction in a few years, and economy and population data comes from annals of Daqing City. On the one hand, the system utilizes capabilities of GIS technology to manage spatially basic environmental information, such as environmental background information, spatial distribution of pollution sources, historical pollution discharge states, and so on. At the same time, environmental quality states and pollution discharge states are monitored dynamically. On the other hand, it integrates modeling for environmental analysis with GIS to simulate and impact environmental states. Meanwhile it makes use of SDM technologies embedded to analyze spatially data and to further discover potential rules and relations among urban environment, population and resources. In addition, decision-making methods are applied by the DQOFEMS to assist environmental planners with decision-making. Its applications in Daqing Oil Field, China has gained promising results, just as following:

(1) Data management, as the chief support layer of the whole DQOFEMS, provides scientific data support for every subsystem of DQOFEMS. Except realizing the management of basic data, including basic geographic layers, applied geographic layers and basic attribute data, the DQOFEMS achieves to manage pollution sources, pollution accidents, pollution discharge charge, pollution discharge license and pollution disposal. To every type of data, the system provides capabilities of query, appending, deleting and amending. Especially in the management of pollution sources, the DQOFEMS further achieves spatial query and position of pollution sources on the Daqing Electronic Map with the help of spatial operation capabilities of GIS technology just as the spatial distribution of pollution sources of Daqing Oil Field is shown in Fig.6.

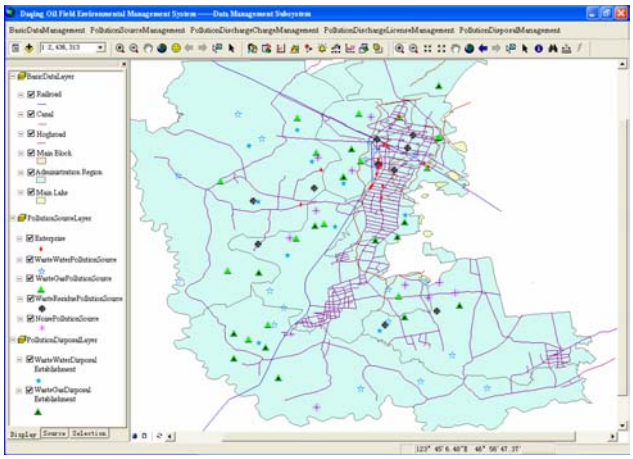

Fig.6 Spatial Distribution of Pollution Sources of Daqing Oil Field

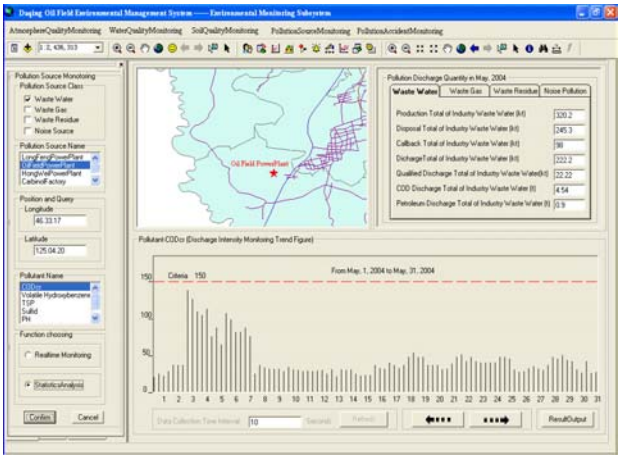

Fig.7 Pollution Discharge States Monitoring of Oil Field Power Plant in May, 2004

(2) Environmental monitoring is the first step of environmental management. It is the key for Daqing Oil Field environmental management department to grasp pollution discharge states and current environmental qualities in time. The DQOFEMS adopts periodic monitoring methods to atmosphere quality, watery quality and soil quality environment around pollution sources. To these above, the system monitors every pollutant 3 times per hour for intensity. To pollution sources themselves, such as pollution discharge outlets, scientific research projects and engineering projects, in one way, the system adopts the real-time monitoring method for every pollutant's discharge intensity in order to find and dispose sudden hidden pollution accidents in time, on another way, discharge quantity of every pollutant is monitored monthly. And moreover, real-time monitoring is applied to monitor current pollution accidents to use in grasping timely pollution diffusion states and pollution disposal states. In addition, the DQOFEMS provides functions of statistic and analysis to analyze all related historical monitoring data and further output results data to the system database of the DQOFEMS. That is convenient for oil field environmental department to make environmental management and planning decisions. Fig.7 shows pollution discharge state monitoring of an oil field power plant in May, 2004.

(3) For the establishment of a new project and old pollution source, the DQOFEMS makes use of spatial analysis capabilities of GIS integrating environmental impact models to calculate, analyze and predict pollution discharge states of every pollution source based on related project establishment parameter setting and environment parameter setting. And with the general consideration of environmental capabilities, the system assesses pollution

discharge's environmental impact degrees with the help of pollution diffusion models and outputs environmental impact assessment results by environmental impact assessment reports and environmental quality communiqués. Fig.8 shows the interface of atmospheric environmental impact assessment. And moreover, with the general consideration of environmental quality states, pollution discharge current states and prediction, environmental impact assessment results, expert knowledge and pollution discharge criteria, the DQOFEMS makes the best of spatial analysis capabilities of GIS integrated with SDM technology and decision methods to make environmental management and planning decisions for environmental department of Daqing Oil Field. Environmental management decisions mainly relates to optimum distribution of pollution discharge outlets and monitoring spots, amending of project structure plans and pollution discharge gross control. Environmental planning decisions chiefly refer to make regional development planning decisions from the point of view of ecology.

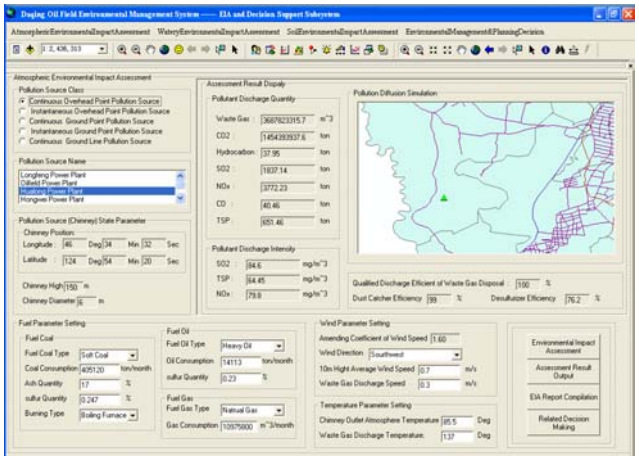

Fig.8 Atmospheric EIA of Hualong Power Plant

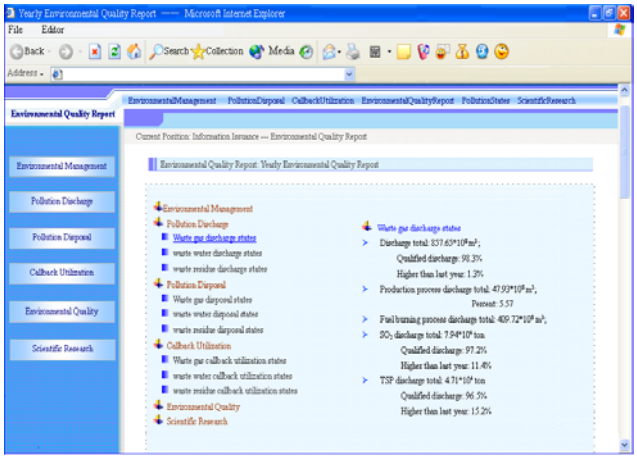

Fig.9 Information Issuance of Environmental Quality Report

(4) In addition, the DQOFEMS provides function of information issuance for special enterprise functionary and public. Different users browse different information by different identifications. Through positioning and querying spatially on electric map of Daqing Oil Field, users can know and grasp easily policies, laws, instructions, enterprise environmental quality report, including pollution discharge, pollution disposal, callback utilization, and environmental quality states just as shown in Fig. 9.

8. Conclusions

This paper presented an Environmental Management System (EMS), termed DQOFEMS, for the oil and gas industry based on the technology of Geographic Information System (GIS). Essential services supplied by DQOFEMS are data management, data analysis and processing, environmental impact assessment (EIA), and the distribution of spatial visualization. The system utilizes capabilities of GIS, network and RDBMS to manage effectively spatial geographic data and environmental pollution discharge data. The system integrates environmental information with spatial geographic information to model environmental impacts with the aid of related environmental mathematical models. Moreover, data-mining is applied to analyze and process environmental data to discover valuable knowledge for supporting sustainable development planning.

The DQOFEMS has been applied successfully for environmental management in Daqing Oil Field, China, with promising results. The establishment of DQOFEMS is significant to environmental management of Daqing Oil Filed. DQOFEMS applies GIS to combine all spatial geographic data and environment information, overcome limitations of former management methods in environmental information management, and realize environmental management of Daqing oil field. The function of environment monitoring realized by DQOFEMS is convenient for environmental management department of Daqing Oil Field to know and grasp pollution discharge states and environment states. Moreover, the DQOFEMS makes use of capabilities of GIS integrated with SDM to realize environmental impact assessment and provide decision support for environment planners of Daqing Oil Field. Finally, the establishment of DQOFEMS provides the use of reference for the realization of environmental management in other regions, and its successful application in Daqing Oil Field environmental management proves that GIS will be indispensable to realize regional environmental management.

9. Acknowledgement

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11. Responsibility notice

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