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G-7 과제에 대한 소개 : 수질관리를 위한 통합 시스템

INTRODUCTION OF THE G-7 PROJECT: Integrated System of Water Quality Management

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要 旨

수질개선을 위한 장기연구 사업(G-7 Project)이 환경처 주관으로 시작되었다. 이 연구사업의 하나인 수질 정보 시스템 개발은 2개의 국립연구소와 대학, 그리고 관련 회사들의 합작으로 추진되고 있다. 이 연구는 통합적 수질관리를 위한 컴퓨터 시스템(ISWQM : Integrated System of Water Quality Management)의 개발을 목표로 하고 있다. 이 ISWQM은 4개의 주된 구성요소 - GIS 데이타베이스, 두개의 인공지능 기법을 바탕으로 한 도심지 오염 부하량 산정을 위한 모델들, 그리고 GIS 데이타베이스와 모델이 연계를 위한 컴퓨터 S/W - 들로서 구성되어 있다. 이러한 ISWQM은 주로 장기적 수질 관련 정책입안을 위한 의사 결정에 도움을 주기 위하여 개발이 시작되었다. GIS는 이러한 수질 관리 시스템의 개발에 있어서 필요시 되는 모든 입력 자료의 공간 데이타베이스 구성에 사용되었으며, GUI(Graphic User Interface)를 통한 위의 4개의 구성요소들을 연계시켜 효율적 SI(System Integration)을 이룩하는데 사용되었다.

ABSTRACT

A long-term water quality study has been initiated by the Korean Ministry of Environment (MOE) - The G-7 Project--in cooperation with two national research institutes, an University research team, and a consulting firm. This study includes the development of computer software for total water quality management system, so called ISWQM (Integrated System of Water Quality Management). ISWQM includes four major components: a GIS database; two artificial intelligence (AI) based expert systems to estimate pollutant loadings and to provide cost-effective wastewater treatment system for small and medium size urban areas; and computer programs to integrate the database and expert systems. ISWQM is to provide user-friendly Decision Support System (DSS) for water quality planners. A GIS was used to create spatial database which stores all the necessary data to run DSS. GIS was also used to integrate the four components of ISWQM from data creation to decision making through Graphic User Interface (GUI). The results from the first phase of this study showed that GIS would provide an effective tool to build DSS using expert system.

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1. INTRODUCTION

Expansion of urban areas and rapid increasing of population aggravate water quality. It is crucial to establish a long-term water quality plan especially for urban watersheds. Such a long-term water quality plan accompanies water quality database, model, and method to design wastewater treatment system, and control practices. To obtain precise pollutant estimation, a locally fit water quality model should be used. Also, relevant factors to use such models should be determined. Results from the water quality modeling can be used for establishing cost-effective control strategy for long-term water quality planning and constructing wastewater treatment facilities for urban areas. Using water quality model and building treatment facilities require a water quality database which stores a variety of input items including landuse activities and topography. Such database should have high accuracy to provide input data for precise pollutant estimation and designing of proper wastewater treatment system. It is desirable to have a total water quality management system which includes data creation to output generation by connecting database and models for water quality planners.

The development of a total water quality management system--ISWQM--has been initialized by Korean government. ISWQM includes four major components: a) a water quality database to provide input data to use a water quality model and to select cost-effective wastewater treatment system; b) an expert system to select locally fit water quality model and to determine various factors to use the model to estimate pollutant loadings for urban areas; c) an expert system to design cost-effective wastewater treatment system through the evaluation of various scenarios; and d) computer programs to integrate the database and expert systems to produce output for long-term water quality planning.

As the water pollution aggravates with rapid industrial development, many factors need to be counted to estimate pollutant loadings and to design a process of wastewater treatment. In this respect, AI based expert system was applied to build a DSS for ISWQM to account experts' knowledge in many aspects. Specifically, expert system was used to build a DSS to select a water quality model and to determine many factors to use the model to estimate pollutant loadings. The DSS also has an expert system based method to select cost-effective wastewater treatment system for mid size (approximately a population of 60,000 to 100,000) urban areas. The application of expert system in water pollution area has relatively short history due to the difficulty of establishing decision making process using multi-disciplinary water related knowledge. Current state-of-the-art shows more than 20 expert systems available for water quality control in the world (NIER, 1993).

Geographic Information System (GIS) would play an effective tool to develop ISWQM. This project tested three potential advantages of a GIS. First, a spatial database which has major types of geographic and political data for the study area can provide necessary data for water quality modeling. This would produce accumulated pollutant loadings for individual administrative units. Such information could be used for building cost-effective wastewater treatment system for individual administrative units. Spatial database can also include existing digital layers made by government agencies to be used as base maps and reference for water quality study. Second, parameters such as landuse and soil characteristics can be transferred between models and databases easily using GIS database management function. As Kim and Ventura[1] (1993) described in their water quality study of large urban area, empirical models can be easily linked to GIS because coefficients can readily be applied to GIS layers. Previous investigators (Kim and Ventura[2], 1993; Prey et al., 1993; Kim et al., 1992) have also demonstrated the advantages of GIS in water quality study using empirical models for data entry, management, display, and transfer to models. It was expected that GIS would contribute to easy transfer of various types of input data to AI based DSS including water quality model and selection method for wastewater treatment system. Third, GIS could play an important role for system integration combining models, selection method, and database. GIS's graphic display capability can be combined with computer programs developed for GUI including user-friendly menu driven system. GUI's functions of data entry, display, management, and validation can be easily linked to GIS to control data flow and to integrate systems.

Background

Most of wastewater treatment systems in South Korea were designed for large cities with capacity of 100,000 ton/day using standard rate of activated sludge process. According to "Master plan for environmental aspects improvements" prepared by MOE (MOE, 1992), we will have individual wastewater treatment facilities for at least 150 medium size cities within 10 years which have different environmental circumstances. Later on, wastewater treatment will be carried out at the smallest administrative unit ("Myun") for densely populated area of approximately 1,500 sites. We believe that it is not cost-effective to use existing wastewater treatment system developed for large size urban areas considering socio-economic cost. To develop cost-effective methodology of wastewater treatment system for mid and small size urban areas, the quantification of effects of wastewater treatment system to environmental circumstances including landuse and special characteristics of regional basin needs to be made. Due to the absence of case studies, such database has not been developed yet. Therefore, we would like to develop a network system which can identify pollution sources, characteristics of treatment system based on the size of discharging area, regional water related database, and water quality parameters in order to select proper method of wastewater treatment. Establishing such a network will accompany selecting locally suitable water quality model, developing method to evaluate proper wastewater treatment facilities, building spatial database storing detailed water quality information, and generating computer programs to integrate model, method, and database for providing useful output for water quality planners.

2. OBJECTIVES

In this 10-year long-term project, the major objective is to develop total water quality management system which includes expert systems, spatial database, and computer programs. As the first part of the project, the specific objectives of three-year period were to develop a) a spatial GIS water quality database; b) an expert system to select a model and to determine input factors for using water quality models; c) an expert system to determine cost-effective wastewater treatment system for small and medium size urban areas; and d) GIS-based computer programs to link the expert systems and database for facilitating water quality planning process.

3. STUDY AREA

The study area includes one lake and two small watersheds--Paldang Lake, Bokha and Yangwha watersheds--located about 40km east of Capital of South Korea, Seoul (Figure 1).

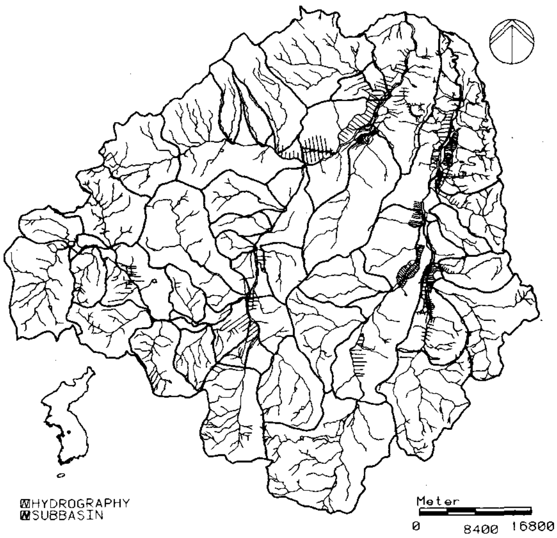

Figure 1. Study Area

Displays hydrography and subbasin boundaries of the study area. Subbasin boundaries were delineated based on the discharging boundaries of the second order stream flows. A total of 44 subbasins were delineated.

Paldang Lake has been major source of drinking water for the Capital area. There has been major concerns for establishing long-term water quality maintenance plan for the lake. Paldang Lake has discharging area of 23,600 km^2 and more than 65 percent of landuse is forest. Annual rainfall amount is about 124 cm and two thirds of the rainfall has occurred during July, August, and September. The other two small watersheds are major upper part of the streams discharging into Paldang Lake. Their small watershed sizes are appropriate for pilot water quality study. Bokha watershed has a total of 21.4 km stream length and discharging area of approximately 300 km^2. The area has a population of 86,622 and 19,853 households with 4.4 average persons per household. Yanghwa watershed has a total of 20.3 km stream length and discharging area of 186 km^2. The area has a population of 55,424 and 12,064 households with 4.6 average persons per household. Major landuses of both watersheds are agricultural, forest, and urban.

4. METHODS

GIS Database

A GIS database was generated. This includes digital line graphs and major thematic layers including landuse (Cadland, 1993). For creation, validation, and retrieval of water related attributes, detailed database design was made. Work station based Arc/Info (ESRI, Redlands, California, 1987) software was used for the GIS.

a) Database Design: Efforts were made for database design to provide easy entry, validation, access, and updating of individual data items for the four parts of ISWQM. Figure 2 shows the process of database design based on the evaluation of end-user requirement through a pilot study. AML (Arc Macro Language) of Arc/Info was used for developing user interface of database. Menu-driven system was developed for easy interface.

b) Digital Line Graph: A total of six digital line graph layers including DEM, road network, hydrography, watershed boundary, subbasin boundary, and administrative boundary were generated. DEM was generated on 20 meter resolution. Road network layer includes the width of roads, the type and status of road pavement. Hydrography layer has stream name and length. Administrative boundary layer has the boundaries of city, town, and the smallest administrative unit "Ri." In addition to these layers, four thematic layers were generated. These are landuse activities, soil, geologic features, and forest types. Five landuse categories were made using recent Landsat TM images. The soil, geologic, and forest layers were made by digitizing four 1:25,000 topographic maps. Recent topographic maps from National Geography Institute were used in an effort to generate digital layers of higher accuracy.

c) Land Use Generation: Recent landuse was made using satellite images due to the absence of airphotos of the study area. Two Landsat TM scenes of September 26 of 1990 and April 19 of 1990 were purchased. Classification was done using maximum likelihood estimator. TM (Transverse Mercator) coordinate system was used for map transformation using ground control points. Work station based ERDAS (ERDAS Inc., Atlanta, Georgia, 1991) image processing software was used for the classification. A total of five classes were made such as urban, forest, agricultural, bare soil, and water. A GIS layer of classification results was merged into the GIS database.

d) Pollution Data Generation: In addition to the GIS layers, water and pollution related data were generated. These are mainly regarding point/nonpoint source of water pollution, water usage, population and housing, and stream flow. A total of 11 types of pollution sources were surveyed and documented for database entry. Housing and agricultural water usage were surveyed for the study area based on individual wastewater treatment facilities. Average population per household, housing types, the status of housing sewage facilities were surveyed based on the smallest administrative unit. In addition to that, hydrographic data were also gathered including runoff volume, width, grade, length of each stream of the study area.

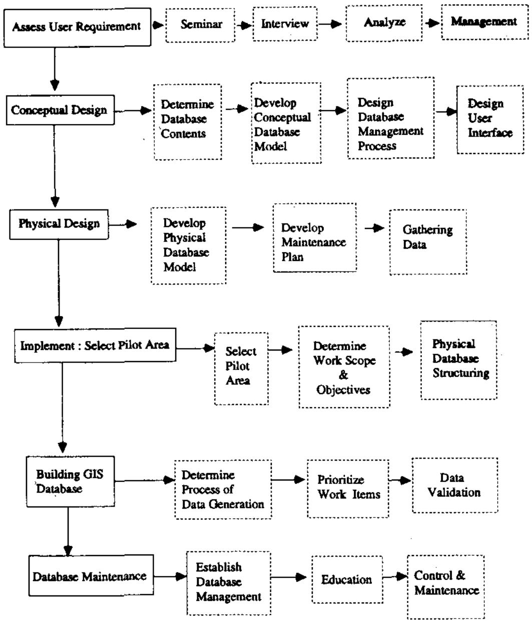

Figure 2. Database Design

Displays major steps of database development including specific flows for each step. A spatial database was made for the pilot study area.

<u>Expert System for Water Quality DSS</u>

Figure 3 shows the basic structure of water quality DSS. Based on the qualitative evaluation, proper model can be selected for quantitative evaluation of water pollution. The output from modeling would provide fundamental information to establish appropriate policy and budget allocation to improve water quality. Expert system has been used to determine coefficients and other factors to use locally fit water quality models and to decide pollution index (PI) (Nemerow, 1974) for implementing policy to improve water quality by government officials (SNU, 1993).

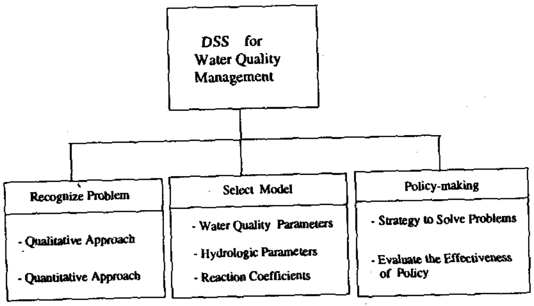

Figure 3. Structure of DSS for Water Quality Management

Displays three main components of DSS. Expert system was used to recognize major problems from water pollution, selecting water quality model, and establishing proper policy for water quality management.

Many different water quality models were used to test a variety of water quality factors (Table 1). Test results were merged in the GIS database for using expert system to determine coefficients and select locally fit water quality model. Models selected were divided into two categories then evaluated: river models and lake models. Ten models were studied for river models and 13 for lake models. Based on the results of pre-evaluation of these models, two models of each category were selected for further analysis: a) QUAL2E (Tufts University, 1985) and MIT-NETWORK (MIT, 1976) models for river model; and b) WQRRS (Resource Management Associate Inc., 1978) and WASP4 (US EPA, 1988) models for lake model. Model calibration was made for four models to determine relatively well-fit models for the study area.

For river models, 20 major parameters out of 34 parameters were selected for the calibration of QUAL2E model, and 11 parameters out of 26 parameters for MIT-NETWORK model. For lake models, 14 parameters out of 44 parameters were selected for WASP4 model, and 20 parameters out of 134 parameters for WQRRS model. For individual watersheds, samples were obtained for the major streams at three places: upper, middle, and lower part of the streams. Results from the calibration implied that the models' default parameter values were not significantly different for the study areas. Following the model calibration, sensitivity analysis was done to see major parameters of higher variation. Results from the evaluation of those models were stored in a GIS database to be used for applying the expert system.

Table 1. Major consideration factors for the selection of water quality model.

Displays five major consideration factors for selecting water quality models. All the detailed consideration items of each factor were evaluated and scored using an expert system to select optimal model for the study area.

Factors	Items	Remarks
Adoptability	- Types of water body applied (lake or stream ?) - Types of water quality items analyzed	- Similar to many available models
Data Requirement	- Types of input data required to run model - Types of input data required for model calibration/verification	- Similar to many available models
Model accuracy	- Accuracy of model output - Sensitivity to input data errors	N/A
Difficulty in operation	- User-friendly system to learn - Types and contents of output - Easy to run on different scenarios - Easy to modify source codes	QUAL2E : relatively easy to use
Cost	- Initial cost - Maintenance cost	Develop on PC to save cost

The PI has been used to provide integrated water pollution indication for rivers and lakes. PI has also been used to suggest proper budget and control practice for government officials to improve water quality. For determining PI, standard criteria of river and lake water quality for major items such as pH, BOD, SS, DO, and Coliform were used. Instead of providing independent values of each item, overall weights of each item was made using neutral network algorithm. This provided more realistic evaluation from the consideration of overall weights between factors.

Wastewater Treatment System

AI based fuzzy expert system was used for proper design of regional wastewater treatment system. For efficient decision making process using experts' opinions, Analytical Hierarchy Process (AHP) was used with AI language (Prolog) to solve difficult problems which can not be easily solved by mathematical methods (NIER, 1993). The system includes main program and three sub-routines using Clipper (Version 5.1) and Turbo Prolog on IBM PC 386. Water characteristics and regionally specified database were designed considering pollutant source information, status of water consumption, and other information. These information were merged into the GIS database. Evaluation criteria for selecting treatment method were determined based on the analysis of six factors: a) effluent standards and the level of planned water quality from individual treatment system, b) problems in maintaining facilities, c) cost for pipe construction, building facilities, and maintenance, d) strategy for variable sledge loadings and temperature, e) site characteristics such as the size of the treatment system, status of adjacent housing development, possibility of groundwater usage, and opinions of residents, and f) flexibility to upgrade treatment system. Each factor was prioritized using experts' opinions then analyzed based on the evaluation of numerous items such as geographic characteristics, the amount of rainfall, temperature, the density of population, landuse activities, planned site of treatment facilities, and the average income of residents. Fuzziness and certainty factors were mainly used for analyzing those factors. Figure 4 shows the structure of the expert system using Clipper and Prolog languages.

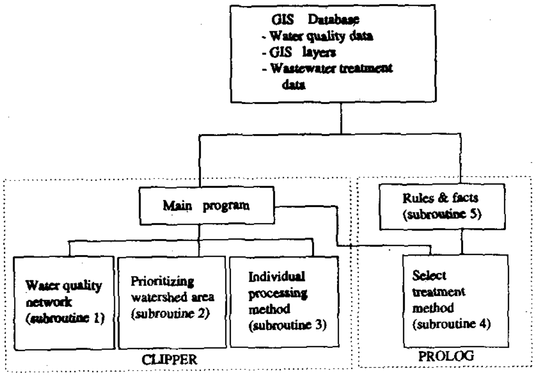

Figure 4. Structure of An Expert System for Selecting Wastewater Treatment System

Displays the structure of expert system to select optimal wastewater treatment system. A GIS database was linked to Prolog and Clipper language based expert system to provide necessary input data.

System Integration

Computer programs were made to integrate GIS database and expert systems to use locally fit water quality models and to select optimal regional wastewater treatment system. The major components of the software are menu driven user interface routine, data conversion routine, and output generation routine. Menu driven user interface is based on GUI to facilitate user-friendly interactive menu system. This leads to easy operation of ISWQM to support DSS for water quality planners. GUI accesses Arc/Info system to access and display major geographic and environmental information of the study area including watershed area, hydrography, landuse activities, and administrative boundaries, etc. The user interface routine can also calculates major pollutant loadings using a water quality model based on current landuse development along the stream flows. The routine calls expert system to evaluate and establish cost-effective wastewater treatment system considering point and nonpoint source loadings from landuse activities. Data conversion routine converts data format to link spatial database, expert systems, and output generation routine. Output generation routine produces variety of report useful for water quality planners in screen and print format. Figure 5 displays a diagram of system integration.

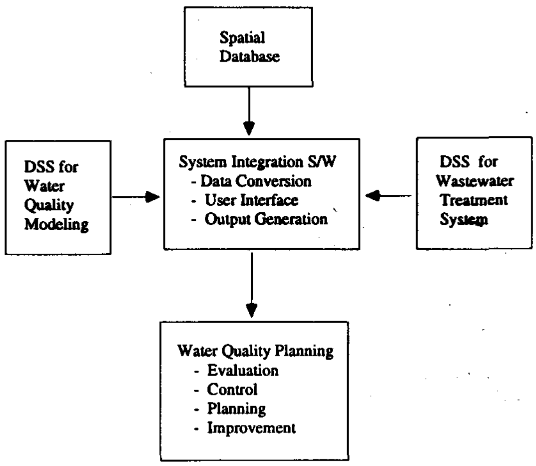

Figure 5. A Diagram of System Integration

Displays system integration for building ISWQM. Spatial database, water quality model, methods for wastewater treatment were connected through computer software which accepts instruction, controls data flow, and output generation through GUI.

5. DISCUSSION

This paper describes the application of GIS to DSS for total water quality management based on the results from the first phase of the project. GIS has been used to provide input to use expert systems to use water quality models and design appropriate wastewater treatment system. GIS has also been used for easier transfer of parameters linking model, expert systems, and database through GUI. The GIS capability was enhanced by adding user-specified computer programs for data conversion, access, and output generation. No major problems existed in the linkage of input data between database, model, and expert systems. The model output, transferred back to individual landuse polygons, was effective for obtaining accumulated pollutant loadings of each administrative boundary. This was helpful to allocate budget for water quality control for individual administrative units.

The generation of database is in progress. More input data for further pollutant analysis using models are required. This includes more information regarding a variety of wastewater treatment system. This will enhance the capability of DSS for total water quality management especially for cost-effective wastewater treatment system. Also, the accuracy of landuse data generated using Landsat TM images (about 65%) needs to be enhanced. High accuracy of landuse data would provide more precise estimation of pollutant loadings. Additional information may be utilized to increase the accuracy such as field survey data or contouring data.

The expert systems developed for this project need more works to enhance the capability and applicability to different larger study areas. First, we have to investigate more different types of water quality models to give more flexibility to the users using expert systems. This would provide more locally fit water quality model for different areas. Second, we have to standardize cost analysis methods in implementing individual wastewater treatment systems. This would increase the contribution of expert systems to select more cost-effective treatment method for small size urban areas. Third, the contribution of expert system to DSS needs to be increased by adding more AI routines to reflect inter-disciplinary experts' opinions for total water quality management.

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