

# **A STUDY OF DEVELOPING GIS-BASED WATER QUALITY MANAGEMENT SYSTEM OF RURAL AREA**

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**ABSTRACT** Water is one of the most important natural resources. The wise and sustainable uses of water, especially paying much attention on the water quality, are very essential. Nowadays, the rapid increase of population and industrial activities has been the major source of pollutants carried off through sewers and drains. This study mainly concentrated on developing a GIS based system which can provide estimation of the amount of pollutants and effective decision making for mitigating water pollution. Major work tasks can be divided into threefold. Firstly, a pollutant database was generated for the study area including different types of digital layers and the Unit Load Coefficients were used to calculate water pollutants. Three types of water pollutants were calculated such as generated, discharged, and flowed. Secondly, one water quality model--QUAL2E--was adopted to simulate the water quality status for the study area such as Hongseong Gun and Yesan Gun of Chungchongnam Do in South Korea. The QUAL2E model was used to forecast water pollution for rivers and streams. Finally, one GIS-based management system was developed to integrate pollutant DB, water quality model, and GUI for decision making process. The results showed that the developed system could facilitate estimation and prediction of water pollution based on GIS. Furthermore, GIS can provide easier process for decision making to decrease water pollution by investigating numerous scenarios of the study area. In addition, more study needs to be made to establish better decision making process including algorithm and programs.

## **1 INTRODUCTION**

Water resources, as defined in the glossary of hydrology, is the water that is available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand. The development of civilizations has led to a shift in the patterns of water use from rural/agricultural to urban/industrial (Bartram, 1996). Normally, the water uses with the highest demands for quantity often have the lowest demand for water quality, but drinking water, by contrast, requires the highest water quality. So the wise and sustainable uses of water, especially paying attention on water quality, are very essential.

However, there are a number of human behaviors (e.g. population, industry, agriculture, etc.) that inevitably discharge the solid and liquid wastes and cause the water pollution, which is a large set of adverse effects upon water bodies. The most direct impact of water pollution is on drinking water, which is also the most common national requirement. As reported by the World Health Organization (WHO) and the United Nations International Children's Emergency Fund

(UNICEF), globally, 2.4 billion were without access to improved water sanitation in 2000 (WHO and UNICEF, 2000). Figure 1(a) shows where the unserved population was found, and Figure 1(b) is the global water sanitation coverage in 2000. Accordingly, the treatment of water quality and water pollution has become an important issue, especially in Asia.

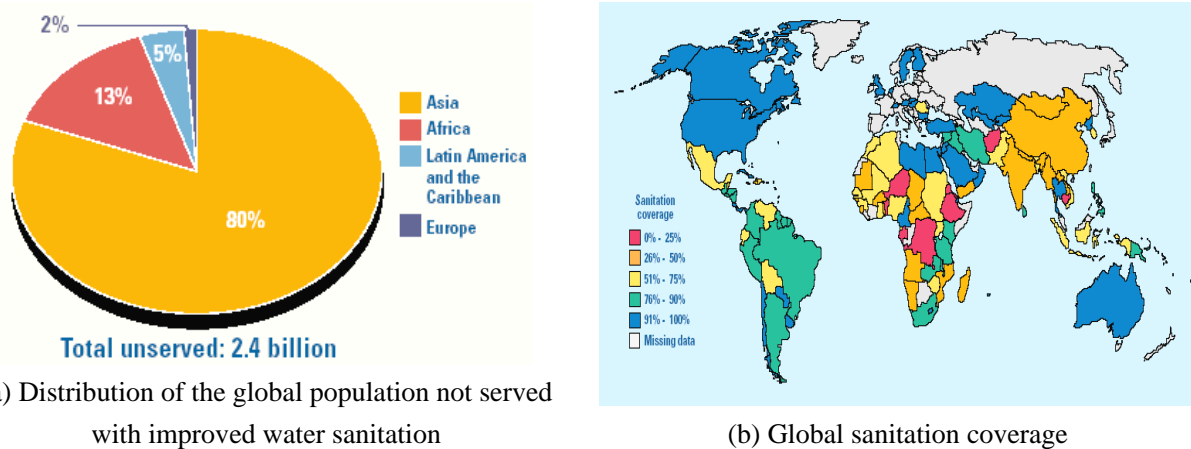


Figure 1. Global water sanitation status in 2000

With the development of water treatment engineering and relevant technologies, a number of solutions have been invented to make water more acceptable for desirable end-uses, especially for drinking (AWWA, 1998). Although these traditional ways have played an important role in treating the water pollution, they are hardly able to give us adequate quantitative and qualitative cognitions such as how much water pollutants were or will be generated in a specified area and how to make decisions or plans with taking into account of water quality. The requirement of systematically managing, analyzing and even predicting the water quality to support decision-makings for local governments is becoming more and more urgently. And as we know, the Geographic Information System (GIS) is a tool that allows users to create interactive queries, analyze the spatial information and edit data. Accordingly, in this paper, a study of developing GIS-based water quality management system is presented to manage and analyze the water quality information, and to support decision-makings on the water quality improvements.

## 2 STUDY SITE AND DATA COLLECTION

### 2.1 Description of Study Site

The study site of this research is situated in the drainage area of the Geum River system in South Korea. This site, as shown in Figure 2, covers two Guns (Hongseong Gun and Yesan Gun of Chungchongnam Do) with an area of 986.76 km<sup>2</sup>. In this area, there are around 20 branch rivers (e.g. Sapgyo River, Muhan River) and more than 70 reservoirs (e.g. Yedang Reservoir). This study site is also a rural area, in which currently about 1.2 million people reside. And as recorded by the Korean Ministry of Environment, there are around 284 factories, more than 2.3 million various livestock and poultry, and totally about 14,740 m<sup>2</sup> fishponds in this rural area. Besides, many other different kinds of land-uses, such as roads, farmlands, rice fields, etc, are distributed. All of these are the sources of water pollution. As observed in 2003, the whole area had discharged about 3172.98 BOD (Biochemical Oxygen Demand, a water quality indicator used to measure the concentration of biodegrades organic matter present in a sample of water)

water pollutants. So it is a challenge to systematically manage and analyze the water pollution of this site, and to make decisions on decreasing water pollutants and improving water quality.



Figure 2. Study Site

	Contents	Description
Pollution Sources	Population	The number of population of having sewer-handling facilities, sanitary devices, removal devices, and excrement-handling facilities, etc.
	Industry	Factory number, type, volume of discharged wastewater, etc.
	Livestock	The number of cow, horse, pig, dog, sheep, etc.
	Fishery	Fishpond number, type, area, etc.
	Land-uses	Cropland, farmland, road, golf course, etc.
Observations	Water Quality	pH, BOD, COD, SS, TN, TP, DO, etc.
	Water Resources	Rainfall, water level, runoff, flow rate, etc.

Table 1. Attribute Data

	Contents	Configuration
Basic Maps	Topography	Line
	Roads	Polygon
	Districts	Polygon
	Constructions	Polygon
	Contour	Line
	Rivers	Line
	Streams	Polygon
	Lakes, Reservoirs	Line
Thematic Maps	Large Watersheds	Polygon
	Middle Watersheds	Polygon
	Small Watersheds	Polygon
	Soils	Polygon
	Land-covers	Polygon
	DEM	Raster
	Farms	Point
	Dumping Places	Point
	Water Quality	Point
	Water Level	Point
	Rainfall	Point
	Funoff	Point
	Filtration Stations	Point
	Pumping Stations	Point
	Dumping Stations	Point
	Excretion Treatment	Point
Effused Water Treatment (in dumping stations)	Point	
Sewage Treatment	Point	
Agricultural Wastewater Treatment	Point	

Table 2. Graphic Data

## 2.2 Data Collection

The data used in a GIS system normally consist of two parts: graphic data and associated attribute data. In this research, both raster data and vector data (Table 2) were used to graphically represent the water resources and water quality related objects of the study site. Further more, a number of attribute data (Table 1), mainly including the attributive descriptions of water resources, water pollution sources, and water quality of the study site, were collected.

## 3 METHODOLOGIES

The overall process of this research includes three major steps: water pollutants calculation, water quality modeling, and application system development.

### 3.1 Water Pollutants Calculation

The calculation of water pollutants in this research was using the Unit Load Coefficients (ULCs), to mathematically estimate and compute the volume of water pollutants from water pollution sources. The ULC is used to differentiate and indicate the degrees of water pollutants load from different pollution sources. Because these coefficients vary with the different pollution sources and different study cases, so the ULCs used in this research were monitored and calibrated by the NIER (National Institute of Environmental Research, Korea). The water pollution sources

are generally classified to two types: Point Source (PS, discharges pollutants by a fixed and stationary location such as pipe, channel or ditch) and Non-point Source (NPS, discharges pollutants by more than one source and in a diffuse manner). Normally, the calculation of water pollutants can be divided to three parts (Figure 3): generated pollutants calculation, discharged pollutants calculation, and flowed pollutants calculation.

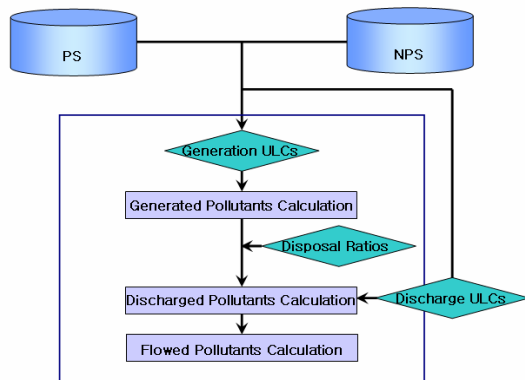


Figure 3. Procedure of Water Pollutants Calculation

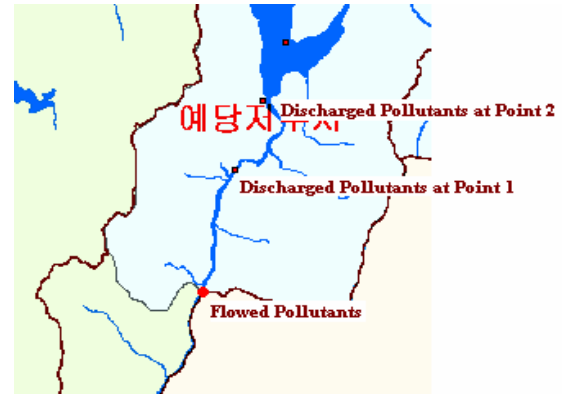


Figure 4. Flowed Pollutants Calculation

**3.1.1 Generated Pollutants Calculation** The generated pollutants calculation is about the volume of water pollutants that the water pollution sources produce. In this research, the Generation ULCs were adopted to calculate the generated pollutants mainly from five types of pollution sources (population, industry, livestock, fishery, land-uses) in the study site.

**3.1.2 Discharged Pollutants Calculation** The discharged pollutants calculation is about the volume of water pollutants that the water pollution sources discharge after some water pollution treatments or not. Normally, these pollution treatments include the disposals of excretion, sewage, industrial and agricultural wastewater, effused water in dumping stations, etc. By contrast, the calculation of discharged pollutants is more complex because of the difficulty in estimating the ratios of disposed or lost water pollutants, especially the discharged pollutants from land-uses. Therefore, a set of disposal ratios defined by the NIER were applied.

**3.1.3 Flowed Pollutants Calculation** The flowed pollutants calculation is about the volume of accumulated water pollutants after a certain distance of flowing through rivers or other water bodies. Normally, the flowed pollutants are calculated by watersheds, and at least two observed water pollutants data are required as shown in Figure 4. In Figure 4, the flowed pollutants can be computed as:  $F = D \cdot e^{-kl}$  ( $l$  is the flowing distance,  $k$  is one constant coefficient of flowed pollutants). This constant coefficient can be determined by those two known pollutants data.

### 3.2 Water Quality Modeling

Water quality modeling is the prediction of water quality using mathematical simulation techniques (Cox, 2003). A typical water quality model consists of a collection of formulations representing physical mechanisms that determine fate and transport of water pollutants in a water body, and each water quality model has its own unique purpose and simulation characteristics. So far, a number of water quality models (e.g. QUAL2E, HSPF, WASP, etc.) have been developed and applied into the simulation and prediction of water pollution around

the world.

In this research, the QUAL2E model was used to predict the water quality of the Sapgyo River. The QUAL2E model is a steady-state model, which was first released in 1985 by the USEPA (United States Environmental Protection Agency) and has been used mainly to simulate the water quality of rivers. It totally has 15 indicators including DO, BOD, temperature, NH<sub>3</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, and so on (Charudhury, 1998). The brief idea of the QUAL2E, as shown in Figure 5, is to divide the river from headwater equidistantly including distributaries, and every unit segment has its sequence number. In each segment, its water quality is assessed by those 15 indicators, which can be computed by a set of equations defined in the QUAL2E.

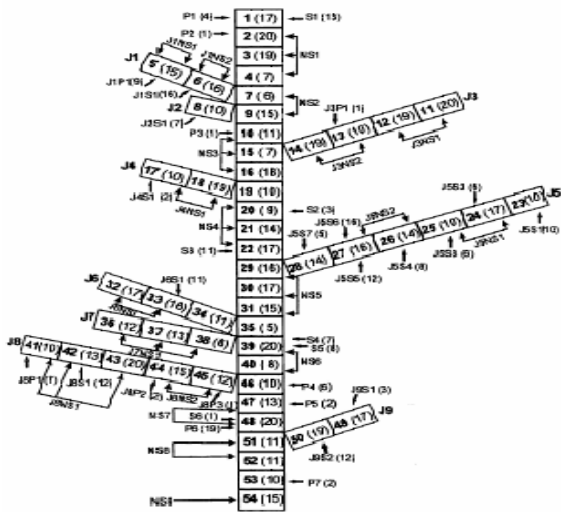


Figure 5. QUAL2E Model

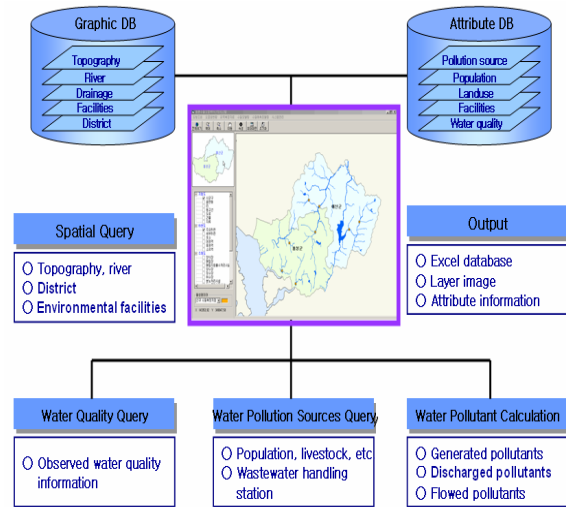
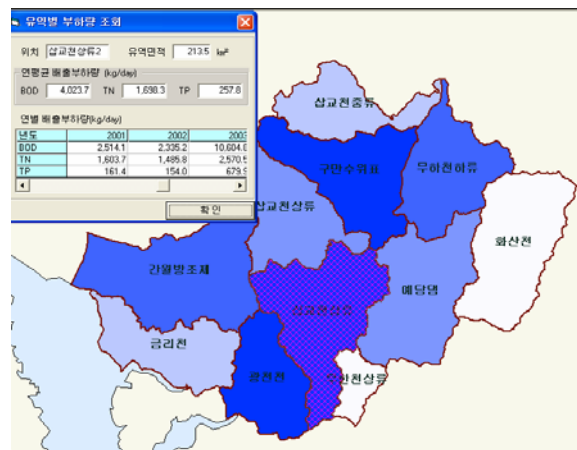


Figure 6. System Infrastructure



(c) Water Quality Modeling Result



(d) Water Quality Query (by watersheds)

Figure 7. Example Figures of the Developed Application System

### 3.3 Application System Development

Using ArcGIS, MapObjects, and GUI, one GIS-based application system was developed to integrate, display and analyze the water resources and water quality information of the study area, and to support decision-makings for local governments based on a developed function of water quality simulation and prediction. The main developing steps consist of data collection, database construction, and programming. Figure 6 is the system infrastructure, and Figure 7

shows two example figures of the developed application system.

## 4 CONCLUSIONS

In this research, a study of developing GIS-based water quality management system was implemented to try to manage and analyze the water quality information of one study site, and to support decision-makings for local governments. Totally, three steps, including water pollutants calculation, water quality modeling, and system development, were carried out. This developed system has the abilities to integrate various water resources and water quality related information, calculate and analyze the water pollutants, and predict the water quality status and trends. Figure 8 shows the comparisons between simulated and observed water quality values. Obviously, the modeling result in this research is rational. Therefore, the system is potential to help local governments make decisions and plans on water quality improvements such as decreasing water pollutants and properly redistributing sources. However, due to the difficulty and complexity in determining the Unit Load Coefficients and the disposal ratios of pollution treatments, a further research of improving the water pollutants calculation is required.

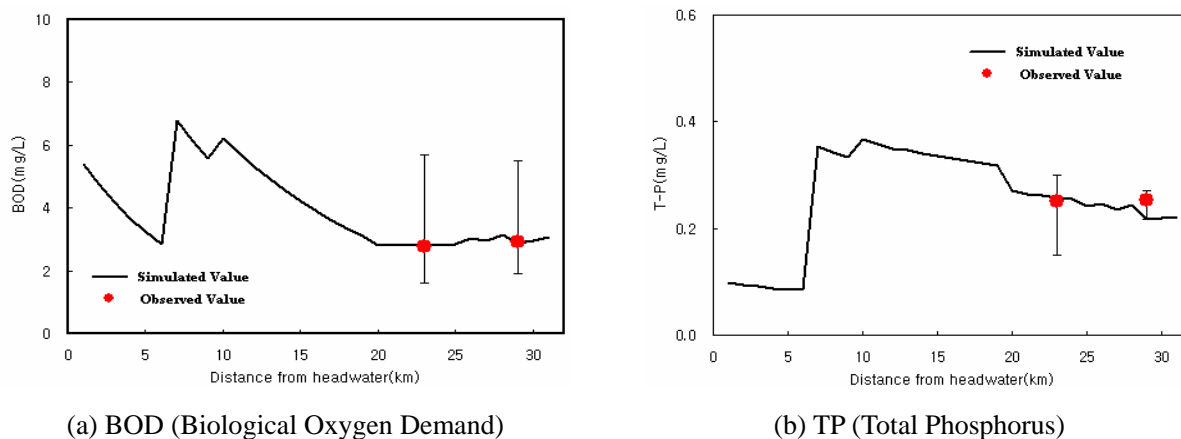


Figure 8. Comparisons between Simulated and Observed Water Quality Values

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