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Spatial Analysis of Ambient Air Quality Using GIS

Byoung-Gil CHOI*, Hee-Kwan LEE* and Young-Woo RA**

Abstract

GIS technique is applied to the analysis of ambient air quality information. For this study, the TMS-monitored air quality information was imported with the geographical information of the TMS stations in Capital Area. It is found that currently available GIS technique has a great extend of potential for air quality management. From the analysis of air quality information, the GIS application demonstrates the poor air quality in the central Capital Area and the it is improved as it travels down to the suburb area. The ambient air quality is also proven to be highly influenced by the ozone concentration in a mid-summer day.

Keywords : *GIS, Interpolation, Air Quality, Air Environment Index*

1. Introduction

The urban air quality in metropolitan cities over the world has been getting worse in recent years. A large number of efforts to improve ambient air environment have been also made to respond. Reinforcing ambient air quality standard and air pollutant emission control and developing new technologies for air pollution control are good examples.

The steadily expanding urbanization, however, is still fast enough to weaken those trials for the improvement of air environment. It leads us to consider another alternative, so-called total emission control. In this total emission control, the allowance of air pollution emission is determined based on the environmental capacity for a concerned area. The allowance is then allocated to each pollution source and controlled.

The fast growing new technology, so-called Geographic Information System (GIS) technology, may have a potential to boost up this process. It is a system to collect geographical information, to analyze, to visualize, and to support our decision making in the long run.

Various GIS techniques have been applied to analyze ambient air quality information. The air pollution emission from transportation was studied while considering running traffic.[10] The air pollution emission was also estimated using remote surveying image information.[11] Recently, the interpolation techniques which have the key role in GIS data processing were studied. IDW method was approved by its applicability but Kriging method was not due to the lack of computing resources.[2]

In this study, GIS technique is applied to support and ease current air quality management approach. IDW and Kriging methods were used to analyze the air quality information in Capital Area. Air Environment Index (AEI) which has been produced by Ministry of Environment was introduced to visualize true air quality information for human-beings.

2. Ambient air quality

The ambient air quality in Korea has been monitored by means of Telemetry Monitoring System (TMS). Currently 279 nationwide stations have been constructed and operating, as demonstrated in Fig. 1. The collected information is then used to watch the state of ambient air quality formed by various air pollution sources, to inspire public concern on the air environment conservation, to provide required information for environmental policy establishment, etc. Table 1 summarizes current National Ambient Air Quality Standards (NAAQS) in Korea.

2.1 Collection of air quality information

The monitored air quality information by the TMS

*Professor, Department of Civil and Environmental Engineering, University of Incheon (E-mail : bgchoi@incheon.ac.kr)
**Graduate Student, Department of Civil and Environmental Engineering, University of Incheon (E-mail : survey@incheon.ac.kr)

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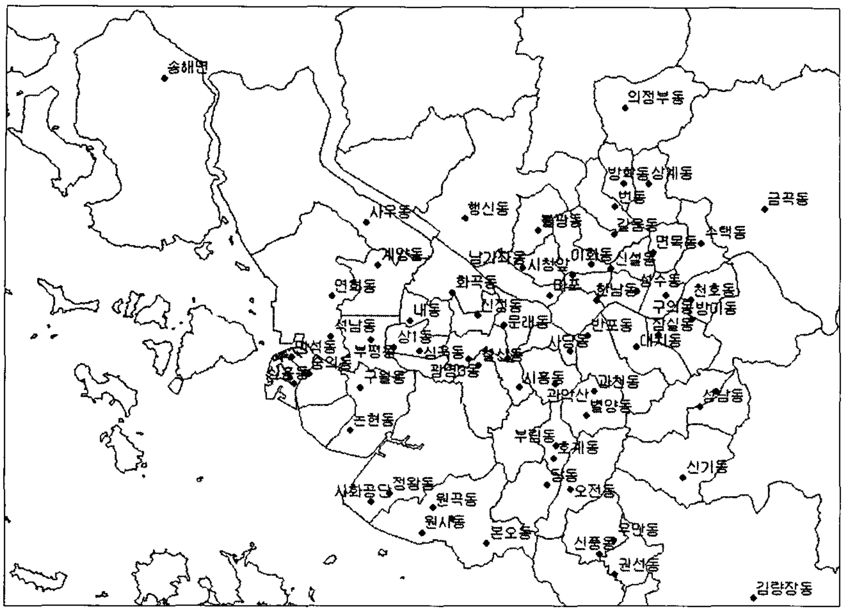

Fig. 1. TMS stations in Capital Area.

Table 1. National ambient air quality standards

			Air quality standards	
			Till Dec. 31. 2000	From Jan 1. 2001
Sulfur dioxide (SO_2)		Mean for a year	less than 0.03ppm	less than 0.02ppm
		Mean for 24-hour	less than 0.14ppm	less than 0.05ppm
		Mean for 1-hour	less than 0.25ppm	less than 0.15ppm
Carbon monoxide (CO)		Mean for 8-hour	less than 9ppm	less than 9ppm
		Mean for 1-hour	less than 25ppm	less than 25ppm
Nitrous dioxide (NO_2)		Mean for a year	less than 0.05ppm	less than 0.05ppm
		Mean for 24-hour	less than 0.08ppm	less than 0.08ppm
		Mean for 1-hour	less than 0.15ppm	less than 0.15ppm
Dust	Total suspended peculate (TSP)	Mean for a year	less than 150$\mu g/m^3$	-
		Mean for 24-hour	less than 300$\mu g/m^3$	-
	Fine dust (PM_{10})	Mean for a year	less than 80$\mu g/m^3$	less than 70$\mu g/m^3$
		Mean for 24-hour	less than 150$\mu g/m^3$	less than 150$\mu g/m^3$
Ozone (O_3)		Mean for 8-hour	less than 0.06ppm	less than 0.06ppm
		Mean for 1-hour	less than 0.1ppm	less than 0.1ppm

Note : PM10 indicates fine particulate smaller than 10μm diameter.

stations are transferred to local environmental authorities and then re-directed to the main-frame in Ministry of Environment after brief pre-processing. In this process, the information with the completeness more than 75% is only accepted for further statistical analysis. In this study, the air quality information for a mid-summer day in 2001 is used for analysis. Table 2 summarizes the detailed weather conditions of the day.

2.2 Air environment index

The collected air quality information is processed in various methods on purpose. The concept of Hourly Air Environmental Index (HAEI) is one of them to inform the states of air environment to the public. Equations (1)~(5) describe the formulae for different air pollutants in national standards. In practice, HAEI's are calculated for all air pollutants and the lowest value out of them is determined to be the corresponding HAEI

Table 2. Weather conditions for the air quality information used

Items	Contents
Time	1~2 pm, Aug. 17, 2001 (Friday)
Wind speed	1.6 m/sec
Temperature	35℃
Precipitation	0
Humidity	73%
Cloud	1.4

at a concerned location and time. Tables 3 and 4 summarize the state of air quality with the corresponding HAEI's and each pollutant concentration respectively. In this study, the air quality information from 62 TMS stations in Capital Area including Seoul, Incheon, and Kyounggi-Do were used.

$$SO_2 : HAEI(SO_2) = 100 - \frac{50}{0.15} \times Mean\ of\ 1-hour\,SO_2 \quad (1)$$

$$NO_2 : HAEI(NO_2) = 100 - \frac{50}{0.15} \times Mean\ of\ 1-hour\,NO_2 \quad (2)$$

$$O_3 : HAEI(O_3) = 100 - \frac{50}{0.1} \times Mean\ of\ 1-hour\,O_3 \quad (3)$$

$$CO : HAEI(CO) = 100 - \frac{50}{25} \times Mean\ of\ 1-hour\,CO \quad (4)$$

$$PM_{10} : HAEI(PM_{10}) = 100 - \frac{50}{200} \times Mean\ of\ 1-hour\,PM_{10} \quad (5)$$

3. GIS application for air quality mapping

GIS is a tool to extract desired information from a wide range of spatial information. A commercial GIS package named ArcGIS (ver. 8.2, ESRI) has been used for analysis.[5,6] It is consisted of five major steps to work; data collection, processing, management, analysis and presentation. Construction of a database normally requires a significant amount of time and effort (more than 70%). In the process, the concept of "spatial analysis" has the key role. It is a process to analyze geographical information for a concerned area to present its potential and risk by means of visible presentation. At the end, it is useful for us to build a master plan.

In this study, the monitored air quality information by national TMS were integrated onto the pre-built geographical information including the distribution of TMS stations as well as the land use of Capital Area. In data analysis, one of important steps is to interpolate existing data in GIS. Currently there are a few techniques for this function such as bilinear interpolation, cubic interpolation, inverse distance weighting (IDW), Kriging interpolation, etc. For environment-related area, IDW and Kriging interpolation are commonly used[2,3] and applied in this study.

3.1 Interpolation methods

(1) IDW method

IDW interpolation is one of popular interpolation methods and uses a non-linear weight value depending on the distance between known and unknown positions. It is also performed using collected information in two dimensions. In the process, it requires the assumption that the influence of a known point to any unknown point decreases with the distance.

$$Z(x) = \frac{\sum_{i=1}^{n} Z(x_i) d_i^{-m}}{\sum_{i=1}^{n} d_i^{-m}} \quad (6)$$

where, x is the unknown point, d_i is the distance from a known point (i), x_i is the position of a known point (i) and m is the weight value.

Table 3. HAEI's and corresponding air quality states

HAEI	~20	20~50	50~80	80~90	90~97	97~
Air quality	Very bad	Bad	Slightly bad	Average	Good	Very good

Table 4. States of air quality, HAEI's, and the corresponding air pollutant concentrations

Air Quality	HAEI	SO_2 [ppb]	NO_2 [ppb]	O_3 [ppb]	CO [ppm]	PM_{10} [$\mu g/m^3$]
Very good	97~	~9	~9	~6	~1.5	~12
Good	90~97	9~30	9~30	6~20	1.5~5	12~40
Average	80~90	30~60	30~60	20~40	5~10	40~80
Slightly bad	50~80	60~150	60~150	40~100	10~25	80~200
Bad	20~50	150~240	150~240	100~160	25~40	200~320
Very bad	~20	240~	240~	160~	40~	320~

This equation is developed to equation (7), which implies the relationship between the weight value (m) and the influence by adjacent points. As m increases, the influence of a farther point decreases.

$$Z(x) = \sum_{i=1}^{n} Z(x_i)\lambda_i \tag{7}$$

where, $\lambda_i = \dfrac{d_i^{-m}}{\sum_{i=1}^{n} d_i^{-m}}$, m = weight value

(2) Kriging method

Kriging interpolation is similar to IDW in the viewpoint of estimating unknown information using adjacent known information, but contains further developed theory for the relative weight value (λ_i). Kriging interpolation is rather a series of statistical algorithms than the geometric distance-based function in IDW. In the process, the semivariance of calculated information is firstly calculated and used to develop a semivariogram model which has a function to validate inter-correlation among observed information. From this, a proper mathematic model for next step is determined and the relative weight value (λ_i) is then calculated.[8,9]

In general, a standard deviation, *i.e.* root mean squares error, is a scalar in equation (8), a semivariance is also given as a vector in equation (9).[3,4]

$$s = \sqrt{\frac{\sum (x_i - x)^2}{N-1}} \tag{8}$$

s : *Standard deviaton (Root mean squares error)*
N : *Nmber of observation*
x_i : *Value at point i*
x : *Most probable number of value*

$$\gamma(h) = \frac{1}{2}\frac{\sum\{z(x_i) - z(x_i + h)\}^2}{N} \tag{9}$$

$\gamma(h)$: *Semivariance*
$z(x_i)$: *Observation at the point* x_i
$z(x_i + h)$: *Observation at the point* $x_i + h$
N : *Nmber of divide h*

3.2 Construction of spatial database

Monitored and collected air quality information are processed into spatial database after a series of statistical pre-processes. The work for this stage is conducted in two large categories; the process of *spatial* information and *attribute* information.

In the process for spatial information, the digital map (1:25,000 scale) produced by National Geography Institute Ministry of Construction & Transportation (NGI) was firstly converted into a compatible format, so-called DXF format. This converted file is then imported into the GIS tool in this study and stored as a separate layer with its Transverse Mercator (TM) coordinates. The TMS stations are also marked on the database. Fig. 2 shows an example for spatial data processing.

The stage for attribute information is the process to add attribute information to the built database. The attribute information is firstly edited and modified using a worksheet and then converted to a database file, *e.g.* MDB for Microsoft Access®, which is compatible with the GIS tool. In this study, the TMS monitored data were inputted with allocated identifications. Fig. 3 shows a part of attribute information.

4. Mapping air quality

Using the GIS tool with the built database, the ambient air quality information in Capital Area including Seoul, Incheon, and Kyounggi-Do, is mapped. As

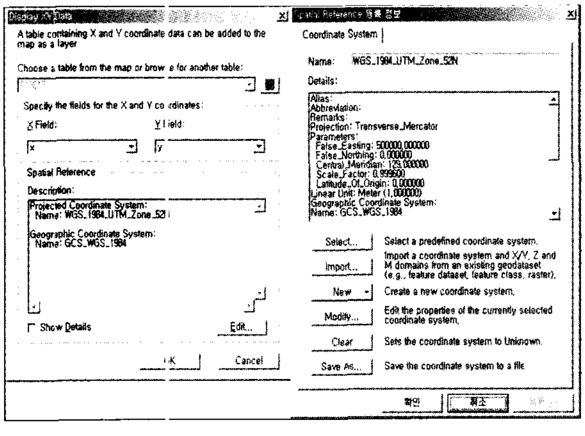

Fig. 2. Example for spatial data processing.

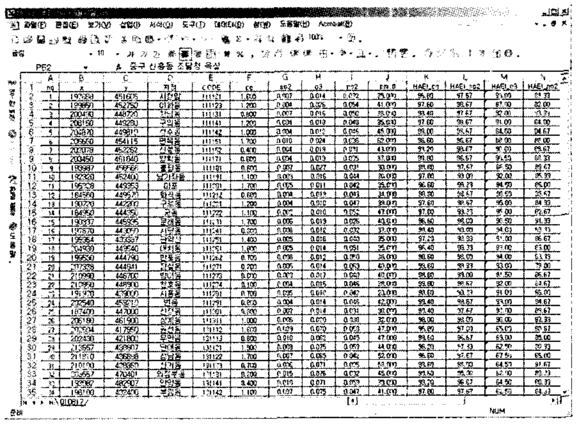

Fig. 3. Example for attribute data processing.

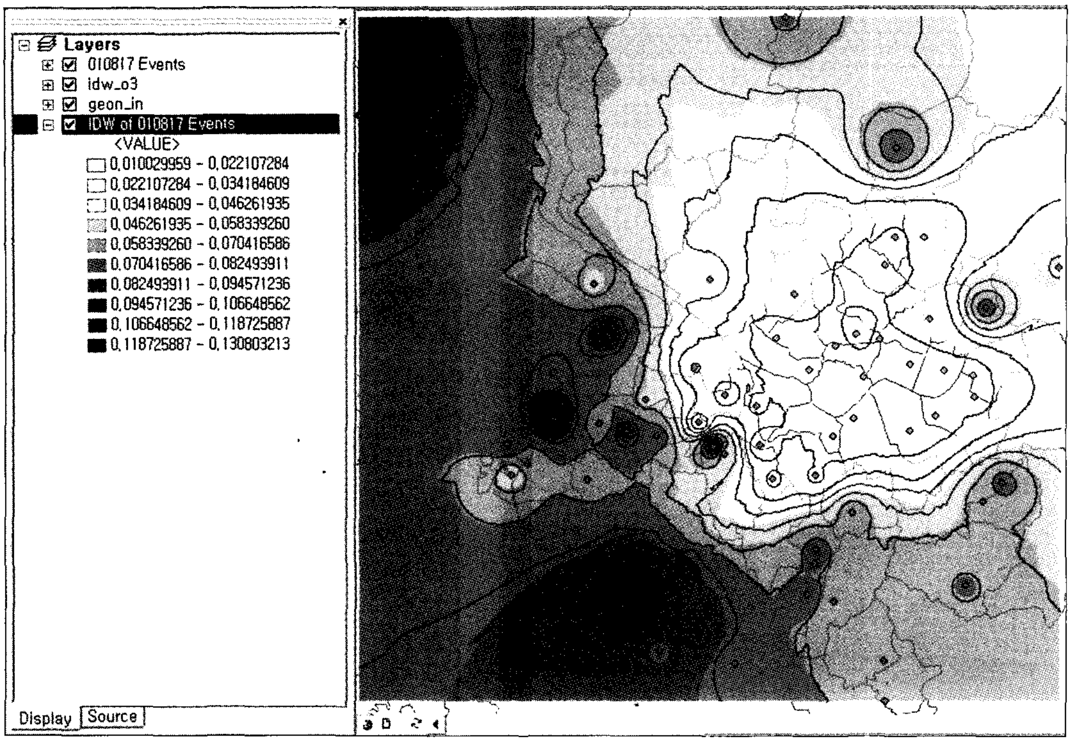

Fig. 4. Ozone concentration using IDW method.

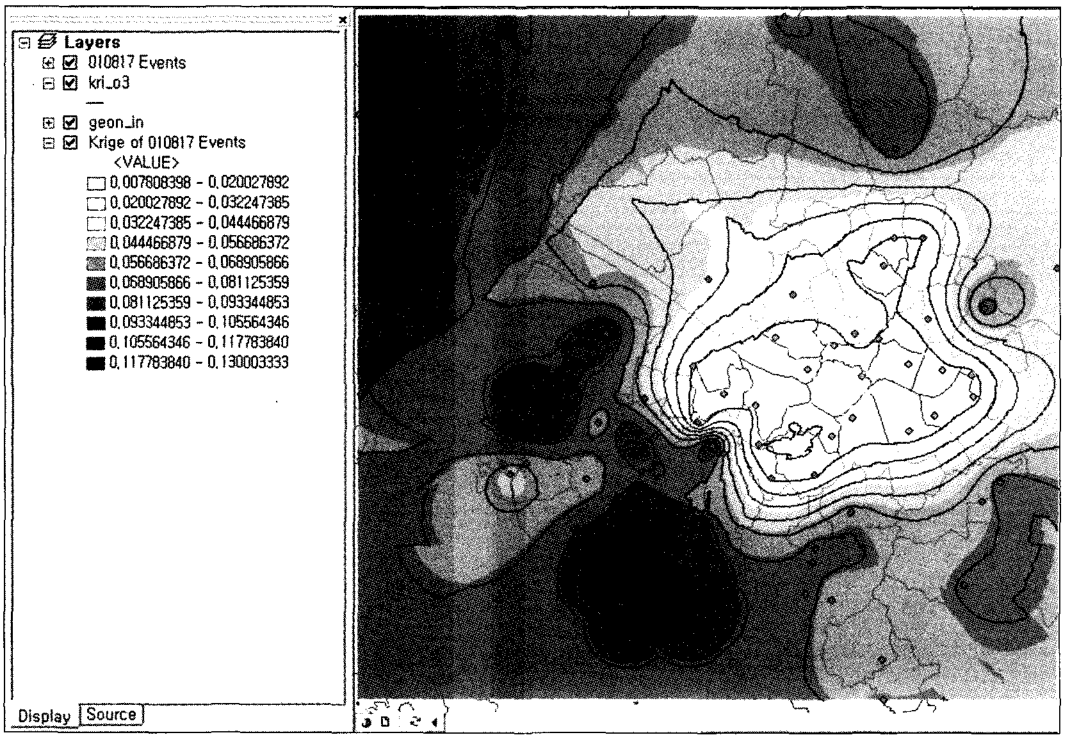

Fig. 5. Ozone concentration using Kriging method.

summarized in Table 2, a typical summer day (Aug. 17, 2001) was selected for spatial analysis using IDW and Kriging interpolation.[5,6,7]

The analysis was conducted for those five air pollutants in NAAQS. Figs. 4 and 5 display the result of ozone concentration used IDW and Kriging method

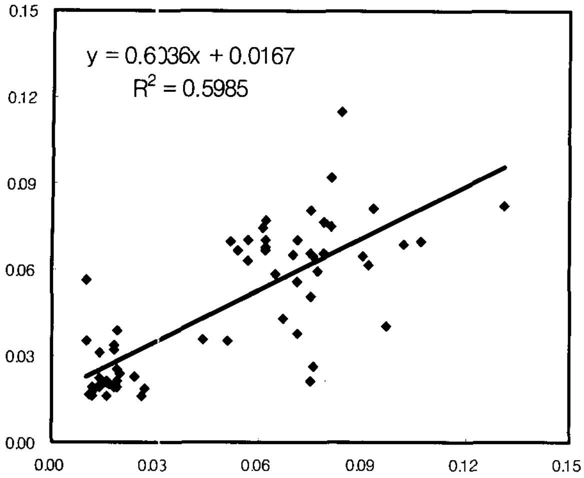

Fig. 6. Correlation of raw and interpolated data using IDW method.

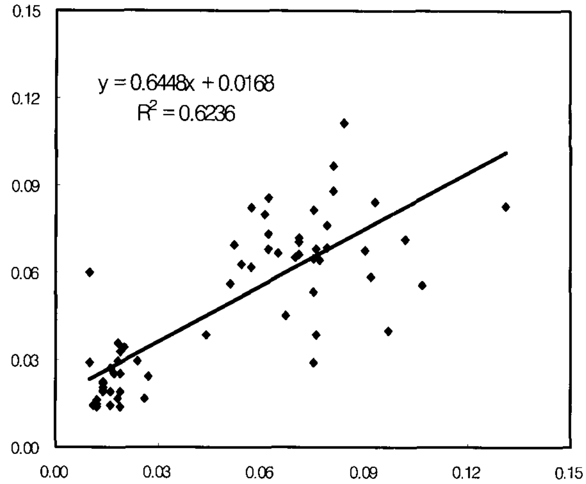

Fig. 7. Correlation of raw and interpolated data using Kriging method.

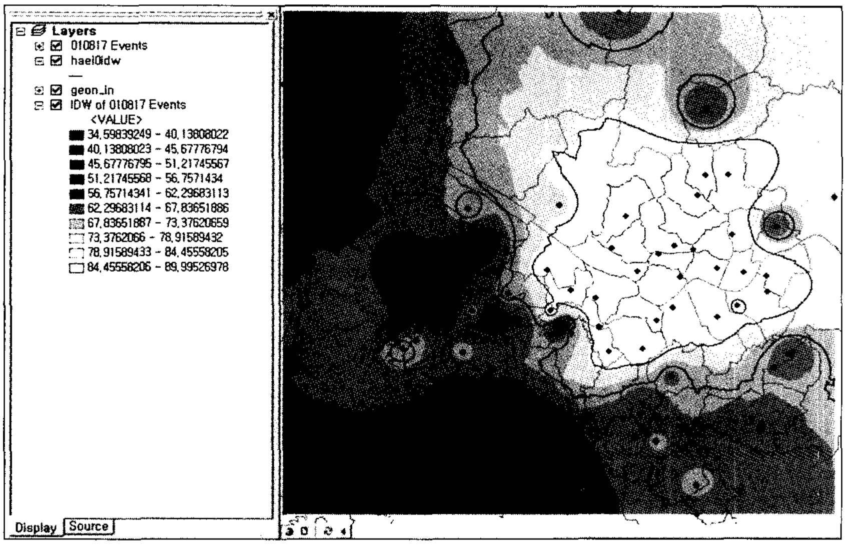

Fig. 8. Air quality index interpolated by IDW.

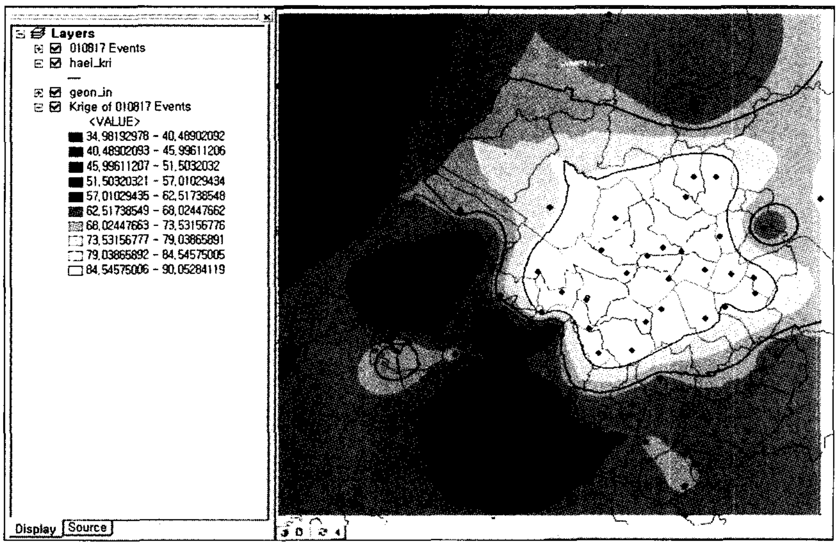

Fig. 9. Air quality index interpolated by Kriging.

respectively.
As plotted, the state of ozone concentration in central Capital Area is worse than the rest area.

From the error analysis using the raw and interpolated data, the correlations (R^2) are found to be 0.5985 for IDW and 0.6236 for Kriging. It proves that the results using both methods are statistically significant. Although Kriging interpolation is further developed in GIS technique than IDW, both techniques are acceptable for the analysis of air quality information.

The processed air quality information was then used to determine HAEI's. Figs. 8 and 9 plot the corresponding HAEI's to the air quality information. From this, the GIS application in this study is confirmed to be capable of presenting the poor air quality in Central Capital Area. It also implies that the state of ambient air quality, *i.e.* the corresponding HAEI, is strongly influenced by the ozone concentration.

5. Conclusion

Managing ambient air quality especially in urban area is one of urgent tasks that we need to solve. In this study, a GIS technique is applied to support and ease current air quality management approach. From this study, the TMS-monitored air quality information is analyzed for governmental officers, engineers, etc. to establish any possible strategy to improve current air quality. This study well proves that current GIS technique has a great deal of potential to analyze those air quality information, to produce useful information, and to ease the efforts for air quality improvement.

Concerning about the data interpolation, the discrepancy caused by applying different method was ignorable, although Kriging method is further developed.

As well known, the state of air quality in Capital Area, which is worse in the central area and getting better as it travels down to the suburb area, is well demonstrated using GIS application in this study. HAEI analysis also reveals that the air quality in a typical mid-summer day is strongly influenced by the ozone concentration.

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