Effects of land use on the spatial distribution of trace metals and volatile organic compounds in urban groundwater, Seoul, Korea

Seong-Sook Park[1] · Seong-Taek Yun[1] · Gi-Tak Chae[1] · Soon-Oh Kim[2]

1. Introduction

In an urban area such as Seoul, there are many potential sources leading to groundwater contamination, such as domestic effluents, septic tanks, leaky sewage systems, gasoline stations, leachate from waste disposal sites, and spillage from industrial sites. The urban groundwater quality primarily depends on land use. Compared to groundwaters in less-developed urban settings, therefore, those in developed settings are characterized by increased concentrations of major and/or minor elements and the changes in oxidation-reduction condition. A myriad of groundwater pollution sources exist in Seoul and are considered to be closely related to land use. Thus, a good understanding on the control of groundwater contamination through land use will be most important and effective for the sustainable management of groundwater in Seoul. However, little is known about the relationships among groundwater quality, anthropogenic contamination sources, and land use in Seoul. Furthermore, contamination of Seoul groundwater by either volatile organic compounds (VOCs) or trace metals has not been investigated in relation to land use. Thus, the present work was initiated to elucidate the impacts of land use on groundwater contamination by trace metals and VOCs. Non-parametric statistical analysis was used in this study to test the hypothesis that the concentrations of trace metals and VOCs are significantly affected by land use.

2. Materials and methods

Groundwater samples for the present study were collected during 2000 to 2001 from 57 preexisting wells currently in use. The land use in Seoul City was classified into five categories: less-developed, residential, agricultural, traffic, and industrial (Fig. 1). Samples for trace metal were analyzed using ICP-MS. The RSD values determined from repeated analyses of standards and duplicate or triplicate samples were less than 5%. Sixty-nine compounds belonging to VOCs were analyzed at the Korea Institute of Science

주요어: Urban groundwater, Trace metals, Volatile organic compounds, Non-parametric statistical analysis

1) Department of Earth & Environmental Sciences and the Environmental Geosphere Research Lab (EGRL), Korea University, Seoul 136-701, Korea (styun@korea.ac.kr)
2) Department of Earth & Environmental Sciences, Gyeongsang National University, Jinju 660-701, Korea

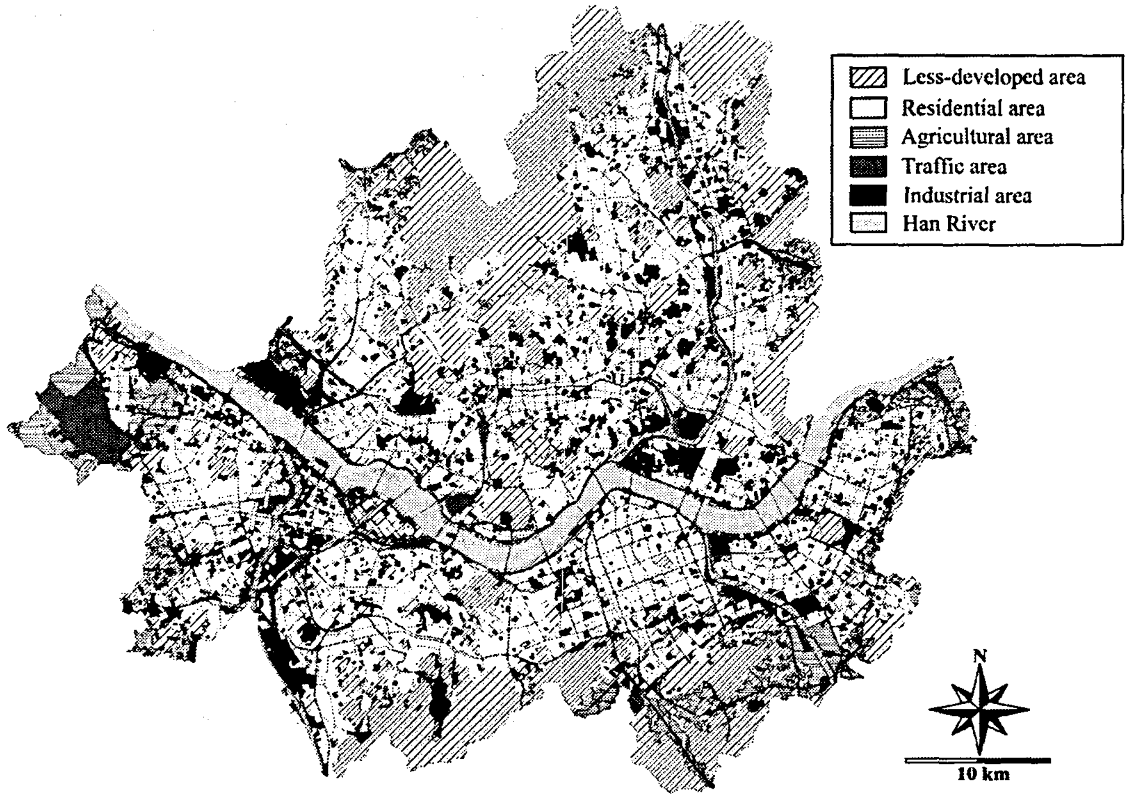

Fig. 1. Land use map of Seoul, Korea

and Technology (KIST) using a Gas Chromatographer (model HP5890) directly interfaced with a HP5970 mass selective detector(MSD). The analyses of field and laboratory duplicates showed the RSD values of <10%. Non-parametric statistical analysis (Kruskal Wallis test in the software package SPSS 10.0) was performed in this study to verify if significant statistical differences were present among land-use categories in terms of the concentrations of trace metals and VOCs. The null hypothesis that the concentration of individual chemicals is not significantly different according to land use was tested using the KW test.

3. Results and discussion

3. 1. Trace metals

Figure 2 summarizes the concentrations of trace metals (Cd, Cu, Pb, Zn, Cr, Fe, Mn, As) in relation to land use in Seoul. Comparison of the data with the U.S. EPA's Maximum Contaminant Levels (MCLs) and Korea Drinking Water Standards (KDWSs) showed that most of the considered metals did not exceed the regulation levels. However, some localities showed the exceeding levels of Fe (2 sites in the traffic areas and 3 sites in the industrial areas), Mn (2 sites in the residential areas, 1 site in the traffic areas, and 3 sites in the industrial area), and Cu (1 site in the traffic areas). According to the land use type, the concentrations of most trace metals were remarkably low in the less-developed areas. On the other hand, agricultural areas are characterized by high concentrations of Zn (avg. 229 g/l); traffic areas by Cu (avg. 186 g/l); and industrial areas by significant enrichments of most metals such as Fe (avg. 2276 g/l), Mn (avg. 248 g/l), As (avg. 4.21 g/l), Cr (avg. 4.15 g/l), Pb (avg. 3.20 g/l), and Cd (avg. 0.09 g/l). The Kolmogorov-Smirnov (KS) test was performed on the distribution of trace metals to determine whether parametric or non-parametric tests might be successfully employed. Because all the *P* values were smaller than the significance level of 0.05, the distribution of all the trace metals was interpreted as non-normal. Therefore, a non-parametric test was used to investigate the effect of land use on the distribution of trace metals. The Kruskal-Wallis (KW) test was applied to the proposed null hypothesis. The results showed that *P* values of six metals (Fe, Mn, As, Cr, Pb, Cd) are smaller than the significance level of 0.05, which indicates that at the 95% confidence level, the distribution of those six metals in Seoul groundwater is significantly changed with the land use. Therefore, it is suggested that anthropogenic contamination with respect to trace metals such as Fe, Mn, As, Cr, Pb and Cd has been proceeding in the industrial, traffic and residential areas of Seoul.

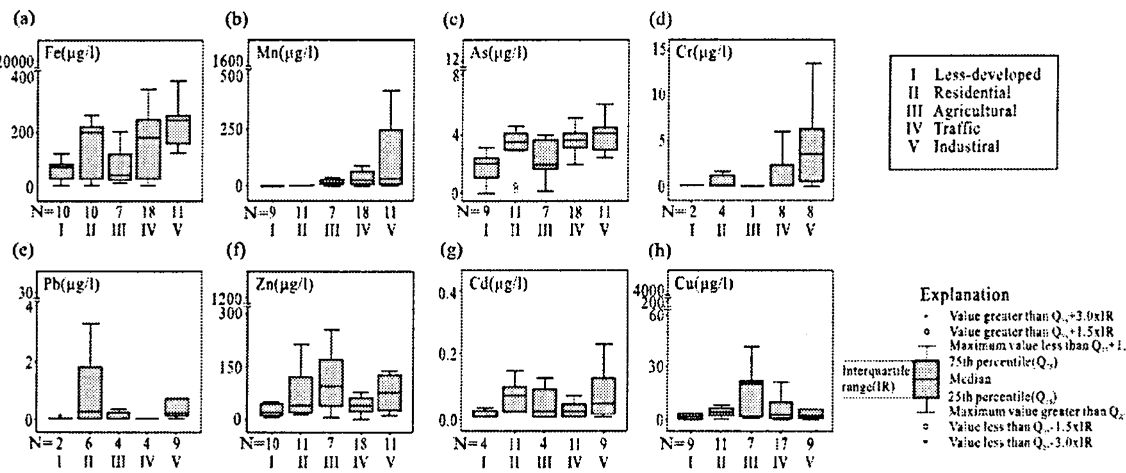

Fig. 2. Box plots of trace metal concentrations in urban groundwater, Seoul, Korea

3. 2. Volatile Organic Compounds

A total of 69 compounds of VOCs were analyzed in this study. These are 47 species of chlorinated compounds (28 halogenated alkanes, 10 halogenated alkenes, 9 halogenated aromatics), 18 species of gasoline-related compounds (3 aromatic hydrocarbons, 14 alkyl benzenes, 1 ether) and 4 other species. Among 69 chemicals analyzed, 19 species were detected in Seoul groundwater. VOCs belonging to the chlorinated hydrocarbons were most frequently detected. A total of 16 chlorinated compounds were detected in a few localities, which include 12 species of halogenated alkanes [methylene chloride, chloroform, carbon tetrachloride, bromodichloromethane, dibromochloromethane, bromoform, 1,1-dichloroethane (1,1-DCA), 1,1,1-trichloroethane (1,1,1-TCA), 1,2-dichloroethane (1,2-DCA), 1,2-dichloropropane, 1,1,2-trichloroethane (1,1,2-TCA), 1,1,2-trichloro-1,2,2-trifluoroethane (CFC113)] and 4 species of halogenated alkenes [cis-1,2-dichloroethene (c-DCE), trichloroethene (TCE), tetrachloroethene (PCE), 1,1-dichloroethene (1,1-DCE)]. Among 18 analyzed species of gasoline-related compounds, only two species of alkyl benzenes (toluene, tert-butylbenzene) and one species of ethers [methyl tertiary butyl ether (MTBE)] were detected. On the other hand, halogenated aromatics and aromatic hydrocarbons were not detected at all.

The kinds and concentrations of the VOCs detected in this study are similar with those reported for shallow urban groundwaters across the United States. A comparison of data with the U.S. EPA and Korean standards for drinking water showed that some compounds from a few localities exceeded the levels, such as TCE in six sampling sites (1 site in the residential areas, 1 in the traffic areas, and 4 in the industrial areas), PCE in 8 sites (1 site in the residential areas, 4 in the traffic areas, and 3 in the industrial areas), 1,2-DCA in one site of the industrial areas, and 1,2-dichloropropane in one site of the industrial areas. In relation to land use, more than one compound of VOCs was detected in all samples from the traffic, industrial, and residential areas. The present study shows that anthropogenic contamination especially by TCE and PCE should be paid a special attention. The very high concentration of TCE was observed in the industrial areas (avg. 309.1 g/l), followed by the traffic (avg. 13.3 g/l), residential (avg. 9.5 g/l), agricultural (avg. 4.5 g/l), and less-developed (not detected, <0.2 g/l) areas. Likewise, the average concentration of PCE was significantly higher in the industrial areas (63.4 g/l) than the residential (6.8 g/l), traffic (6.0 g/l), and less-developed and agricultural areas (not detected, <0.5 g/l) (Fig. 3). The measured concentrations of TCE and PCE frequently exceeded the U.S. EPA's and Korean Drinking Water Standards in many of the industrialized and traffic areas. This indicates that TCE and PCE may cause serious impacts on ecosystems and human health and therefore should be carefully monitored in Seoul.

A non-parametric statistical test was conducted to confirm the dependence of VOCs contamination upon land use. The KS test showed that all the *P* values for detected VOCs were smaller than the significance level of 0.05, suggesting that the distribution of detected species can be considered to be non-normal. Sequentially, the KW test was performed as a non-parametric statistical analysis to compare the distribution of VOCs among different land-use types. The results showed that for seven compounds (toluene, TCE, PCE, chloroform, carbon tetrachloride, bromodichloromethane, CFC113) among 19 detected species, the *P* values are smaller than the significance level (0.05). This may indicate that the occurrence of these compounds closely depends upon the land use. Accordingly, those seven compounds may reflect the progress of anthropogenic contamination and can be effectively used as indicators to identify the degree of anthropogenic contamination in relation to land use. In comparison, six trace metals (Fe, Mn, As, Cr, Pb, Cd) with the *P* values of <0.05 can also be recommended as indicators of anthropogenic contamination in Seoul groundwater. Furthermore, three compounds (TCE, PCE, chloroform) among the seven species are parameters in evaluating the effect of land use on groundwater likely the best quality in Seoul, because they occur frequently and show relatively high concentrations.

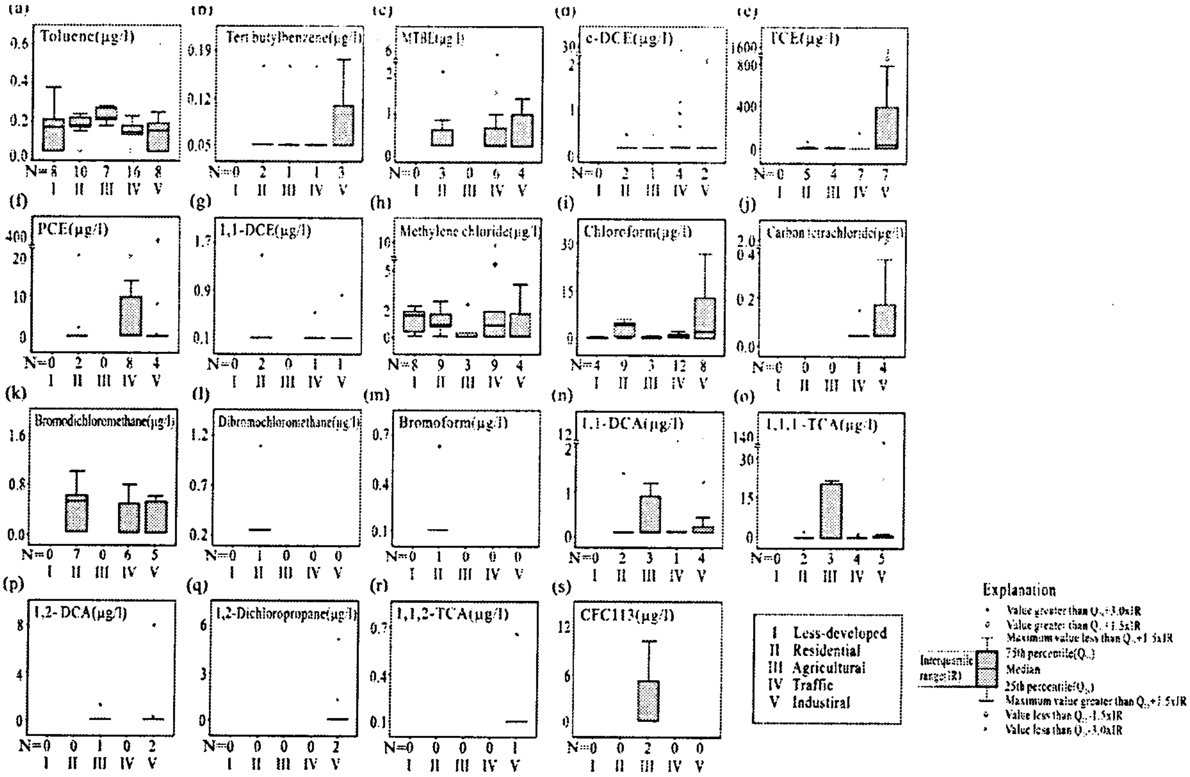

Fig. 3. Box plots of VOCs concentrations in urban groundwater, Seoul, Korea