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Spatiotemporal Analysis of Environmental Radioactivity in Soil around Nuclear Plant

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1. Introduction

Geostatistical techniques make it possible to qualitatively and quantitatively analyze spatiotemporal inherent characteristics of environmental radiation or radioactivity. Spatial patterns and trend analysis of environmental radioactivity, e.g., ^{137}Cs and ^{40}K, in soil around nuclear facilities (Kori, Wolsung, Yeonggwang, Uljin, and Daejeon) will be investigated and discussed.

2. Methods and Results

A data set which seems random to the eye may have a property of strong spatial correlation. Geostatistical approach utilizes this fact that variations of data are not always random, but have some spatial structures. It is based on the regionalized variable (RV) theory which takes into account the random and structured characteristics of spatially distributed variables.

Consider a field of A, for which a set of n values are measured [$Z(x_i)$, i=1,…,n], in which each x_i identifies a coordinate position in the space. Each $Z(x_k)$ can be considered a particular realization of a certain random variable for a particular fixed point, x_k. The regionalized variable $Z(x_i)$, for all x_i inside A, can be considered a realization of the set of random variables [$Z(x_i)$, for all x_i inside A]. This set of random variables is called a random function [1]. Application of RV theory assumes that the covariance between any two locations in A depends only on the distance and direction of separation between the two locations and not on their geographic location (second-order stationarity). The assumption of second-order stationarity implies that the mean and variance are functions of separation distance, h, only. However, most of the physical data do not satisfy this condition, because the variance increases with the size of the domain. Therefore another less stringent hypothesis, known as the 'intrinsic hypothesis', is used. This intrinsic hypothesis does not require the variance of Z to be finite, but the variance of the first-order increment, [Z(x+h)-Z(x)], to be finite and second-order stationary;

$$E[Z(x+h)-Z(x)] = m(h) \quad (1)$$
$$Var[Z(x+h)-Z(x)] = 2\gamma(h) \quad (2)$$

where $m(h)$ is the mean and $\gamma(h)$ is the variance of the increment known as a semivariogram. The application of variogram modeling allows a quantification of the spatial variability. The experimental semivariance γ as a measure for the spatial correlation structure at a given distance h is:

$$\gamma_e(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i+h)-Z(x_i)]^2 \quad (3)$$

where h (called lag) is the distance between two sampling positions, $Z(x_i)$ is the measured value at the position x_i and $N(h)$ is the number of pairs with the distance h.

The spatial distributions of measured values are visualized in contour maps using ordinary kriging. Kriging is a method for making optimal, unbiased estimates of RVs at unsampled locations using the structural properties of the semivariogram and the initial set of measured data. A useful advantage of kriging compared with the other traditional linear interpolators is that an error term, expressing the estimation variance or uncertainty in estimation, is calculated for each interpolated value. Moreover, kriging has the property of exactitude, i.e., it returns the datum value for the estimate if the location to be estimated coincides with a sampled location. Kriging is also known as the best linear unbiased estimator (BLUE). It is linear because the kriging estimate at an arbitrary point X based on N neighboring sampled values is given as:

$$Z^*(x_0) = \sum_{i=1}^{N} \lambda_i Z(x_i) \quad (4)$$

where Z are measured value at the observed location x_i and Z^* are estimated value at the interpolated location x_0. The theory of geostatistics has been described and well documented in a wide number of texts [1,2,3,4,5]. Geostatistical routines from the software package GSLIB [4] are programmed using Matlab® [6] to analyze spatial variability of environmental radioactivity such as ^{137}Cs and ^{40}K, which are artificial and natural gamma radioisotopes, respectively [7,8].

Figure 1 displays contour maps for the spatial variability of concentration of ^{137}Cs around Kori units. Regional distribution of ^{137}Cs shows that any peculiar increase of artificial radioactivity level around nuclear site is not observed during 2003~2004. ^{137}Cs generally shows a nationwide distribution in Korea because it is known to be a leftover due to fallout of an atmospheric nuclear test of the powers in past 1950~1960's.

In order to test whether two populations are identical or not, i.e., to test the mean or median difference between two independent samples which may have missing data, we use the Wilcoxon rank sum (WRS) test which is the nonparametric alternative to a two-sample t-test under the assumption of normality [9]. Although four groups of ^{137}Cs does not look similar to the eye as shown in Figure 2, the test reveals that all groups are not significantly different with the level of significance of 5%; that means no increase or decrease in ^{137}Cs concentration during two years of 2003 and 2004.

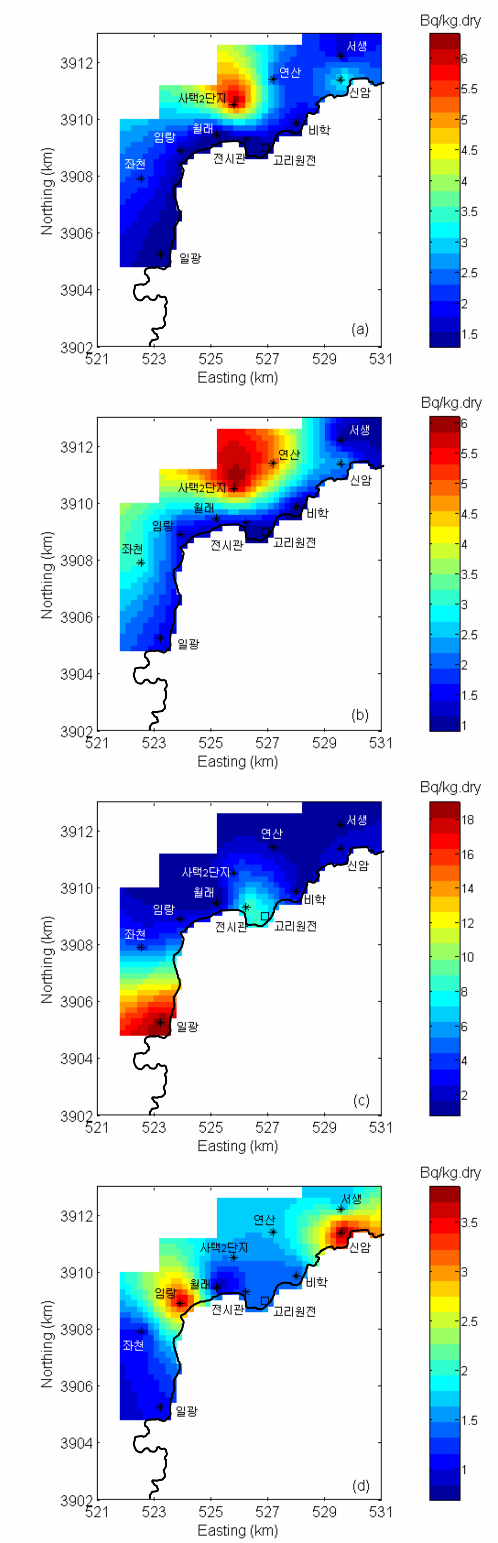

Figure 1. Geostatistical prediction maps of ^{137}Cs in soil around Kori nuclear power plant (a, b, c, and d above correspond to the date of spring and fall of 2003, spring and fall of 2004, respectively).

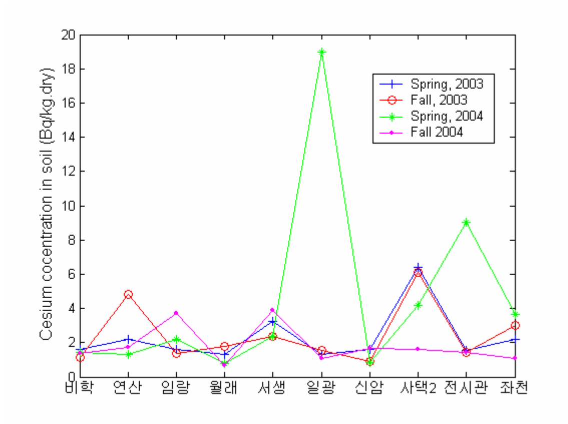

Figure 2. Spatiotemporal variations of ^{137}Cs in soil around Kori nuclear power plant.

3. Conclusion

A visualization tool for the spatiotemporal analysis and prediction of environmental radioactivity is developed using geostatistics and Matlab®. It can be used as the web-based real-time information system along with IERNet of KINS. The developed technique can be also applied to the radiation environmental impact assessment and the formulation of risk map of the public.

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