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A Flex and ArcGIS Server based system for farmland environmental quality assessment and prediction in an agricultural producing area

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ABSTRACT

A farmland environmental quality assessment and prediction system was developed based on the database technology, WebGIS and model theory to provide intuitional information of farmland environmental pollution situation and the pollution trend for scientific decision making regarding monitoring soil quality. The designed system could be used for the query of agricultural environmental information, assessment of farmland environmental quality, and forecasting of farmland environmental pollution. An environmental quality assessment model was developed and integrated in the system by single factor index and weighted pollutant index method. The application of the assessment model showed that the single factor index of soil heavy metal Hg in the study area reached light pollution levels. The pollutant area occupied 21.3% of the entire study area. The other five soil heavy metals (Pb, Cu, Cd, Cr, and As) were in safe levels of soil environmental quality assessment classification standard. The average weighted pollutant index was 0.54, indicating good soil environmental quality. Most parts of the region was in safe level. An exponential smoothing forecasting model was established based on the time series characteristics of the heavy metal pollution in the agricultural producing area to predict heavy metal pollution. The analytical results showed that the prediction accuracy of the models was approximately 90%, indicating that the exponential smoothing model can fit the variation of heavy metal pollution.

1. Introduction

The quality of agricultural producing area, the main environmental factor of planting, directly determines the quality and quantity of agricultural products. The characteristic of agricultural producing area contaminated by heavy metals is commonly influenced by the total heavy metal contents. Heavy metals in soil have two main sources. One is the enrichment of heavy metals under the natural environment, which includes weathering from high background source rocks and minerals such as black shale. The other is the anthropogenic contamination of heavy metals caused by the excessive use of chemical fertilizers and pesticides, industrial and municipal discharges, animal wastes, and sewage irrigation (Tiller, 1989; Li et al., 2009; Chon et al., 2011). Soil polluted by heavy metals is difficult to biodegrade, and heavy metals can persist in the soil for thousands of years. These pollutants may be further transferred from the soil to underground water and plants, thereby posing a long-term threat to human health, plant growth, and the environment (Folinsbee, 1993; Liu et al., 2013). This situation is a serious concern because of the potential human health risks.

Hence, the development of a farmland environment quality assessment and prediction system is necessary to monitor soil heavy metal accumulation level and provide scientific decision support for soil heavy metal control.

Despite the absence of a unified assessment system, many studies have provided valuable information on soil environment quality assessment. Various assessment methods were used to evaluate soil environmental quality. These methods include fuzzy comprehensive assessment (Chen et al., 2012), grey clustering (Liu et al., 2009), and index assessment (Glover et al., 2000; Guo et al., 2008). Fuzzy comprehensive assessment and grey clustering consider the fuzzy and comprehensive soil environmental quality, making the calculation relatively complex compared with index assessment. Index assessment is the most frequently used method, which includes single factor pollution index method, superposition index calculation method, Nemerow pollution index method, and weighted pollutant comprehensive index method. The weighted pollutant index method can comprehensively reflect the different effects of pollutants in soil, according to the contribution of pollutants to determine the weight (Wu et al., 2010). The analytic

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hierarchy process (AHP) based on the environmental quality standard of edible agricultural products (HJ/T 332-2006) was used in this study to objectively determine the weight of each assessment factor. AHP was introduced by an American operational research in the early 1970s (Saaty, 1977). It is a multi-criteria decision making method that combines qualitative and quantitative criteria in assessment (Saaty, 1996). To simplify the calculation process, a three-grading AHP method easily accepted by experts and policy makers was applied in the present study to determine the weights (Zhu et al., 1999; Li et al., 2007).

The extent of the problem should be identified to prevent or remediate soil quality impairment from heavy metals. Liao et al. (2004) used the exponential smooth method to establish the mathematical models on the basis of the historical measured data for forecasting the heavy metal concentration. Exponential smoothing prediction is widely applied because it does not need to store historical data and consider the importance of each phase of the data. The farmland environmental quality is a historical process that slowly and steadily changes with time. In addition, the process has one-way trend features that conform to the application condition of time series methods. At the same time, the measured values of heavy metals in the agricultural soil reflect the current quality situation and the historical status, facilitating the creation of a time series. In the present study, the exponential smooth method was selected to predict the accumulation trend of heavy metals in the farmland.

Soil quality has time–space-varying characteristic. With the help of WebGIS technology, the developed system could well organize agricultural environment resources as well as integrate soil quality assessment and soil heavy metal accumulation prediction models. WebGIS promotes the sharing and synthesis of multi-source data and enables widespread sharing of spatial data and geoscience models (Qu et al., 2002). WebGIS technology can also be applied to decision support systems for the management of agricultural production and pollution emergency decision support system (Qiao and Wu, 2003; Qi et al., 2008; Qian et al., 2012). At present, the systems mentioned above mainly use the C/S model of GIS system. Some studies have applied the WebGIS system, which uses the traditional dynamic web technologies (ASP.NET and JavaScript) combined with the map control. However, this system is still limited by scarce client interaction, poor geospatial information expression, monotonous data transmission and update method, and difficult maintenance. To overcome the flaws of the traditional WebGIS system, Flex technology was applied in the developed system.

The objective of this study is to develop a farmland environment quality assessment and prediction system by investigating the heavy metal content (Pb, Hg, Cd, Cu, Cr, and As) in an agricultural producing area. The designed system could monitor soil heavy metal accumulation level and provide scientific decision support for soil heavy metal control. The designed system could also provide information on the current soil quality, heavy metal accumulation level in the future, and regulatory thresholds for pollutants.

2. Materials and methods

2.1. Sample processing and analysis

The experimental site was in Bincheng District, Shandong Province. It is located in the North China Plain. The studied area (117.47–118.09°E, 37.13–37.36°N) has a total area of 1040.06 km^2. The area is composed of moist and solonchak soils.

To assess farmland environmental quality, 47 soil samples were collected from different sides from 21 to 23 April 2012. The distribution map of the 47 sampling points and experimental field is shown in Fig. 1. A handheld global positioning system device was used to record the sampling position. To build the environmental quality prediction model, the soil samples were collected every three months from January 2010 to April 2013 at the experimental field. Fourteen sets of data were acquired. At each sampling point, four sub-samples were taken in block range and then mixed to obtain a composite soil sample. The soil samples at each sampling location were taken at a depth of 0 cm to 20 cm. After the soil

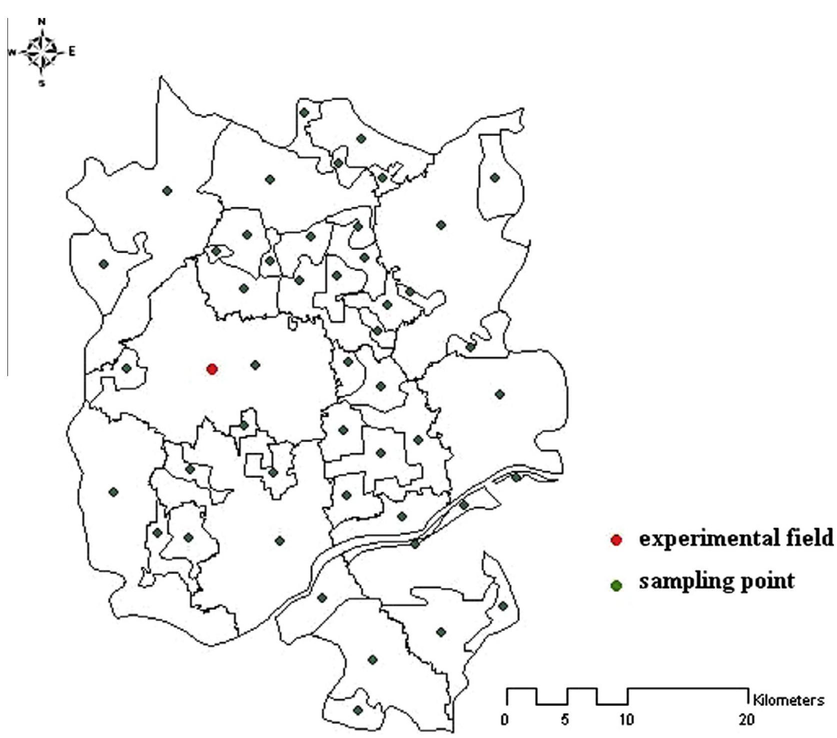

Fig. 1. Distribution map of sampling points and experimental field.