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Establishing Generic Soil Suitability Evaluation Model Using A Relational Database Geographical Information System

Kyoo-seock Lee
Lab. for Geographical Information Systems
Dept. of Landscape Architecture
Sung Kyun Kwan University
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관계형 데이타베이스 토지정보체계를 이용한 포괄적인 토양적지 평가모델의 수립

이 규 석
성균관대학교 조경학과 토지정보체계연구실
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요 약

토양의 특성은 토지이용에 제한을 가하는 물리적 요소로 활용되고 있으며, 이러한 토양 특성정보는 전통적으로 전문가에 의한 해석에 기초하여 토양도에 서류 형태로 저장, 보관되어 왔다. 최근에 널리 쓰이기 시작하는 토지정보체계(Geographical Information System, GIS)는 종래의 자료저장, 해석기법을 digital database라는 특성을 이용하여, 새로운 자료분석이 가능한 도구를 제공하게 되었다. 본 연구에서는 위상적으로 체계화된(topologically structured) vector형 토지정보체계의 관계형 Database Management System(DBMS)과 토양 전문가의 지식을 결합하여 포괄적인 토양적지 평가모델을 수립한 후, 전문가에 의한 평가, 토양도에 수록된 평가와 각각 비교하였다. 비교한 결과, 본 연구에서 수립된 토양적지 평가모델은 전문가에 의한 평가와 크게 다르지 않았으며, 이는 토양도의 평가와 비교하여서도 마찬가지였다. 따라서, 본 연구에서 시도된 포괄적인 토양적지 분석모델은 계속 발전하여 토지정보체계에서의 전문가 기법으로 활용이 가능하다고 판단되어진다.

Introduction

Soil scientists and land use planners for years have processed and analyzed large volumes of soil characteristic data and maps for soil resource management. Also, they have interpreted sets of soil characteristics for specific land uses or technologies, applying knowledge of technology to the resource information. This time consuming reports of the results of the analyses were in the form of hand prepared tables and maps.

Recently introduced Geographical Information Systems(GIS), computer software that can manage soil characteristics and map information, are tools to aid with the manipulation of the vast quantities of soil information. In contrast to early computer mapping software, topologically structured GIS with a relational database management system(DBMS) provide both cartographically acceptable locational data(maps) and manageable thematic data(characteristics).

Expert systems are being developed in GISs for land use evaluation(Burrough, 1986). Expert systems incorporate the knowledge of an expert about a specific land use or the application of a technology in the software for non-expert use. By combining GISs and the concepts of the expert systems it is believed that the process once done by highly trained and experienced professionals can now be done by the non-expert in less time and with less chance of data handling errors.

The purpose of this study was to determine whether a generic soil suitability expert system using a topologically structured GIS with a relational DBMS could provide similar information as the judgement of an expert. Further the relationship of technologies to the limitations ratings now used in soil survey reports was determined.

Materials Used

Study Site

A 2,230 ha area in the unglaciated hilly terrain of southwestern Dane County in Wisconsin, was selected for study. Typic Hapudolls and Aquic Hapludolls are the dominate soils and are characterized by silt loam surface textures and silty clay loam subsurfaces. Bedrock at depths of less than 180 cm is common.

Digital Soil Database

ARC/INFO and ODYSSEY GISs installed on a VAX/VMS 11/8600 at the Madison Academic Computing Center(MACC) at the University of Wisconsin-Madison, and a remote terminal connected to that system was used for handling the soil data and maps. A Hewlett Packard(HP) 7475A plotter was used to plot the maps.

The study site digital soil data was trimmed from the larger county ODYSSEY data base of the Dane County Land Records Project(DCLRP), University of Wisconsin-Madison, and converted to ARC/INFO format. A feature attribute table was created for encoded soil data in ARC/INFO for soil absorption of on-site wastewaters.

Development of the Generic Soil Suitability Evaluation Model

Application of Expert Systems in Topologically Structured GIS with Relational DBMS

The technique used in ARC/INFO for relational map processing is to handle polygon attribute table whose rows are called records(soil attribute value) and columns are items(soil attribute name) (Morehouse, 1985). The major advantage of this relational DBMS is to allow different kinds of data to be searched, combined, and compared, because this just involves adding or removing a record.

The relational DBMS of the GIS furnishes the data needed to perform the deductive functions of the expert system(Missikof and Wiederhold, 1986). The ARC displays the geographic results as an interpretive soil maps. Figure 1 shows the concept of the generic land use evaluation program developed in this study.

Rule-based Programming

(1) Knowledge Acquisition and Organization

The knowledge for the several types of soil absorption field systems considered in this study was provided by the soil scientist(E. J. Tyler). The knowledge provided by the expert was organized in order that heuristic searches were used-simplifications that effectively limit search for solutions, which is organized with most limiting conditions, then searching the candidate soil map units, not whole map units. For example, in finding soil map units suitable for mound system, only map units suitable for mound-recommended were searched instead of the whole

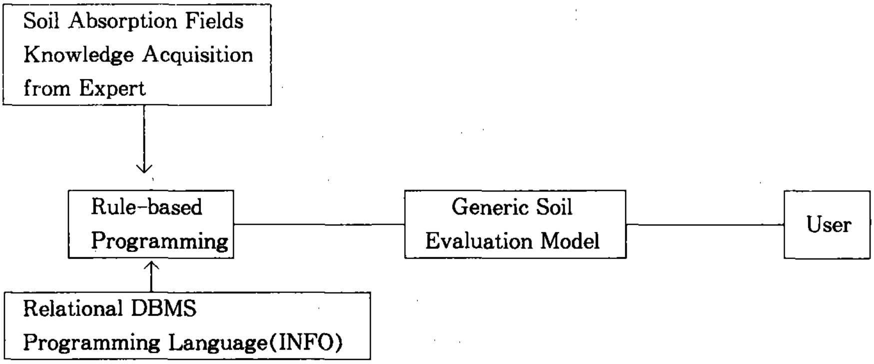

Figure 1. Concept of the Model.

map units, because every soil map unit suitable for mound system is also suitable for mound-recommended system, while the converse is not true.

(2) Knowledge Representation

In terms of structuring knowledge in the program-knowledge representation, rule-based methods were used. If sets of attributes of the soil map unit searched correspond to those defined by the expert, then the map unit is assigned to the corresponding soil absorption field type. The most limiting individual rating was used as an overall rating.

Structure of the Model

The program asks the user to choose the study site. Figure 2 shows the framework of the program. After specifying the study site, the user chooses the type of evaluation. In soil absorption field evaluation, three options were available; 1) to evaluate the whole site by determining what waste disposal system is suitable for each soil mapping unit, 2) to evaluate the specific soil unit for the most suitable type of waste disposal, and 3) to evaluate the user specified soil characteristics for a suitable waste disposal. If several systems are useable, the program shows the most economical system.

In the first option, six types(mound, mound-recommended, at-grade, subsurface system depth, subsurface system depth recommended, and deep subsurface) of waste disposal systems are evaluated using knowledge provided by the expert. At this stage, the program allows the user to specify criteria for evaluating the waste disposal systems if the criteria to be used are

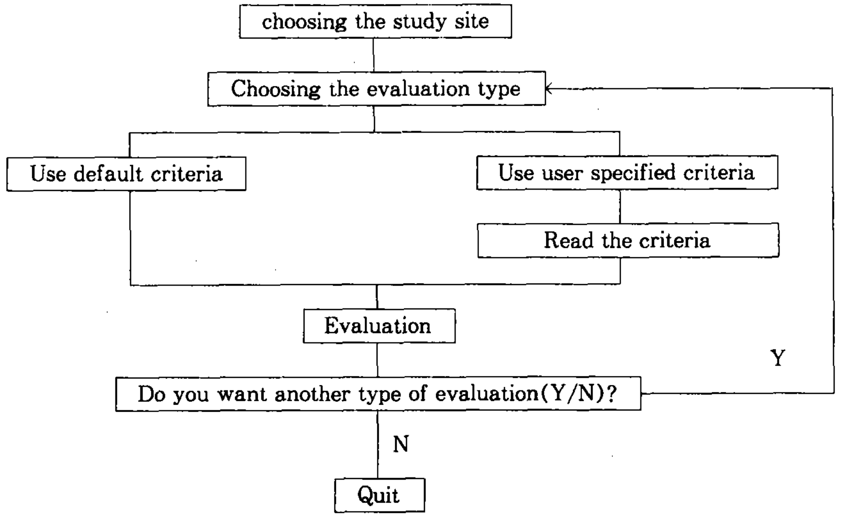

Figure 2. The Framework of the Generic Evaluation Program.

different than suggested by the expert. This change may be based on local rules and regulations on expert knowledge found locally.

After an evaluation is done, the output information is filed externally. The program then allows the user to choose another evaluation or quit the program.

Test of the Model

The model reliability was assessed at the study site in southwestern Wisconsin. There was no other ground truth data available to provide the judgement about how systems evaluations relate to actual land use. So, it was assumed that mapping of soil survey report is correct.

The generic model output was compared with the subjective judgement of an expert encoded in the ODYSSEY, and the limitation ratings in the soil survey report.

The Generic Model vs. the Subjective Judgement of the Expert

Originally, the expert's judgement was based on a probability rating for each type of soil absorption field, for each map unit. However, this probability estimation is based on the subjective judgement. In the comparison, the highest probable soil absorption system, for each map unit, was compared with the generic model since the generic model cannot make this judgements.

Figure 3 is a map showing the kind of soil absorption system recommended for use on various soils at the study site by the program developed in this study. The site consists of 373 soil polygons(59 map units), more than three-quarters of the whole soil polygons tested were classified by this model and the expert do requiring the same technology. Of the 76 soil polygons classified differently(Table 1), most were evaluated only slightly different such as at-grade versus a mound system which are both constructed above the original ground surface.

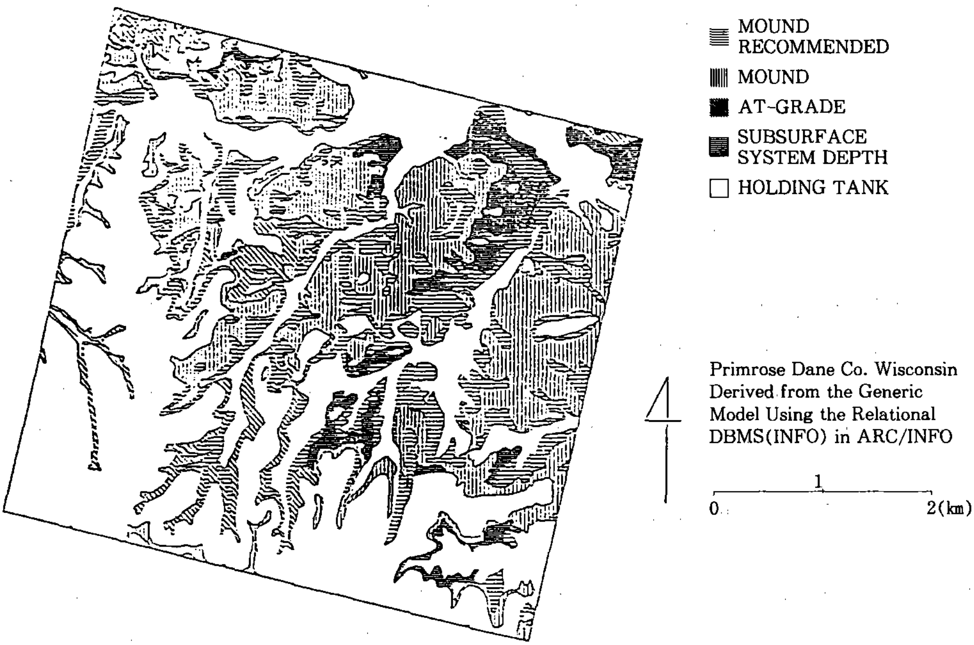

Figure 3. Analytical Evaluation from Generic Model.

Seven soil mapping units(19 soil polygons) were evaluated somewhat or very differently. Of these units, some units showed that the generic model did a better job than the human expert because the former evaluated the map unit based on given rules while the latter might ignore some soil properties of a map unit during the process of evaluating large volumes of data. However, the human expert's judgements were better than the generic model in terms of handling local variations of map units, because the former has adaptive aspects while the latter does the job only as been told.

Table 1. Comparison Results from the Generic Model and the Expert's Judgement

Generic Model	Expert's Judgement					
	Holding Tank	Intercep. Mound	Mound	At-Grade	Intercep Conventional	Conventional
None	159		4		3	
Mound-Recommneded	23	54				
Mound	8	1	68		11	
At-Grade		2	22			
Subsurface Sys. Recom.						
Subsurface System		2				16

Lack of Data Definings

Heterogeniety of soil map units is one of the most serious limitations in the application of soil survey maps for natural resource management. Most detailed soil maps contained up to 15 to 25% different soils within a map unit. The differing soils often have similar characteristics. The generic model, as used by people who are not expert in the field, works similar to the judgement from an expert.

The Interpretation in the Soil Report vs. the Generic Model

The soil report has a different linguistic classification scheme based on four categories for subsurface systems. Soil survey interpretation is done in terms of limitations and soils are listed as being very severely, severely, moderately, and slightly limited. In addition, there are two intermediate rating categories: very severely/moderately, severely/moderately limited. Each evaluation category in the soil report was matched with one of several soil absorption field systems which contained the majority of soil report evaluation category(Table 2). When comparing the limitation ratings with that of the generic model(Table 3), it is seen that certain systems tend to match specific system types(Table 2).

Table 2. Matching Scheme for Comparison among Three Evaluations

Generic Model	Expert's Judgement	Soil Map
Holding-Tank	Holding-Tank	Very Severely Very Sev./Moder.
Mound-Recomm.	Intercep.-Mound	Severe, Sev./Moder.
Mound	Mound	Moderate
At-Grade	At-Grade	
Subsurface Sys. Depth Recomm.	Intercep.-Convent.	
Subsurface Sys.	Conventional	Slight
Deep Subsurface		

Table 3. Comparison Results from the Generic Model and the Soil Survey Report

Soil Survey Report	Expert's Judgement					
	None	Mound Recommended	Mound	At-Grade	Subsurface Sys. Recom.	Subsurface System
Stony	4					
Very Severe	90	36	5			
Very Severe Moderate	66					
Severe	6	39		4		1
Severe Moderate		2	8			
Moderate			75	20		17

It should be noted that at-grade recommendation, as given in the generic model may not be greatly completely different than a moderate limitation as given in the soil survey report. In this test, the mound category was matched with the moderately limited category in the soil survey report. In as much as at-grade and mounds are not greatly different, the moderate category may be constructed to cover at-grade systems depending on the situation.

Figures 4, and 5 are maps showing the comparison between generic model and subjective judgement from an expert, the generic model versus soil survey report, respectively. Therefore, the areas depicted would have different interpretation depending on the method used.

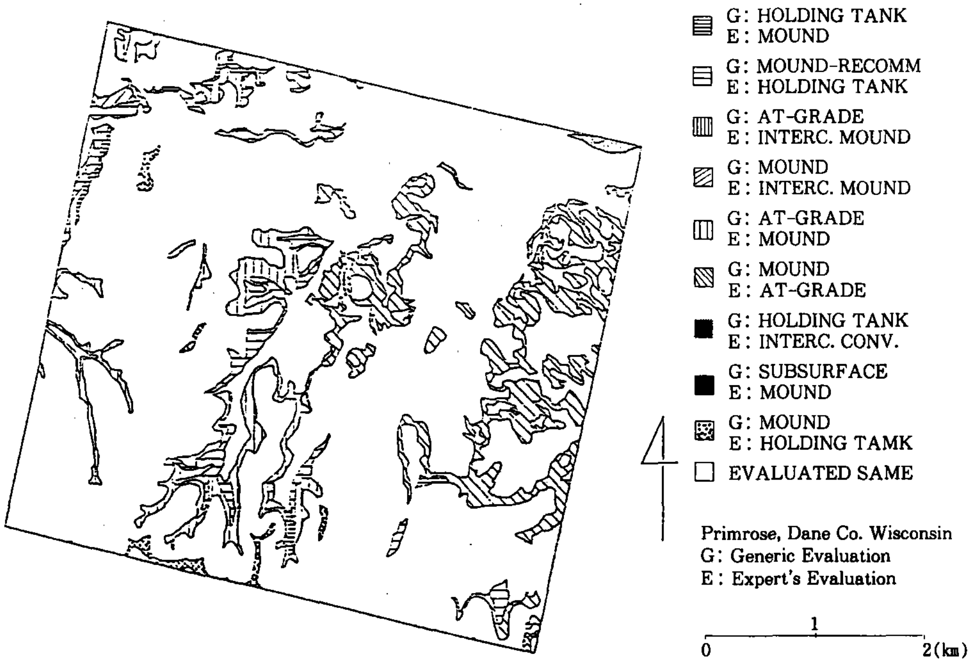

Figure 4. Difference B/T Generic Model and Expert.

The Advantages and Limitations of the Generic Model

Rule based approach with expert judgement was easily combined with relational DBMS. The rule based approach provided the decision rules, and the relational DBMS provided the necessary data quickly. After comparing the results with that from and expert's judgement, it was found the generic model developed in this study can be used advantageously to evaluate various soil absorption field systems. The generic model can provide objective data or judgement for expert's better judgement, and accumulate knowledge which can be stored and transferred easily for future use. It has the predictive power in land use evaluation.

The limitations of the generic model used in this study are 1) its lack of ability to consider soil profile characteristics, and 2) its inability to handle probability concept, and 3) its lack of ability to consider the heterogeniety of soil map units. The first two limitations can be solved by designing more sophisticated programming, and the probability approach requires a more complex programming step and more data than is currently available.

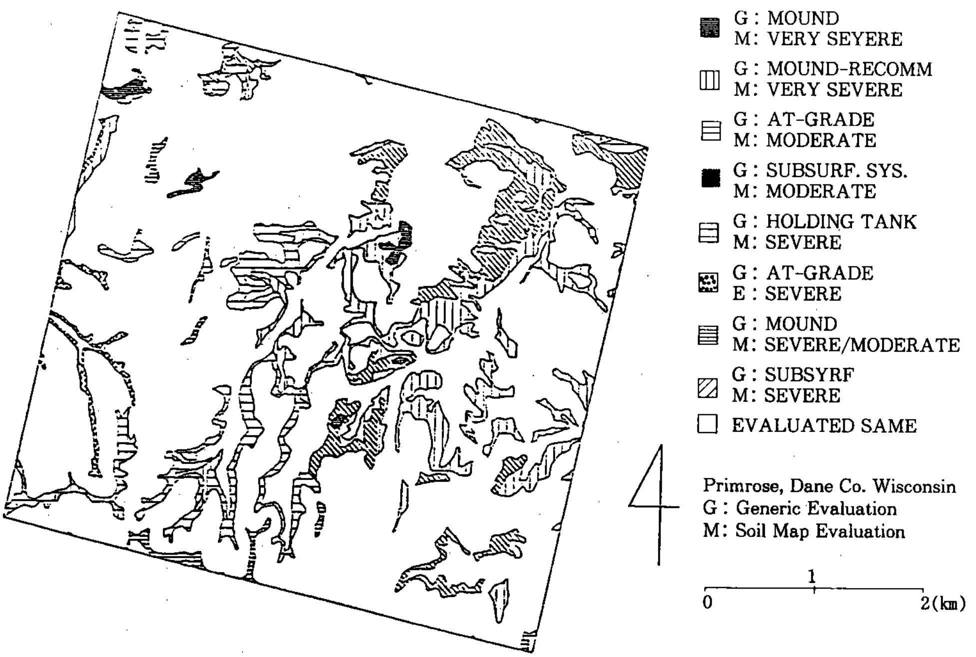

Figure 5. Difference B/T Generic and Soil Map.

However, the last limitation is not easy to handle within vector-based GIS. In order to handle heterogeniety of the soil mapping unit, Burrough(1986) described several approaches including a well-defined central concept, surrounded by a less-defined cloud of observation points or membership function to express the degree to which a cell or area is a member of the set. This fuzziness of attributes is also dependent on the characteristics of the data used, and the location from which it is collected. The heterogeneous characteristic was not included in the generic model used in this study, and is beyond the scope of this research.

Conclusions

The advantage of the generic land suitability model developed in this study is that it can utilize the expert's knowledge within a computer system so that non-expert users can make use of it.

Based on the application of the generic model for soil absorption fields evaluation at the study site, the following conclusions were derived.

(1) The generic model developed in this study is easy to use by non-expert.

(2) The expert can integrate more knowledge of the systems and soils to make for different and hopefully better judgements.

(3) It has predictive power in land use evaluation, and accumulates knowledge which can be easy to transfer.

(4) The soils limitations in the soil survey report can be related to system type in the study site.

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