QUALITATIVE AND QUANTITATIVE LAND EVALUATIONS

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Summary

Land evaluation operated in a traditional or modern system can focus on qualitative or quantitative aspects. Traditional systems are most often qualitative assessments depending largely on experience and intuitive judgement; they are real empirical systems. Parametric systems allocate a numerical value on the most significant land characteristics, and the account for interactions between such significant factors are expressed through a simple multiplication or an addition of single-factor indexes. In statistical systems, correlation and multiple-regression analyses are used to investigate the relative contributions of the selected land characteristics on land suitability. The

single-factor systems try to quantify the influence of individual land characteristics on the performance of the land-use system.

Within modern technologies, expert-system models express inferential knowledge by using qualitative decision trees giving a clear expression of the matching process comparing land-use requirements with land qualities. In fuzzy-set methodologies, the rigid Boolean logic of land suitability as determined by limiting land characteristics is replaced by fuzzy membership functions. Neural-network models have shown good capability in dealing with nonlinear multivariate systems as those analyzed in semiquantitative land evaluation.

It is pointed out that there is a current “cross fertilization” between quantitative simulation modeling and qualitative land evaluation techniques, leading to excellent scientific and practical results and gradually improving the accuracy and the applicability of the models. In hybrid systems, the linkages between two types of models simulate both the qualitative reasoning functions and the quantitative modeling part. Finally, the practical automated application of land evaluation systems is described as a land-use decision support tool, which makes use of information technologies allowing for linkages of integrated databases and various kind of models. Land-attribute databases, computer programs, optimization tools, and spatial analysis are reviewed as essential parts of land-use planning.

1. Introduction

In biophysical land evaluation analysis and land performance assessment, there are two major trends: qualitative and quantitative. In general terms, a land evaluation system is considered qualitative when in its development the values of diagnostic properties define categories. The system is considered quantitative when these values are combined mathematically to give an index on a sliding scale.

Qualitative land evaluations may be as simple as narrative statements of land suitability for particular uses, or they may group the land in a subjective way into a small number of categories or suitability classes. This assumes a thorough knowledge of the optimum land conditions and of the consequences of the deviations from this optimum. These relatively simple systems of land evaluation depend largely on experience and intuitive judgement and are, therefore, real empirical systems. No quantitative expressions of either inputs or outputs are normally given.

Arithmetical or parametric methods are considered as a transitional phase between qualitative methods, which are entirely based on empirical expert judgements, and standard mathematical models that would be the real quantitative systems. The statistical models can be also considered as semiquantitative methods.

Current progress in information technology has given opportunities for the application of many different modeling techniques to the most complex systems. These newly emerging methodologies facilitate the enhancement of the quantification and integration trends of land evaluation analysis. Empirical expert modeling has moved from simple statistical models to other more sophisticated ones, based on artificial intelligence techniques. Also, the process-oriented modeling which simulates crop growth following a deterministic path (through mathematical equations) and based on the understanding of the actual mechanisms of plant growth, has been integrated in land evaluation.

This contribution reviews the qualitative and quantitative trends in land evaluation as follows. Section 2 discusses the traditional systems in land evaluation, from the real qualitative systems until the single-factor models. Section 3 reviews the newly emerging modern methodologies, following also a quantification line from the qualitative expert systems until the quantitative simulation models. Finally, in Section 4, the computer processing of data for land evaluation as a decision support tool is analyzed.

2. Traditional Systems

2.1. Maximum-Limitations Systems

The USDA Land Capability Classification is an example of the most traditional land evaluation system that provides conceptual definitions of capability classes according to the degree of limitation to land use imposed by land characteristics on the basis of permanent properties. This qualitative system and its adaptations, such as the British Land Use Capability Classification, the Canadian Land Capability Scheme, and the Dutch system (for more details see Chapters *The FAO Guidelines for Land Evaluation* and *Other Land Evaluation Systems*) have been widely used around the world; and they remain today as important tools for natural resources evaluation.

Also, in many approaches to express land suitability classes for a given particular land use qualitatively, the principle of the maximum limitation factor is followed. In these cases, simple matching tables such as the following are used (Table 1). Refinements are possible by making the suitability class ratings dependent on more than one limiting land characteristic. This leads to more complex rating tables or diagrams

Suitability class	**Land characteristics**			
	Soil depth, cm	**Texture**	**Salinity, mS/cm**	**Slope, %**
S1. Very high	>120	Medium	0–2	0–3
S2. High	60–120	Medium to Heavy	2–4	3–8
S3. Moderate	30–60	Medium to Coarse	4–8	8–15
S4. Low	15–30	Coarse	8–10	15–30
N. Not suitable	<15	Very Heavy	>10	>30

Table 1. Example of maximum limitation factors for defining land suitability classes

2.2. Parametric Methods

Semiquantitative land evaluation methods such as parametric assessments are positioned halfway between qualitative and quantitative methods. These are derived from the numerical inferred effects of various land characteristics on the potential behavior of a land-use system. Arithmetical systems consider the most significant factors and account for interactions between such significant factors, either by simple multiplication or by addition of single-factor indexes.

Multiplying systems assign separate ratings to each one of several land characteristics or factors, and then take the product of all factor ratings as the final rating index. These systems have the advantage that any important productivity factor controls the rating. Another advantage is that the overall rating cannot be a negative number. A limitation of the system is that the overall final rating may be considerably lower than the ratings of each one of the individual factors.
The first and most widely known effort to spell out specific, multiplying criteria for rating soil productivity through an inductive assessment was developed by R. Storie in 1933. The original Storie Index Rating (SIR) was calculated by multiplying separate ratings for profile morphology (*A*), surface soil texture (*B*), slope angle (*C*), and modifying conditions such as soil depth, drainage, or alkalinity (*X*).

$$\mathrm{SIR} = A \cdot B \cdot C \cdot X \qquad (1)$$

Storie made it quite clear that the factor ratings he provided were to be taken as guides rather than as absolute values and that the ratings were to be changed as soil scientists gained experience with the index.

Three other well-known systems—the Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE), and the Revised Universal Soil Loss Equation (RUSLE)—take a very similar form to the Storie Index, and operate by multiplying the most critical factor values. The USLE has, in many cases, superseded the USDA Land Capability System for on-farm planning function in the 1980s.

Additive systems also allocate a numerical value to the most important land factors, but instead of being multiplied these parameters are added. These numbers are either summed up or subtracted from a maximum rating of 100 to derive a final rating index. Additive systems have the advantage of being able to incorporate information from more land characteristics than do multiplying systems. Experience has shown that four or five factors appear to be a good average to use in multiplying systems; otherwise most final ratings become so low that the approach can no more distinguish small differences in response. Additive systems allow the consideration of many more criteria, both single and in combination with the effects of other factors. Other advantages of this approach are that no single factor can have enough weight to unduly influence the final rating, and that it is generally easier to specify the criteria and their factor ratings for an unambiguous land performance determination.

Limitations of additive systems stem from their complexity. As the number of factors evaluated increases, so does the difficulty in juggling factor ratings so that the final ratings derived for a number of land units or soils are all realistic. Another problem might occur in cases where negative ratings have to be taken into consideration.

Combined methods for rating soil productivity levels utilize both additive and multiplying procedures. Most combined methods use additive processes to derive single-factor ratings, and subsequently multiply these single-factor ratings together to derive final rating indexes. It is obvious that each of the factors taken into consideration has to be judged and validated through individual response curves before these can be integrated in the formula.

The major advantage of these combined systems is that they allow us to integrate information from several selected factors without creating an unrealistically low or even negative final result.

The complexity of the approach is obviously higher than that of simple multiplying systems. Most of the combined methods have been derived from Storie's original concept.

2.3. Statistical Systems

The statistical land evaluation systems are powerful semiquantitative methods for predicting land suitability on the basis of selected land characteristics. Correlation and multiple regression analyses have been used to investigate the relative contributions of selected land characteristics. Where suitable basic and response data are available, statistical models can provide the basis for objective ratings of land attributes.

The land suitability or response variable Y is analyzed as a function of the type:

$$Y = \phi\ (X_1, X_2, \ldots, X_n) + \varepsilon \qquad (2)$$

where Xn corresponds to the selected land characteristics or independent variables (e.g., soil depth, clay content, organic matter, caption exchange capacity, pH, sodium saturation, etc.), and ε measures the residual factors. As the mathematical form of the ϕ is not known, this function can be approximated satisfactorily, within the experimental scenario, by a polynomial equation. The calibration of this polynomial model can be treated statistically as a particular case of multiple regression. The regression coefficient (R^2) facilitated by this analysis represents an inductive validation index of the model corresponding to the accounted value for the percentage of the observed variation.

In the development of these systems, correlation analysis provides a convenient starting point in the selection of X variables, according to their simple effects on the Y variable; as well as the possible interactions between independent variables.

This methodology has been used to predict soil productivity for major crops, and is based on an integrated knowledge of a wide variety of disciplines. Hence, competent statisticians, agronomists, and soil scientists must work together to develop polynomial regressions for a maximal benefit from such statistical analysis. However, in soil survey interpretations for engineering uses, statistical relationships are often used to estimate certain geotechnical properties of soils, (e.g., plasticity, compaction, and water status), from pedological characteristics (e.g., clay content, organic matter, bulk density). In this last case, it is better to speak of pedo-transfer functions rather than of land evaluation systems.

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Biographical Sketches

Diego de la Rosa is a Scientific Professor of land evaluation at the Spanish Research Council (CSIC), Sevilla, Spain. His research is focused on the application of information technology for developing agro-ecological land use decision support systems. Since 1990, all these investigation results are being included into the MicroLEIS system (http://www.microleis.com). He has conducted numerous studies in the area of soil survey and land evaluation funded by regional and national governments, EU, and FAO; which have been reported in numerous publications.

Professor De la Rosa has worked as a visiting professor at the University of Florida, USA. He is currently head of the Natural Resources Evaluation Service, Junta de Andalucia, Spain, and director of the Institute for Natural Resources and Agrobiology, CSIC. He is also leader of the European Topic Center on Soil, European Environment Agency. Professor de la Rosa operates and manages his family’s farm in western Sevilla.

Kees van Diepen is senior scientist land evaluation at Alterra, Wageningen University and Research Centre, Wageningen, The Netherlands. He has conducted many studies combining qualitative and quantitative methods for estimating the productive potential of lands for various purposes and at different scales. These usually involved the combination of judgment-based land suitability ratings with numerical deterministic crop models, and their application in a GIS environment.

He was coordinator for the development of the WOFOST (World Food Studies) crop model, and was leader of the team that built the Crop Growth Monitoring System for the MARS (Monitoring Agriculture with Remote Sensing) project of the European Union, an agrometeorological information system for crop yield prediction across Europe. Related systems dealt with the quantification of effects of climate change on crop yield and water use, and comparative analysis of regional crop production potential. He participated in eco-regional studies in support of regional land use planning. He has written a number of review articles on approaches in physical land evaluation.