Chapter 47
Spatial Modeling of Natural Phenomena and Events with Artificial Neural Networks and GIS

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ABSTRACT

Artificial neural networks (ANN) are used for statistical modeling of spatial events in geosciences. The advantage of this method is the ability of neural networks to represent complex interrelations and to be "able to learn" from known (spatial) events. The software advangeo® was developed to enable GIS users to apply neural network methods on raster geodata. This statistic modeling can be displayed in a user-friendly way within the ESRI ArcGIS environment. The complete workflow is documented by the software. This paper presents three pilot studies conducted to illustrate the possibilities of spatial predictions with the use of existing raster datasets, which described influencing factors and the selection of known events of the phenomenon to be modeled. These applications included (1) the prognosis of soil erosion patterns, (2) the prediction of mineral resources, and (3) vulnerability analysis for forest pests.

INTRODUCTION

Natural phenomena and events are usually caused by a complex of interacting factors. An exact mathematical formulation of a geo-scientific task, however, (with equations describing the dependence of a phenomenon on several main influencing factors) is rarely feasible. Typically, a model only refers to some aspects of the phenomenon in question. Due to the lack of data and knowledge of details of many geo-processes, mathematical models cannot be successfully defined and applied with reasonable amounts of effort. As a result,

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the exploration of artificial intelligence (artificial neural networks, ANN, e.g., Haykins, 1998) as a means to provide a reliable tool to analyze causal relationships and to make the knowledge available for predictive tasks was initiated. This approach differs from traditional methods in that viable results may be obtained with reasonable efforts invested in data processing, model design and computational time.

Results for three different case studies are discussed in this paper, following an introduction on the theoretical background of the neural network approach. The outcomes, predictive maps illustrating the probabilities of occurrence for a given event of interest, form an important basis for planning activities. The case studies deal with various tasks in applied earth sciences and demonstrate the rather universal applicability of the coupled ANN/GIS approach that is presented in this paper. In particular, the following objectives applied to the case studies presented here:

1. Spatial prediction of soil erosion channels to localize damage on arable land and to infrastructure and to model effects of mitigation measures;
2. Prediction of the most promising locations for mineral exploration, based on available geological data within a gis environment;
3. Spatial prediction of the most vulnerable forest stands in case of spreading bark beetle infections.

Although the value of the application of neural network technologies in GIS environments was recognized in the past, actual application of this remained a challenge for standard users due to the lack of user-friendly tools. Thus, the overall goal of the three case studies was to study the quality of model outputs and the general applicability of the ANN/GIS approach included in the software advangeo®.

RATIONALE AND OBJECTIVES OF THE STUDY: SELECTION OF AN APPROPRIATE MODELLING METHOD FOR SPATIAL EVENTS

The location of a natural event is determined by a complex network of influential causes and subsequent effects. Hence, the relationships between the parameters are usually characterized by qualitative descriptors rather than quantifiable means, if they can be described at all in a reasonable amount of time. This hampers the (mathematical) modeling and spatial prediction of natural phenomena. In general, spatial pattern of events can be modeled by two different approaches:

1. By conducting detailed studies of physical, chemical and other relations to establish an accurate quantitative model of the processes with mathematical-analytical methods (e.g., using finite elements to model slope stability). With this approach, equations are used to parameterize and model natural processes. Equation calibration is usually accomplished by adjusting “constants”, based on the comparison of modeled results and measured data.
2. By a statistical approach, whereby potentially influential factors are evaluated by multivariate methods, based on statistical correlations. The influence of several independent factors on the dependent variables (e.g., the development of a geo-hazard such as slope failure) is investigated.

The calibration of analytical models is usually connected with time-consuming and cost-intensive field studies. As a result, it is not uncommon that complex natural processes cannot be adequately described with derived physical equations for more extensive areas of interest, even given reasonable efforts to do so.