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Two models for evaluating landslide hazards

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Abstract

Two alternative procedures for estimating landslide hazards were evaluated using data on topographic digital elevation models (DEMs) and bedrock lithologies in an area adjacent to the Missouri River in Atchison County, Kansas, USA. The two procedures are based on the likelihood ratio model but utilize different assumptions. The empirical likelihood ratio model is based on non-parametric empirical univariate frequency distribution functions under an assumption of conditional independence while the multivariate logistic discriminant model assumes that likelihood ratios can be expressed in terms of logistic functions.

The relative hazards of occurrence of landslides were estimated by an empirical likelihood ratio model and by multivariate logistic discriminant analysis. Predictor variables consisted of grids containing topographic elevations, slope angles, and slope aspects calculated from a 30-m DEM. An integer grid of coded bedrock lithologies taken from digitized geologic maps was also used as a predictor variable. Both statistical models yield relative estimates in the form of the proportion of total map area predicted to already contain or to be the site of future landslides. The stabilities of estimates were checked by cross-validation of results from random subsamples, using each of the two procedures. Cell-by-cell comparisons of hazard maps made by the two models show that the two sets of estimates are virtually identical. This suggests that the empirical likelihood ratio and the logistic discriminant analysis models are robust with respect to the conditional independent assumption and the logistic function assumption, respectively, and that either model can be used successfully to evaluate landslide hazards.

Keywords: Landslide; Logistic model; Likelihood ratio; Prediction; Spatial modeling; Cross-validation; Kansas

1. Introduction

In 1995 a landslide in a Kansas suburb of Kansas City, Missouri, destroyed two new houses and highlighted the need for landslide hazard maps in the US Midwest, an area of low relief considered to have few landslide problems. However, incised rivers and other topographic escarpments create local areas favorable for landslides. This study compares two landslide hazard estimation procedures using data from topographic digital elevation models (DEMs) and a digital geological map of an area in Atchison County, Kansas. The multivariate logistic discriminant model assumes that likelihood ratios can be expressed in terms of logistic functions, while the empirical likelihood ratio model uses non-parametric empirical univariate frequency distributions under assumed conditional independence.

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Both models yield relative estimates as the proportion of total map area predicted to contain or to be sites of future landslides. The stability of estimates is checked using random subdivision and cross-validation.

2. Geomorphic setting

Atchison, Kansas, is located in northeastern Kansas about 65 km northwest of Kansas City along the Missouri River (Fig. 1), which meanders through a mature valley with well-developed bluffs. Tributaries of the Missouri River dissect the bluffs, creating hills whose maximum local relief is about 73 m. The western portion of the study area consists of gently rolling hills having very low relief. The study encompasses two 7.5-min quadrangles, an area of 202 km^2. The dominant land use is rural agriculture, but the study area also includes the city of Atchison, Kansas, which has a population of about 10,000 (Helyar, 2000). The area has picturesque local vistas that overlook the Missouri River Valley; these may attract more residents to the area, resulting in greater development.

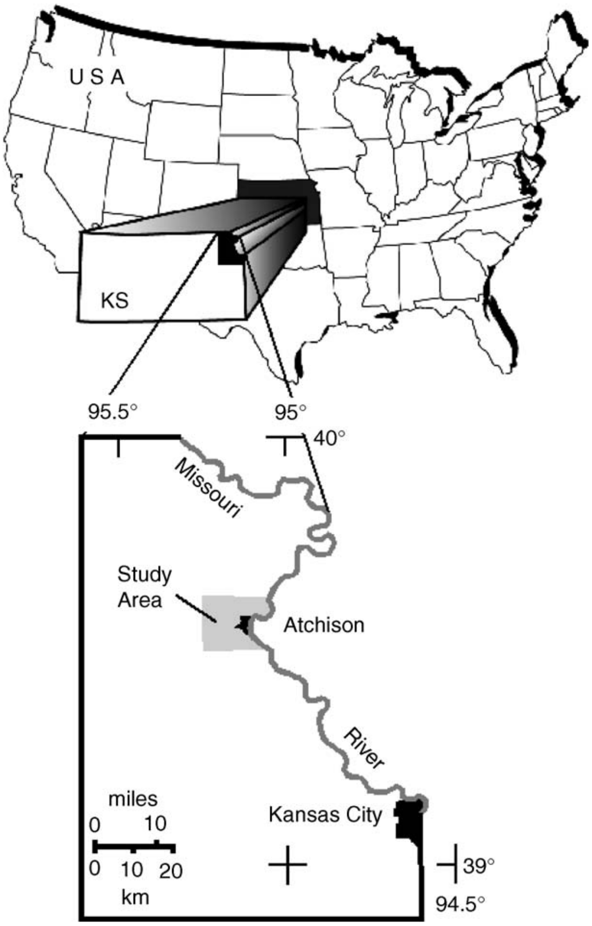

Fig. 1. Index map showing location of study area in northeast Kansas, USA.

3. Landslides

A landslide is the downslope movement of a mass of soil and rock material (Cruden, 1991). All the necessary conditions for landslides exist in the study area, including steep slopes, adequate precipitation, and susceptible soil and rock units. Bedrock geology consists of horizontal layers of Upper Carboniferous (Pennsylvanian) shales, limestones, and sandstones exposed along the steeper hillsides. The western portion of the study area and hilltops in the eastern portion are covered by Quaternary glacial drift and loess. Quaternary alluvial deposits occur along the Missouri River and its tributaries. The weathering of shale and limestone produces clayey soils that are prone to landslides. Much of the material in the Quaternary alluvial deposits are derived from local bedrock and are only slightly less susceptible to landslides than are soils developed on bedrock. There is the potential for a variety of natural and anthropogenic triggers for landslides in the study area, including occasional intense rainfalls, seasonally wet climatic conditions, and stream erosion along the lower slopes of hills. Possible anthropogenic triggers include improper grading of road and construction cuts, improperly designed fill placement, and poorly controlled surface drainage.

The landslide classification developed for the National Research Council, Transportation Research Board (Varnes, 1978; Cruden and Varnes, 1996) is used here. Landslides in the study area include *earth flows*, *earth slides*, and combinations of these types, along with some *rock falls* and *rock topples* that occur along river bluffs, road cuts, and in quarries (Ohlmacher, 2000; Ohlmacher and Davis, 2003). Ohlmacher (2000) mapped landslide features in the study area, subdividing the landslides into three classes: *recent landslides*, *older landslides*, and *rock-fall hazards*. Recent landslides include earth flows, earth slides, and combined types with distinct features, easily recognized boundaries, and that are known to have moved within the past 100 years. Older landslides are earth flows, earth slides, and combined types with muted features and indistinct boundaries that include areas of hummocky and lobate topography. This class includes