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Landslide and Flood
Hazard Assessment

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The Preliminary Damage Assessment of Properties Based on Massive Appraisal Maps

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Abstract This paper examines a feasible solution for the preliminary assessment of potential damage costs for dwellings in areas prone to the risk of landslides and subsidence. The assessment uses different spatial layers as input parameters and concentrates on the implementation of different spatial databases that are already available as public data. These databases include land-use suitability (LUS), building height typology (BHT) databases and massive appraisal maps that are specifically developed for the real estate market. Massive appraisal maps were produced based on the spatial-econometric hedonic dwelling price model that was developed previously for the Belgrade metropolitan area using cross-sectional and georeferenced transaction data.

The massive appraisal maps were used in combination with LUS and BHT databases to obtain a spatial layer that would indicate potential sites vulnerable to landslides and subsidence with an estimate of damage costs included.

In this study we go one step further by attempting to enhance all the advantages of GIS utilization in risk and mitigation management through the use of the Web 2.0 concept. Web Mapping 2.0 is an important part of the Web 2.0 concept and facilitates the integration and visualization of different geographic information on base maps (such as Google Maps/Earth, Virtual Earth, or Yahoo Map).

Keywords hedonic price modelling, land use suitability, web mapping

Introduction

GIS technology provides suitable tools to support planning and regulation of emergency management activities. These tools have led to the development of risk information systems that can be used to analyze risk and evaluate the consequences of decisions made that mitigate or reduce risk (van Westen 2004). Based on available spatial data, GIS models can be used to combine a set of input maps or factors to produce an output map that specifies levels of susceptibility and hazard (Fell et al. 2008). Damages caused by landslides and subsidence represent significant risks to buildings and dwelling objects (Fell 1994) and providing estimates of potential damage could be of benefit to economic loss assessment and long term mitigation management.

The contribution of this work to the field is to point out a simple GIS solution that can generate a massive appraisal data layer by integrating the spatial econometric hedonic model (Anselin 1988) with supplementary data layers. The obtained appraisal map could be of interest not only for appraisers, real-estate companies and bureaus, but also for landslide hazard experts and stakeholders that could all gain insight into location prices.

The final results of the GIS solution are portrayed as a thematic map that can be communicated and shared easily through many web map-based services. These thematic maps were achieved using recently developed packages in the R language environment including plotGoogleMaps and plotKML.

Materials and methods

Hedonic price models

The basic hedonic price function can be represented as (Can and Megbolugbe 1997):

$$Y = f(S\alpha, N\gamma) + \varepsilon \qquad [1]$$

where Y is a vector of observed housing values, S is the matrix of the structural characteristics of properties, the N matrix characterizes neighborhood characteristics including measures of socio-economical conditions for residential area including environmental conveniences and public accommodations, α and γ are vectors corresponding to S and N, and ε is a vector of random error terms.

The given formula can be expressed as a common regression function:

$$Y = X\beta + \varepsilon \quad [2]$$

where $Y_{n \times 1}$ represents the vector of observed sale prices of n dwellings, $X_{n \times k}$ is a vector of k explanatory variables characterizing housing units. $\beta_{k \times 1}$ is the vector of unknown coefficients and $\varepsilon_{n \times 1}$ is a vector representing error term.

By using ordinary least squares (OLS), the unknown coefficients are solved as:

$$\hat{\beta} = (X^T X)^{-1} X^T Y \quad [3]$$

Recently developed R language packages designed for managing, processing and visualisation of data given in GIS formats facilitate the advanced approach in this field.

R language environment

Preparing and processing of input data were performed in the GIS environment by SAGA GIS (http://www.saga-gis.org) and R open-source software packages. R is an open source system for statistical computation and graphics that provides different programming facilities, high-level graphics, interfaces to other languages and debugging facilities.

The newly developed R package *plotGoogleMaps* (Kilibarda and Bajat 2012), based on Asynchronous JavaScript and XML technology (AJAX) and Google Maps Application Programming Interface (API) service produces HTML file map mashups (web maps). These maps combine geographic data from one source with a map from another source (Miller 2006, Gartner 2009, Haklay et al. 2008). In addition, the R package *plotKML* (http://cran.rproject.org/web/packages/plotKML/plotKML.pdf) was used to visualize spatial and spatio-temporal objects in Google Earth for a more interactive presentation of results.

Case study of Belgrade metropolitan area

The administrative boundary of the Belgrade metropolitan area includes an area of 3,223 km² with a population of 2 million inhabitants. Its territory is divided into 17 municipalities where the urbanized area and the inner part of city accounts for a total area of 360 km² and include 10 urban municipalities that are taken into consideration in this study. There are approximately 420 000 households with 1 200 000 inhabitants in the area of interest according to official census data records (Statistical Office of the Republic of Serbia 2003). The original data set used in this study consists of 747 records of apartment transactions in the year 2010 and were comprised of total transaction value, covered flats size and their corresponding addresses. On the other hand, additional information on internal living space including the age and availability of garage spaces were not taken into consideration. A geographic information system (GIS) was used to match street addresses of the transactions with the official data set of building geographic coordinates in order to geocode observations into the study area.

Explanatory variables

The determinants of house prices can be divided into four groups when applying the hedonic price model for real estate evaluation (Lake et al. 1998): structural variables (e.g. age, the number of rooms in each house), accessibility variables (e.g. the proximity of schools, bus routes, railway stations, shops, parks, and the Central Business District), neighborhood variables (e.g. local unemployment rates), environmental variables (e.g. road noise and visibility impact). The explanatory variables that refer to accessibility and environment could be considered as spatial determinants that are specifically referred to as the distance variables (Koramaz and Dokmeci 2012). In this study we were confined to accessibility, neighborhood and environmental variables as predictors Table 1.

Table 1 List of explanatory variables and their typology.

Variable	Type
Proximity (Euclidean distance) to: airport; museums; theatres; University/science facilities; elementary/high schools; parks/playgrounds; green markets; big green areas/forest; sport stadiums; station of public transport; shopping centers; main streets; religious facility; kindergarten; ambulance/hospitals.	accessibility
Proximity to: highway; main roads/ boulevards; river banks; railway.	environmental
Percentage of illiteracy habitants; Average income in municipality.	neighborhood

The explanatory variables referring to accessibility and environment were arranged as input maps/grids with 20 m resolution by using a proximity function within the SAGA GIS environment. The values assigned to grid cells are calculated by Euclidean distances between input features (roads, schools, parks, etc.) and each cell in the grid map. Two neighborhood variables (illiteracy and income) are based on census data. The illiteracy layer/map was generated as a factorial variable that is referenced to each municipality, where each cell represents the proportion of illiterate inhabitants in a particular municipality with respect to the whole city of Belgrade. The income variable represents the average income in the municipality so that every grid cell within each municipality area has the same value. Variables that include neighborhood, proximity to markets, schools and rivers were indicated as highly significant predictors (Bajat et al. 2012).

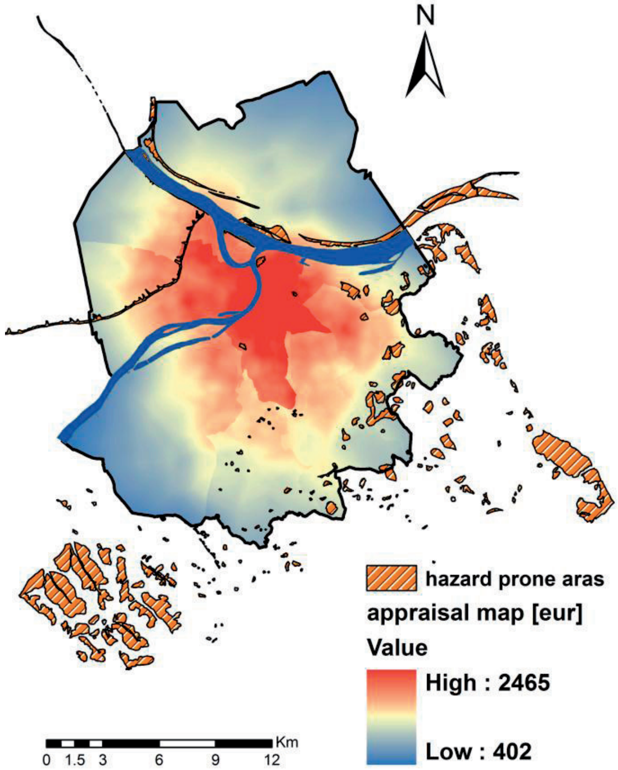

Figure 1 Hazard prone delineated areas over the massive appraisal map of Belgrade urbanized city area.

Data processing and results

The spatial predictors, given as raster maps, were used as auxiliary inputs that are necessary for hedonic regression modelling. The socio-economic data, such as distribution, ages and income of inhabitants were prepared in the same manner enabling their use in the GIS support environment and help achieve a reliable spatial assessment of dwellings prices per square meter. The massive appraisal map was obtained by direct application of the OLS model over the auxiliary grid layers of predictors in the grid format with 20 m resolution Figure 1.

The land-use suitability data layer (given in vector format) was recently prepared for the Master Plan of the city of Belgrade and was used to delineate areas susceptible to the landslide and ground subsidence hazard (Djurić et al. 2013). The other class of input data concerns residential blocks. They are an integral part of planning documents that have already been prepared for the Master Plan of Belgrade from the year 2000 and exist in digital form, readily usable in the GIS environment. The residential blocks are presented in vector format (shp. files) with associated attributes indicating the average number of stores (floors) within the building block. Obviously, a building block is designated as a residential area clearly delimited by roads.

The hazard-prone areas were delineated by overlaying the produced massive appraisal map raster with LUS layer polygons that refer to unsuitable and very unsuitable land classes Figure 1. Vulnerable objects were identified by applying a polygon intersection function on the layer of delineated hazard-prone areas and the layer depicting building footprints (digital cadaster plan). After joining identified building objects with BHT layer data, the total building areas were calculated for each object by multiplying the building footprint area with the number of total stores. The estimated building values were calculated using the mean price value of enclosed raster cells within the footprint of an object and its multiplied total building area. Identified shape files representing vulnerable buildings with associated estimated price values were embedded in interactive web maps available through web browsers Figure 2. It is possible to obtain details of the total value of specific objects and corresponding area by simply clicking over the object Figure 2 left. The balloon that appears in the Figure 2 left shows the total area of the hazard prone object (2,268 m^2) and its estimated value in thousands of Euros (3,237.3 €).

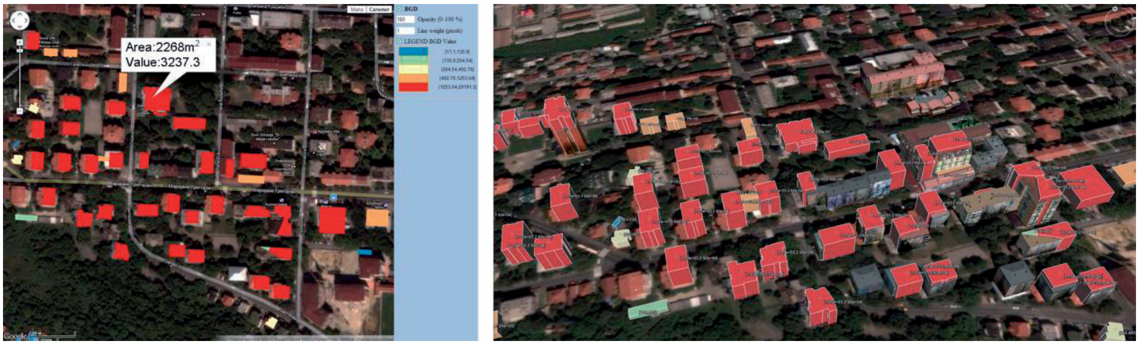

Figure 2 The screenshots of HTML web map (left) produced by plotGoogleMaps package, available at http://www.grf.bg.ac.rs/~bajat/BGD.htm and web map in KML format (right) produced by by plotKML package, available at http://www.grf.bg.ac.rs/~bajat/BGD.kmz .

Conclusion

Considering that a cross-sectional analysis of house prices involves georeferenced information, GIS tools and spatial statistics are suitable for modelling building price values over an area of interest. The results of spatial prediction were produced as digital maps in raster format. The digital maps could be used to assess potential damage costs when combined with data contained in town planning documentation concerning information on land-use suitability and height of residential buildings. One could then easily calculate potential damage costs of residential buildings due to the risk of landslides over the whole case study area by using simple map algebra of the combined layers. The obtained results were exported in HTML and KML web formats and included some GIS functionality that allowed for the suitable visualization of spatial data and facilitates communication between stakeholders.

A similar methodology could be applied to model the impact of risk hazards on the general population by using a dasymetric population spatial layer (Bajat et al 2011) instead of a massive appraisal map layer.

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