Land Developability: Developing an Index of Land Use and Development for Population Research

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Abstract

This research proposes an approach for linking land use and development to population data by using the ModelBuilder function in ArcGIS. The layers of land use and development are aggregated into a layer representing undevelopable lands via the intermedium of pixels. The layer of undevelopable lands in pixels is then aggregated to political or geographical areas from which a developability index representing the proportion of lands available for development can be derived. The index can then be linked to population data for demographic research. For demonstration purposes, the proposed approach is used to generate a land developability index for all minor civil divisions of Wisconsin, USA. This approach and the generated land developability are useful for studying the relationship between land use and development and population dynamics based on political or geographical areas.

1. Introduction

Population growth and redistribution are limited by the potential for land conversion and development (Chi, 2009). The developability of lands in a region is determined by a variety of factors, including geophysical characteristics, the extent of built-up lands, cultural and aesthetical resources, and legal constraints. When studying these factors' collective effects on population growth and redistribution, existing social demographic studies often aggregate them into one or more indices by factor analysis or other statistics-based weighted aggregation methods (Kim et al., 2005). However, such generated indices cannot provide an accurate estimate of the amount of lands available for development.

A more accurate estimate of the total lands available for development (called “land developability” in this study) can be estimated by GIS-based spatial overlay methods. One of the spatial overlay methods is the ModelBuilder™ function of ArcGIS (ESRI, 2000). Environmental analysts often employ the ModelBuilder function to study the interactions between environment, population, land use, and legal constraints by overlaying these layers at fine pixel sizes. Similar work includes the extent of land development (Cowen and Jensen, 1998), qualitative environmental corridors (Lewis, 1996), quantitative environmental corridors (Cardille et al., 2001), and work dealing with growth management (Land Information & Computer Graphics Facility, 2000, 2002).

Although demographers may be interested in borrowing the spatial overlay approach to study the relationship between land use and development and population dynamics, the fact that population data are aggregated at rather coarse sizes (mostly political or geographical areas) imposes difficulties in taking into account land use and development variables that generally can be studied usefully only at very fine data resolution. For example, geophysical factors such as elevation and slope likely influence housing development, but they can be measured meaningfully only at the pixel level of analysis.

This research proposes an approach for linking land use and development to population data by using the ModelBuilder function in ArcGIS. The ModelBuilder function aggregates the layers of land use and development into a layer representing undevelopable lands via the intermedium of pixels. The layer of undevelopable lands in pixels is then aggregated to political or geographical areas from which a developability index representing the proportion of lands available for development can be derived. The index can then be linked to population data for demographic research.

2. Methods

Technically, the ModelBuilder function can be used for generating developability indices at any unit of geography that is larger than the pixel sizes of the available data layers. However, this methodology is usefully for population research especially at sub-county levels of geography, where the components of land conversion and development can be measured more meaningfully. These sub-county units of geography can include units within political boundaries, census-delineated boundaries, and boundaries defined for other purposes.

The present research focuses on geographies within the U.S. state of Wisconsin at the minor civil division (MCD) level. It is important to note that Wisconsin is a “strong MCD” state that contains a mix of rural areas, small cities, and large cities found in throughout the United States. MCDs (towns, cities, and villages) in Wisconsin are the smallest functioning governmental units with elected officials who provide services and raise revenues. The MCD geography consists of non-nested, mutually exclusive, and exhaustive political territories from 1,837 MCD units with an average size of 29.56 square miles. The advantage of using MCDs is their relevance to planning and public policy making. In most parts of the state, census tracts have similar average sizes to MCDs and might serve as alternative units of analysis. However, census tracts are delineated by the U.S. Bureau of Census for counting population purposes and have rare political and social meanings.

2.1 Variables and Sources of Data

Land developability is generated on the basis of five variables representing land use and development: water, wetlands, slope, tax-exempt lands, and built-up lands (Figure 1). Their relevant data are addressed below.

Water. Surface water is, as a practical and legal matter, not suitable for building. The data for water in Wisconsin are derived from the 2001 National Land Cover Database (NLCD). The 2001 NLCD was produced by the Multi-Resolution Land Characteristics Consortium, an umbrella organization that coordinates multi-agency NLCD mapping productions and funding contributions (http://www.mrlc.gov). The 2001 NLCD was produced on the basis of the methods as outlined in Homer et al. (2004) using 65 mapping zones for the conterminous United States. Typical zonal layers included multi-season Landsat 5 and Landsat 7 imagery centered the nominal year of 2001. The accuracy across mapping zones ranged from 70% to 98%, with an average of 83.9%. The 2001 NLCD identified 16 land cover classes for every 30-meter cell in the United States. Refer to Homer et al. (2007) for a review of the methods and data quality of the 2001 NLCD product. The water area derived for this study are the cells classified as open water, generally with less than 25% cover of vegetation or soil.

Wetlands. As both a type of geophysical characteristic and a legal constraint for protecting ecological systems purposes, wetlands are usually seen as not developable. Like the data for water, the data for wetlands come from the 2001 NLCD. The wetlands considered in this study are woody wetlands (including palustrine forested wetland, palustrine scrub/shrub wetland, estuarine forested wetland, and estuarine scrub/shrub wetland) and emergent herbaceous wetlands (including palustrine emergent wetland, estuarine emergent wetland, palustrine aquatic bed, and estuarine aquatic bed).

Built-up Lands. Built-up lands are also derived from the 2001 NLCD. The built-up lands considered in this study are those with impervious surfaces accounting for 20 percent or more of total land cover. These areas most commonly include single-family housing units, apartments, and commercial and industrial developments.

Slope (≥20%). A steep slope is difficult for residential development physically and often cannot pass legal requirements such as Wisconsin's Erosion Control and Stormwater Management Ordinance of 2002. The areas with slope greater than or equal to 20% are viewed as undevelopable (Stephen J. Ventura of the Soil Science Department, University of Wisconsin-Madison, suggests that slopes less than 20% is more realistic for land development in much of Wisconsin; personal communication, August 2006). The Digital Elevation Model (DEM) data from the U.S. Geological Survey (http://rockyweb.cr.usgs.gov/nmpstds/demstds.html), which are composed of 30-meter cells, are used to calculate the slope and generate a slope file. The areas with slope greater than or equal to 20% are then extracted and are seen as undevelopable.

Tax-Exempt Lands. Publicly owned lands usually are not available for residential or other-purpose land development. In this research, tax-exempt lands are considered legally protected lands such as federal and state forests and parks, trails, wildlife refuges, and fishery areas. Three data layers are used to represent tax-exempt lands. The first one is the Managed Lands of Wisconsin Department of Natural Resources (WDNR), which includes state forests, parks, wildlife refuges, trails, and fishery areas proximately in 2001. The second data layer is the National Forests, which was created by the U.S. Forest Service at a 1:24,000 scale in the early 1990s but has not been updated since then (John Laedlein, WDNR; personal communication, September 2010). The third data layer is the Federal Lands, which was created by the WDNR in the 1990s from the USGS 1:100k digital line graphs but has no been updated since then (John

Laedlein, WDNR; personal communication, September 2010). The data include national wildlife and fish refuges, lakes, and scenic riverways.

There are other types of tax-exempt lands, such as cultural and aesthetic resources. However, such data for the entire state of Wisconsin are not georeferenced or digitally available and thus are not included in this analysis. Similarly, data for legal constraints of land use and development—such as land-use planning legislation and programmes such as comprehensive plans, “smart growth” laws, zoning ordinances, farmland-protection programs, environmental regulations such as the Clean Water Act, and shoreland and wetland zoning, etc.—are not available and therefore are not considered for this study. When such data become available, these variables should be included in analyses, as they would help improve the accuracy of land developability estimates.

2.2 Analytic Procedures

In this study, the ModelBuilder function is employed to generate a developability index that refers to the potential for land conversion and development. ModelBuilder is a tool in the ArcView Spatial Analyst extension (ESRI, 2000) that helps create a spatial model for geographic areas. It is often used by environmental and land-use planners to answer “what-if” scenario questions. In ModelBuilder, a spatial model is represented by a flowchart that is composed of input data, spatial functions, and output data.

The general idea is to identify undevelopable lands at the pixel level and then aggregate these to the MCD level for which the developability index is produced. The ModelBuilder function is first used to overlay the data layers of the variables (water, wetland, slope, built-up lands, and tax-exempt lands) and create one layer representing undevelopable lands for

Wisconsin (Figure 2). Second, this layer is converted from raster format to vector format and then intersected with a geographic MCD layer to create a layer that contains the information for undevelopable lands at the MCD level. (An alternative approach is to convert the data from raster to vector format and then use the union function of ArcGIS to integrate these layers together. However, this approach imposes a much larger demand for computing power than does the ModelBuilder approach.) Third, the proportion of undevelopable land for each MCD is calculated, and the developability index is generated by subtracting the proportion of undevelopable land from 1 (see Figure 3).

3. Discussion and Conclusion

Figure 3 roughly portrays land developability in each MCD. The numbers on the Map represent the proportions of lands that are developable in each MCD in Wisconsin. Higher numbers represents higher proportions of lands available for development. Such information can be used to predict the direction of future land development in Wisconsin and, thus, serve as a useful predictor of population growth and redistribution. As shown by the Map, the developmental potential exists for MCDs from roughly the northwest part to the southeast corner of Wisconsin as well as for MCDs from the peninsula in the northeast to the southwest corner of Wisconsin (with many “island” MCDs being exceptions). Northern counties that are rich in natural resources (with a majority of the natural resources in national forestry or parks and thus protected from land development; Chi and Marcouiller, 2010), southwest MCDs along the Mississippi and Wisconsin Rivers, and urbanized areas of Metropolitan counties do not have much land for further development.

This study proposed a way to employ the ModelBuilder function in ArcGIS to generate an index of land developability, which can be used for various traditional demographic studies and land use planning, especially those based on political or geographical areas. For example, researchers can study the relationship between land developability and population change at aggregated political or geographical scales. The developability can then be used for forecasting future population dynamics in geographic areas once a relationship between developability and population is estimated based on historical data (Chi and Voss, 2010).

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Figure 1. Undevelopable Lands in Wisconsin

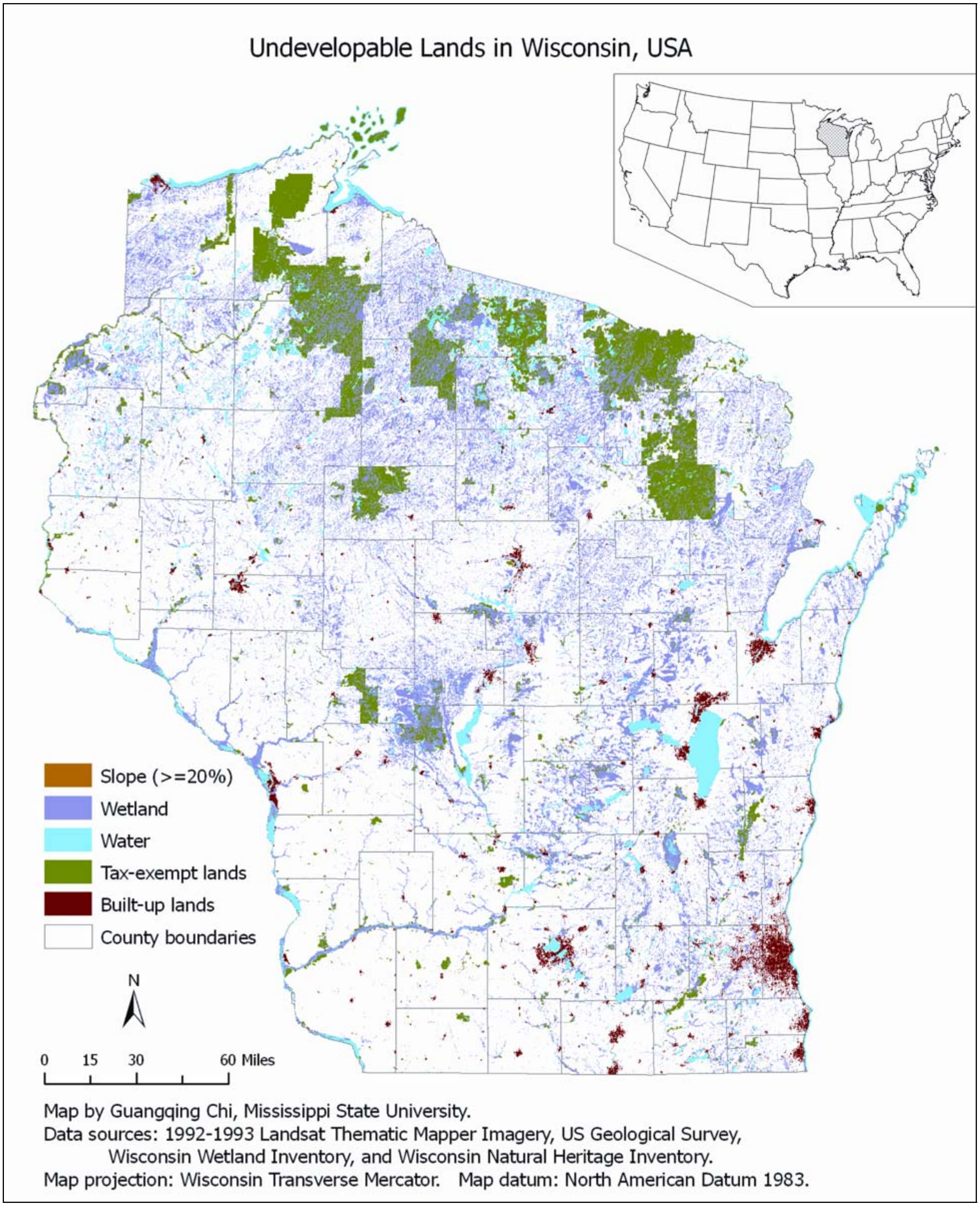

Figure 2. The ModelBuilder Function for Generating a Layer of Undevelopable Lands

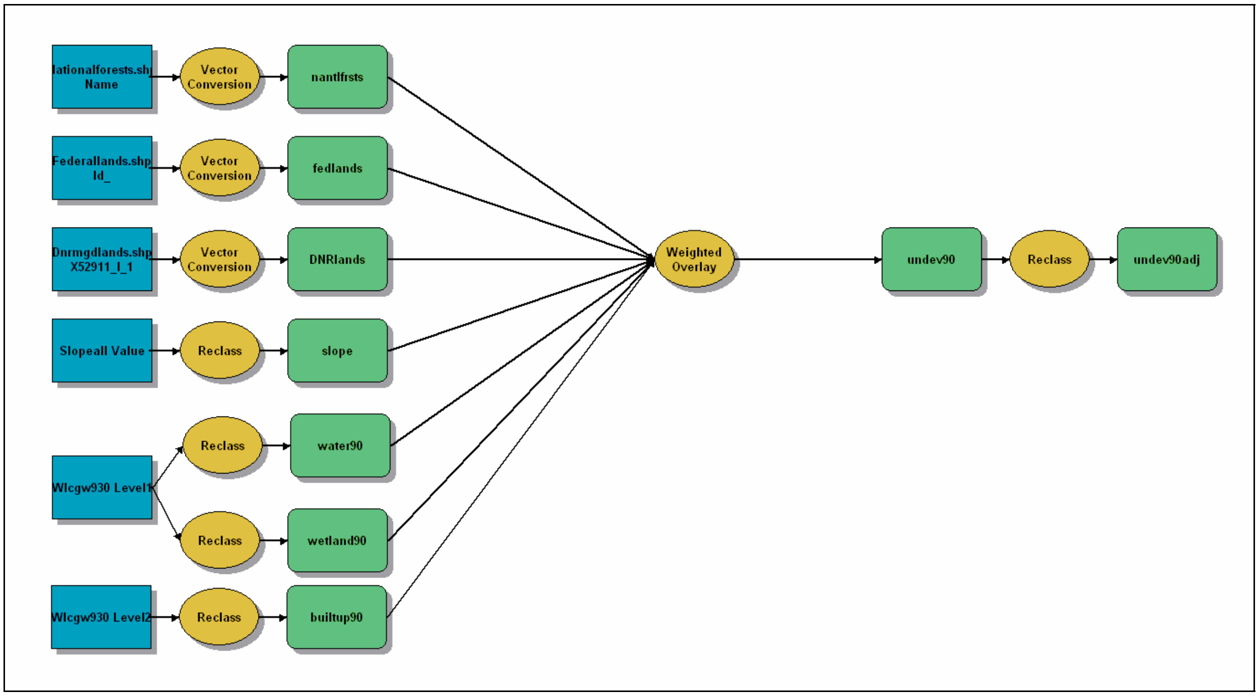

Figure 3. Land Developability in Wisconsin at the Minor Civil Division Level