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Impervious surface regulation and urban sprawl as its unintended consequence

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A B S T R A C T

In this paper, we presented the effect of impervious surface regulation on spatial development pattern in urban fringe. We investigated the change in spatial development patterns before and sixteen years after the enactment of the Save Our Springs (SOS) ordinance, a land use regulation that limits impervious surface in the Barton Springs Zones (BSZ) of the City of Austin, Texas, USA. We compared the spatial development pattern of the Williamson Creek (WC) subwatershed in the BSZ where the SOS ordinance limits impervious surface to 15% of the total site area to those of five control subwatersheds with less stringent impervious surface regulations. To rule out other factors that potentially affected the spatial development pattern, we selected the five control subwatersheds that had similar impervious surface percentage and land use type to the WC subwatershed before the SOS ordinance. We quantified the spatial development patterns of the study subwatersheds before and after the SOS ordinance using the lacunarity index. The lacunarity analysis showed that spatial development patterns of the five control subwatersheds did not significantly change after the adoption of the SOS ordinance. In contrast, the WC subwatershed exhibited a more dispersedly developed pattern after the adoption of the SOS ordinance. Large forests disappeared and remnant forests were finely fragmented in the WC subwatershed. Our findings suggest that the impervious surface regulation aggravates urban sprawl.

Introduction

Urbanization has detrimental impacts on water resources. Impervious surface generates more stormwater runoff and increases floods in urban streams (Rose and Peters, 2001; Burns et al., 2005). The increased stormwater runoff also degrades water quality by washing off pollutants from an urban watershed (Brezonik and Stadelmann, 2002; Li et al., 2008). These impacts further alter aquatic and riparian ecosystems, such as the change in population and species composition of fish (Sutherland et al., 2002) and vegetation communities (Sung et al., 2011).

To mitigate the negative impacts of urbanization on water resources, a growing number of local governments have adopted impervious surface regulations that limit the ratio of impervious surface to the total site area (Arnold and Gibbons, 1996; Moglen and Kim, 2007). Such regulations, usually in a form of zoning code, intend to maintain relatively high watershed permeability by forcing developers to pave less surface area. In reality, however, developers may simply purchase more land instead of reducing impervious surface area (Jones et al., 2005). This is particularly so in urban fringe where purchasing more land does not significantly raise development cost. For instance, Glaeser and Ward (2009) investigated the cost of housing development in the Greater Boston, USA, and found that cost for purchasing extra square meter of land would be only 39.5 US dollars (USD) in 2000–2005, which is not much expensive compared with the average home sales price of 450,000 USD in the same time period. Results of a housing survey also indicated that most suburban residents who wanted large lot houses were willing to bear cost for large lot houses (Thorsnes, 2000). Combining the low land price and the preference for large lot houses suggests that the cost for extra land seems not to affect residents' decisions on spending million dollars to build houses in the regulated areas (Esparza and Carruthers, 2000; Talen, 2001). The consequence is the aggravation of urban sprawl, or dispersed urban development that consumes vast land in the United States or elsewhere around the world (Pendall, 1999, 2000). Some argued that urban sprawl is a desirable urban form because it improves neighborhood satisfaction and decreases commuting distance in a polycentric city where both job and houses were located in suburban areas (e.g., Gordon and Richardson, 1997), but many others claimed that urban sprawl triggers various social and environmental problems: it requires longer road and utility lines per capita (Carruthers and Ulfarsson, 2003); longer automobile travel distance consumes more energy and ultimately contributes to climate change (Ewing, 1997; Johnson, 2001); it

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increases habitat fragmentation that threatens local and regional biodiversity (Hawbaker et al., 2006; Sung, 2012).

Previous studies showed that similar land use regulations intended to control the density of urban development, such as minimum lot size regulation and urban growth boundary (UGB), encouraged urban sprawl. For instance, Cho et al. (2008) found that, in Knoxville, new housing construction decreased within the UGB but increased outside of it, which suggests that UGB fueled more dispersed development. Levine (1999) and Landis (2006) independently studied local land use regulations in California, USA, and found that those regulations were unable to suppress urban development but simply displace development to neighboring areas without such regulations.

Although many studies addressed the effect of land use regulations on urban sprawl, only few directly examined spatial development patterns in regulated areas (e.g., Munroe et al., 2005; Robinson et al., 2005). Quantifying spatial development pattern is critical in understanding the effect of land use regulations because urban sprawl, perhaps an outcome of those regulations, has many dimensions that cannot be captured by a aspatial measure alone (Tsai, 2005). Also, to our knowledge, no study has examined how impervious surface regulation affects spatial development pattern. We believe that an empirical study on an impervious surface regulation is still needed because it has a similar but different regulatory mechanism than other land use regulations.

This paper fills the gap in the literature by investigating the change in spatial development patterns before and after the City of Austin adopted the Save Our Springs (SOS) ordinance that regulates impervious surface area at a maximum 15–25% of the total site area. We compared one subwatershed with the SOS ordinance to five control subwatersheds with less stringent impervious surface regulation. Impervious surface was derived from Landsat TM images before and sixteen years after the SOS ordinance, and the spatial patterns of urban development were quantified using the lacunarity index. We hypothesized that the SOS ordinance would have led to a more dispersed development pattern than other subwatersheds with less stringent impervious surface regulation.

Material and methods

Study sites selection

The study area is the City of Austin, Texas, USA, that is located over the Edwards Aquifer, a karst aquifer that is susceptible to surface water contamination (Sung and Li, 2010). The study area has been developed since the early nineteenth century when Austin was established as the capital city of the state of Texas, but the major suburban development began in 1980s when high technology industries settled in this region (Wiggins and Gibson, 2003). Now, Austin is one of the most rapid growing cities in the United States. Austin's population doubled from 345,000 in 1980 to 767,000 in 2008 (US Census Bureau, 2009). To protect the aquifer from this rapid urban growth, Austin has adopted a series of watershed protection policies (City of Austin, 2010). The cornerstone is the enactment of the SOS ordinance of 1992. Established by the citizen's initiative, the SOS stipulates a stringent impervious surface regulation on development in the Barton Springs Zone (BSZ), 270 km^2 area that is hydrologically connected to the Barton Springs segment of the Edward Aquifer. The BSZ is divided into the three subsections based on the hydrologic connections to the aquifer. The Recharge Zone subsection where rainwater falling on this subsection directly discharges into the aquifer has the most stringent impervious surface limit. Only 15% impervious surface is allowed for development in this subsection (Table 1). Currently, Austin has five watershed protection zones (Urban Zone, Suburban Zone, Water Supply Suburban Zone, Water Supply Rural Zone, and BSZ) that have different levels of impervious cover limit, water quality measures, and riparian buffer protection.

Table 1
Impervious surface limits of the five watershed protection zones in the City of Austin (2010).

Watershed protection zone	Single-family	Multi-family	Commercial
Urban	No limit	No limit	No limit
Suburban	45–60%	60–70%	80–90%
Water Supply Suburban	30–40%	40–55%	40–55%
Water Supply Rural	1 unit/1–2 acres	20–25%	20–25%
Barton Springs Zone[a]			
Recharge zone	15%	15%	15%
Barton Creek	20%	20%	20%
Contributing zone	25%	25%	25%

[a] Barton Springs Zone is divided by three subsections based on their hydrologic connection to the Edwards Aquifer.

We examined the spatial effect of an impervious surface regulation by investigating how spatial development patterns changed on the Recharge Zone in the BSZ between 1991 and 2008, i.e., before and sixteen years after the SOS. The Recharge Zone consists of four subwatersheds. Of them, we selected a Williamson Creek (WC) subwatershed as a study site because only this subwatershed has a significant increase in impervious surface between 1991 and 2008 (Fig. 1). Other subwatersheds had either a large preserved area or no significant demand for urban development due to the distance from the urban center. The WC subwatershed (20.7 km^2) is a typical North American suburban area that was predominantly used as single family housing neighborhoods. Impervious surface occupied 25.3% and 52.1% of the WC subwatershed in 1991 and 2008, respectively (Table 2). We then exhaustively searched other watershed protection zones within the jurisdiction of Austin and found five control subwatersheds that have similar development characteristics to the WC subwatershed. The search criteria for the control subwatersheds were (1) similarity to the WC subwatershed in size, land use, and development density in 1991 and 2008, (2) similarity to the WC subwatershed in spatial development patterns in 1991, and (3) no large undevelopable lands, such as greenbelt, natural preserves, and large parks (Table 2). The subwatershed boundaries were determined basically by natural watersheds. In the case that a watershed was too large compared to the WC subwatershed, for fair comparison, they were subdivided using highways and major arterials. These selection criteria allowed us to, in part, control other factors that potentially affected the spatial development pattern. Coincidentally, all of the five control subwatersheds were located in the Suburban Zone that limits impervious surface to 30–45% of the total site area depending on land use type.

Impervious surface mapping

To assess spatial development patterns of the study area, we generated two impervious surface maps from two Landsat TM images obtained before (February 8, 1991) and after (February 7, 2008) the SOS ordinance. We used remote sensing images because they are the only data source that provides impervious surface information in the pre-SOS era. Although impervious surface and developed area are from different land classification systems, i.e., impervious surface from land cover and developed area from land use, we used them interchangeably because, in the study subwatersheds, most impervious surfaces were used by one land use type, i.e., single family houses. Impervious surface has been widely employed as an indicator of urban development (Arnold and Gibbons, 1996; Brabec et al., 2002). The winter images were selected to reduce the underestimation error caused by dense tree