Land Use Policy 64 (2017) 38–55

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Modelling the urban heat island effect of smart growth policy scenarios in Brisbane

Kaveh Deilami, Md. Kamruzzaman *

School of Civil Engineering and Built Environment, Queensland University of Technology (QUT),2 George Street, Brisbane, QLD 4001, Australia

ARTICLE INFO

Article history:
Received 1 December 2016
Received in revised form 31 January 2017
Accepted 19 February 2017

Keywords:
Smart growth
Policy scenarios
Urban heat island
Geographically Weighted Regression
Neighbourhood planning
Support vector machine

ABSTRACT

Smart growth policy has been identified as a panacea to tackle a range of undesirable outcomes of sprawl development. Various neighbourhood planning concepts have been developed following smart growth principles such as transit oriented development, and infill development. Existing empirical studies, however, do not answer to a key policy question: can smart growth policies reduce the urban heat island (UHI) effect? If so, what type of smart growth policy would be most effective? This research examined the questions by deriving five alternative neighbourhood planning scenarios for Brisbane for 2023: a) business as usual, b) transit oriented development (TOD), c) infill development, d) motorway corridor oriented development, and e) sprawl development. The research utilises Landsat remote sensing images of 1991, 2004, and 2013 to: first, estimate and validate a Geographically Weighted Regression model in order to identify statistically significant factors influencing the UHI intensities in Brisbane; and second, predict the UHI intensities of the five policy scenarios. Two factors were identified to have significant influence on the UHI intensities in Brisbane: population density, and porosity. Results show that compared to the 2004 and 2013 levels, Brisbane will respectively experience a higher and lower levels of UHI effect in 2023, irrespective of the policy scenarios. On average, the infill development scenario, as a smart growth policy, has a marginally better potential to mitigate the UHI effect in Brisbane in 2023 compared to the sprawl development scenario conditional on the definition applied in this research. The UHI effect would be more equitably balanced spatially under the sprawl development scenario.

1. Introduction

This research aims to assess the urban heat island (UHI) effects of alternative smart growth policies. Various neighbourhood planning concepts have been developed over the past few decades following smart growth principles and applied in different contexts to control urban sprawl. Concepts such as planned neighbourhood development, traditional neighbourhood development, corridor and compact city development have been operationalised around the world (Newton et al., 1997; Rohe, 2009). The underlying construct of all these planning concepts is to foster compact development through densification. Sprawl development (low density outward expansion of cities) is associated with a range of problems including long commute trips, air pollution, and traffic congestion. It has also been linked to a lack of opportunity for recreation and walking, high infrastructure costs, social homogeneity, and the loss of natural habitat. Smart growth principles have been developed as a response to address these problems. Research has been conducted investigating the effectiveness of smart growth policies in terms of reducing congestion (Chen et al., 2008), air pollution (Van Der Waals, 2000), car dependency (Liao et al., 2015), and building social capital (Kamruzzaman et al., 2014b). The findings from these studies are supportive of smart growth policies. However, little is known about the impacts of these policies on reducing the UHI effect. This lack of research is in contrast with the numerous studies that have shown that sprawl development is a major cause of the UHI effect (Cui and Qin, 2013; Debbage and Shepherd, 2015).

UHI effect is a phenomenon when urban areas experience a higher temperature compared to their surrounding non-urban areas (Ward et al., 2016). Studies have found that urban sprawl reduces vegetation cover and thus contributes to the UHI intensity (Ahmed et al., 2013b; Al Kuwari et al., 2016; Lemonsu et al., 2015). The adverse effect of UHI has been widely documented in the literature. For example, it increases temperature of cities; contributes to global warming (EPA, 2016); initiates storms/precipitation events (Bornstein and Lin, 2000; Dixon and Mote, 2003); increases energy demand of cities (Santamouris et al., 2015); and contributes to heat-

* Corresponding author.
E-mail addresses: k.deilami@qut.edu.au (K. Deilami), md.kamruzzaman@qut.edu.au (Md. Kamruzzaman).

http://dx.doi.org/10.1016/j.landusepol.2017.02.027
0264-8377/

related mortality (Hondula et al., 2014). These devastating effects necessitate devising ways to mitigate the UHI effects (Chow et al., 2012; Gago et al., 2013; Susca et al., 2011). The implementation of smart growth principles (compact building design with variety of transport choices and mixed land uses) could be a way forward in this regard given its multiple policy co-benefits (Pacione, 2009). However, a lack of empirical evidence hinders the justification of their operationalisation.

It is evident that sprawl development increases the UHI effect (Zhao et al., 2016). It is also evident that high-density urban development can amplify the UHI intensities (Elsayed, 2012). Note that high-density is an important characteristic of smart growth policies. This implies that smart growth policies could also lead to increasing UHI effect. Research has also identified that the UHI intensities vary between low-populated sprawl and high-populated sprawl (Lemonsu et al., 2015). These findings suggest that the UHI intensity is a function of at least two factors: sprawling – conversion of vegetated land to low density urban areas, and population density. This finding raises the central question of this research: Do smart growth policies really reduce the UHI effect over sprawl development, and if so, what type of smart growth policies would be the most effective? An empirical answer to this question is challenging for three reasons: first, it is impractical to implement different neighbourhood planning policies and then to assess their UHI effects; second, city plans often direct single neighbourhood planning policy for an entire city spanning over a longer period. This limits the opportunity for a comparative study between different neighbourhood types. Although neighbourhood planning policy changes over time, but a comparison of the UHI effects between neighbourhoods with inconsistent temporal exposure is subject to biasness; and third, alternative neighbourhood types cannot be selected from multiple cities for a comparison because UHI is a relative concept – relative to the non-urban context surrounding an urban area. A way forward to overcome these challenges is to generate alternative neighbourhood planning scenarios through simulation of existing land uses in a city (Houet et al., 2016). This study generates five neighbourhood planning scenarios for Brisbane, Australia for 2023 and assesses their UHI effects. The scenarios are: a) business as usual, b) transit oriented development (TOD) c) infill development, d) motorway corridor oriented development, and e) sprawl development.

2. Literature review

2.1. Neighbourhood planning concepts

Neighbourhood planning incorporates practices to improve the physical characteristics of one or multiple neighbourhoods in order to enhance living conditions of residents (Rohe, 2009). Various neighbourhood planning concepts were evolved in the 20th century in response to degenerated environment and social conditions of post-industrial revolution (Meenakshi, 2011). Clarence Arthur Perry developed the neighbourhood planning unit (NPU) concept which has been documented as the first published attempt to define a neighbourhood (Gillette, 1983; Perry, 1998). Briefly, Perry used an elementary school as the focal point of a neighbourhood and then estimated the number of people require for a proper functioning of the school. Despite the weaknesses of this concept (e.g. creating a small town within a bigger town), its principles yet are used as the basis of neighbourhood planning in various cities globally (Cowie and Davoudi, 2015). In the 1960s, the concept of planned unit development (PUD) was introduced as a response to overcome many of the shortcomings of the NPU concept. The PUD concept provides a regularity framework for practices while meeting the overall community density and land use goals (UWSP, 2005). A key advantage of this concept is that developers are not bounded by existing zoning requirements (David, 2015; UWSP, 2005). Rohe (2009), however, reported various drawbacks of this concept such as the high cost of constructing curvilinear street patterns and a lack of pedestrian amenities. To tackle the shortcomings of PUD, Andres Duany proposed the concept of traditional neighbourhood development (TND) in the 1980s (Duany and Plater-Zyberk, 1994). This concept is also known as village-style development. The TND concept is based on the principle of mixed land use, well-connected streets and blocks in tandem with the construction of stores, schools and other amenities within a walking distance of residences (National League of Cities, 2016).

The modern urban problems (e.g. traffic congestion and air pollution), however, required to reform the TND concept into transit oriented development (TOD) concept. TODs are also known as transit villages, transit-supportive development, and transit-friendly design (Cervero et al., 2002). The main difference between the TOD and TND concepts is that TOD is based on development around transit stops whereas the TND concept does not specify such requirements (Rohe, 2009). The TOD concept often applies on multiple city blocks/neighbourhoods. The transit joint development (TJD) is a similar concept to that TOD concept but the TJD focused on a single block or specific real estate development (Cervero et al., 2002; Landis et al., 1991). Closely related to TOD and TJD is corridor oriented development which focuses on growth of neighbourhoods that intersect with main transit corridors of a given city (Newton et al., 1997).

2.2. UHI effect: its measures and determinants

The UHI effect can be mathematically demonstrated through the surface energy balance model (Eq. (1)) (Coutts et al., 2010; Sass, 2003).

$$R_n + F = H + LE + S \tag{1}$$

where R_n is the net radiation (i.e. energy generated by the sun and earth systems); F denotes the anthropogenic heating (e.g. heat from buildings and vehicles); H stands for sensible heat (i.e. the heat that causes change of temperature in an object); LE is the latent heat (i.e. the heat required to convert a solid into a liquid or vapour); and S represents heat storage.

A city experiences heat emitted from the sun (i.e. R_n) together with anthropogenic heat (i.e. F). As a recycling process, this amount of heat/energy is transferred into three alternative energies: 1) it is stored in the city (i.e. S), for example absorbed by the building materials; 2) it causes evapotranspiration (i.e. LE); and 3) it heats the atmosphere. In urban areas, the generate heat ($R_n + F$) is mostly stored in rough and low albedo materials (i.e. asphalt) whereas vegetated areas act as a significant heat sink. Urban areas, thus, experience a higher temperature than vegetated areas which is defined as the UHI effect (Roth, 2013).

Studies have derived the UHI effect in three ways depending on their measurement altitudes: boundary UHI, canopy UHI, and surface UHI (Zhang et al., 2009). Boundary UHI is measured from the altitude of rooftop to the atmosphere (Mirzaei and Haghighat, 2010). It is generally examined to investigate the UHI effect at mesoscale (i.e. 1–10,000 km^2) and is derived using, for example, radiosondes (Voogt, 2007). Canopy UHI is measured at the altitude ranges from the ground surface to the rooftop (Voogt, 2007). An assessment of canopy UHI is most suitable for a microscale study and is derived based on weather station data (Kato and Yamaguchi, 2007). Surface/skin UHI is measured at the earth surface level. Researchers often used satellite images (e.g. thermal bands of Landsat TM/ETM/OLI and ASTER) to derive the surface UHI effect.