

# Metrics and Tools for the Analysis of Urban Expansion



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## Introduction

The world's urban population is expected to double between 2000 and 2040, from 2.8 billion to 5.7 billion. The urban expansion need to accommodate this dramatic increase in population is likely to take the form of unplanned or low-density development known as "urban sprawl". Sprawl has negative impacts on natural resources, air quality, transportation costs, and even human health. The global scale of the urban sprawl anticipated in the coming decades will undoubtedly be a serious strain on global resources and economies if reasonable planning measures and precautions are not taken.

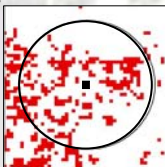
This project develops the metrics needed to quantify rigorously the attributes typically associated with sprawl in both the common and scientific literature. The metrics are based on land cover data that can be derived for any region of the world, from satellite imagery, and may be used to analyze trends in urban sprawl over time. Knowledge of historic trends will allow for anticipation of the nature of future urban expansion. Here we explain a sample of these metrics.

## Sprawl Manifested in the Urban Land Cover

Manifestations are evident in built-up areas with low spatial densities. We identify these manifestations by mapping the "urbanness" of the built-up pixels:

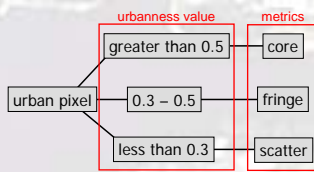
- urbanness is the fraction of pixels within 550 meters that are urban.

- a roving window statistical tool counts urban pixels within 550 meters of a built-up pixel. This count is divided by the total number of pixels in the window to get urbanness.



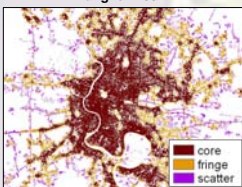
## Metric Definitions

The metrics used to identify sprawl manifestations are defined by the urbanness of the built-up pixels

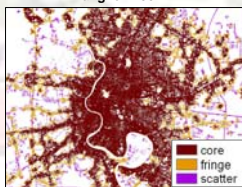


## Metric Examples (Bangkok)

Bangkok 1994



Bangkok 2002



Metric	1994	2002	Annual AT
Built-Up Area	km <sup>2</sup> 683.0	1025.9	7.0%
Core	%* 42.8	56.1	1.8
Fringe	%* 29.5	23.9	-0.8
Scatter	%* 27.8	20.0	-1.1

\*Manifestations are represented as percentages of the Built-Up Area

## Interpretation

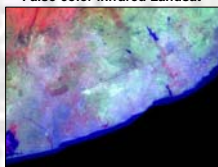
One would expect the spatial density of the urban area to decrease over time if a city is becoming more sprawled. In terms of the sprawl manifestation metrics, one would expect *fringe* and *scatter* to make up increasingly larger shares of the built-up area over time in a sprawling city.

In Bangkok, the share of the built-up area in *fringe* and *scatter* has declined over the study period while the share in *core* has increased. In terms of urban spatial density, Bangkok is becoming less sprawled over time.

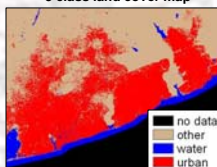
## Land Cover - the Basis for the Analysis

Landsat imagery (28.5 meter resolution) was used to derive land cover maps for a given city for two time periods: T<sub>1</sub> (circa 1990) and T<sub>2</sub> (circa 2002). Land cover images contained 3 classes: urban, water, and other. In this project, non-urban land covers were considered *open space*.

False-color infrared Landsat



3 class land cover map



## Sprawl in Terms of Impacted Open Space

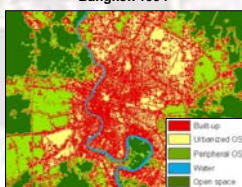
Urban sprawl has a negative impact on open land since there is an increased amount of open land in close proximity to development. The effects of edge disturbances on open lands, as a result of land use change, have been well documented in the scientific literature.

The metrics recognize two types of impacted open space:

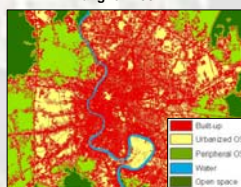
- Urbanized open space:** corresponds to city parks and fields located in areas with *core* urban development. Severely degraded by close proximity to dense developments.
- Peripheral open space:** any open land within 100 meters of developed land excluding urbanized open space. Less degradation by development but still impacted by "edge effects".

## Metric Examples (Bangkok)

Bangkok 1994



Bangkok 2002



Metrics	1994	2002	Annual AT
Built-up area	km <sup>2</sup> 683.1	1026.1	7.0%
Urbanized OS	%* 39.0	42.0	0.4
Peripheral OS	%* 127.2	104.3	-3.2
Total Affected OS**	%* 166.2	146.2	-2.8

\*Manifestations are represented as percentages of the Built-Up Area

\*\* Total Affected OS represents all open land affected by the built-up area which includes the urbanized open space and the peripheral open space

## Interpretation

One would typically expect a sprawling city to be rapidly expanding over time in terms of its built-up area. Since sprawl is also associated with low-density development, one would expect the relative area of the open lands affected by the city to increase over time.

In Bangkok, the built-up area has expanded substantially during the study period with its area increasing by 7% per year. The relative amount of *urbanized open space* also increased slightly over time. The peripheral open space, however, experienced a significant decline in its relative area over time which resulted in a decline in the relative amount of open land affected by the built-up area.

The rapid increase in the built-up area of Bangkok is an indicator of a potentially sprawling city. However, the relative decline in the overall amount of open land affected by the built-up area is not what one would intuitively expect for a sprawling city.

## Global Sprawl Indices

Global sprawl indices quantify a particular attribute of sprawl for the urban area as a whole...

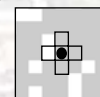
## Population Density

Low population density is the most common attribute of sprawl mentioned in the literature. Population densities are expected to decline over time for cities that are becoming more sprawled. We measure population densities based on the built-up area.

## The Interspersion of Urban and Open Land

Sprawling development has a tendency to leapfrog away from existing development resulting in an indistinct boundary between city and countryside. This interspersion of developed and open lands is expected to increase over time for sprawling cities. We quantify this phenomena with the *Interspersion Index*:

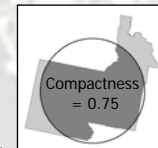
- interspersion index:** the fraction of built-up pixels that are adjacent to at least one open land pixel.
- a roving window is used to check for cardinal adjacency of built-up and open land pixels



## Compactness of the Urban Area

The urban area of a sprawling city is expected to be non-compact due to the propensity for leapfrog type development. Over time, the urban areas of sprawling cities should become less compact. The *Compactness Index* measures shape compactness relative to the circle - a shape with the highest possible compactness for a given area.

- Compactness is measured as the fraction of the urban area that is contained within the *equal area circle* - a circle with an area equal to that of the urban area and centered on the centroid of the urban area.
- Index values range between 0 and 1 with higher values indicating greater compactness.



## Metric Examples (Bangkok)

Indices	1994	2002	Annual AT
Population density (persons per hectare)	121	95	-3.2%
Interspersion	0.56	0.47	-1.00%
Compactness	0.62	0.66	0.56%

## Interpretation

The decline in population density for Bangkok is a clear indicator of a sprawling city. However, the decline of the *Interspersion Index* and the increase of the *Compactness Index* indicate that the spatial density of Bangkok is increasing over time - characteristics not intuitively expected for a sprawling city.

## Conclusions and Future Work

The rapid expansion of the world's cities will be inevitable with the dramatic increase in the urban population expected to occur over the next several decades. The nature of this urban expansion has the potential to impact profoundly natural resources and raise serious socioeconomic issues if proper precautions and planning measures are not taken.

We have assembled a comprehensive set of metrics that consistently and rigorously quantify the characteristics that are typically associated with sprawl. This set of metrics will be used to analyze sprawl in a global sample of 120 cities, over a period of 10 years, in order to correlate trends in sprawl with political regions, income levels, and city population size. The analysis will help identify factors driving sprawl as well as motivate and justify efforts addressing the issue of urban sprawl.