Spatial Patterns of Impervious Surface Cover (ISC) in the Cave Creek Watershed

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Introduction

Impervious surface cover (ISC) refers to any nonporous land cover that prevents water infiltration into sub-surface layers. A bare rock area is natural impervious surface cover, while urbanization results in a dramatic increase in non-natural impervious surface cover, including rooftops, paved roads, sidewalks, parking lots, and driveways. ISC can significantly alter stream structures and hydrological regimes in urban areas. Such alterations often lead to increased stream temperature and pollutant loadings, changed stream biogeochemistry, and even malfunctions of the whole watershed ecosystem.

The total amount of impervious surface cover (TISC) has been used as an important indicator for urban planning and ecological research. A threshold of severe ecological effects was usually assumed as the TISC reaches 30% of a watershed. However, directly measuring TISC is difficult, and often needs to be done on a fine scale. Spatial configuration of ISC and its association with ecological processes have not been well studied. To understand mechanistic linkages between urbanization and stream ecology, it is necessary to analyze the spatial pattern of ISC at multiple scales, and take into account landscape heterogeneity.

Research Questions

(1) How to quantitatively and cost efficiently measure ISC at landscape and watershed scales?

(2) Does any continuous gradient of ISC exist within an urban watershed?

Data and Methods

Spatial data:

- 3 m resolution digital imagery (Landiscor,1999) was used to extract the ISC data.
- Digital Elevation Model (DEM) was used to delineate watershed boundary and achieve topographic information.
- U.S. Census 1990 and 2000 data: total population density, housing density, and block group boundary files.
- GIS themes and layers of the Phoenix Metropolitan Region: streets, industry sites, streams, recreation and parks.

Study area:

The Lower Cave Creek Watershed from the Cave Creek Dam to the Arizona Canal. Two scales approach:

At watershed scale: a 17,600 m longitudinal distance of the watershed, along the stream channel and an urban-rural transect, was divided into 11 transect zones across the entire watershed (Figure 1). Each of the transect zones has identical interval as 1,600 m (or 1 mile). Total area of the studied watershed is 10,713.80 hectares.

At landscape scale: spatial extension of sampled landscapes: 800 X 800 m, and 800 m stream channel buffer zones.

Image interpretation:

- Image Analysis Extension and Spatial Analysis Extension in ArcView GIS (v. 3.2).
- Erdas Imagine (V. 4.2) with applying spatial enhancement techniques (CONVOLUTION and Focal Analysis).

Patch analysis: Patch Analysis Extension in ArcView GIS (v. 3.2).

Category of ISC: Two groups of ISC were classified based on spectral characteristics of the digital imagery:

***ISC Type I* (ISC-I):** the impervious surface cover having lower reflection of light (i.e. lower digital number (DN) in pixel intensity on the imagery), including asphalt paved roads, sidewalks, parking lots, and driveways.

***ISC Type II* (ISC-II):** the impervious surface cover having high reflection of light (i.e. very high digital number (DN) in pixel intensity on the imagery), including most buildings, concrete roads, sidewalks, driveways, compacted bare ground, and other cement structures such as water canals and swimming pools.

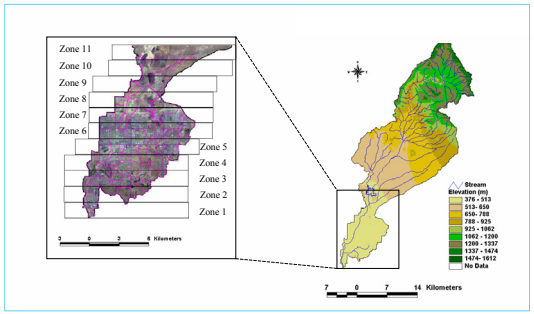

Figure 1. Elevation gradients and stream network of the Cave Creek Watershed (right map), sub-watershed boundaries (purple lines) and the eleven laterally extended transect zones (left map) for studying ISC.

Results (Part 1): Spatial Patterns of the ISC at Watershed Scale

- Overall TISC is 40.52 % of the Lower Cave Creek watershed, including the natural impervious areas.
- TISC varies from downstream (near center of the urban region) to upstream (outside the urban fringe), with a decreased TISC gradient range from 47% to 20% (Figure 2).
- Two zones (Zone 5 and Zone 10) with lower TISC are associated with low housing density of residential areas and large areas of recreational landscape (i.e. the North Mountain Preserve and desert region between the Union Hills and Desert Hills).
- The patterns of ISC-I and ISC-II seem to result from urban development and land use heterogeneity. Patterns of higher ISC-I and Lower ISC-II combination are distributed in well-developed urban regions from Zone 1 to Zone 6, with exception of Zone 5; while the patterns of higher ISC-II and Lower ISC-I combination are located across the urban-rural ecotone from Zone 7 to Zone 11, except Zone 10 that covers most desert areas downstream of the Cave Creek reservoir (Figure 1 and Figure 2).

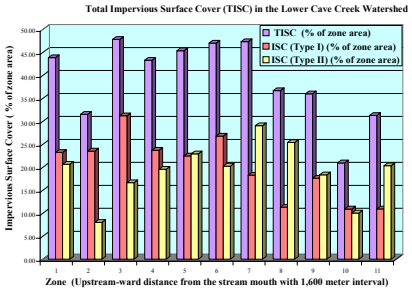

Figure 2. Distribution of the two types of impervious surface cover (ISC-I and ISC-II) and the total impervious surface cover (TISC) in the eleven laterally extended zones across the entire watershed.

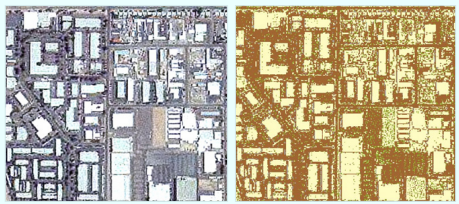

Figure 3. A sample site of mixed industrial-commercial landscape from the digital image (left) with 90.78 % TISC; the classified land cover results (right): ISC-1 (brown color) = 51.54 %; ISC-II (yellow color) = 39.24 %; The green color areas are pervious surface.

Figure 4. A sample site of industrial landscape from the digital image (left) with 71.29 % TISC; the classified land cover results (right): ISC-I (brown color) = 39.28 %; ISC-II (yellow color) = 32.01 %; The green color areas are pervious surface.

Figure 5. A sample site of high housing density residential landscape from the digital image (left) with 73.33 % TISC; the classified land cover results (right): ISC-I (brown color) = 47.43 %; ISC-II (yellow color) = 25.90 %; the green color areas are pervious surface.

Figure 6. A sample site of mixed residential-recreational landscape from the digital image (left) with 50.40% TISC; the classified land cover results (right): ISC-I (brown color) =21.49%; ISC-II (yellow color) = 28.91%; the green color areas are pervious surface.

Results (Part 2): Spatial Patterns of the ISC at Landscape Scale

- The industrial-commercial land use dominated landscape has the highest TISC (usually 60-90%), ISC-I > ISC-II, and large size of the impervious patches.
- High housing density residential landscape has extremely high TISC, ISC-I > ISC-II, small patch size, and high fragmental impervious surface cover with well connected ISC-I corridors, such as streets, roads, sidewalks.
- Mixed residential-recreational landscape has medium to high TISC, ISC-I close to ISC-II, or ISC-I < ISC-II.

Conclusions

- The spatial distribution patterns of relative percentages of ISC-I and ISC-II in the watershed exhibit different spatial gradients changing longitudinally in the watershed and across the urban-rural ecotone as well. It suggests possible human induced gradients of ecological threat or effects on hydro-ecological processes and eco-landscape of the watershed, for examples, reconfiguration of flowpaths of nutrients and pollutant transportation, and reconstruction of hydrological connectivity of surface water and groundwater in the high TISC areas.
- TISC in all of the zones but Zone 10 exceed 30 % of the total zone areas, the threshold of severe ecological effects on urban ecosystem. This is critical for many ecological processes occurring in the urban watershed ecosystem.
- Spatial patterns and configuration of the ISC is highly correspond to spatial changes in land use of urban landscape. The ISC can be quantitatively measured using high resolution photograph and image enhancement techniques. However, accurate and efficient accounting of the TISC is better preformed at landscape scale.

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