Does the spatial arrangement of vegetation and anthropogenic land cover features matter? Case studies of urban warming and cooling in Phoenix and Las Vegas

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Background: The relationship between the percentage of land cover and land surface temperatures (LST) has been well examined. It is well understood that urban trees and other vegetation reduce LST, while impervious surfaces (e.g., buildings and pavements) increase LST. However, the configuration of these land cover features and their impacts on LST and UHI have not been studied in depth.

Objectives: This study aims to address the following questions using a spatial autocorrelation approach:

(1) Does the spatial arrangement of urban landscape influence urban LST warming and cooling?
(2) Are the impacts of spatial pattern on LST similar in magnitude among different land cover features?
(3) Is the type and level of relation between the spatial pattern of each land cover type and LST different from one city to another?
(4) Do spatial patterns of vegetation and built features still show similar impacts when other land cover fractions are controlled?
(5) What are the implications for future urban design and planning?

Study Areas

Phoenix, Arizona and Las Vegas, Nevada are the cities observed in this study. These two subtropical desert climates have intensely hot summers where daytime temperatures frequently exceed 40°C, resulting in high water use for irrigation and heat-related health problems. These issues are exacerbated by the UHI effect. Phoenix and Las Vegas also share similar land cover features, which enables a cross-city comparison.

Materials

High resolution satellite data and land cover mapping

QuickBird image for the city of Phoenix was acquired on 29 May, 2007. The dataset has a 2.4 m spatial resolution with four wavelength bands: Blue (0.45–0.52 µm), Green (0.52–0.60 µm), Red (0.63–0.69 µm), and Near Infrared (0.76–0.90 µm).

Geoeye-1 image of Las Vegas was taken on October 12, 2011. The image has a spatial resolution of 3 m with four similar bands: Blue (0.45 – 0.51 µm), Green (0.51 – 0.58 µm), Red (0.66 - 69 µm), and Near Infrared (0.78 – 0.92 µm). An object-oriented approach was employed to identify six land cover classes: buildings, trees, grass, unmanaged soil, paved surfaces, and water. **Figure 1** shows a subset of the two images and their land cover classification maps.

ASTER surface temperatures

We used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images at 90 m spatial resolution to derive summer daytime and nighttime LST in Celsius. The acquisition dates for daytime and nighttime temperature data are June 10, 2011 and October 17, 2011 for Las Vegas, and July 6, 2005 and August 27, 2005 for Phoenix, respectively.

Proposed Methodology

We extracted individual land cover types from each image and constructed binary maps of buildings, trees, grass, unmanaged soil, paved surfaces, and water. For each binary map of a specific land cover type. We then computed local Moran's *I* values for every 90m×90m area to match the ASTER images' spatial resolution. The average Moran's *I* values were normalized to the range of −1 to 1, with values of −1, 0, and 1 representing highly dispersed patterns, random patterns, and highly clustered patterns, respectively. To minimize the confounding effects of land cover fractions on the relationships between spatial pattern and LST, we grouped observations with similar fractions of land cover types at 10 % interval (i.e., 0–9 %, 10–19 %, 20–29 %, ------ 80–89 %, 90–100 %).

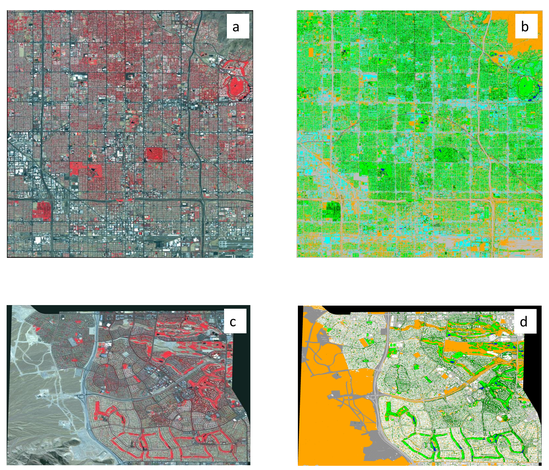

Figure 1. (a) QuickBird image over Phoenix, (b) Classification map of QuickBird, (c) Geoeye-1 image over Las Vegas, (d) Classification map of Geoeye-1 (cyan = buildings, dark green = trees/shrubs, light green = grass, orange = unmanaged soil, gray = paved surfaces, blue = water).

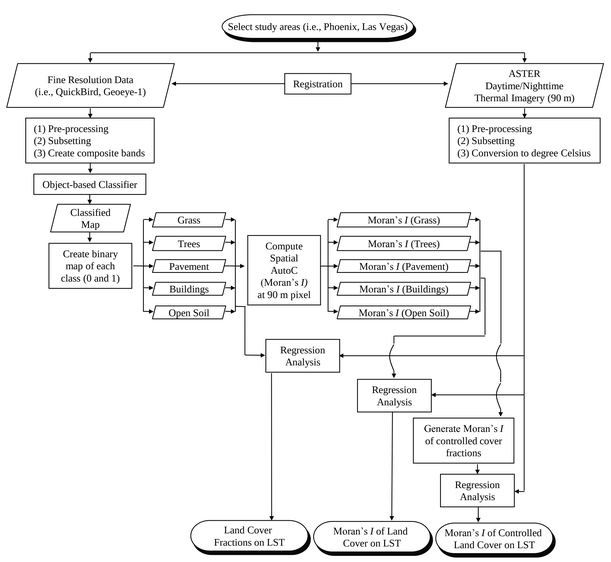

Figure 2. Research Design.

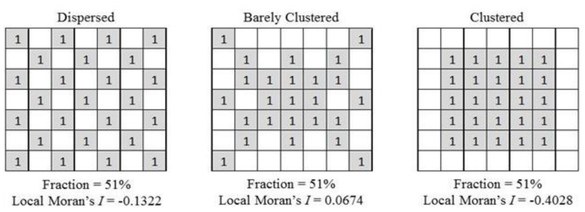

Figure 3. Three hypothetical spatial configurations of a land cover (e.g., grass = 1) in a 7x7 grid area and local Moran's *I* values.

Spatial Autocorrelation (Moran's *I*)

$$I_i(d) = \frac{x_i - \bar{x}}{\sum (x_i - \bar{x})^2} \sum_j w_{ij}(d)(x_j - \bar{x})$$

where x_i represents the attribute value (i.e. zero or one in the binary map) at location *i* and $\bar{x}$ denotes the average attribute values for pixels in the entire image. $\{w_{ij}(d)\}$ is a spatial weight matrix where the diagonal elements are all zero, and the off-diagonal elements are either one or zero, depending on whether the corresponding pixels are neighbors or not. The neighborhood is defined by the distance .

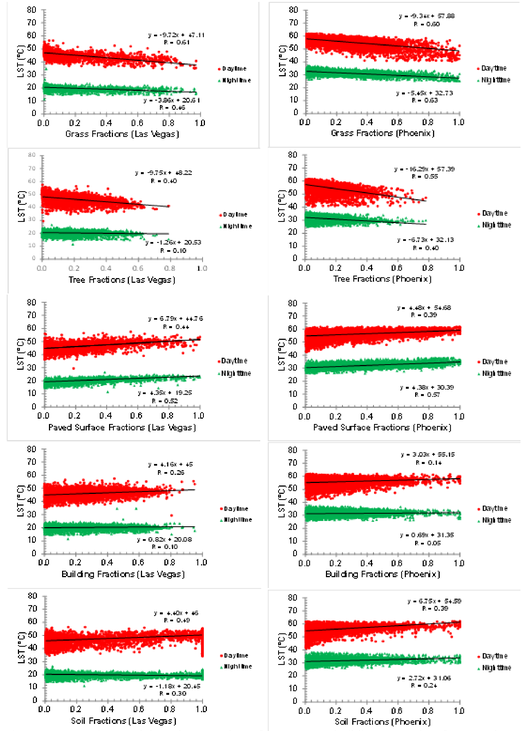

Figure 4. Regression models and scatterplots of grass, trees, buildings, paved surfaces, and open soil vs. daytime and nighttime LST for Las Vegas and Phoenix.

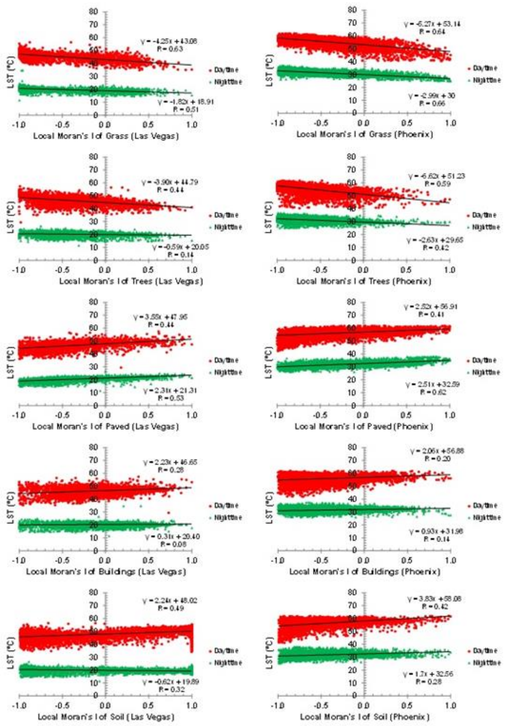

Figure 5. Regression models and scatterplots of the spatial configuration of grass, trees, buildings, paved surfaces, and open soil vs. daytime and nighttime LST for Las Vegas and Phoenix..

Table 1. Pearson correlation between local Moran's *I* of paved and daytime LST under different controlled land cover compositions (only those groups with r > 0.3).

Land cover %				Paved Moran's *I*					
Paved	Vege	Soil	Bld.	Min.	Max.	Slope	*r*	r^2	*n*
				LAS VEGAS					
10-19	20-29	0-9	50-59	-0.79	-0.28	5.73	0.45	0.20	136
10-19	20-29	10-19	40-49	-0.75	-0.34	5.34	0.37	0.14	58
10-19	40-49	0-9	30-39	-0.77	-0.23	3.29	0.30	0.09	90
20-29	0-9	10-19	50-59	-0.69	-0.29	5.58	0.55	0.30	18
20-29	10-19	0-9	40-49	-0.58	-0.24	5.64	0.39	0.15	30
20-29	10-19	10-19	40-49	-0.69	-0.08	2.51	0.33	0.11	40
20-29	10-19	0-9	50-59	-0.65	-0.15	4.26	0.37	0.14	166
20-29	10-19	10-19	50-59	-0.69	-0.21	2.90	0.31	0.10	44
20-29	10-19	0-9	60-69	-0.65	-0.22	5.99	0.53	0.28	40
20-29	10-19	20-29	30-39	-0.64	-0.09	4.85	0.60	0.36	21
20-29	20-29	0-9	40-49	-0.65	-0.05	4.03	0.36	0.13	199
20-29	20-29	10-19	40-49	-0.60	-0.34	6.52	0.45	0.20	17
20-29	20-29	0-9	50-59	-0.65	-0.09	4.22	0.40	0.16	64
20-29	30-39	10-19	20-29	-0.68	-0.19	4.17	0.39	0.15	20
20-29	30-39	0-9	30-39	-0.58	-0.25	4.04	0.35	0.12	131
30-39	20-29	10-19	20-29	-0.50	0.20	4.12	0.49	0.24	24
30-39	30-39	0-9	30-39	-0.51	0.07	3.15	0.41	0.17	42
40-49	10-19	10-19	30-39	-0.39	0.42	2.19	0.39	0.15	82
40-49	10-19	0-9	40-49	-0.28	0.22	2.45	0.30	0.09	27
40-49	20-29	20-29	10-19	-0.36	0.23	2.73	0.40	0.16	61
50-59	10-19	0-9	30-39	-0.12	0.49	2.46	0.35	0.12	55
60-69	20-29	0-9	10-19	0.11	0.51	7.65	0.50	0.25	22
70-79	0-9	0-9	10-19	0.34	0.76	7.93	0.47	0.22	22
70-79	10-19	0-9	0-9	0.33	0.78	4.95	0.61	0.37	15
80-89	0-9	0-9	0-9	0.49	0.91	4.32	0.36	0.13	20
				PHOENIX					
10-19	0-9	30-39	40-49	-0.74	-0.27	4.49	0.45	0.20	21
10-19	0-9	40-49	30-39	-0.69	-0.08	3.49	0.37	0.14	21
10-19	0-9	50-59	20-29	-0.77	0.13	3.46	0.53	0.28	19
10-19	0-9	60-69	10-19	-0.77	-0.33	4.53	0.43	0.19	22
10-19	0-9	80-89	0-9	-0.64	-0.25	3.73	0.33	0.11	16
10-19	20-29	0-9	50-59	-0.76	0.18	2.84	0.43	0.18	31
10-19	20-29	10-19	40-49	-0.83	-0.15	5.14	0.48	0.23	48
10-19	30-39	0-9	40-49	-0.81	-0.15	3.90	0.38	0.15	49
10-19	30-39	10-19	30-39	-0.81	-0.17	4.21	0.51	0.26	122
10-19	40-49	20-29	10-19	-0.86	0.08	3.20	0.38	0.15	245
10-19	40-49	30-39	0-9	-0.78	-0.21	1.54	0.34	0.11	20
10-19	50-59	20-29	10-19	-0.83	-0.16	3.40	0.36	0.13	58
10-19	70-79	0-9	10-19	-0.85	0.18	2.84	0.34	0.12	133
10-19	80-89	0-9	0-9	-0.68	-0.28	7.13	0.60	0.37	27
20-29	10-19	40-49	10-19	0.73	0.07	2.39	0.37	0.13	72
20-29	20-29	0-9	40-49	-0.62	0.02	1.34	0.31	0.09	43
20-29	30-39	0-9	30-39	-0.69	-0.06	4.87	0.46	0.22	68
20-29	30-39	10-19	20-29	-0.77	0.03	3.81	0.41	0.16	198
20-29	30-39	20-29	10-19	-0.69	0.08	2.54	0.33	0.11	135
20-29	30-39	30-39	0-9	-0.71	-0.15	5.04	0.51	0.26	36
20-29	40-49	10-19	10-19	-0.77	0.06	2.48	0.33	0.11	242
20-29	40-49	20-29	0-9	-0.71	0.03	3.71	0.39	0.15	38
20-29	50-59	10-19	0-9	-0.75	0.10	2.35	0.38	0.14	78
30-39	20-29	30-39	0-9	-0.70	0.16	2.81	0.35	0.12	41
40-49	0-9	40-49	0-9	-0.31	0.21	2.82	0.33	0.11	47
40-49	0-9	50-59	0-9	-0.28	0.28	5.21	0.43	0.18	25
40-49	20-29	0-9	20-29	-0.37	0.19	3.76	0.39	0.16	57
40-49	20-29	20-29	10-19	-0.38	0.24	4.28	0.48	0.23	38
50-59	0-9	40-49	0-9	-0.09	0.37	6.00	0.53	0.29	44
50-59	30-39	0-9	0-9	-0.19	0.36	3.02	0.38	0.15	22
60-69	0-9	20-29	0-9	0.01	0.55	3.56	0.30	0.09	73
60-69	0-9	30-39	0-9	0.06	0.60	6.53	0.47	0.22	47
60-69	10-19	0-9	10-19	-0.03	0.48	3.74	0.32	0.10	55
70-79	0-9	0-9	10-19	0.07	0.67	4.46	0.42	0.17	126
70-79	0-9	10-19	0-9	0.15	0.62	4.71	0.35	0.12	121
70-79	0-9	20-29	0-9	0.18	0.65	11.61	0.71	0.50	59
80-89	0-9	0-9	0-9	0.33	0.86	5.00	0.39	0.15	120
80-89	0-9	10-19	0-9	0.34	0.85	11.26	0.66	0.44	76

Table 2. Pearson correlation between local Moran's *I* of grass and daytime LST under different controlled land cover compositions (only those groups with r > 0.3).

Land cover %				Grass Moran's *I*					
Grass	Tree	Paved/Soil	Bld.	Min.	Max.	Slope	*r*	r^2	*n*
				LAS VEGAS					
10-19	20-29	20-29	30-39	-0.83	0.07	-2.72	0.35	0.12	30
10-19	20-29	30-39	20-29	-0.82	0.09	-5.30	0.60	0.36	34
10-19	30-39	20-29	20-29	-0.85	0.13	-3.05	0.37	0.14	28
20-29	20-29	10-19	20-29	-0.54	0.17	-3.61	0.36	0.13	20
30-39	20-29	20-29	20-29	-0.56	0.46	-5.14	0.47	0.22	15
70-79	10-19	0-9	0-9	0.15	0.61	-9.83	0.44	0.19	28
80-89	3-15	0-9	0-9	0.35	0.72	-9.32	0.60	0.36	17
				PHOENIX					
10-19	0-9	20-29	50-59	-0.82	-0.34	-5.76	0.36	0.13	32
10-19	0-9	30-39	40-49	-0.81	0.25	-3.32	0.33	0.11	104
10-19	0-9	80-89	0-9	-0.90	-0.10	-3.72	0.34	0.12	55
10-19	10-19	20-29	40-49	-0.82	-0.42	-9.51	0.33	0.11	45
10-19	10-19	60-69	0-9	-0.82	-0.29	-5.55	0.36	0.13	95
10-19	20-29	20-29	30-39	-0.75	-0.50	-10.17	0.36	0.13	23
10-19	20-29	40-49	10-19	-0.82	-0.37	-7.50	0.40	0.16	50
10-19	20-29	50-59	0-9	-0.84	-0.35	-7.17	0.34	0.12	22
20-29	0-9	40-49	20-29	-0.72	0.12	-5.50	0.36	0.13	335
20-29	0-9	50-59	10-19	-0.69	0.24	-5.19	0.40	0.16	244
20-29	10-19	10-19	40-49	-0.59	-0.32	-10.79	0.47	0.22	26
20-29	10-19	40-49	20-29	-0.67	0.11	-5.97	0.35	0.12	230
20-29	10-19	50-59	10-19	-0.72	-0.09	-5.65	0.36	0.13	82
20-29	20-29	20-29	20-29	-0.67	-0.17	-6.88	0.33	0.11	66
30-39	0-9	20-29	30-39	-0.56	0.46	-6.30	0.33	0.11	121
30-39	0-9	30-39	20-29	-0.54	0.12	-6.83	0.43	0.18	301
30-39	0-9	40-49	10-19	-0.58	0.21	-5.79	0.45	0.20	144
30-39	10-19	20-29	20-29	-0.51	0.03	-6.31	0.32	0.10	385
30-39	10-19	40-49	10-19	-0.52	0.20	-6.23	0.34	0.12	87
30-39	20-29	10-19	20-29	-0.47	-0.01	-7.80	0.31	0.10	117
30-39	20-29	20-29	10-19	-0.46	-0.01	-10.13	0.41	0.17	160
30-39	20-29	30-39	10-19	-0.50	0.15	-9.10	0.44	0.19	78
30-39	30-39	10-19	10-19	-0.41	-0.02	-11.52	0.44	0.19	86
30-39	40-49	10-19	0-9	-0.43	0.11	-9.00	0.50	0.25	27
40-49	0-9	30-39	10-19	-0.32	0.30	-4.08	0.35	0.12	78
40-49	0-9	40-49	0-9	-0.35	0.34	-5.22	0.36	0.13	27
40-49	10-19	10-19	20-29	-0.11	0.15	-10.98	0.40	0.16	241
40-49	10-19	20-29	10-19	-0.36	0.24	-7.21	0.34	0.12	383
40-49	10-19	30-39	0-9	-0.35	0.32	-6.36	0.36	0.13	91
40-49	20-29	0-9	20-29	-0.36	0.06	-11.65	0.41	0.17	52
40-49	20-29	10-19	10-19	-0.37	0.24	-8.80	0.35	0.12	288
40-49	20-29	20-29	0-9	-0.35	0.20	-6.72	0.31	0.10	113
50-59	0-9	20-29	10-19	-0.15	0.37	-6.44	0.41	0.17	41
50-59	10-19	0-9	20-29	-0.17	0.28	-12.64	0.51	0.26	31
50-59	10-19	10-19	10-19	-0.19	0.42	-12.60	0.54	0.29	165
50-59	10-19	20-29	10-19	-0.12	0.27	-6.98	0.33	0.11	54
50-59	20-29	0-9	10-19	-0.14	0.27	-13.85	0.60	0.36	60
50-59	20-29	10-19	0-9	-0.15	0.03	-10.34	0.37	0.13	85
50-59	30-39	0-9	0-9	-0.12	0.31	-18.26	0.57	0.33	33
60-69	10-19	10-19	0-9	0.02	0.50	-11.11	0.38	0.15	32
60-69	20-29	0-9	0-9	0.03	0.60	-9.58	0.39	0.16	36
60-69	30-39	0-9	0-9	0.06	0.60	-17.33	0.40	0.16	30
70-79	0-9	10-19	0-9	0.17	0.67	-10.62	0.51	0.26	26
70-79	20-29	0-9	0-9	0.22	0.66	-17.64	0.46	0.21	32
80-89	10-19	0-9	0-9	0.34	0.83	-10.89	0.43	0.18	56

Conclusion

1. Both vegetation features (i.e., grass, trees) were found to have strong negative correlations to LST.
2. Trees can lower LST more effectively than grass.
3. Buildings were found to have a low positive or no relationship to LST.
4. A strong relationship exists between paved surfaces and LST.
5. Unmanaged soil can elevate LST as strongly as paved surfaces.
6. Spatial configuration of urban landscape influences surface temperatures.
7. Clustered configuration of grass significantly lowers summer daytime LST.
8. Clustered spatial arrangements of paved surfaces significantly elevate nighttime LST.
9. It is recommended that policy makers incorporate and optimize the spatial configuration of urban landscapes by clustering vegetation (i.e., grass, trees) and making unmanaged soil and paved surfaces dispersed.

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