Higher temperature effects of impervious surface due to urbanization in South Berkeley, California

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ABSTRACT

City developments have caused an increase in the overall area of impervious surface and decreases in the area of vegetative cover. Higher temperatures of impervious surfaces can be considered one of the most important urban pollution issues that result in economic and biological losses. Understanding the precise impacts of impervious surface after land conversion of vegetation cover to urbanization will provide benefits for urban society. I used multispectral data from Geospatial Innovation Facility (GIF) in College of Natural Resources, University of California – Berkeley and thematic data from U. S. Geological Survey (USGS) to collect the data for surface temperatures and land type. I used eCognition software to classify vegetation and impervious surfaces, and compared the temperatures over each land type. I found the average impervious surface temperature of 307.67 ± 1.83˚K compared to the average vegetation surface temperature of 306.86 ± 2.08˚K resulting in a temperature difference of the two land surface classes is 0.8˚ Kelvin. The impervious surface adds to the urban environment by adding more heat. This research will provide a possibility for improved urban environment with regard to impervious surface in the field of both energy and public health.

KEYWORDS

vegetation cover, solar energy, heat stress, land conversion, urban heat island

INTRODUCTION

With technology and product development powered by human desire and industrial efficiency, cities also have developed in their function and have increased in their sizes and numbers. Increases in the urban population along with increased birth rates and dense population have enlarged the city even more (Stanaitis 1988). Centralized infrastructure has intensified and other negative effects have arisen as the required spaces and infrastructure increase to sustain the population and industry (Voogt and Oke 2003, Stobart 1996). Unintended negative effects have resulted from consolidating everything into a limited area. The high urban density has caused psychological stress, disease, and physical stresses as well to individuals (Fandrem et al. 2009). Unprecedented air pollution by fossil fuel consumption is compromised even more by the decreased amount of vegetation that acts as an alleviator (Gonzalez, G. A 2003, Yin et al. 2011). This vegetation loss has led to downfall in aesthetic value and, indirectly, resulted in heat waste as one of the serious urban pollutants.

The decrease in vegetation is related to the increase of impervious surface characterized by preventing water and other materials from penetrating the surface. The level of sanitary conditions has been improved over time by decreasing waterborne diseases by reducing the water holding time of the surface and reduced exposure of surface life to potential harmful materials such as open sewage (Godfrey and Julien 2005). However, the impervious land surface inhibits plants from sprouting (Bayer 2001). The impervious surface is subject to a temperature factor more than the previously vegetated land surfaces (Ma et al. 2010). After all, the temperature sensitivity of the impervious surface caused urban surface temperature increase.

Higher temperatures are considered one of the most important urban pollution issues because they cause economic and biological losses (Weng and Lu 2008). Economic loss is connected to higher consumption of electricity from indoor air conditioning systems, refrigerators, and water use (Izquierdo et al. 2011). Although the impervious surface devoted to public health improved sanitation levels, the impervious surface also has been suspected as a driving factor of intensive heat stresses which causes casualties and increases in hospital patients as heat waves sweep cities (Rodrigo and

Cayla 2011). For this reason, public health costs are higher as the magnitude of heat increases. Micro climate change from vegetation decrease and shift of surface matrix also accelerates the temperature increase (Machlis et al. 2009). Previous societal physical structure of agriculture and economy has been dislocated as temperature increases and affects urban life. Adapting each field (e.g., agriculture, economy, and biosphere) to the new optimum climatic scenario will require capital that is too complicated and large to be estimated. For this reason, it is important to study the correlations among impervious land surface, higher temperature, and losses to alleviate and eliminate the loss.

Revealing the precise impacts of impervious surface after the conversion of vegetation cover to urbanization will provide a benefit for urban society, if it can be analyzed despite the depth of its complexity and enormous size of the data on the topic (Nordhaus 2007). However, even after the impacts are scrutinized it is unclear if manipulation of the landscape is feasible because it will raise another numerous research topics. This uncertainty can occur because the mechanism of heat stress from impervious surface contains technical complexity and is rooted in the social, organizational, technical, and political fields. Currently the largest unknown issue is to consider why and how the impervious surface affects heat stress. The first step of this large issue is to determine if there is a strong positive correlation between higher temperatures of urban and impervious land surface.

In this study, the first step of improving urban environment will be achieved by studying the urban land surface material effect on the surface temperature. Temperatures will be collected with Geographic Information System (GIS) based on the land surface classes of impervious surfaces and vegetation covers.

METHODS

Data collection using ArcGIS ver.10.0

To collect the datasets for surface temperatures and land type, I used (1) Combined Natural Color/Infrared (4-band) data National Agriculture Imagery Program (NAIP) from Geospatial Innovation Facility (GIF) in College of Natural Resources, University of California – Berkeley and (2) LandSat Enhanced Thematic Mapper Plus (ETM+) data from U. S. Geological Survey (USGS). I chose Berkeley, CA for this project because vegetation is comparatively well integrated, compared to other cities, into the urban fabric of the city. For the best chance of a clear difference of surface temperature I chose LandSat image of midday temperatures on warm sunny day (center of the image scanned at 18:36:27, July 2nd, 2009). And I chose a NAIP dataset for the closest date as possible to the LandSat data to minimize the disparity of land composition between two image collection events of NAIP and ETM+. The closest available date of proper NAIP data was from June 19th, 2009. Specifically I collected and focused temperature data from South Berkeley. I tended to exclude North Berkeley where, compared to the South, is located at higher altitude such that wind may significantly affect its surface temperature.

Data arrangement

For the first step to classify vegetation cover and impervious, I drew polygons using eCognition. I used the object based image analysis on the NAIP imagery to segment vegetation and impervious surfaces. I used NDVI (Normalized Difference Vegetation Index) to differentiate vegetation cover from other cover types. It was calculated as follows:

$$\mathbf{NDVI = (IR-R)/(IR+R)}$$

Polygons having NDVI value greater than -0.05 were defined as vegetation cover. I used total band reflectance (TR) for impervious surface differentiation.

$$\mathbf{TR = Red+Green+Blue+Infrared}$$

Polygons having TR value of 300 or more were defined as impervious surface. I exported the final data as a shape file. I converted the thermal band values from thematic band to kelvin using ENVI and exported to a TIF file. I clipped the temperature file and the classification from eCognition. I assigned a centroid to each polygon and classified the shape. Each point was assigned with the temperature and the land class of the polygon. I summarized the values of data by vegetation type using (3) R (mean, standard deviation, and the number of points for each land surface type).

RESULTS

Data collection

I achieved surface temperature weighted map of south Berkeley (Fig. 1). From NAIP imagery I drew out classification of vegetation cover and impervious surface as polygons. Classification on the parameter scale of 30 gave a classification map (Fig. 2). Pink polygons represent the impervious surface and green polygons represent the vegetation surfaces.

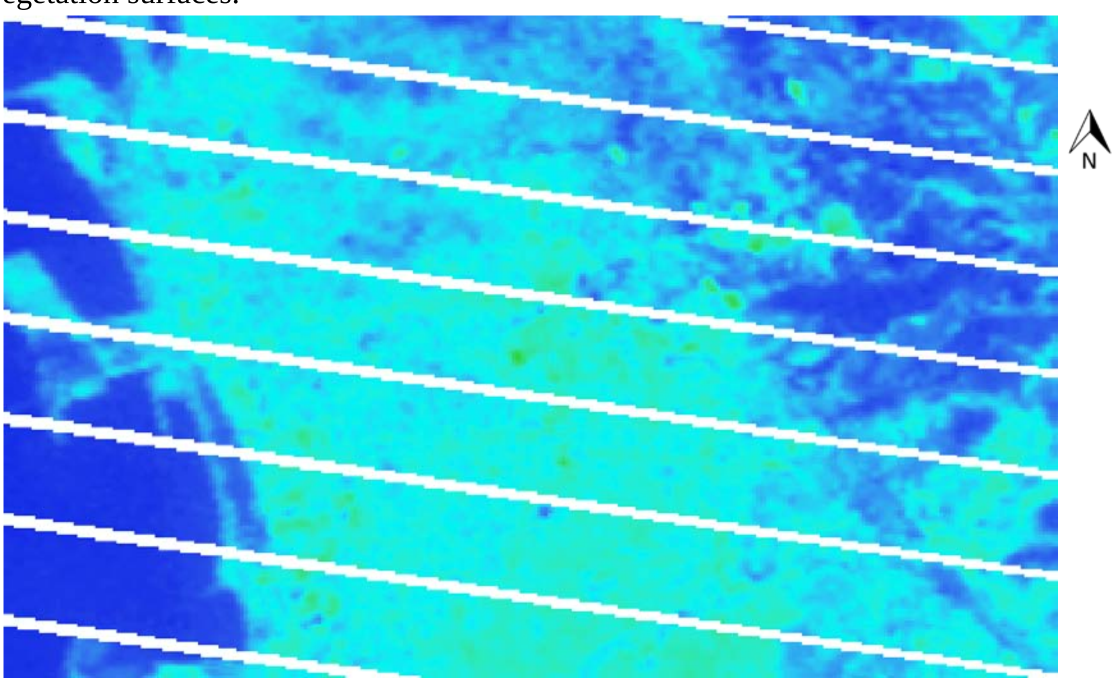

Figure 1. Kelvin Temperature weighted image of south Berkeley. Blue represents lower value and green represent higher value

Figure 2. Classification of vegetation and impervious surface near UC Berkeley. Impervious in pink; vegetation in green

Centroid process gave an image with points assigned on each polygon (Fig. 3).

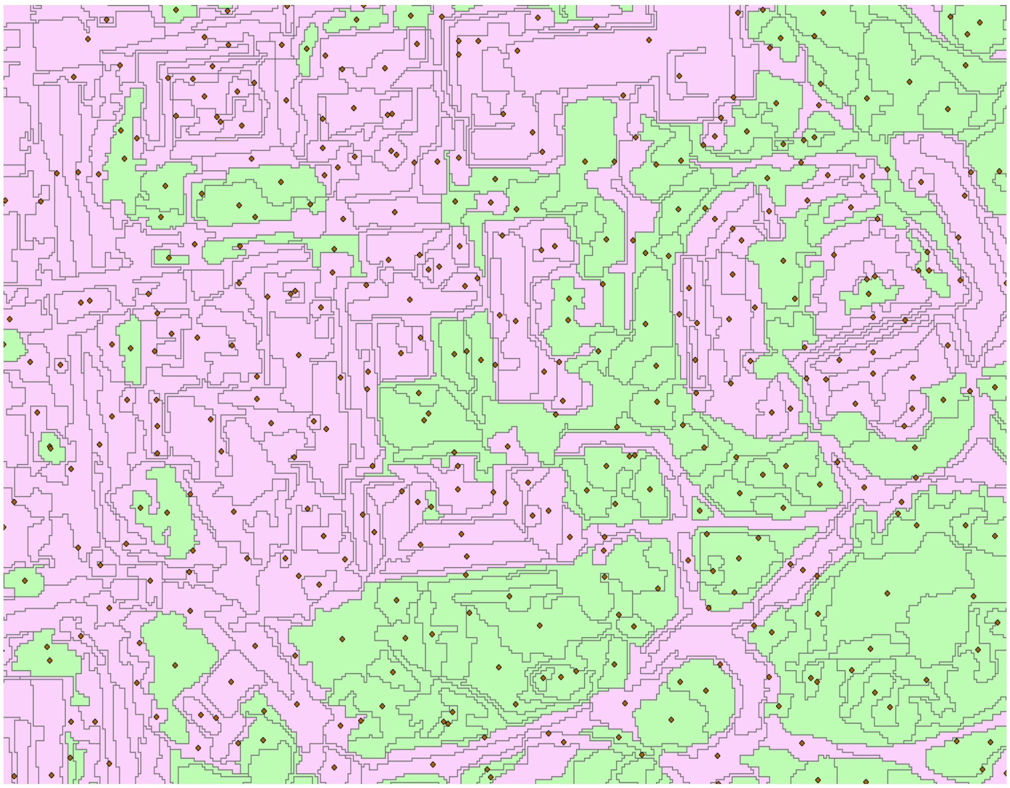

Figure 3. Classification map of Northwest UC Berkeley Campus with centroids

Analysis

Using R, I found the average impervious surface temperature is 307.67 $\pm$ 1.83 Kelvin and vegetation surface temperature is 306.86 $\pm$ 2.08 Kelvin (Table 1). The dataset totaled 95,519 centroid points as impervious surface and 38,957 centroid points as vegetation cover. Vegetation had a lower average vegetation temperature value than impervious surface temperature (Fig. 4).

Table 1. Summary of surface temperature data.

	mean	sd	0%	25%	50%	75%	100%	data:n
Impervious	307.67	1.83	294.6	306.61	307.70	309.05	319.13	95519
Vegetation	306.86	2.08	294.6	305.79	307.16	308.24	317.37	38957

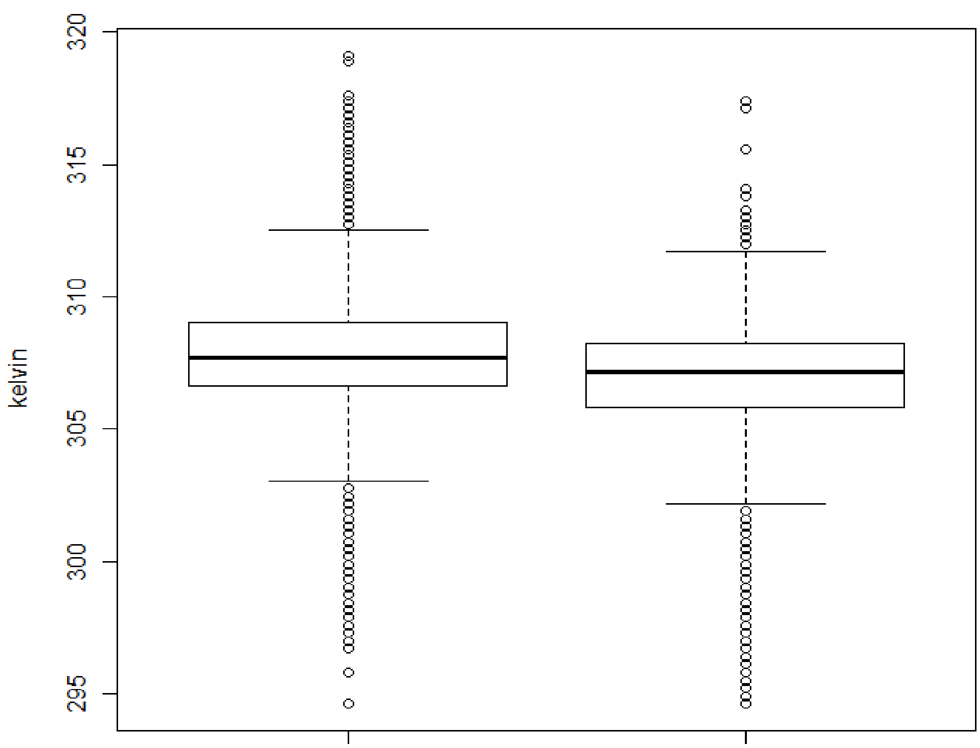

Figure 4. boxplot of surface temperature between impervious surface and vegetation cover

DISCUSSION

Urban heat stresses have been an unprecedented problem. Compared to the well-recognized controversy of global warming, the urban heat stress is uncontroversial and clear. The characteristics of the urban situation are over built land, deforestation, crowdedness, and structural differences related to vegetation in the form of impermeable surfaces. I focused on the absence of vegetation cover and the presence of impervious surface, because these two land cover types are inversely related. Impervious surface was suspected as the cause of the urban heat. I could conclude that impervious surface is tends to increase the Land Surface Temperature (LST), 0.8˚K in this study, compared to the vegetation's relatively low temperature.

The first results to support this study that impervious surfaces are hotter can be found by comparison of the thematic map (Fig. 1) to the satellite image (Fig. 5). The second support can be found from Kottmeier et al.'s (2007) study indicating that vegetation cover has comparatively lower temperature, maximum as 8 degrees Celsius, than the impervious surface. During the analysis the unexpectedly higher temperature of barren land has also been observed and the lower temperature of vegetation cover has been highlighted even further (Shen and Leptoukh 2011). The last point is that the difference between vegetation and impervious LST is remarkable as 0.8 degree Kelvin in mixed orientation. More importantly, the difference of high outliers of impervious

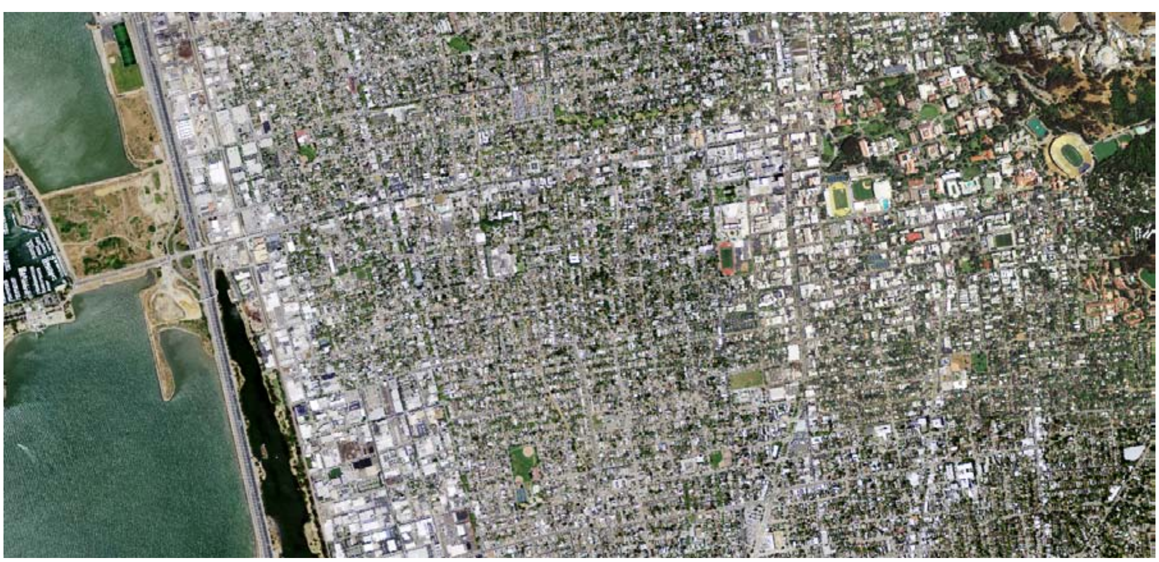

Figure 5. Satellite image of South Berkeley for comparison

surface and low outliers of vegetation cover is over 20 degrees. These observations imply the pure characteristic temperatures of each land type under similar conditions.

The land gives heat energy from solar energy

From the result indicating temperature difference of 0.8°K, it is clear that impervious surface results in hotter temperatures than vegetation. From the imagery calculation, comparing and contrasting show brighter gradation, reflecting higher temperatures generally matches to where the impervious surface is. At the landscape scale, the difference is about 4 degrees Celsius in northern mid-latitude, subtropics at night (Fisher 2012). The city is warmer than its adjacent park where the dense vegetation is occupied by trees and less impervious area. At small scales, asphalt is hotter than adjacent tree areas (Yilmaz et al. 2007). This trend can be seen in my study where higher LST occurs where vegetation is absent and thus by high chance impervious surface is present. Up to this point, my findings suggest that either impervious surface or vegetation is related to LST, or both are.

I focused on the properties of impervious surface to examine the mechanism. The impervious surface refers to land type that covers surface thoroughly and blocks substances such as water from penetrating the surface. This blocking means that impervious surface receives direct solar radiation and converts the radiation to only heat energy thereby increasing the temperature of the impervious surface. Heated surface emits heat back to atmosphere and increases the overall heat stress of the city (Trusilova et al. 2009).

The vegetation cover uses solar energy

The vegetation cover is comparatively cooler than the other surface types, especially compared to the impervious, non-vegetated surface (Zhou 2010). In the temperature weighted image (Fig. 5), vegetation and water are colored blue, representing a cooler surface, and the other land cover types are white and occasionally green representing a hotter surface. Other studies support this temperature difference between surface types with the water and vegetation demonstrate decreased LST (Zhou 2010). The primary reason for this cooler temperature effect of vegetation can be explained by the role of photosynthesis playing in carbon dioxide uptake (Bounoua et al. 2009). Photosynthesis is a biological mechanism powered by solar energy. By the energy conservation rule, solar energy used for photosynthesis will not be contributed to production of heat. This means less energy is available for heat, and thus less radiated heat occurs. Another effect of the vegetation is transpiration. This mechanism refers to evaporation of water molecules from inside of leaves to atmosphere. Water molecules in atmosphere absorb heat efficiently for the water is a substance with relatively high heat capacity. In this context the evaporation can play an important role in buffering temperature because the rate of evaporation increases as temperature rise (Nakazato 2012). The fact water has high heat capacity thus stay cool during day time is clear from the bay in the large blue area on the left side of the image (Fig. 1).

Implications of temperature differences

The overall temperature difference of the two land surface classes neighboring each other is 0.8 degrees Kelvin. This amount of temperature difference is significant under the consideration that more than half of the world population lives in urban areas since 2010 (Zhang 2008). The surface temperature difference between higher temperature extremes of impervious and the lower extremes of vegetation is as remarkable as 20 degrees. This difference is derived from the solar energy utilization where impervious material converts the solar energy into producing thermal energy, and where vegetation uses more, but not all of the solar energy for biological activities. This energy difference from impervious surfaces can be more than 10 degree Celsius compared to existing vegetation cover before the conversion to impervious surface (Lee 1979; Myrup et al. 1993; Schueler 1995). Although thermal energy from impervious surfaces converted from solar energy is a negative consequence in most of urban area where the surface heats up air, the biological energy from solar energy of vegetation produces overall positive effects. The effects are growth of the vegetation and energy storing in seeds and fruits. From a vegetation perspective, the solar energy is used for environmental improvements include aesthetic value, atmospheric purification by uptake of pollutants, and temperature decrease (Nakazato 2012). Regardless, if the energy is not consumed, solar energy converts to additional heat. This heat then becomes the reason of heat stress and thus stress on the native ecosystem.

Limitations

When I assigned the polygons over the vegetation covers and impervious surfaces, a discrepancy between area of temperature data (raster image) and the vector-based polygons occurs. Polygons are approximately $30m^2$ and random shapes while the raster values are $900m^2$ of a grid. Thus polygons of land classification did not exactly fit in a raster grid but in some cases might be overlaid over two or more grids. This method resulted in a discrepancy of expressing actual temperature as some polygons fell into only one temperature value while they are overlaid two or more temperature values. Another possible restriction is that the orientation and proportion of vegetation and impervious surfaces in the temperature grid could not be included. Last, by not including the correlation of the proportion and orientation to the temperature, the model fails to calculate the magnitude of effect of both impervious surface and vegetation cover to temperature. My result represents only a temperature difference between impervious surface and vegetation cover only based on a day in a year.

Future research

Further research is guided from my limitations. The proportion of each land class in a raster grid should be analyzed. This weighting would help to determine which land class is more related to the surface temperature. Another point is further subdivision of land classes. The vegetation class can be divided into darker covers in which less light is reflected and brighter covers which more light is reflected. Impervious class will also need to be divided into subdivisions depending on its light reflections as well. Detailed light reflection criteria will be required for this step. Impervious surface can have negative image because this research only studied a higher negative effect as heat stress on a hot sunny day. Hence the future research will require, not to be biased in the hypothesis of the phenomenon as a negative effect as heat stress, the temperature effect of impervious surface and vegetation cover in cold regions or season to determine if this would make the area colder or warmer. All together these research approaches can help to understand the issue.

Broader implications: *The value of the study*

Clearly the impervious surface contributes heat to the urban environment. This has caused severe heat stresses in urban areas especially in warm seasons. Because urban heat has been a clear cause for increases in public health costs, studying the impact of these land classes could not be more important. Vegetation would be an ideal choice as a substitute for unnecessary impervious surfaces to decrease surface temperature. As a possible practical solution, buildings and other urban structures can include vegetation in their portion of outer wall. Vegetation will improve urban environment not only by decreasing temperature but also by improving air quality by uptaking air pollutants like ginkgo. Otherwise, the difference of 0.8 degree Kelvin could be converted to electricity using photovoltaic cells. Using solar energy instead of heating the impervious surface would result in a synergistic effect by decreasing temperature and converting available energy.

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