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A conceptual framework for environmental risk and social vulnerability assessment in complex urban settings

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ABSTRACT

High numbers of weather-related mortalities are associated with extreme heat events in the United States. Satellite data confirms that urbanization leads to higher temperatures within microclimates and formation of heat pockets that are linked to higher risks of heat related illnesses and heat stroke. The goal of this study was to examine the influence of different surface types on the impact of UHI by looking at physical properties of the urban system through a framework to formulate risk and social vulnerabilities. A conceptual model was developed using data from Landsat, department of building, U.S. census and USGS. The factors of interest include people, environment, and building/infrastructure. This model quantifies risk as a function of temperature and physical properties of the surrounding environment. Results show, neighborhoods of Manhattan, Queens and Bronx are at the highest risk of social and environmental vulnerability and should be targeted for policy changes, implementation of green infrastructures and vegetation coverage to counteract the heating effects. Neighborhoods which need to be targeted for urban planning due to high environmental risk are Harlem, Upper Manhattan, East Harlem, Elmhurst, Jamaica, Ridgewood, Flatbush, University height and Woodlawn.

1. Introduction

UHI reflects an elevated temperature in cities as compared with nearby rural areas which is due to landscapes changing from permeable moist surfaces to impermeable and dry surfaces (EPA, 2015). This phenomenon is most prevalent in large cities like NYC in which the surface type is mainly impermeable concrete. UHI is most predominant in metropolitan cities, which consist of dense buildings, sidewalks and mix use neighborhoods (commercial and residential). The preliminary statistical analysis of a study done to measure the impact of UHI in Manhattan using high resolution data sets indicates that "higher buildings have a cooling effect in streets, while in the sunny avenues higher buildings have a warming effect"(Vant-Hull et al., 2014). Another study also helped predict subdivisions of UHI throughout Manhattan using weather campaign data to "find the smallest UHI effect and map out hot spots in a densely populated city, by understanding different land surface types and classes" which can increase or decrease the impact of UHI (Karimi et al., 2015). Human thermal comfort is at risk when higher levels of ambient temperature are felt. In this study and many

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studies Land surface Temperature (LST) measurements from Landsat are used to measure the impact of UHI on urban environment and human health. Even though LST is not “directly equivalent to ambient air temperature”, it gives information on “thermal inertia of surface characteristics” by tracking changes of LST in the morning and the afternoon in cities (Johnson et al., 2009). Even though the exact relationship between LST and ambient air temperature is not certainly clear; Johnson et al. (2009) and Tomlinson et al. (2011) suggested that LST can also contribute to human discomfort while heat waves occur and as result remote sensing data are useful for such studies (Johnson et al., 2009 and Tomlinson et al., 2011).

Manik and Syaukat (2015) found “land use patterns and land use cover” as the strongest drivers of urban temperature. From few of the land surface characteristics; building height and building density can also add to increasing ambient air as they reradiate the heat back to air. Wolf et al. (2013), and Tomlinson et al. (2011), find building height to be the most important factor behind UHI effect. Higher building heights with high building density cause a greater insulation effect than low building density with high building heights. Building density provides the proximity of buildings within a region which when related to building height and population greatly influences risk. Similarly, a greater negative effect can be expected with high building density and high population. Income and socioeconomically status can as well affect the health and wellbeing of people (Johnson et al., 2009).

Few factors can amplify human vulnerability to heat such as the environment, infrastructure, social and economic status, age, exposure and sensitivity level. Rosenthal et al (2012) evaluated the “impact of the urban heat island on public health” as a “spatial and social determinants of heat-related mortality in New York City”. Highest numbers of mortality were among neighborhoods that had lived in “poor housing conditions, poverty and impervious land cover” (Rosenthal et al, 2012). Other studies touched on social, biophysical and environmental factors that influence human comfort (Cutter et al., 2003; Reid et al., 2009; Stafoggia et al., 2008 and Vescovi et al., 2005). For the purpose of this study, NYC was investigated for a relationship between building, infrastructure, nature, and people. The hope is to correlate these factors so regulations will change accordingly for the health of people in urban areas. The optimum locations of study are the areas where people who are most susceptible to heat-related mortality live.

A conceptualized model has been designed to find common heat pockets that form over the city of New York while it targets populations that are at higher risks of susceptibility by analyzing 11 years of Landsat satellite data and combined socioeconomic and environmental variable such as: build height, building density, vegetation index and temperature. The model is used to map and project population vulnerability to heat in NYC. The goal of this study is not only to map vulnerable population based on their socioeconomic status and age but also to identify primary land surface characteristics that play a stronger role in developing UHI effect in cities for intervention guide of heat mitigation.

1.1. Impacts of UHI on human health

Warmer days can contribute to heat related problems such as heat stroke, heat cramps and heat related mortality. Health related responses of populations to heat are commonly assessed using regression analysis of long records of daily observations of health events (most commonly deaths) vs. temperature measured at a single urban monitoring site. A citywide exposure-response function is estimated to quantify the excess mortality or morbidity that occurs above a temperature threshold. Fig. 1 shows the response of daily deaths in Manhattan, New York to daily max temperature measured at Central Park (Li et al., 2013). Heat-related mortality is quantified above a reference temperature based on a statistical analysis of deaths from all causes in relation to daily temperatures, as illustrated in the Fig. 1. However, to date, this and all similar analysis in the literature rely on central site temperature data to characterize the exposure of persons at risk of adverse health impacts.

This studies shows that mortality increases in NY's Heat-related mortality is a function of temperature and a population's

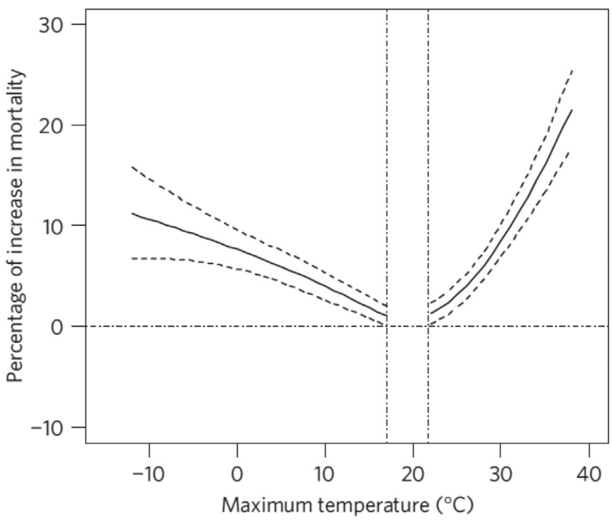

Fig. 1. Exposure-response function for temperature-related mortality in Manhattan, NY Based on daily data from 1982 to 1999 (Li et al., 2013).