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Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka

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Abstract

In this paper we analyze the historic trends in thermal comfort (measured in terms of Temperature–Humidity Index [THI] and Relative Strain Index [RSI]) in the Sri Lankan primate city of Colombo and correlate them with land cover changes in the region. Land cover is calculated form time-series aerial photographs in terms of ''hard'' cover (buildings, paved areas and roads) and ''soft'' cover (trees, green areas and waterbodies). The period selected for analysis includes pre-rapid (up to 1977) and rapid urban phases (1978 onwards) in the city. Contemporary Sri Lanka's urbanization is peculiar in that mid to late 20th century urban rates (approx. 22% of the population) had remained virtually unchanged till the economy was liberalized in 1977, but have recently intensified (currently at about 35%). This offers a unique window of opportunity to look at the thermal comfort transition consequent to urbanization. Since many tropical cities are at a similar stage of demographic transition, lessons from Colombo may generally be applicable to other tropical developing cities as well.

An increasing trend in thermal discomfort—particularly at night—is seen especially at the suburban station and it correlates well with hard land cover changes. The study also brings out the relative importance of land cover in city center vs. rural areas (e.g. hard cover has more effect on thermal discomfort in city center than in rural areas). Based on these findings, we postulate an outline for a climate-sensitive urban design policy for tropical cities.

Keywords: Tropical bioclimate; Urban heat island; Land cover changes; Moisture island; THI; RSI

1. Introduction

The first ever systematic study of city-induced climate change was carried out by Luke Howard in London in 1833 [1]. Since then studies on urban climate modifications has progressed from descriptive (up to about the 1930s) to complex spatial and temporal variability studies, linking climate effects to weather and urban structure (up to 1965) [2]. In the recent past, emphasis has shifted to seek the physical basis of urban climate modifications and to construct models to simulate them [2].

However, from a development policy/design point of view, the findings of these studies cannot be directly used unless the human consequence of urban climate change is specified. Thus, climate-sensitive architects and urban designers in the recent past have focussed on the human comfort (''bioclimate'') effect of urbanization (cf. [3–7]).

The modifications to a city's climate in contrast to its rural surroundings, known as the Urban Heat Island (UHI) phenomenon, is sparsely studied in the tropical areas. Early work in the tropics occurred only in the late 1960s [8]. Yet, tropical urbanization remains the largest and the most pressing man-made environmental issue in the world. Of the 170 cities with more than one million inhabitants each, a vast majority are in the tropical belt [9]. Almost 90% of the global urbanization between now and 2025 will occur in countries of the developing world located mostly in tropical/subtropical regions [9]. Such

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statistics underscores the urgency of studying the human consequences of tropical urbanization.

There is evidence that researchers are increasingly turning their attention to tropical urban climate issues. For example, [9] noted a two-fold increase in research articles on tropical urban climate published in the Meteorological and Geoastrophysical Abstracts between the 1980s and the 1990s. Yet, urban design and planning policy instruments for the mitigation of the negative impacts of tropical urban climate remains largely unexplored. One way to fulfil this need is to focus our research attention upon the human consequence of urbanization, particularly its thermal comfort dimensions.

The study of the UHI phenomenon in Sri Lanka lags far behind that of even the other tropical countries. The first ever comprehensive historical survey of the UHI phenomenon in the Colombo Metropolitan Region (CMR) was completed only in 1999 [10,11]. More in-depth studies on CMR's climate changes—particularly the causes for its bioclimate changes—are needed to advance the knowledge base.

Such an advanced knowledge is essential for two reasons. On the one hand, an unprecedented acceleration of urbanization is currently underway in Sri Lanka. From a steady rate of approximately 22% urbanization in the decades leading up to the 1980s [12], Sri Lanka has now entered a rapid phase of urbanization whereby the 2010 urban levels are expected to top 50% of the population [13].

Most of this rapid urbanization is centered around the CMR. Being the only metropolitan region in the country, the CMR enjoys the status of a primate city. In 1996, with a population of about 4.5 million, the CMR accounted for over 80% of all industrial establishments in Sri Lanka, provided jobs to a third of the Sri Lankan workforce and generated over 44% of the national GDP [13]. Due to its economic and administrative importance, the CMR is expected to grow rapidly in the coming years. By 2010, an expected 6.5 million people will be living in the CMR [13].

The second reason is that the environmental changes and associated quality of life issues that arise from the changing urban climate has hitherto received little or no attention from architects, urban designers and policy makers. A sound understanding of the phenomenon and the associated causes is necessary before policy initiatives could be formulated to arrest the negative impact of the UHI.

The present study correlates the land cover changes in and around the three first-order weather stations in the CMR with the bioclimatic trends in the region during the last 30 years. Land cover is measured in terms of "hard" cover (buildings, paved areas and roads) and "soft" cover (trees, green areas and waterbodies). Bioclimate is quantified using thermal comfort indices (Temperature–Humidity Index—THI and Relative Strain Index—RSI). Based on the findings, a possible urban development policy is outlined.

2. Background

2.1. Bioclimate quantification

That human comfort is a complex reaction to a number of environmental parameters was clearly recognized as early as in 1938 (cf. [14]). Yet, practical difficulties in measuring more than a few parameters kept initial attempts at quantifying bioclimate confined only to a few environmental variables. These include, Effective Temperature (ET) [15] and THI (originally known as the Discomfort Index) [16].

After the 1960s, heat balance models of the human body gained more prominence and this led to better quantification of human bioclimate. Some examples include, ET (SET), Heat Stress Index (HSI), [17]; Predicted Mean Vote (PMV) [18]; Winslow's Skin Wettedness Index (DISC) [19]; ANSI/ASHRAE 55-1992 [20].

2.1.1. Urban bioclimatic quantification

Urban bioclimate quantification is more complicated than indoor comfort due to a number of reasons. This has led some researchers to even conclude that indoor climate standards are not applicable to outdoor settings (cf. [21]).

Höppe [22] suggested three basic reasons for the differences between indoor and outdoor bioclimatic sensation:

(i) psychological;
(ii) physiological;
(iii) energetic.

Psychological reasons for differences between indoor and outdoor comfort have to do with human "expectations." Physiological differences arise from time spent in indoors vs. outdoors (typically, long exposure in indoor situations as against short, quick exposure in the case of outdoors). Energetic differences arise from the variation between Mean Radiant Temperature (MRT) and air temperature. While it is safe to assume that the two are equal indoors, large differences exist between them in the outdoors (particularly in warm outdoors).

Attempts at quantifying urban biolclimate are relatively new. Early efforts began only in the 1970s. Jendritzky and Nubler [23] provide a summary of these attempts. Although these attempts merely modified existing indoor climate models to suit the outdoor purpose, some new indices specifically suited for outdoor applications have recently been developed, the