A Systematic Review of Urban Heat Island Impact on Selected Asian Cities

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1. ABSTRACT
The UHI effect occurs in warm, calm environments, when the city's core temperature is considerably higher compared to that of the surrounding rural areas. This research systematically examines the impacts that UHI makes on economy, energy, and health in 22 selected Asian cities supported by 30 peer-reviewed research published between the years 2000 and 2019. The analysis identifies urbanization and vegetation loss are some of the main causes of temperature change; UHI is aggravating heat-related diseases that raise death rates and decrease labor productivity. While the temperatures within the metropolitan are growing, it enhances the use of energy to be costly in the economy as it rises. Heat intensity, exacerbated by land-use changes and changing climatic conditions, affects the microclimate of the urban heat island and thermal comfort. The study identifies three main strategies: increasing solar reflectivity, enhancing evapotranspiration, and optimizing urban geometry. These findings emphasize the need for policymakers, urban designers, and engineers to implement effective mitigation measures to safeguard urban populations from UHI effect.

Keywords: Urban Heat Islands, Heat Island Intensity, Mitigation Strategies

2. INTRODUCTION
Rapid urbanization is manifested by rapidly increasing population density, transformation of vegetation cover into built-up surfaces, adverse environmental impacts, and strong intensification of urban economic activities. Such changes disturb the natural equilibrium of absorption and reflection of heat within a city. As a result, ambient air temperatures within the urban environment are considerably warmer compared with suburban and rural environments. The temperature gradient between these zones has been commonly identified as the Urban Heat Island (UHI) effect, a well-documented phenomenon in urban climatology [1][2][3][4].

UHI Intensity [5] refers to the temperature difference between the urban peak and its rural environs. Therefore, it is most marked under clear and calm nighttime conditions, with regional atmospheric and geographical factors playing a paramount role in determining its magnitude. Clouds, wind velocity, and relative humidity, among other factors, are known to interact with

UHI intensity: for example, the intensity of UHI increases with higher cloud cover but decreases as wind velocity and relative humidity increase [3]. Commonly, UHI conditions are monitored through the use of either remote sensing techniques or temperature measurement stations situated on location or mounted on mobile units [6][7].

However, compared to the negative impact which also increases exponentially when the temperatures increase in summer this minor gain in winter is negligible, and to tropical countries, and states that do not have icy winters, the so-called benefits are irrelevant [6].

The negative effects of UHI are a very serious problem for urban settings. This increases the demand for energy used in cooling during extreme heat events and reduces soil evaporation, which presents significant economic and environmental challenges [8]. This is evidenced by studies that indicate a 1°C temperature rise is correlated to a 4.6% increase in peak electricity load while the total electricity consumption in buildings increases by 8.5% [9]. Apart from energy issues, the intensity of UHI is normally associated with serious health hazards during heat waves, causing increased mortality rates and other health complications. These health challenges reduce labor productivity and hinder economic output [2][10][11].

At the global scale, exposure of UHI in urban areas has grown by 199% and impacted around 1.7 billion people. In this context, Asia is facing the fastest growth rate of the urban population, which is not confined to the two giants, China and India, but also prevalent in other Asian countries experiencing rapid urbanization [11][12]. Therefore, Asia is a hotspot for UHI challenges and demands immediate attention from regional policymakers and urban developers to combat its adversities.

This article systematically reviews the UHI phenomena in 22 Asian cities. In this context, we have chosen 30 reputable journal papers for evaluation based on the pre-defined inclusion criteria relating to data collecting dates, verified adverse impacts, and data acquisition methodologies. The results are compiled under four main topics that fill out the discussions of possible mitigation techniques.

3. MATERIALS AND METHODS

This review investigates the impacts of the UHI effect within the Asian region. The methodology employed to identify and select relevant literature for this study is outlined below.

- Stage 1: Identifying all UHI studies done only in the Asian region. Particular keywords/Phrases used in this context include "Asian region," "Data collection methods," "Investigation period," and "Impacts of UHI effects." Moreover, other specific terms, like "Energy consumption," "Urban geometry," and "Mitigation strategies," were used to narrow the search. The outcome of this step revealed relevant papers of about 50 in number.

- Stage 2: Removal of non-English language publications, leaving only the English language published articles. This filtered it further down to 45 papers.

- Stage 3: The articles published in regional or worldwide peer-reviewed journals are given priority. 30 of them, which were published between 2000 and 2019, were chosen as the review's primary sources.

4. RESULTS AND DISCUSSION

This review provides a historical perspective of the UHI effect and its impact on urban societies across the Asian region. In most instances, the magnitude of the UHI effect was higher during nighttime, as earlier posited by Chandler [13].

4.1 Diversity of Observations

Throughout the reviewed studies, various important climatic parameters were included: Land Surface Temperature (LST), humidity, wind velocity, rainfall, distance from water bodies, industries, satellite data, and urban geometry represented in terms of Sky View Factor (SVF) and Height-to-Width ratio (H/W). These climatic factors directly affect the UHI phenomenon and are seen to occur in many different geographical and meteorological regimes. In the more complicated climate of the Asian region, the maximum UHI intensity frequently exhibited seasonally. At Delhi [14], the sequence of UHI varied according to summer > monsoon > spring > post-monsoon > winter. In Seoul, the UHI intensity varied from 4.8℃ in autumn to 3.5℃ in summer, depending on the prevailing weather and anthropogenic activities of the season [15][16]. In Kuala Lumpur [17], the UHI intensities increased from 4℃ to 5.5℃ within the years 2004 to 2008, indicating an urgent need for controlling measures to be implemented [18].

4.2 Investigative Challenges

Many methodologies were used in the investigation into UHI impacts, such as ground observations, satellite images, and meteorological models, which all have different drawbacks:

- Ground Observations: In atmospheric UHI scenarios, researchers gather more spatial and temporal information across cities via vehicles [6]. Though useful in gathering spatial and temporal information, mobile traversing and fixed stations are usually expensive and logistically cumbersome [19][20][21][22][23][24].

- Satellite Imagery: Satellite
  data are useful in identifying the spatial variation of temperature within cities. AVHRR, MODIS, Landsat TM/ETM+, and ASTER are some of the commonly used satellite imagery that efficiently provide temporal and spatial coverage [25][26][27][28][29]. Nonetheless, there are problems with cloud interference and resolution, which reduce data accuracy.

- Climate Models: These models, such as the Colorado State University Mesoscale Model (CSU-MM), allow researchers to simulate UHI scenarios by inputting urban-specific climate characteristics, including albedo, evaporation efficiency, roughness, and anthropogenic heat [30]. However, general difficulties persist in representing such complex urban landscapes due to limitations in capturing the variability in building materials and urban geometry, as well as difficulties in incorporating heat generated by human activities.

4.3 Heat Risk Assessments

Urbanization is one of the most important factors contributing to the UHI, as it affects the population density, land cover, and road density. There is a significant relationship between population density and surface temperature. A higher surface temperature was recorded in highly populated areas and vice versa [31]. In Shanghai, research has shown that urban development between 1997 and 2008 greatly enhanced the SUHI (Surface Urban Heat Island) effect in summer [28]. In Kuala Lumpur, the UHI intensity increased from 4℃ to 5.5℃ during 1985-2004 [17]; in Colombo, land cover changes resulted in increased nighttime thermal discomfort in the city [32]. Moreover, the positive correlations of NDBI (Normalized Difference Built-up Index) and LST in Colombo for the years 1997, 2007, and 2017 indicate SUHI formation [25].
Land-use/land-cover (LULC) distribution patterns, such as built-up, cropland, and urban fringe, directly influence UHI intensities. The SUHI effects are discussed through the variations of LST over impervious surfaces [33]. Due to land-surface variations, there is a high possibility of population exposure to heat. In Delhi, three UHI intensity levels were corroborated with LULC classifications [34]. In Seoul, commercial areas in Jung-gu and Gangnam-gu were identified based on LULC patterns and Landsat data [15]. In Shanghai, compacted urban centers demonstrated higher UHI intensities [28]. Hot spot analyses in coastal areas further emphasized the SUHI dynamics in Colombo from 1997 to 2017 [29].

Advanced techniques like isopleths [35], computational fluid dynamics simulations [36], and satellite imagery, combined with data from mobile surveys and fixed stations [21][24][37] offer effective means of assessing and mitigating UHI effects across varying urban and rural environments.

4.4 Health Implications

The UHI effect increases daytime temperatures and reduces cooling at night, exacerbating heat-related health issues such as heatstroke, respiratory problems, and mortality during heatwaves [38]. Vulnerable groups, including children and individuals with pre-existing conditions, are at heightened risk. Between 1998 and 2004, heat-related mortality was notably higher in urban centers compared to suburban areas [39].

4.5 Economic and Energy Implications

In Shanghai, there is a straightforward association between increased energy consumption with the development of the economy. This study emphasized that, with the weakening of energy demand, economic growth slowed down [40]. In addition, about 60% of total electricity consumption was for space conditioning because of UHI in summertime [41]. In Japan, energy consumption under UHI conditions was analyzed, showing that commercial energy consumption increased, while residential energy consumption decreased because commercial buildings were more compacted [30] Energy consumption could be reduced by applying high-albedo coatings or rooftop greening methods. However, all these strategies have been validated only for limited conditions. The high-albedo coatings were useful in reducing energy demand for commercial buildings but were less effective in residential areas.

Energy demand in buildings could be effectively managed by the incorporation of specific strategies and the use of certain materials. Most of these methods could efficiently improve the performance of walls, floors, roofs, and windows and control heat loss during winter and heat gain during summer [42]. Vegetation ET emerged as a broad solution to reduce urban and global temperatures [43]. Urban greening was found to be an effective energy-saving solution for both commercial and residential spaces. However, space limitations in urban areas have hindered the full utilization of urban greening. These mitigation strategies are discussed in the following section.

4.6 Mitigation Strategies

This review recognizes three major mitigation strategies for the UHI effect. The first approach is to increase solar reflectivity by cooling or using reflective building materials. It has been reported that low-reflective facade materials in Singapore contribute to UHI effects because of their ability to retain heat [36]. High solar reflectivity and thermal emittance materials, or increasing albedo levels, can effectively reduce heat absorption [20][44][45].

The second method is intensification of evapotranspiration by the greening of cities or water bodies. Due to the thermal effect produced by water bodies, they show temperatures that are $2°C - 6°C$ lower than that in the built-up areas surrounding them [26][43]. Vegetation lowers the LST by a process of absorption of the surrounding heat through photosynthesis and evapotranspiration. This can be illustrated through the negative correlation of vegetation with the NDVI (Normalized difference vegetation index) [27]. Green roofs [20][25][27][46][47] also help to insulate and reduce energy demands by maintaining indoor temperatures. However, their actual performance does depend on the roof type, climate, and maintenance needs [27].

The last strategy involves the optimization of urban geometry for maximum airflow and control of the urban microclimate. High-rise buildings can block wind flow, but strategic placement could enhance air circulation and lower temperatures within the urban canyon [36]. However, the mitigation of UHI can also be achieved through some increase in the Sky View Factor (SVF) caused by controlling site coverage ratios and building heights, whereas constant land-use density should also be maintained [23]. Vertical urban development must be complemented with an effective wind management system with consideration of productivity and temperature [33]. Water within built-up areas, such as central canals, to give cooling, if ill-designed, may enhance the humidity during hot summers [44]. The effective UHI mitigation, without risking public health, requires a comprehensive understanding of land use, building design, and traffic strategies [48].

5. CONCLUSION

The review underlines that the UHI effect plays an essential role in affecting urban areas significantly across Asia. Rapid urbanization, reduced vegetation cover, and altered urban geometry are some of its major causes. The UHI effect increases the health risk, energy consumption, and hence affects the economy, which requires immediate attention.

Such mitigation strategies involve urban greening, reflective surfaces, and optimized urban planning, all of which may potentially reduce the impact of UHI. However, these need a good understanding in terms of various methodologies and applicability. Future research should fill the gap between academic findings and practical applications to empower policymakers, urban planners, and engineers to implement sustainable urban solutions.

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