A systematic review on prediction methods, tools, impact and mitigation strategies with climatic condition classification used for Urban Heat Island Effect

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Abstract: Urban Heat Island (UHI) is the emerging problem of modern world. The urban structures consume the heat in day-time and release that heat in the atmosphere in night-time, causing the UHI effect. It is observed that developed and developing cities are highly prone to UHI effect. In the worst case of UHI, mortality is seen in metropolises and cities that are highly populated. Hence, multidimensional research efforts are required to be carried out to overcome and reduce UHI. For this purpose, prediction as well as identification of UHI prone area has become prominent research for researchers and various organizations. Hence, in this paper, a review is carried out to summarize the research on UHI effect and to explore the prediction models based on neural network, image processing, Geographical Information System (GIS) and remote sensing algorithms. In addition, the tools required for the prediction and the mitigation strategies to be followed are reviewed. Lastly, as per our review, the discussion is carried out to identify prediction methods and mitigation strategies for various climatic conditions. The aim of the paper is to help the researchers, organizations and urban planners to select appropriate prediction models based on the affecting parameters and geographical regions to predict and reduce UHI effect.

Index Terms **- Urban Heat Island (UHI) effect, urbanization, prediction methods, prediction tools, mitigation strategies**

I. Introduction

The rapid urbanization and industrial expansion has established better-quality living customary world-wide. However, on the other side, it has elicited new environmental challenges in the society *viz. global warming, air pollution, increase in solid waste etc*. According to World Urbanization Prospects – 2018, the continuing urbanization and overall growth of the world's population is projected to add 2.5 billion folks to the urban population by 2050, with nearly 90% of the growth targeted in Asia and Africa [1]. Cities take up around 2% of the earth's surface. In the world today, urban population area unit is rising speedily in amount and size as additional individuals are migrating to cities from rural areas. Specifically, because of the rising population, cities require huge quantity of energy to perform daily routine. In reality, city dwellers use over seventy fifth of the total energy resources as a result of activities distributed within the urban location [2]. Part of this energy is regenerated in different types of heat *viz. vehicle heat, building heat, land surface heat* that is strengthened by radiation coming from the Sun. The heat is being captured by the urban structures during daytime and it is gradually released at night time. This generates phenomena known as Urban Heat Island (UHI) that raises temperatures in densely populated urban areas. When there is a scarcity of green areas, this effect is even additional accentuated as a consequence of greenhouse gas emissions [3]. The temperature increase caused by the urban heat island reduces the need for heating within the winter, but proportionately, increases the cooling demand in the summer.

According to IPCC AR4, the modified land surface in cities affects the storage, turbulent and radiation transfers of heat and its partition into sensible and latent elements. The relative warmth of a town compared with encompassing rural areas, known as the UHI impact, arises from these changes and may even be altered by changes in water runoff, pollution and aerosols. This impact is usually terribly nativeized and rely upon local climate factors like breeziness and cloudiness (that successively rely on season), and on proximity to the sea [4]. However according to EPA, “The annual mean air temperature of a city with one million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. In the evening, the difference will be as high as 22°F (12°C). Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality” (EPA, 2014).

Urban Heat Island is a phenomena generally observed in urban areas. It is an irrational growth in warm periods of urban areas as compared with its surrounding rural areas. It is an example of unwanted climate change caused by anthropogenic activities [5]. This anthropogenic activity includes heat released from vehicles, power plants, air conditioners and other heat sources, and due to the heat stored and released by massive and complex urban structures [6]. Huge quantities of solar radiations are mainly stored in urban structure in day-time and released in atmosphere at night-time in urban areas [7], [8]. According to the literature review, there are two main factors that increase the urban heat island in cities. These are city parameters *viz. vegetation cover, built-up area, population density etc.* and meteorological parameters *viz. solar radiation, geographical region, climatic condition etc.* as discussed in detail in third section. Consequently, intensity of urban heat island varies in each city according to the physical, morphological characteristics such as location, size, and density of their built-up areas, land uses, population and air pollution together with climatically characteristics.

As global warming and other climate change problems (greenhouse effect, depletion of Ozone layer) are increasing day by day, it is necessary to resolve these problems. For this purpose, it is required to predict and identify the UHI prone regions. The prediction of UHI intensity helps us to understand the hazardous impact of it. It will also suggest that energy requirement in urban areas may get increased in these days. The prior prediction of UHI intensity helps in the formation of mitigation strategies and urban designing. The existing literature presents number of review articles on UHI effect [5-15].

The applicable prediction methods are Local Climate Zone, Observational Method using automobile devices, GIS method etc. [17-27]. At present, various models and tools are used predict UHI effect viz. ENVI-met, WRF, Statistical downscaling approach etc. are discussed in this paper [28-35]. Mitigation measures to reduce UHI were also discussed like green cover, blue cover and urban structure and design [36-57].

As per our observations, the emphases of these studies are on satellite technology, methodology, modelling techniques and mitigation measures of the UHI effect. However, a thorough understanding of the factors contributing to the UHI effect is also essential to devise suitable policies and planning for cities to mitigate the UHI effect. This also avoids harsh or undesirable consequences for both human being and the environment. In addition, it is observed that the UHI effect differs as per different geographical climatic conditions. Hence, our contributions in this paper are as follows:

- Review of different dimensions of the UHI effect viz. (a) factors and/or parameters affecting UHI, (b) prediction methods – the methods used to predict UHI intensity, (c) tools that are used to predict UHI intensities and (d) mitigation strategies used to counter UHI effect.
- Analysis of different factors causing UHI effect and how the UHI intensity varies according to the geographical locations and the methodology applied to derive it.
- As per our observation, different geographical climatic conditions have different UHI effect enhancing factor. The preferred prediction models for various climatic conditions are discussed in detail. In addition, the corresponding mitigation strategies and research directions are summarized for these climatic conditions.

Thus, the review presented in the paper is useful to the urban planners to make a UHI effect resistance city model based on the affecting factors and the prediction of UHI in the acropolis. The researchers can enhance the prediction models for various climatic conditions.

The rest of the paper is organized as follows: Section-II discusses about the related work and their limitations. The factors affecting UHI effect like Land Surface Temperature (LST), Land Cover Land Use (LULC), Natural difference Vegetation Index (NDVI), Albedo etc. are discussed in third section. Fourth section, summarizes methods used to predict UHI effect like Local Climate Zone (LCZ) classification, observational method using automobile devices, linear time series model with least-square method, Geographic Information System (GIS), Ant Colony, etc. and also summarizes tools that are used to predict UHI effect viz. ENVI-met, WRF (Weather Research Forecast), statistical downscaling approach etc. Fifth section summarizes mitigation strategies. Sixth section discusses the UHI prediction method with respect to Köppen climatic condition along with regions, mitigation strategies and future directions. Lastly, conclusion and future directions are presented in last section.

II. RELATED WORK

In this section, the existing reviews in UHI are discussed along with their limitations. Kaveh Deilami & Liu presented systematic review of data, methods, spatio-temporal factors and mitigation measures for UHI [5]. They compared categories of reviewed literature based on the methods used to study UHI. They also compared types of satellite images used in the different studies for the estimation of UHI intensities. Further, they presented the methods used to identify land cover change patterns in the literatures reviewed. In addition, they presented comparison of analytical methods applied to assess the relationship between spatio-temporal factors and UHI intensities. They also discussed factors affecting UHI intensity viz. vegetation cover, season, built up area, population density etc. However, this review can further be enhanced by considering discussion on prediction methods with applicable mitigation strategies.

Sarah Chapman et al. have done systematic review on impact of urbanization on urban temperature [6]. Their discussion is based on location, temperature change, released anthropogenic heat and urban structures. They found urban growth is responsible for increasing UHI effect in metropolitans. However, only anthropogenic heat is considered as a factor that affects the climate change. Thus, the effect of other factors like vegetation index, cloud cover, aerosol etc. can also be reviewed. The discussion can further be extended to include the prediction models and the corresponding mitigation strategies.

Mohajerani et al. reviewed the thermal properties of pavements used in construction of urban structure and their impact on UHI effect [7]. They analyzed the asphalt type and its thermal conductivity. In addition to this, they presented the details of green vegetation and mitigation strategies to deal with UHI effect. By increasing albedo of cool pavements and making it more reflective would help to reduce UHI effect. Their work summarized the land surface temperature, albedo and other limiting factors of AC (Air Conditioner) and linked these closely to the UHI effect. However, analysis in cool pavements for construction is required for qualitative measures in the paper to deal with UHI.

M. Santamouris et al. discussed the impact of UHI and global warming on the power demand and electricity consumption of buildings [8]. They also gave facts regarding increase in peak electricity use due UHI effect. They analyzed geographical region with additional load of electricity, percentage increase of the base electricity load, threshold inflection temperature. Wong et al. had studied the increased mortality due to UHI across the globe [9]. They had shown the relationship between the temperature and mortality. This review can further be strengthened by discussing the mitigation strategies and tools for UHI along with its geographical area to deal with mortality and adverse effect of UHI.

E.J. Gago et al. reviewed the mitigation strategies for UHI [10]. According to their study, cities consume more energy in peak hours. Further, they discussed that high albedo coefficient of coating of urban structure helps in reducing the adverse impact of UHI. They differentiated mitigation strategies in two parts, first mitigation strategy deals UHI with green spaces, trees, albedo and pavements. The second strategy deals UHI with planning strategies for the urban design.

I. D. Stewart represented the research on modern UHI literature and scientific critique of methodology used in UHI [11]. He proposed grading scheme based on points for evaluating methodological quality in the urban heat island literature sample. In this paper, three tiers were discussed representing UHI estimation as highest methodological quality, conditionally acceptable and unacceptable respectively of sample literature. Further, the study categorized the literature of UHI effect in three criteria that is critical, desirable and somewhat essential. He had graphically illustrated the literature publication of UHI in various countries across globe. He had calculated frequency distribution and compared results on the basis of the pass and fail ratios by scientific criterion and method of data collection for UHI. Thus, this research provides guidelines and framework to scrutinize research in the field of UHI.

Table 1: The existing review studies on UHI

Review Study	Focus of the Review
Kaveh Deilami et al. (2018) [5]	Review of different spatial and temporal factors affecting the UHI effect. The percentage of satellite data, methods, spatio-temporal factors (like vegetation cover, season, built-up area, population density, etc.) used for UHI effect estimation is calculated.
Sarah Chapman et al (2017) [6]	Review of the impact of climate change and urban growth on upcoming urban temperatures and the potential for enlarged heat stress on metropolitan inhabitants.
Abbas Mohajerani et al. (2017) [7]	Review of causes and mitigation UHI effect in relation with pavements and asphalt.
M. Santamouris et al. (2014) [8]	Review of the methods and technologies used to enhance the albedo of cities to lessen the UHI effect. The impact of ambient temperature and increase in demand of peak electricity is analyzed.
Kaufui Wong et al. (2013) [9]	Review of UHI at global level and its relation with the increasing mortality is examined.
E.J. Gago et al (2013) [10]	Review on UHI effect and mitigation strategies used to reduce its adverse effects.
I. D. Stewart (2011) [11]	Review on UHI effect and methodologies used for it. Various types of literatures of UHI are studied.
David J. Sailor (2011) [12]	Review of methods to estimate anthropogenic heat and moisture release in environment.
Mirzaei et al. (2010) [13]	Review various methods and approaches with their capability and limitations. The factors associated with UHI effect are analyzed.
Shahmohamadi et al. (2010) [14]	Review on correlation between UHI intensity and energy consumption balance.
Rizwan et al. (2008) [15]	Review on generation, estimation and mitigation measures to deal with of UHI.

David J. Sailor reviewed various methods for the estimation of anthropogenic heat and moisture emission in urban areas [12]. The sources of urban heat are discussed in detail. He presented intra-comparison of estimates based on inventory approaches, energy budget closure and building energy models. The framework is proposed for using inventory approaches in conjunction with building energy modelling approaches to arrive at comprehensive estimates of sensible and latent heat emission. It can be validated using local micrometeorological measurement. This research can further be extended by constructing the model to calculate anthropogenic heat in cities in order to mitigate UHI effect.

Mirzaei et al. reviewed various approaches and methods to study UHI [13]. They discussed various techniques for UHI viz. multi-scale phenomena, observational approaches and simulation approaches. They analyzed and compared urban heat island simulation approaches like Urban Canopy Model (UCM) and Computational Fluid Dynamics (CFD). Further, they presented the tools for UHI mitigation and prediction. They also summarized currently developed tools (like UHSM, TEB, RAMS, WRF, etc.) and its types (like Energy balance Model, CFD (Micro-scale), Energy Balance Model – CFD (Meso-scale)) with major limitations, including complexity and plethora of urban details, theoretical weaknesses of approaches, high computational cost of simulations, and shortcomings in providing high-resolution, continuous and real time boundary conditions. Thus, the review of recently developed methods based on supervised classification for UHI prediction can further be added in this review.

P. Shahmohamadi et al. had studied the reduction of UHI using energy consumption balance [14]. They contributed the detailed analysis of how energy consumption in urban areas is increasing compared to rural areas with the equation of UHI intensity. They provided strategies like cool roof and natural ventilation to deal with UHI. Further, they compared energy consumption of electricity in USA, UK and Sri Lanka. However, this review summarizes commercial energy consumption and its effect on UHI intensity with mitigation strategies. Furthermore, analysis of methods and tools for UHI along with its geographical area can be included to enhance the review.

Rizwan et al. studied and presented their review paper on generation, determination and mitigation of UHI [15]. In this paper, the details of Urban Heat Island (UHI) intensity and reduction of UHI intensity using controlled variables and uncontrolled variables are given. They compared geographical areas, methods, types of UHI and quantified UHI intensity in degree Celsius. They analyzed the other technologies used in UHI like space technology, numerical modeling and small-scale physical models. In addition, they compared mitigation measure with their maximum temperature reduction and reported savings. Further, they discussed adverse effect of UHI and suggested to develop new methods to reduce UHI effect. However, it is required to develop both the qualitative and quantitative methods for ascertaining the UHI reduction with a change in the design and planning parameters.

The summary of existing reviews on UHI is given in Table 1. Thus, as per our observations, the existing literature review of UHI effect can be enhanced by additional considerations as follows:

- Reanalyzing the factors affecting UHI with their applicability and recovery in terms of UHI effect.
- Suggestion of a prediction method that predicts UHI intensity and discussion about corresponding mitigation strategies to recover the UHI effect
- Discussion of the suitable prediction methods, tools and mitigation strategies based on climatic condition classification

III. FACTORS AFFECTING UHI

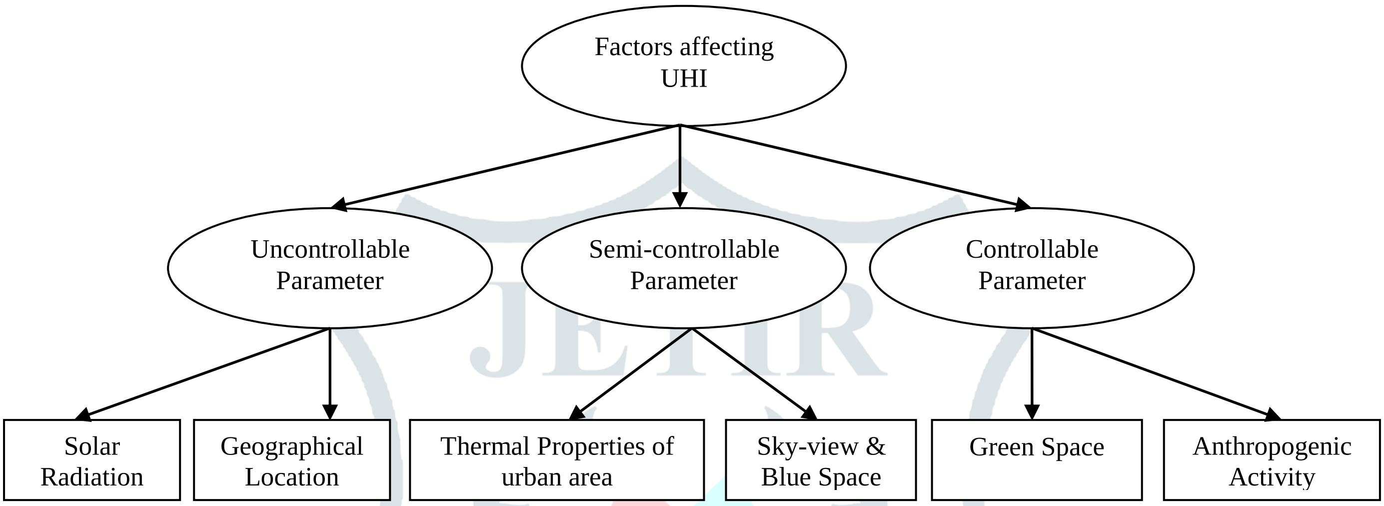

Figure 1: Factors affecting UHI

In the existing literature, various factors affecting UHI are categorized as uncontrollable parameters and controllable parameters [8]. As per our study, the parameters that directly or partially affect the UHI effect can broadly be categorized as follows:

1. Uncontrollable Parameters: The factors in which modification or alteration is not possible are considered as uncontrollable parameters. Solar radiation and geographical location (altitude, longitude, latitude etc.) are examples of these.

2. Semi-controllable Parameters: The factors in which partial modification or alteration is possible are considered as semi-controllable parameter. They partially affect the UHI intensity. Thermal properties of urban structure used in construction, sky view (the ratio of free sky space to the entire fish-eye view) and blue space (the ratio of aqua space surrounding urban area) factors are included in this type of parameters. Further, thermal properties of urban structure posses various parameters like albedo, density of building, pavement used in construction, Land Surface Temperature (LST) etc.

3. Controllable Parameters: The factors in which major modification or alteration is possible are considered as controllable parameter. It directly affects the UHI intensity. Green space and anthropogenic activity are example of this type of parameters. Further, the green space includes natural vegetation like forest and grasslands and artificial green cover like parks, gardens, farms etc. Similarly, the anthropogenic activity includes energy consumption by air-conditioners, waste-heat released from vehicles, power plants, physical data-warehouse centers etc.

According to classification of parameters, various factors affecting UHI are summarized in Table 2. It's really difficult to recover from UHI effect once it started occurring in metropolitan areas. UHI effect cannot be fully resolved but it can be reduced by proper planning of urban geometry and increasing green space. Recovery form UHI effect is possible but its recovery differs on the basis of mitigation strategies implementation.

Table 2: Factors affecting UHI

Parameters	Uncontrollable Parameter	Semi-controllable Parameter	Controllable Parameter
Identification	The factors in which modification or alteration is not possible.	The factors in which slight modification or alteration is possible.	The factors in which modification or alteration is possible.
Factors	Solar radiation and geographical location	Thermal properties of urban structure, sky view and blue space	Green space and anthropogenic activities
Recovery From UHI effect	Not possible	Possible	Possible
Recovery Speed	NA	Slow	Fast (Comparatively)

Apart from above discussed parameters, the parameters affecting the UHI intensity directly or indirectly are as follows:

- Land Use Land Cover (LULC): Land cover indicates the physical land type such as forest or open water whereas land use documents how people are using the land
- Density of population concentrated in urban area: The population density of a country or city or other place is a number showing how crowded that place.
- Urban design geometry (urban canyon): Urban design is about making connections between people and places, movement and urban form, nature and the built fabric.

IV. Prediction of UHI Intensity

Due to hazardous results of the UHI effect, it is necessary to predict it with long-term and short-term implications. There are various models, methods and tools used to predict UHI intensity in urban areas are given below and discussed in detail.

4.1 Methods used to predict UHI intensity

In this section, the prediction methods for UHI are discussed on the basis of their application and input parameters. Once the UHI intensity in specific area is predicted, the corresponding mitigation strategy can be identified and applied in advance in order to prevent or reduce the UHI intensity.

4.1.1 Local Climate Zone classification

Kotharkar & Bagade used Local Climate Zone (LCZ) method to evaluate urban climatic zones in the Nagpur city [17]. In this, remote sensing data is used to calculate NDVI, LST and LULC. They have taken meteorological data from regional meteorological department of the Nagpur city. They have used HOBO data logger for stationary data. This paper uses temperature buffer analysis, sensor lag determination, forecasting, outlier analysis and Pearson-correlation technique. They estimated CLHI (Canopy Layer Heat Island) through traverse survey in the range between 1.76 – 4.09 °C within built class. However, they admitted the need of more parameters to predict UHI more precisely.

4.1.2 Observational method using Automobile Devices

In this method, data is collected using different sensors mounted on devices. Mutani et al. had analyzed UHI effect in the city of Turin [18]. He used multiple regression model and established correlation between air temperature and urban parameters like urban morphology, solar radiance, albedo coefficient etc. These devices are placed on various urban structure or urban area having high elevation or urban morphology. The result shows 1-1.5 °C with the average air temperatures respectively in summer-time and winter-time. However, for future research they want to improve prediction models by using hourly weather data.

Amirtham analyzed impact of urbanization on UHI intensity in the city of Chennai [19]. He used HOBO data logger for collecting temperature data to analyze UHI intensity and took reference data from Numgambakkam Meteorological station as data source. In his studies, he revealed presence of cool valley effect in the city of Chennai at the time of winter with a temperature difference of 10.4ºC in summer and 3.7ºC in winter.

4.1.3 Linear Time Series (LTS) Model with least-square method

Mathew et al. used this model to predict UHI intensity in Ahmedabad [20]. They developed a linear model for prediction of LST in any area based on historical temperatures and parameters representing vegetation, road density and elevation of that area. They used last 10 years data of MODIS and ASTER. LST can be predicted from previous year LST images with good accuracy and will be helpful to monitor SUHI effect which is helpful in planned development city. They discovered high correlation between the prediction model and observed LST with an average regression co-efficient (R^2) value of 0.96 (of LST). However, LST models are sensitive to outliers and they have tendency to over-fit data.

4.1.4 GIS Method

Nakata-Osaki et al. developed THIS tool based on GIS technique [21]. They calculated UHI maximum intensity along with height-width ratio. They concluded that the UHI maximum intensity increases when the height-width ratio goes up, but the urban canyons with greater roughness result in UHI maximum intensity values of around two times smaller than canyons with less roughness for the same value as the height-width ratio. They analyzed the geographical measurements in the city of f São José do Rio Preto with the altitude above sea level, census and distance in kilometer from town to center. In their work, all the linear regression models had a relative error lower that 10 %. The results shows 1-1.5 °C UHI intensity with the average air temperatures respectively in summer-time and winter-time; and of 2.6-2.46 °C with the minimum air temperatures respectively in summer-time and winter-time. However, THIS tool considered temperature data as main affecting factor.

4.1.5 Ant Colony

Diamond et al. analyzed UHI effect of three cities using ant colony algorithm [22]. They used data of Dryad Digital Repository. They collected acorn ants from urban and rural populations across three cities in the eastern USA viz. Cleveland, Ohio, Cincinnati, Ohio, Knoxville and Tennessee. They predicted increase in heat tolerance of urban population across each urbanization gradient. The results of this study suggested that the phenotypic changes in thermal tolerance that they observed in acorn ants from urban populations are adaptive. They linked phenotypic shifts in temperature tolerance with environmental changes in temperature. Among three selected cities, two cities produce same result as their urban morphology is quite similar. However, Temnothorax is a very heat-tolerant species as compared with other ants; it is possible that low-latitude populations are beginning to push the evolutionary limits of heat tolerance, leading to reduce evolved response with increased warming in cities.

4.1.6 Artificial Neural Network (ANN)

Ashtiani et al. utilsed Artificial Neural Network(ANN) algorithm to predict the indoor air temperature and relative humidity in a house where indoor and outdoor temperature and relative humidity were measured every 15 min for 30 days [23]. They performed cross-comparison of a traditional and an advanced heat warning model with the help of the regression and ANN models respectively. The developed regression and ANN models were used to predict the hourly indoor dry-bulb temperatures of units located in the downtown Montreal and the heat wave in July 2010. It is well established that outdoor dry-bulb temperature has significant influence on the indoor environment thermal condition. The variation of predicted results of ANN model about maximum and minimum indoor dry-bulb temperatures are 2.64ºC and 1.99ºC, respectively. However, they assumed many variables in their study; for example, total building volume is assumed to be proportional with building thermal mass. Apart from this, the value of emittance, ε, is assumed to be one.

Moustris developed ANN model for complex human thermal comfort index associated with urban heat and cool island patterns [24] . This model has Penteli and Ilioupolis as study area. The values of Physiologically Equivalent Temperature (PET) index for a number of different locations with different urban environment configuration were predicted applying the developed ANN models for the warm period of the year 2007. The multi-layer perceptron ANN models were developed using the back-propagation training algorithm to predict PET hourly values.

4.1.7 Maximum Likelihood, Physical Scaling (using downscaling model) and other methods

Geoffrey and John analyzed UHI intensity in the Manchester city by developing their own method [25]. The parameters used in this work were wind speed, the cloud cover, and the solar radiation. It is used to predict the hourly values of UHI intensity all over the year. They collected weather data from the British Atmospheric Data Centre. However, they had not included temperature as a factor in their work.

Gaur analyzed the Surface Urban Heat Island (SUHI) of 20 Candidan cities [26]. They collected MODIS data for their work. They analysed data from 2002 to 2012. Results of UHI effect are encouraging in these regions, that is, 16 out of 20 cities were facing positive impact while the other 4 cities were experiencing negative impact of SUHI phenomena. They selected Physical Scaling downscaling model for this work. Various parameters viz. size, elevation, and surrounding landcover of city are considered in the study to predict UHI intensity. In addition, they estimated future prediction for the same study area. However, as the nature of UHI varies and it is based on anthropogenic activities of human, it is possible that the estimation may differ.

Khandar and Garg used maximum likelihood method to analyze the nagpur area and its surrounding [27]. They utilized Landsat ETM+ data of Nagpur and its surrounding area. They selected mono window algorithm to retrieve Land Surface Temperature (LST). They also analyzed the correlation between NDVI and LST and observed that LST is weakening where NDVI is high. The result shows that UHI intensity is high in the center of Nagpur city.

The summary of prediction methods, input and calculated results for the prediction of UHI intensity is given in table 3.

Table 3: Prediction methods used to predict UHI intensity

References Title	Prediction Method	Input Parameters/factors	Calculated Results
Evaluating urban heat island in the critical local climate zones of an Indian city [17]	Local Climate Zone (LCZ) classification	Air temperature, Wind speed and cloud cover data	The result shows that UHI intensity within built LCZ (IUHI), in winter season for Nagpur city, ranges from 1.76 to 4.09 °C
The urban heat island of the Metropolitan City of Turin. Strategies for a sustainable urban planning [18]	GIS-based method, linear regression model, multiple linear regression	Albedo, LST, NDVI, Distance. BCR (building coverage ratio), H/W (aspect ratio or height to distance ratio), H/Havg (relative height of a building), BD (building density), BH (buildings height), MOS (main orientation of the streets), Altasl (altitude above sea level), H_2O.	The results are of 1-1.5 °C with the average air temperatures respectively in summertime and wintertime; and 2.6-2.46 °C with the minimum air temperatures respectively in summertime and wintertime
Urbanization and its impact on Urban Heat Island Intensity in Chennai Metropolitan Area, India [19]	Real-time Observation method using HOBO Data Logger	Temperature isopleths of CMA	10.4º C in summer and 3.7º C in winter
Prediction of surface temperatures for the assessment of urban heat island effect over Ahmedabad city using linear time series model [20]	Linear Time series Model with least-square method	LST (Land Surface Temperature), EVI, Road Density, Elevation	6.54 K. (avg. UHI intensity for three periods of 10 years)
THIS – Tool for Heat Island Simulation: A GIS extension	GIS	roughness length, average height of buildings in the urban block, vertical	All UHI_{max} values were below those simulated by

model to calculate urban heat island intensity based on urban geometry [21]		surface average area facing the canyon, average area occupied by each building of the urban block-the horizontal projection	the Oke model, but with differences ranging from 0.34°C to 5.69°C
Evolution of thermal tolerance and its fitness consequences: parallel and non-parallel responses to urban heat islands across three cities [22]	Ant colony collections, Common-garden experiment, Thermal tolerance models, Fitness models, Tests of parallelism among cities. likelihood ratio tests	Temperature data, fitness data and thermal tolerance trait data, Impervious surface area (ISA), rearing temperature and their interaction on worker ant thermal tolerances	Knoxville exhibited a shift of 3.648°C and Cleveland exhibited a shift of 4.458°C, that is the difference between the maximum values of the kernel density distributions of environmental temperature
Indoor thermal condition in urban heat island: Comparison of the artificial neural network and regression methods prediction [23]	Artificial Neural Network (ANN) and regression method	outdoor dry-bulb temperature, wind speed, solar radiation, and relative humidity	The variation of predicted results of ANN model about maximum and minimum indoor dry-bulb temperatures are 2.64ºC and 1.99ºC, respectively.
Development and application of artificial neural network models to estimate values of a complex human thermal comfort index associated with urban heat and cool island patterns using air temperature data from a standard meteorological station [24]	Multi-layer perceptron (MLP) ANN models were developed using the back-propagation training algorithm to predict PET hourly values (New model is designed using ANN)	Air temperature data (from Ilioupoli meteorological station and Penteli meteorological station)	ANNs present a remarkable ability to estimate hourly PET values within various urban clusters using only hourly values of air temperature
An empirical model for the urban heat island intensity for a site in Manchester [25]	New numerical model is designed to estimate UHI intensity	Adapted wind (AW), adapted cloud (AC), adapted shortwave (AS)	The model-predicted loads are all within 10% of the actual loads for the city centre site with the UHII
Analysis and modelling of surface Urban Heat Island in 20 Canadian cities under climate and land-cover change [26]	Penalized likelihood maximization algorithm, split-window algorithm Physical Scaling (SP) downscaling model	Remotely sensed surface temperature, bilinear interpolated model simulated surface temperature, elevation, land-cover class of the pixel (p) of interest. (from MODIS)	largest increases in SUHI magnitudes are obtained for Toronto (0.4 K under RCP 2.6) whereas the largest decreases are obtained for Winnipeg (0.3 K under RCP 8.5)
Heat Island Analysis of Nagpur and Surrounding Area using Geomatics Techniques [27]	Maximum-Likelihood Classification	Land surface emissivity, Atmospheric transmittance, mean atmospheric temperature, LST, NDVI	1° C increased UHI

4.2 Model or Tools for prediction of UHI intensity

Based on the prediction method, various models and tools are developed and used for UHI intensity as follows:

4.2.1 ENVI-met

ENVI-met is a prognostic model based on the basic laws of fluid dynamics and thermodynamics. The model includes the simulation of vegetation parameters, bioclimatology, particle dispersion and pollutant chemistry, urban structure parameters etc.

Aida et al. demonstrates the fundamental procedures of calibrating and preparing a numerical model for the simulation of the urban microclimate [28]. They selected plant database, soil profile database, soils database, materials database and sources database in their study and considered BPI and WIS weather station data. They calculated index of agreement, coefficient of variation of the Root Mean Square Deviation (RMSE) and Root Mean Square Error (RMSE). However, the accuracy of the microclimate simulation results was strongly dependent on the quality of the input data, and the initial/boundary conditions in this research work.

Ambrosini et al. used ENVI-met climate model for the evaluation of mitigation effects of Urban Heat Island. ENVI-met helps to simulate the temporal evolution of some thermodynamics parameters on a micro-scale range, creating a 3D, non-hydrostatic model of the exchanges among building-atmosphere-vegetation [29]. They analyzed three different case studies viz. base case, cool case and green case. and calculated albedo of roofs in all the cases. However, ENVI-met is freeware, but is not Open Source and also its simulation is time consuming with large dataset.

4.2.2 WRF (Weather Research and Forecasting Model)

This model is developed by the National Center of Atmospheric Research (NCAR). It is a mesoscale, numerical weather prediction model, which can also be used for climate modeling. Jiachuan Yang and Elie Bou-Zeid analyzed the positive impact of Urban Heat Island (UHI) and advocated to use UHI as a protection cover from extreme cold [30]. They analyzed 12 cities of the USA. They found that UHI intensified during cold waves up to 1.32º + 0.78ºC (mean 6 standard deviation) at night relative to precedent and subsequent periods. They considered weather station data in their study. Tool based on WRF model and an integrated land–atmosphere framework developed by the NCAR, was used for high-resolution weather simulations in this study.

4.2.3 Statistical downscaling approach

Statistical downscaling is a two-step process consisting of i) the development of statistical relationships between local climate variables (e.g., surface air temperature and precipitation) and large-scale predictors (e.g., pressure fields), and ii) the application of such relationships to the output of global climate model experiments to simulate local climate characteristics in the future. Yating Zhang et al. analyzed Washington DC using this approach [31]. They proposed a method to estimate the urban heat island (UHI) effect and heat waves using an asynchronous regional regression model (ARRM) that statistically downscaling Coupled Model Inter-comparison Project Phase 5 (CIMP5) simulations into local observations. Projections based on the highest greenhouse gas concentration scenario, representative concentration pathway (RCP) 8.5, indicates a continuous increasing trend of heat waves.

4.2.4 Micro-Climatic Model RayMan to assess climate change on city scale

RayMan is an abbreviation of "radiation on the human body". It is used for Boundary conditions from ENSEMBLE model RT2B and REMO regional climate model and calculation of the Physiological Equivalent Temperature (PET). It is used in calculation of short- and long-wave radiation fluxes affecting the human body and takes complex urban structures into account calculated mean radiant temperature, required for the human energy balance meteorological and thermo-physiological data as input. This model is used for various applications like applied meteorology and climatology, landscape and ecological planning, forest and agricultural meteorology, urban meteorology and climatology, health, recreation and tourism. E. Tapias & G. Schmitt used this method for UHI estimation and used RayMan model for validation [32]. They calculated PET and Sky View factor (SVF) and established correlation in them. Their proposed algorithm was evolutionary in nature.

4.2.5 SURFEX combined with TEB

SURFEX (Surface Externalisée) is the surface modelling platform developed by MeteoFrance. It is used to compute averaged fluxes for momentum, sensible and latent heat for each surface grid box boundary condition for meteorological model input land cover information from ECOCLIMAP database.

TEB (Town Energy Model) is used to compute energy balance considering canyon concept. It is used for indoor air temperature influences HVAC energy demand. Demand of HVAC increases anthropogenic heat flux. This can have important implications for urban climate (mainly UHI). Main prognostic variables are roof, wall, road, mass and floor temperature (several layers), town sensible and latent heat flux, town net solar and net infra-red radiation, indoor air temperature and humidity and HVAC energy demand. Main diagnostic variables are street canyon air temperature and humidity along with canyon horizontal wind speed, town effective albedo and town average radiative surface temperature. Fanxing Zeng and Naiping Gao used this model to analyze the canopy layer of Toulouse city center, France from February 2004 to February 2005. However, computational cost is constraint in this study [33].

4.2.6 Regional Climate Model (RegCM)

The Regional Climate Model system RegCM , originally developed at the National Center for Atmospheric Research (NCAR), is maintained in the Earth System Physics (ESP) section of the ICTP [34]. The model is flexible, portable and easy to use. It can be applied to any region of the World with grid spacing of up to about 10 km (hydrostatic limit) and for a wide range of studies from process studies to paleo-climate and future climate simulation.

4.2.7 Neural Network Model for Climate

Weather forecasting has become an important field of research in the last few decades [35]. In most of the cases, the researcher had attempted to establish a linear relationship between the input weather data and the corresponding target data. But with the discovery of nonlinearity in the nature of weather data, the focus has shifted towards the nonlinear prediction of the weather data. Although, there are many literatures in nonlinear statistics for the weather forecasting, most of them required that the nonlinear model be specified before the estimation is done. But since the weather data is nonlinear and follows a very irregular trend, Artificial Neural Network (ANN) has evolved out to be a better technique to bring out the structural relationship between the various entities. The applicability of ANN approach is examined in the research by developing effective and reliable nonlinear predictive models for weather analysis. It also compared and evaluated the performance of the developed models using different transfer functions, hidden layers and neurons to forecast maximum temperature for 365 days of the year.

Table 4: Models or Tools used in UHI intensity prediction

Affecting Parameters	Geographical Location	Analysis/Discussion
ENVI-met		
Vegetation (NDVI) [28]	Vienna,	- ENVI-met and STEVE model are compared

	Austria	- Evaluation of microclimate like thermal properties - Minimum, average and maximum Temperature is calculated.
Albedo, Atmospheric Temperature, Windiness [29]	Teramo, Italy	- The analysis shows differences of up to 8K during hottest hours and greater than 3 K during nighttime - ENVI-met does not model vegetative shielding of vertical surfaces, like green walls.
WRF (Weather Research Forecast)		
Temperature data, High-resolution weather simulation, Heating degree-day [30]	US	- UHIs warm urban areas in the winter and intensify cities during cold waves by up to 1.32° ± 0.78°C (mean ± standard deviation) at night relative to precedent and subsequent periods. - Anthropogenic heat released from building heating contributes more than 30% of the UHI intensification.
Average early morning temperatures and the urban heat island, Diurnal cycle of air temperatures and wind [31]	New York City, USA	- Observed temperatures reached 39ºC or more at central urban sites over several days and remained high overnight due to urban heat island (UHI) effects, with a typical nighttime urban–rural temperature difference of 4º–5ºC.
Statistical downscaling approach		
Temperature (Daily maximum and minimum temperatures) [32]	Washington, USA	- CMIP5 model is used for calculating UHI intensity.
Micro-Climatic Model RayMan to assess climate change on city scale		
Physiological Equivalent Temperature (PET), Sky View Factor, air temperature, relative humidity, global radiation, vapour pressure and wind velocity [33]	Switzerland	- Long-term thermal comfort model is designed. 'Sky View Factor' analysis is done and an evolutionary design is made for systematic exploration of different factors that are correlated to each other.
SURFEX combined with TEB (Town Energy Model)		
Air temperature, specific humidity, air pressure, downward direct and diffuse radiation and wind speed which are averaged over 30 min [34]	Toulouse, France	- Pigeon study is used to modify newly obtained data of thermal and radiative parameters - Annual roof and road temperature cycle do not have much significant difference.
Regional Climate Model (RegCM)		
Mediterranean [35]	-	- Comparison between atmosphere-only and coupled simulations with RegCM-ES on various parameters is tested to obtain better results.

V. Mitigation Strategies for UHI Effect

Mitigation strategies are the solutions which are used to reduce UHI effect. Measures can be practically applied to counter or lessen the heat island effect on urban elements that influence the local temperature. In this case, assured parameters can be used to evaluate the impact of the variation of urban morphology on energy utilization. These results are conducive to the reduction of CO2 emissions into the atmosphere [37]. Examples of these parameters are the green plot ratio, sky view factor, building density, wall surface area, pavement area, albedo etc. as categorized in Figure 2.

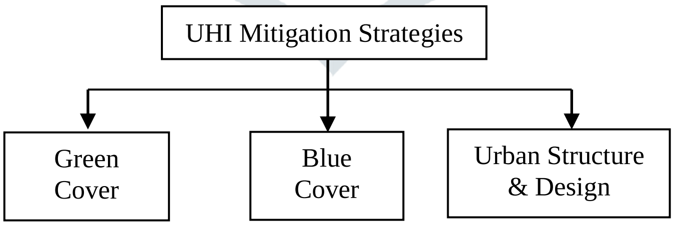

Figure 2: Classification of UHI mitigation strategies

Sadownik and Jaccard proposed a set of urban development strategies based on more sustainable energy utilization [37]. They studied the case of China and concluded that by 2015, these strategies could decrease emissions in the uptown sector and from transportation by approximately 14% for CO_2, 10% for SO_2, 40% for NO_x, and 14% for particle emissions. However, while applying mitigation strategies, the limitations in land use planning; the site and plan of buildings, alternative energy supply and transportation management are hindrance to the implementation of these strategies.

5.1 Green Cover

Green cover refers to a wide range of strategies that combines green, permeable and reflective surfaces into cities and towns.

5.1.1 Parks and green areas

The temperature in parks and beneath trees are studied and analyzed to apply this mitigation strategy [36-38]. According to the studies of Shashua-Bar and Hoffman, in parks and green areas, the joint effects of evapo-transpiration and shading was the reason behind significant decrease in temperature and even causes the opposite effect of UHI known as cool islands or urban cool valley in the city [36]. The general conclusion was that green spaces were cooler than spaces without any green cover.

Eliasson showed that the mean air temperature difference between the park and the city center was as high as 41ºC [38]. They carried out their work in the city of Göteborg in Swedish west coast. They had taken air and surface temperature as input and applied GIS model to obtain the results.

Cao et al. proposed a park vegetation and shape index (PVSI) that can be used to predict the intensity of the cool island in parks [39]. This could help urban planners to better comprehend the formation of cool islands and thus be able to design cooler parks that counteract the effects of the urban heat island.

5.1.2. Trees and vegetation

Various authors analyzed the reduction of energy utilization caused by vegetation and tree shade [40-42]. Robitu et al. showed that it was possible to accumulate up to 10% in cooling buildings, simply from the temperature reduction caused by vegetation. This temperature reduction was estimated at 3–51K [41]. Akbari et al monitored the power peak and the energy savings in cooling produced by tree shade in two houses in Sacramento, California [42]. The data related to air-conditioning electricity utilization, roof and ceiling surface temperatures, inside and outside wall temperatures, wind speed and direction, insolation, indoor and outdoor dry bulb temperatures, and humidity was collected and analyzed. Shaded trees covering two houses yielded seasonal cooling energy savings of 30%, related to mean average daily savings of 3.6 and 8 kWh/d. It was found that the shade from trees reduced the temperature of external building surfaces as effectively as the wind speed.

These research studies coincide and validate that the site climate, the tree species at the location and number of trees in relation to the surface area are all factors that affect the energy utilization of nearby buildings.

5.1.3. Green roofs

Conventional building roofs are impervious gray surfaces that contribute to the heat island effect in cities and increase flooding problems. Green roofs are practical solutions for multi-story buildings, commercial buildings, residential buildings and other constructions. They perk up building energy performance as well as the ecological conditions of the surroundings.

Niachou et al. analyzed the thermal properties of green roofs and noted that during the summer, such roofs facilitate to keep air temperatures low during the day and higher at night [43]. However, they found that night-time ventilation kept temperatures low during the day as well as at night. Energy consumption in buildings with green roofs was found to be lower than those without such roofs and could even be improved by natural ventilation during the summer.

Despite the considerable amount of information on the microclimatic effects of green spaces, there are very few authors that have quantitatively estimated these effects and incorporated them into the design process. However, this is critical so that scientific findings can have a practical implementation in the real world. An effort should thus be made to “transform” research outcome into the language of project design, where it can be used to assist society.

5.2 Blue Cover

It includes areas having large amount of surface waterbodies or watercourses [44]. It helps in falling the risks of heat related illness from high urban temperatures and their significance to future urban planning strategies. The terms ‘urban bluespace’ and ‘urban waterbodies’ refer to all substantial bodies of static or dynamic surface water found in urban areas. Substantial bluespaces naturally exist as essential features of the geography of many cities because of their historical geopolitical significance. For example, in the port city of London the River Thames is a leading feature, which with other bluespace stands for ~2.5 % of the city's surface area.

According to Gunawardena, greenspace and bluespace helps to deal with UHI effect [45]. However, heavily populated area has less bluespaces. They reviewed impact of greenspace and bluespace in mesoscale and microscale atmospheric layers.

Theeuwes carried out study and revealed that in some occurrences ~60% of the comfort attained by the sensible cooling effect of bluespace might be negated by this humidity modification [46]. Through consideration of the diurnal thermal exchanges, the evidence suggested that bluespace can in fact warm urban environments when it is least desirable and as it such offer limited potential for urban heat risk mitigation if considered in isolation.

5.3 Urban Structure and design

The design and distribution of urban buildings and structures in a city affects the formation of the urban heat island since this distribution can determine the amalgamation of solar radiation and the formation of wind streams. The performance of an urban area in considered to solar radiation and air flows between buildings validated its contribution to the dispersal of suspended particles and of polluting gases. The urban structure absorption to solar radiation and air flows can be controlled by means of urban design. Optimal designs can reduce energy consumption and CO_2 emissions, which can counteract the negative effects of the heat island.

According to Yamaguchi et al. an effective design/planning of city neighborhoods, the distribution of buildings, and energy utilization equipment can achieve a reduction of 60–90% of the current CO_2 emission by the middle of the 21st century [47].

5.3.1 Albedo

By increasing albedo, a great improvement of the urban temperature is observed; the temperature can be decreased by 2°C in the city of Terni [48]. Authors developed a multi-layer UCM, is the most refined urban modelling in WRF, since it recognizes the moisture, 3-D nature of urban surfaces and accounts for buildings as sources and sinks of heat and momentum through the whole urban canopy layer.

According to Reena, In ancient India the construction of Hindu temples and residential structures, mortar was rarely used which is used to mix in high albedo materials, but they used a technique where the stones could be affixed to one another with the force of gravity [49]. The technique followed in doing this was similar to the one used in the Roman aqueducts. Those structures are still present in some form.

5.3.2. Pavements

The pavement materials of urban ground surfaces also have a major impact on the heat island effect. For example, in an urban layout in a conventional grid design, sidewalks inhabit roughly 16% of the ground surface. This percentage can be as high as 23% in rectangular sections typical of community housing complexes. Important factors to be considered are the following: (i) the horizontal surface uncovered in solar radiation; (ii) the absorption (iii) the high thermal capacity of the materials.

Scholz and Grabowiecki conducted a review on original materials, as permeable and porous pavement systems, as a part of storm water management system [50]. This technique intends to manage the runoff in urban areas. The water collected by the pavement is discharged into a sustainable drainage system later. A permeable pavement system is composed typically by (from lower to upper): native sub-grade, geo-textile (optional), base, bedding layer and permeable paver unit with drainage cells. The application of the described system encompasses vehicular and pedestrian access, slope stabilization and parking, among other uses. The use of permeable pavement systems is being established among engineering techniques, although more research is needed.

5.3.3 Urban design and solar radiation

Urban areas are differentiate by many types of surface (building façades, pavements, roofs, etc.) which soak up short wave solar radiation and consequently reflect it more slowly with a longer wavelength during the night. These long wave radiations are preserved by suspended particles and combustion gases. The capturing of solar radiation as well as light exploitation and protection systems through urban design are important energy saving strategies to substitute conventional fossil fuels, and thus reduce environmental pollution and the urban heat island effect [51]. Baker and Steemers formulate a procedure to estimate the effects of shading systems on cooling loads [52].

Krüger monitored a inhabited building from January to August 2006 to ascertain variations in cooling energy utilization for aspect ratios (H/W) and street axis orientations [53]. When three dimensional density was high, N–S streets with high aspect ratios allowed for mutual shading of building façades and glossy openings, and reductions in cooling loads. Wide streets with an E–W axis and with north/south-facing building façades were found to allow for comparatively low cooling loads even without mutual shading.

As reflected in the previously described studies, various authors have addressed the difficulty of solar access in obstructed and heavily built-up environments. Their studies provide design guidelines or methods that guarantee solar access [54].

5.3.4 Urban design and air flow

The combination of high buildings and narrow streets that capture hot air and decrease the airflow generates low-speed winds, which do nothing to scatter suspended particles and polluting gases, but rather produce the heat island effect [55]. According to Ratti et al., the maximal dispersion of pollutants needed maximum turbulence. For example, the dispersion of pollutants from traffic in urban areas requires a maximum turbulence and vertical transport – and therefore high values of aerodynamic roughness [56].

There are different types of interference stemming from the space between buildings. Isolated buildings have an isolated roughness flow regime. However, when there is an array of buildings, the regime changes to wake up interference flow with secondary flows in the street canyon space. At even greater H/W and density, there is a transition to a skimming flow regime where the bulk of the flow does not enter the canyon. All of these flow regimes depend on urban geometry [57].

VI. Discussion

The Köppen climate classification is one of the most widely used climate classification systems [58]. The Köppen climate classification divides climates into five main climate groups, with each group being divided based on seasonal precipitation and temperature patterns as shown in the Table 5. The five main groups are A (tropical), B (dry), C (temperate), D (continental), and E (polar) and additional group is type H (High land areas). The brief discussion about each type is given in table 5.

Table 5: Köppen Climate Classification – Major Groups

Köppen Climate Type	Köppen Climate Subtype	Description
A	4, each begins with A	Tropical Moist Climates: all months have average temperatures above 18° Celsius.
B	2, each begin with B. this two is further divided into 2 sub types	Dry Climates: with deficient precipitation during most of the year

C	3, each begin with C. this two is further divided into 3 sub types	Moist Mid-latitude Climates with Mild Winters
D	3, each begin with D. this two is further divided into 4 sub types	Moist Mid-Latitude Climates with Cold Winters
E	2, each begins with E	Polar Climates: with extremely cold winters and summers

As per Köppen climate classification, the geographical zones are divided into regions and the region wise study of UHI effect is shown in the Table 6. In this, prediction method and the corresponding model or tool are discussed. The mitigation is suggested by analyzing the researchers' work. In addition, the research directions are discussed for each classification for future work.

Table 6: Analysis of prediction models based on climatic condition

Köppen Climate Classification	Region	Prediction Method and Model or Tool	Suggested Mitigation Measures	Research Directions
Cfb (Oceanic climate)	[16] Basel, Switzerland	Multiple linear regression model	Urban Planning	Testing of the method with less air temperature input data and the application in other cities can improve future results.
	[28]Vienna, Austria	ENVI-met model	Urban Planning	It is used to build 3D model for small geographical area
As (Tropical dry or savanna climate)	[17] Nagpur, India	Local climate zone (LCZ) classification	Urban Planning	Identification of critical LCZs in terms of UHI intensity and suggests the need for intervention.
	[27] Nagpur, India	Maximum Likelihood		NDVI and LST are inversely proportional to each other. UHI effect is reduce by increasing NDVI.
Aw (Tropical wet or savanna climate)	[19] Chennai, India	Observational Method using automobile device. Model is prepared using ArcGIS.	Building regulation in Urban geometry	Correlation established between urban rural difference and urban density.
	[21] São José do Rio Preto and Bauru, Brazil	THIS – Tool for Heat Island Simulation	Urban geometry	The possibility of incorporating equations adapted to the algorithm makes it a very promising tool and its potential must be better used in other climatic conditions
Bsh (Hot semi-arid climate)	[20] Ahmedabad, India	Linear Time Series Model	Vegetation	Assist in predicting SUHI (Surface Urban Heat Island)
Csa (dry-summer subtropical or Mediterranean Climate)	[24]Athens, Egypt	ANN (Artificial Neural Network)	Green Vegetation	Efficient techniques to direct the results of ANN models to be used for interpretation of modeled scenarios in UHI problems with respect to warming trends in summer.
Cfa (Humid subtropical climates)	[29] Teramo, Italy	ENVI-met model	Green roof	Applicable to small area
Dfa (Hot summer continental climates), Cfa (Humid subtropical climates), Dfb (Warm-	[22] Knoxville, Cleveland, USA	Ant Colony	Green Vegetation	Exploration of additional urbanization variables to evaluate the thermal tolerance traits and their fitness consequence in acorn ants and other species.
	[26] 20 Canadian Cities, USA	SP downscaling model	Reforestation	Investigation and improvements in SP model in this direction are ongoing

summer humid continental climates), Bsk (Cold semi-arid climate) and Csb (Mediterranean warm/cool summer climates)	[30] 12 cities, USA	The Advanced Research version (3.5.1) of the Weather Research and Forecasting (WRF) Model	Green or cool roofs	Benefits of UHI during Winter.
	[31] Washington DC, USA	Asynchronous Regional Regression Model (ARRM) using Coupled Model Intercomparison Project Phase 5 (CIMP5) simulations	Combined Mitigation and adaptation efforts from both local governments and global collaborations in terms of policy making for urban planners.	It assist in planning and initiating appropriate climate adaptations for cities

As per our observations of different studies by scholars and researchers on UHI, it is analyzed that the numerical models are widely used to analyze and predict UHI effect [16], [20], [26]. Similarly, the mitigation measures mainly focus on improving urban planning and vegetation [17], [19]. The new mitigation strategies are being developed by various organizations and researchers, however, the experimental results are yet to be deployed on real world applications [29], [31].

As shown in table 6, Basel city of the Switzerland has oceanic climate (cfb) [16]. This type of climate have moderately cool summers and comparatively warm winters and do not have the extremely dry summers, precipitation is both adequate and reliable at all times of the year in oceanic climates. In addition, Vienna city in Austria has similar climatic conditions [28]. In the former case, the researcher applied multiple linear regression model to evaluate Urban Heat Island (UHI) effect. In this land cover, Landsat data and urban morphology are used as input factors. As the study is based on evaluating urban heat island effect, urban morphology is an important factor. Validation using random sampling indicated that an RMSE is clearly below the standard deviation of the measurements. The regression coefficients are varying within nocturnal runs with best results. While in the later case, ENVI-met model is used to predict UHI effect. The 3D model of given area is developed using ENVI-met tool to analyze UHI effect. However, both the studies suggested that the urban planning is suitable mitigation strategy for this type of climatic condition.

The Nagpur city of India possesses tropical dry or savanna climate (As) [17], [27]. It exhibit dry season, with the driest month having precipitation less than 2.36 inch of precipitation. In essence, a tropical savanna climate tends to either see less rainfall than a tropical monsoon climate or have more pronounced dry seasons than a tropical monsoon climate. The researchers divided the whole Nagpur city using Local Climate Zone (LCZ) classification to evaluate UHI. They estimated factors like elevation, station height from ground (in m), building surface fraction, impervious surface fraction, pervious surface fraction and height of roughness [17]. In addition, Maximum Likelihood method is also used in this city to estimate UHI intensity [27]. For both the studies, urban planning mitigation strategy is preferable as per our analysis. However, LCZ classification method is preferred by urban planners as one can identify critical urban heat zones using this classification.

The Chennai city of India is located below Tropic of Cancer [19]. It has tropical savanna climates (Aw), dry season observed here. In essence, a tropical savanna climate tends to either experience less rainfall than a tropical monsoon climate or has more pronounced dry seasons than a tropical monsoon climate. The researchers used automobile device to collect temperature and humidity data and applied Observational Method using the collected data for the prediction of UHI effect. This method consumes more time and cost than the other methods like numerical or GIS, however, it produces more effective results than the other methods.

The same Köppen climatic condition of tropical savanna climate (Aw) prevails in the two cities of Brazil [21]. The researchers developed GIS based THIS tool to predict UHI. They considered input variables like location of street axes (lines), perimeters of buildings (polygon), the heights of these buildings (number associated with the object polygon) and the distance radius of building-axis (single value). The maximum UHI value is calculated for buildings. It is helpful to city dwellers in designing UHI resistant urban geometry. Thus, as per our observations, urban plan geometry mitigation strategy can be applied to reduce UHI effect in tropical savanna climates.

The city of Ahmedabad in India has extremely variable temperature conditions [20]. The Köppen Climate Classification subtype for this climate is "Bsh". Its annual means are decreasing and annual ranges are increasing poleward and it experiences relatively little precipitation than the other climatic zones. Remoteness from sources of water vapor is enhanced in some regions by mountain barriers upwind. Mathews et al., predicted surface UHI using MODIS Re-projection Tool (MRT). They evaluated MODIS data for EVI, Road density and elevation of study area. However, the other affecting factors like NDVI, elevation, aerosol etc. can be considered for this type of regions. According to their study, vegetation can be used as an effective measure to mitigate UHI effect.

The climate is warm and temperate in Teramo city [29]. Teramo has a significant amount of rainfall during the year. The climate here is classified as Cfa by the Köppen climate system. The researchers evaluated mitigation effects of UHI using ENVI-met climate model. They used albedo of roofs, albedo of walls and green roof as input variables for evaluation. The suggested mitigation strategy is green roof in their study.

The USA is a wide geographical zone that has varying climatic conditions that includes humid continental climate (Dfa), Humid sub tropical climate (Cfa), humid continental climate with dry winter (Dfb), Semi-arid climate (Bsk) and cool dry-summer (Csb) climatic conditions [31]. Based on the climatic conditions and available data, statistical downscaling model [26], WRF model [30] and Asynchronous Regional Regression Model (ARRM) [31] are used to calculate UHI effect in different regions. In statistical downscaling method, the researchers used daytime and nighttime surface temperature data as input variables to calculate surface temperature data. In WRF model, they analyzed anthropogenic heat and focus on positive aspect of Urban Heat Island effect. In ARRM model, land use change is used as an input variable that estimates the concentration of green house gases like NO(Nitrogen Oxide), NO_2(Nitrogen Dioxide), NH_3 (Ammonia) [31]. The suggested mitigation strategies are green roof and reforestation for climatic zones like Bsk, Cfa and Csb. However, the UHI has positive effect in climatic zones like Dfb [22].

Thus, as per the existing literature on UHI effect, our observations are as follows:

- In the regions having tropical moist climatic condition (type A like Nagpur, Chennai), LCZ and GIS methods can be preferable to predict UHI effect. In addition, urban planning and green cover are the suitable mitigation strategy in such type of climatic condition.
- In the regions having dry climatic conditions (type B like Ahmedabad), the regression and statistical methods can be used. However, it is required to predict shorter UHI intensity in these areas. Urban geometry and green vegetation are suitable strategy in this type of climatic condition.
- In the regions having Moist Mid-latitude Climates with Mild Winters climatic condition (type C like Athens, Teramo, Washington), UHI effect has negative impact during summer. In this case, statistical prediction method and ENVI-met prediction model is used .In this type of conditions, urban green cover should be increased to mitigate UHI effect. Cool Pavements are used in building materials so that it can maintain indoor temperature.
- In the regions having Moist Mid-Latitude Climates with Cold Winters climatic condition (type D like Knoxville, Cleveland), UHI effect has positive impact during summer. It helps to create sustainable environment in this regions. The computing methods like regression, statistical and ant colony are implemented in the existing studies. WRF Model is suitable model used in this region. Arctic greening is also a positive effect seen in this type of region. Mitigation strategies like reforestation, cool roof, green vegetation and urban planning are suggested mitigation measures
- Similarly, in the regions having polar climatic condition (type E), UHI effect has positive results.

The satellite technology and numerical simulation appeared to be widely applied supporting techniques in learning the UHI effect. The computer technique could especially be useful in determining the building temperature and has been widely applied for determining the benefits of mitigating measures. However, as being pointed out, computer simulation needs strong validations and outcomes. Lastly, as per our analysis, the projected mitigating measures could be divided into three types:

1. Could not be implemented in anyway (replacement of already built infrastructure with low albedo)
2. Having considerable benefits but have not implemented yet (green roof)
3. Already implemented either through simulation or through field survey (cool pavement, green vegetation and urban planning)

In comparison to the former, the last two types might be more promising, however, they are still lacking in practical implementation as they may not yield the reported huge savings and benefits. The best scenario could be the one where the probable temperature reduction due to the implementation of mitigating measures could be evaluated.

VII. CONCLUSION

. Urban cities utilize more energy than rural areas because of activities such as the heating and cooling of buildings, urban transportation, commercial and industrial activities, etc. This high level of energy utilization is leading to the Urban Heat Island (UHI) effect. This study has been carried out to summarize and review the basic concepts, latest prediction methods, models/tools and mitigation strategies used for understanding the estimation and reduction of UHI effect. Anthropogenic heat and urban geometry are the two main leading factors of UHI effect. The other factors and their importance in causing the UHI have been discussed in detail. In addition, it is observed that satellite data is widely used in various studies.

Different factors are categorized in parameters viz. controllable, semi-controllable and un-controllable related with UHI effect. As per our observation, anthropogenic activity and urban geometry are most controllable factors. It is possible to apply a series of strategies that mitigate the effects of the heat island in the design phases of urban planning.

Various prediction methods and models (or tools) are reviewed in this paper to identify the appropriateness of the method or tool for UHI prediction as per the regional climatic condition and available resources. The regions are classified as per Köppen Climate Classification and suitable prediction methods are identified as per this classification. It is observed that the numerical and GIS based prediction methods are widely used; while Observation based prediction method is more efficient as compared to other prediction methods. In addition to the prediction methods, the corresponding mitigation strategies and research directions are summarized for these climatic conditions.

As per the analysis, it can be concluded that the majority of the promising benefits of mitigating measures have been reported for the controllable part of anthropogenic activities i.e., the design and planning parameters. Thus, there is a need to put more research efforts in quantifying the importance of these design and planning parameters.

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