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Urban Heat and Spatial Dynamics Planning Towards Climate Resilience: The Case of Bangalore

Minakshi Jain, Ayon K Tarafdar, Adinarayanane R, Faiz Ahmed C

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Abstract: The scarcity of water and intermittent flooding has now become a common phenomenon in cities across India. The traditional or latent knowledge was being used historically for water resilience in India. Jodhpur city in Rajasthan, taken up for this study, found apathy of public institutions as one of the causes of water stress in the city. Co-production of water is being undertaken through community efforts to address the water stress, using traditional methods. Through a detailed interview, visual observations and interactions with the officials, community-based individuals, local leaders, etc., the study approaches Jodhpur's water resilience in various wards within the city. The study through its scientific analysis brings out that, the water stress can be addressed through tacit knowledge and co-production of water.

1 The Phenomenon of Urban Heat

The health impacts of heat waves are emerging environmental health concerns. This is especially so for large cities where the concentration of people within certain spatial limits is extremely high. In addition, temperatures within cities reach stressful levels during extreme temperature conditions. To better manage heat related health risks, it is pertinent to evolve a planning framework that recognizes the link between urban heat zones and urban built and natural features and accordingly evolves development strategies (Kim, 2014).

Health hazards posed by heat vulnerability is a worldwide issue. In it understandable that climate change is expected to increase the intensity and frequency of periods of extremely hot weather with resulting significant effects on human health. As per a report submitted in Lok Sabha of the Government of India dated 4th April, 2018 it is stated that 6167 deaths have been reported in between the year of 2010 and 2018 in India due to heat stress in urban areas. An article published by Hindustan Times dated 2nd June 2019 states 'Heat wave in urban India, soaring up to 123 degrees F, has killed at least 36 persons during the summer of 2019'. There are many global occurrences as well. As per Meteorological Service Singapore (MSS), the island is heating up twice as fast as the rest of the world - at 0.25 degrees Celsius per decade. Apart from the health impacts, urban heat stress has also proven to impose an economic burden on the cities. As per United Nation news dated 2nd June 2019, heat stress spike predicted to cost global economy $2.4 trillion a year. A difference of 3°C is capable of raising electricity demand by 1,856gwh over the base electricity requirement of the city with a corresponding increase in CO_2 emissions by 1.52 million ton.

Heat stressed areas need an assessment to the extent to which communities are vulnerable to changing environmental conditions, and thus identify what steps should be taken to adapt to these changes (Mohan, 2011). Intra-urban variability of vulnerability due to heat stress and its linkages with urban planning is a domain that is not much explored. In this context, this study tries to delve into the relations between heat stress and urban characteristics, and evolve inferences that help urban planning process.

2 Need for Resilience Oriented Planning

Total global damage (averaged over a 10-year period) from disasters increased tenfold between 1976–1985 and 2005–2014, from $14 billion to more than $140 billion (GFDRR, 2016). Social inequalities increase the exposure and sensitivity to hazards related to climate. People's ability to cope with extreme climatic conditions are varied and hence, in a heterogeneous society with widespread inequalities, it is difficult to become resilient. Nevertheless, it is not impossible. The poorest are often strained to adapt in difficult climatic conditions and live in constant risk within disaster-prone areas. It is the economically deprived who often dwell within the densely populated slums in developing countries (Anderson, 2016). Alongside, rapid urbanization, unplanned growth, diverse economic activities, and climate extremes which put at risk decades of development gains.

In this milieu, while it takes efforts and uncertainty to ease out socio-economic inequalities, there is more realization potential if we focus and evolve informed spatial planning processes. Such informed planning processes can be more tuned to tackle heat.

City administrators and planners do have a significant role is defining and projecting the land use functions of various zones, plots, and stretches within a city which in turn have direct consequences to livability and adaptation to climatic stress. However, most traditional urban planning practices and plan making processes do not consider aspects of climate change or extreme climatic conditions while developing planning strategies. This study attempts to evolve an understanding of the relation between heat stress zones in the large city of Bangalore in India, to guide future city planning processes to become heat resilient and climate sensitive.

3 Case of Bangalore

Despite the influence of urban heat island (UHI) on heatwaves, the role of UHI on heatwave intensification in urban areas in India remains unrecognized (Rahul, 2019). Bangalore is one of the top seven metropolitans of India, in terms of spatial extent, population size, and its growth rate in the last ten years. It has expanded over 240% of its original size on the last 15 years and has seen population growth of over 3-4% per annum continuously in the last two decades. The city has witnessed huge amounts of foreign investment and has become a nerve centre of IT sector attracting millions of young highly skilled professionals. In tandem, it has seen massive development of commercial centres, recreational hubs, hundreds of housing colonies, and social amenities to cater to the young professionals. Unfortunately, the city also witnessed loss of hundreds of its lakes and green spaces (Taubenböck 2009). Over one hundred lakes and water bodies of the city has succumbed to urbanisation pressures. The green cover of the city has come down from 27% to 16%, as depicted in the subsequent sections of analysis. The population density has almost doubled and in some pockets, the building density is very high (Sudhira, 2013). The growth pattern of Bangalore shows exciting city development concepts but appears to be silent on climate resilience and sustainability.

Bangalore provides an apt case to study the rising heat stress in the city with the changing water and green and built mass context. The subsequent sections discuss these in more detail.

4 Study Framework

This study identifies five critical urban elements that several studies in existing urban planning literature have already established links with formation of urban heat islands. The hypothesis of this study is - if we can identify heat accumulation zones based on these parameters and plan accordingly, there will be better resilience to high heat conditions. While each of these five critical elements have individual connections with forming heat zones or dissipating heat, they are rarely discussed in aggregate. This study evolves a logical analytical presumption that aggregates or spatially overlays these five elements to arrive at calculated potential heat stress zones at the city scale. These heat stress zones are then analyzed in the context of existing land use and possible land use functions. The five urban indicators of analysis linked with heat stress zones and resilience towards them, are as follows:

A) **Local Built Index (through NDBI):** The volume of built mass in a part of the city or the lack of built mass in it has a relation to the amount of heat that part of the city can accumulate over the day and release after sunset. Built mass in an urban context comprises buildings, bridges, roads and paved volumes that represent masses of bricks, concrete, steel, stone, glass and artificial material. This study captures the built index through a process that calculates 'normalized differential built index' (NDBI) of the spatial extent of Bangalore city at a local level using satellite imageries. Such index gives us an idea of the concentration of built mass in the city at the local level and its propensity to further concentrate.

B) **Local Surface Temperature (through LST):** The local surface temperature of public and open areas during daytime of summer months (April and May) are indicative of the real surface conditions up to 3 metres from surface. Such local surface temperatures can be measured using satellite imageries and geospatial processing in a accurate manner for different times of the day and also during the year. This study captures the local surface temperature in the summer months of 2019 during the afternoon and uses its average to develop an understanding of the surface conditions.

C) **Local Water Index (through NDWI):** Any quantum of surface water in a locality has a tendency to cool its surroundings and hence, dissipate heat to some extent. This is predominantly because of the large amount of latent heat it can absorb from the atmosphere to eventually evaporate. This study captures the concentration of water bodies across the expanse of the city using small analytical grids of 500m by 500m by an analytical tool called 'normalized differential water index' (NDWI) processed from satellite imageries. Such water index gives us an idea of the concentration of water bodies in the city at the local level and its propensity to further concentrate.

D) **Local Vegetation Index (through NDVI):** Any quantum of vegetation on the surface in a locality also has a character to cool the surroundings and hence, dissipate heat. This is predominantly because of the ability to provide shade and the capacity to absorb carbon from the local atmospheric conditions. This study captures the concentration of urban green surfaces across the expanse of the city using small analytical grids of 500m by 500m by an analytical tool called 'normalized differential vegetation index' (NDWI) processed from satellite imageries. Such vegetation index gives us an idea of the concentration of urban green in the city at the local level and its propensity to further concentrate.

E) **Population Density (through PD):** Concentration of people staying in different pockets of the city of Bangalore is linked to the planned density gradients and the amount of additional building activities that has happened over the years beyond planned capacities. A large concentration of people also indicates unauthorized growth or highly cramped living conditions which may be potential risk zones in durations of heat waves and extreme heat. This study takes up population density as an element of analysis. It calculates the persons per unit area staying in different pockets of the city using census data and methods of spatial extrapolation.

The above five elements of the Bangalore city are first analysed in depth to arrive at an understanding of the baseline situation of – a) prevalent built up concentration, b) existing local surface temperature conditions, c) availability of contiguous water, d) availability of contiguous green, and e) patterns of population density. This information is analysed at local scale of grids of 500m X 500m.

Thereafter, the data are aggregated and spatially overlaid to form urban heat stress index zones at the local sub-city level using 'normalized composite index method' in GIS. This gives us an understanding of the 'heat stress' is not just a local temperature recording but is an outcome of aggregating aspects of population concentration, building concentration, surface temperature, absence of green and absence of water.

The potential heat stress zones are then spatially correlated with the existing land use pattern to arrive at understanding of where there is a need to intervene with land use relaxations or control to adapt to a potential heat stress condition. Any such planned adaptation to heat stress is a logical step towards building resilience. It is important to understand that the calculation of urban heat stress zones can be intellectually enhanced if we add more layers of data or parameters beyond the five mentioned above. In data related to economic conditions, if data related to building material conditions and if data related to child and old age proportions are added in the spatial overlay analysis, we can get a more accurate picture of the levels of risk related to heat stress. Depending on availability of data and time, several more indictors can be added to form more accurate and informed heat stress zones. The idea here is to project a framework of analysis that can help rationalize the planning process and make it sensitive to heat conditions, which can then be replicated.

5 Data Assimilation and Analysis

The understanding of Bangalore is presented here in terms of the five main elements of analysis as presented in the preceding sections. 'Landsat' which is an American satellite providing spatial data of land surface at fairly accurate scales has several bands based on their wavelength (blue band, green band, red band, infrared band, thermal band, panchromatic etc.) which can be used for classification and analysis of the land surface. This study uses Landsat data available in public domain for its analysis. Landsat 8 data has 11 bands. But, for analysis of Normal Difference Vegetation Index (NDVI), Normal Difference Built-up Index (NDBI) and Normal Difference Water Index (NDWI), only four bands are used (Green, Red, NIR, SWIR). The five elements of analysis are processed on satellite image processing platforms to arrive at understanding of concentration of each of the elements in each pixel of the satellite imagery, which inherently depicts to its spatial presence or absence and the pattern of its spread (Lillesand and Kieffer, 1994).

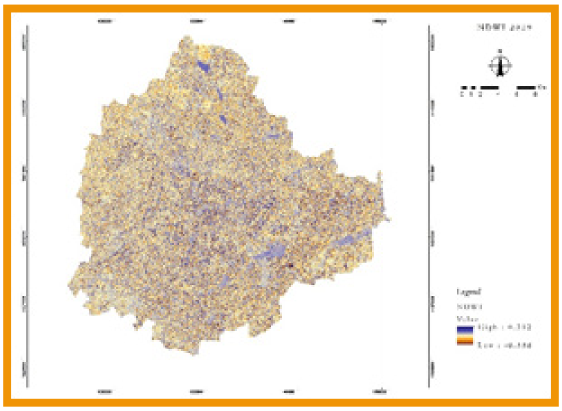
5.1 Local Water Index (through NDWI) Details

By processing satellite imageries, the Normal Difference Water Index (NDWI) is developed and used for accurate mapping of water bodies and to determine the presence of moisture in vegetation cover and to assess risk of fire. For this study the NDWI values have been used to see the presence and concentration of water bodies on the surface. NDWI values lie between -1 to 1. Higher NDWI value indicates sufficient moisture, whereas low value indicates water stress. Generally, for water bodies NDWI value is greater than 0.5. Vegetation has much smaller values which helps in distinguishing vegetation from water bodies. NDWI is calculated by the formula:

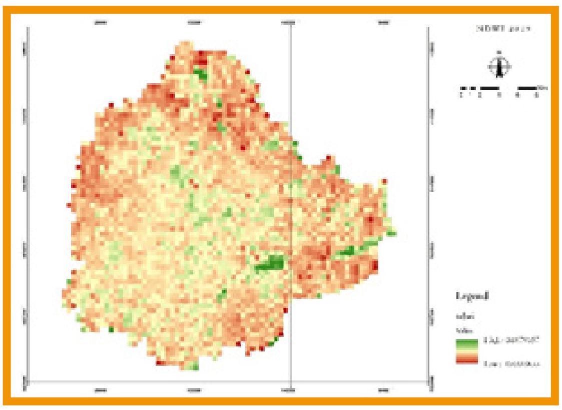
NDWI = (NIR – SWIR) / (NIR + SWIR)

To calculate NDWI using ArcGIS, Landsat 8 data from USGS website has been downloaded and for Landsat 8 data, NDWI = (Band 5 – Band 6) / (Band 5 + Band 6) has been processed.

To discuss in more depth, first, Image Analysis Toolbar in ArcGIS needs to be enabled. Thereafter, under image analysis options one has to select the 'red band' and the 'near infrared band'. Then, one needs to select the option "Scientific Output" so that the value ranges from -1 to 1. Thereafter, we highlight the layer by selecting it and selecting the NDVI in properties. This creates a temporary layer in the table of contents of ArcGIS. Bright green indicates high NDVI whereas red indicates low NDVI. Thereafter, one needs to highlight the



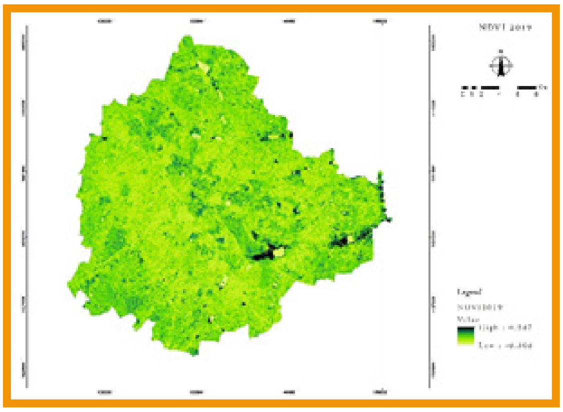
Map 1: NDWI Analysis, Bangalore - 2019



Map 2: Fishnet Analysis of NDWI, Bangalore - 2019

new NDVI layer that we want to extract or export by selecting it in the image analysis toolbar. We right click the layer, and export the raster. Map 1 below is the GIS output by this research indicting the Water index in the city of Bangalore as on November 2019. Map 2 below analyses this into 500mX500m grids and presents the concentration of the water index using regional statistics and fishnet analysis tools.

5.2 Local Vegetation Index (through NDVI) Details

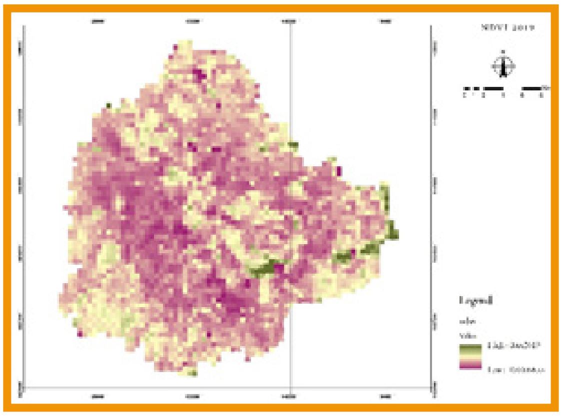


Map 3:NDVI Analysis, Bangalore - 2019

The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. The NDVI value varies from -1 to 1. Higher the value of NDVI reflects high Near Infrared (NIR), means 'dense ecologically productive greenery'. Generally, NDVI values from -1 to 0 represent water bodies, -0.1 to 0.1 represent barren rocks, sand, or snow, 0.2 to 0.5 represent shrubs and grasslands or senescing (process of aging in plants or crops) crops and 0.6 to 1.0 represent dense vegetation or tropical rainforest. It is calculated by the formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

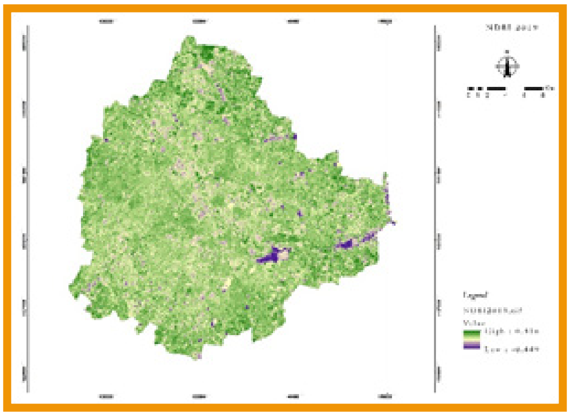
To calculate NDVI using ArcGIS Landsat 8 data from USGS website is downloaded and for Landsat 8 data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4). From the NDVI Map generated for the Study area for the year 2019 it is observed that the peripheral area and the core area havecomparatively higher NDVI value. Map 3 below is the GIS output by this research indicting the absolute value of vegetation index in the city of Bangalore as on November 2019. Map 4 below synthesizes this into 500mX500m grids and presents the concentration of the vegetation index using regional statistics and fishnet analysis.



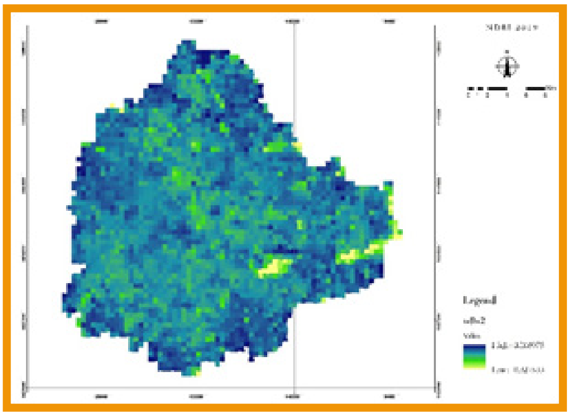
Map 4: Fishnet Analysis of NDVI, Bangalore - 2019

5.3 Local Built Index (through NDBI) Details

It is used to extract built-up features from satellite imagery. NDBI value lies between -1 to +1. Negative value of NDBI represent water bodies whereas higher value represents build-up areas. NDBI value for vegetation is low.



Map 5: NDBI Analysis, Bangalore - 2019



Map 6: Fishnet Analysis of NDBI, Bangalore - 2019

It is calculated by the formula:

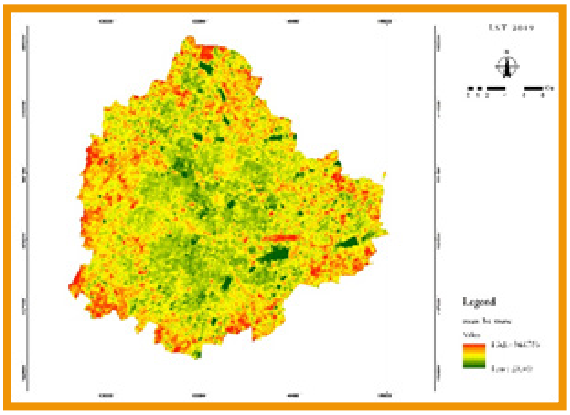
$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

To calculate NDBI using ArcGIS Landsat 8 data from USGS website is downloaded and for Landsat 8 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5). From the NDBI Map generated for the Study area for the year 2019 it is observed that the built up concentrations are more towards the periphery of the study area having higher NDBI values. Map 1 below is the GIS output by this research indicting the absolute value of built up index in the city of Bangalore as on November 2019. Map 2 below synthesises this into 500mX500m grids and presents the concentration of the built mass index using regional statistics and fishnet analysis tools.

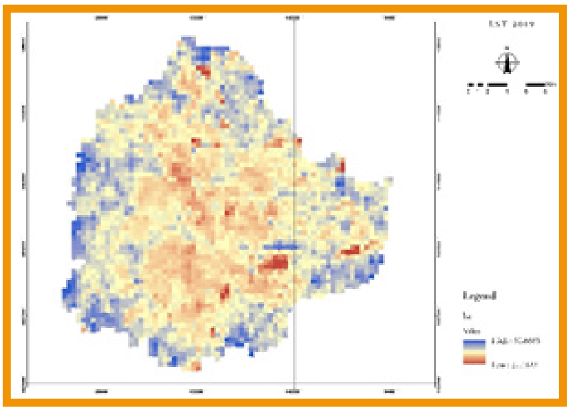
5.4 Land Surface Temperature (LST) Details

LST (land surface temperature) is used to determine the temperature distribution at the global, regional and local scale. At the same time, it is used in climate and acclimate change models in particular. LST, calculated from remote sensing data is used in a lot of sphere of science, like: agriculture, climate change, hydrology, forestry, urban planning, oceanography etc. Obtaining surface temperatures and using them in different analysis is important to determine the problem associated with the environment.

To calculate LST using ArcGIS the study downloaded Landsat 8 thermal bands from USGS website. First, the study calculated TOA



Map 7: LST Analysis, Bangalore 2019



Map 8: Fishnet Analysis of LST, Bangalore - 2019

(Top of Atmospheric) spectral radiance by the formula :

$$TOA\ (L) = ML * Qcal + AL$$

TOA values are then converted to Brightness Temperature. Then the 'proportion of vegetation' or 'Pv' is calculated from the NDVI values by the formula:

$$Pv = Square\ ((NDVI - NDVImin) / (NDVImax - NDVImin))$$

After proportion of vegetation, the study calculated the Emissivity(ε) by the formula:

$$\varepsilon = 0.004 * \mathbf{Pv} + \mathbf{0.986}$$

Finally the study calculated the Land Surface Temperature (LST) for band 10 by the formula:

$$LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(\varepsilon)))$$

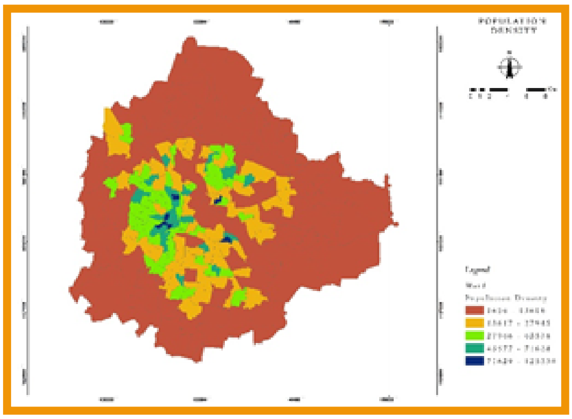
Similarly, one has to find LST for Band 11 and the mean values of both the bands gives the required LST value for the region. From the LST map generated for the study area for the year 2019, it is observed that the center of the area is having comparatively lower LST value than the periphery of the area. Map 7 below is the GIS output by this research indicting the absolute value of local surface temperature in the city of Bangalore as on November 2019. Map 8 below synthesizes this into 500mX500m grids and presents the concentration of the local surface temperature using regional statistics and fishnet analysis tools.

5.5 Population Density Details

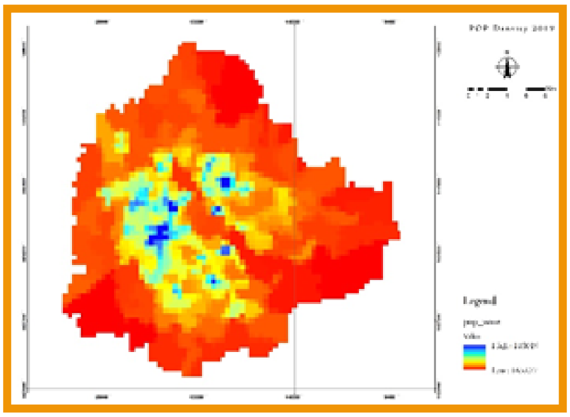
Population density allows for broad comparison of settlement intensity across geographic areas. It is defined as the number of people per unit area of land. This parameter is taken into consideration as part of anthropogenic heat which is released to the atmosphere as a result of human activities. It is calculated by the formula:

Population Density = Number of People/Land Area

Map 9 below is the GIS output by this research indicting the absolute value of Population Density in the city of Bangalore as on November 2019. Map 10 below synthesises this into 500mX500m grids and presents the concentration of the Population Density using regional statistics and fishnet analysis tools.

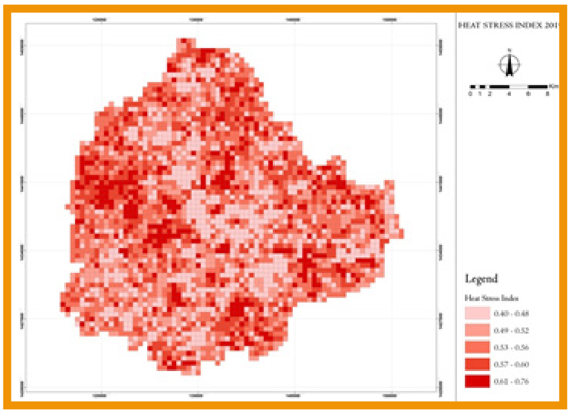


Map 9: Population Density – Bangalore 2019



Map 10: Fishnet Analysis of Population Density – Bangalore 2019

5.6 Heat Stress Zones



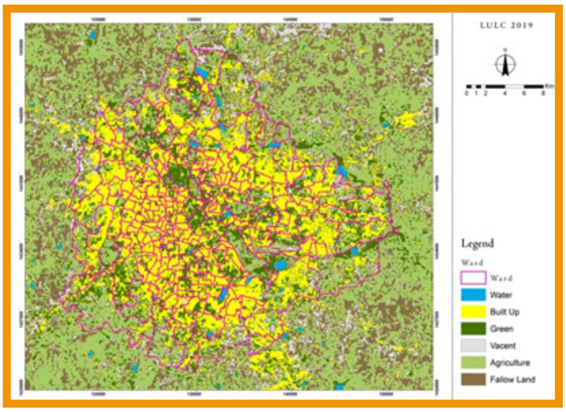
Map 11: Heat Stress Index – Bangalore 2019

A total of 3023 grids, each of 500m X 500m size were computed on a GIS platform to get the overall picture of the Bangalore city. Each grid had data related to the above five urban elements totaling to an amalgamation of 3023 X 5 = 15,115 data sets for the city. The above five fishnet analysis grid maps were aggregated using composite functional index method to arrive at the heat stress zones of the city. Each parameter as discussed before was assigned equal weightage and then scored on a logic of urban heat propensity. The scores were then aggregated for each grid. It may be noted that weights may be assigned by a practitioner using Delphi method or AHP if required.

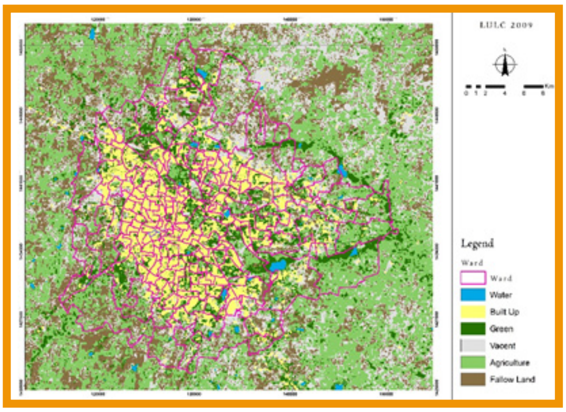
The heat stress index map (refer Map 11) needs to be understood at the grid level or local level. Each grid in Map 11 above indicates a part of Bangalore of 500mX500m which shows a certain level of heat risk and stress which is a score evolved out of composite indexing method on GIS platform using 5 data sources from live and latest satellite images and census. It is imperative to understand that depending on availability of more localized data and time, several more local indictors can be added to form more accurate and informed heat stress zones. The idea here is to project a framework of analysis that can help rationalize the planning process and make it sensitive to heat conditions. It is also imperative to understand that the above heat stress needs to be examined together with the present land use of the city to arrive at an understanding of the relation between land use and heat stress.

6 Linkages between Heat Stress and Landuse

At this juncture it is important to understand and visualize the landuse context of the city of Bangalore. The Map 12 below indicates the landuse distribution of Bangalore city as on 2019 as derived from Bangalore Metropolitan Development Authority and spatially juxtaposed



Map 12: Land Use – Bangalore 2019



Map 13: Land Use – Bangalore 2009

with data derived from Bhuvan, which is an Indian satellite providing land use data.

The Map 13 indicates the landuse distribution of Bangalore city as on 2009. It is evident that the Bangalore city is now losing its green patches steadily. In 2019, the percentage of lakes is approximately 1.5-2%, which is much lower than 4.1% in 2009. Many of these urban blue patches have now been converted to housing colonies or infrastructures as a result of rapid urbanization, such as bus stands, stadiums and playgrounds, etc. (Sudha and Ravindranath 2000). The built up mass has grown from 64% to 78%. Urban green has declined to 7% compared to 16% in 2009. Most of the agricultural and fallow land of 2009 are now built up mass.

7 Empirical Relations between Heat Stress and its Causative Factors

This section shall delve into bringing out the latent and significant interrelations which can be observed from the analysis of the 15,115 data sets derived from the 3023 grids of 500m X 500m in terms of which factors out of the 4 elements studied in this paper has the most influence on heat stress and hence, how on addressing those factors heat stress can be reduced with planning interventions.

7.1 Relation between Built Mass and Heat Stress Zones

Statistical correlation between Built Mass and Heat Stress Zones indicate a strong direct and positive relation. The relation can be modelled with the linear trendline equation of :

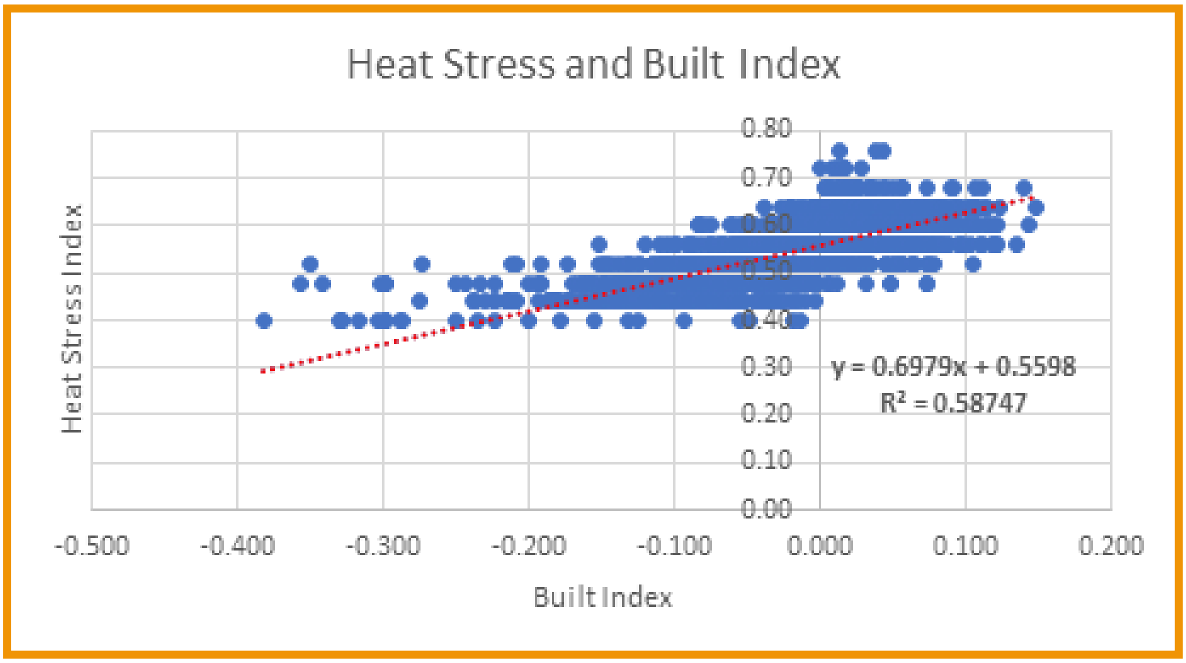


Fig 1: Spatial Correlation between Built Index and Heat Stress – Bangalore 2019

y = 0.6979x + 0.5598, with $R^2 = 0.58747$

R2 value being above 0. 5 indicates strong correlation between the two variables. This points to the need to plan the built form of the city in such a manner that it does not enhance heat stress beyond a particular extent. This can be done by identifying the grids where the relation is strongest, i.e., the girds represented by the dots which are above the trendline suggesting higher heat stress for a particular built mass in comparison to the trendline. It indicates the need to evoke development control norms in those areas by controlling the FAR or imposing building height restrictions or reducing the ground coverage norms in the plots so as to not allow further densification of built mass. Also, the top 25 grids in terms of heat stress and which are above the trendline can be earmarked have strict enforcement by cross checking upon unauthorized construction of floors or extension of ground coverage beyond limits and taking rectification measures. This is because such areas have statistical and spatial relation between built activity and heat stress.

7.2 Relation between Water Index and Heat Stress Zones

Statistical correlation between Water Bodies and Heat Stress Zones indicate a weak, indirect direct and negative relation. The relation can be modelled with the linear trendline equation of:

y = -4.4035x + 0.5552, with $R^2 = 0.3898$

R2 value being below 0. 5 indicates weak negative correlation between the two variables.

This highlights a need to understand the inverse relation between water and heat. The absence of water in the city is linked with accumulated heat stress. The more the presence of water bodies, the lesser the heat stress zones. This is understood by the negative slope. The planning implication is that in areas having more water index and less heat stress, measures have to be taken to preserve the water boundaries and the water quality.

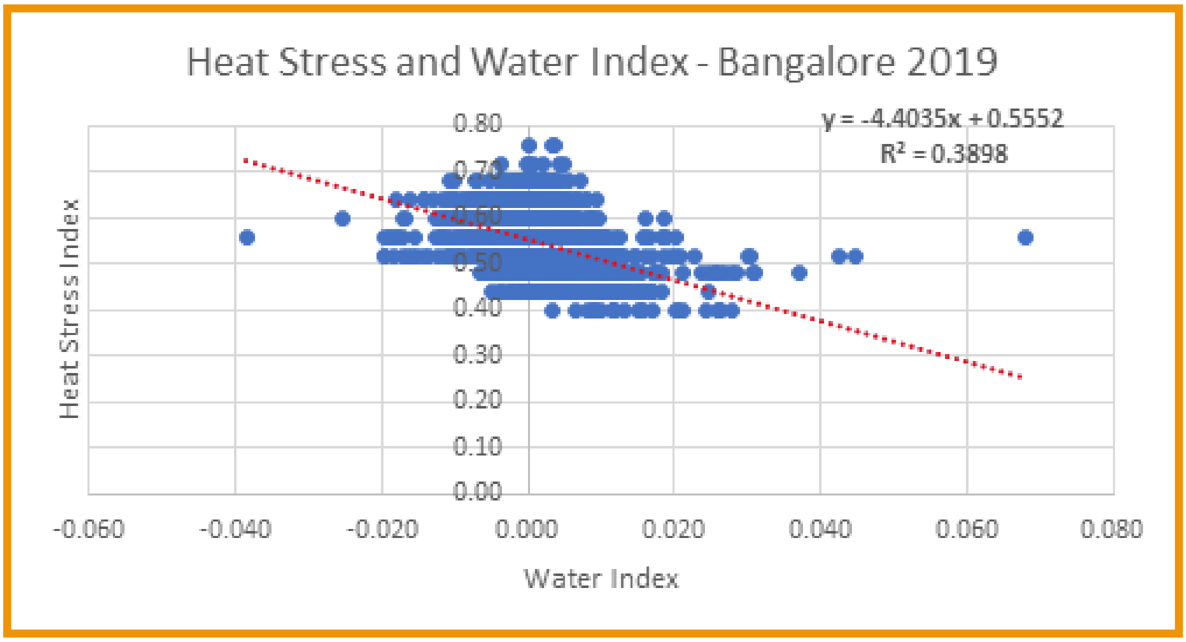


Fig 2: Spatial Correlation between Water Index and Heat Stress – Bangalore 2019

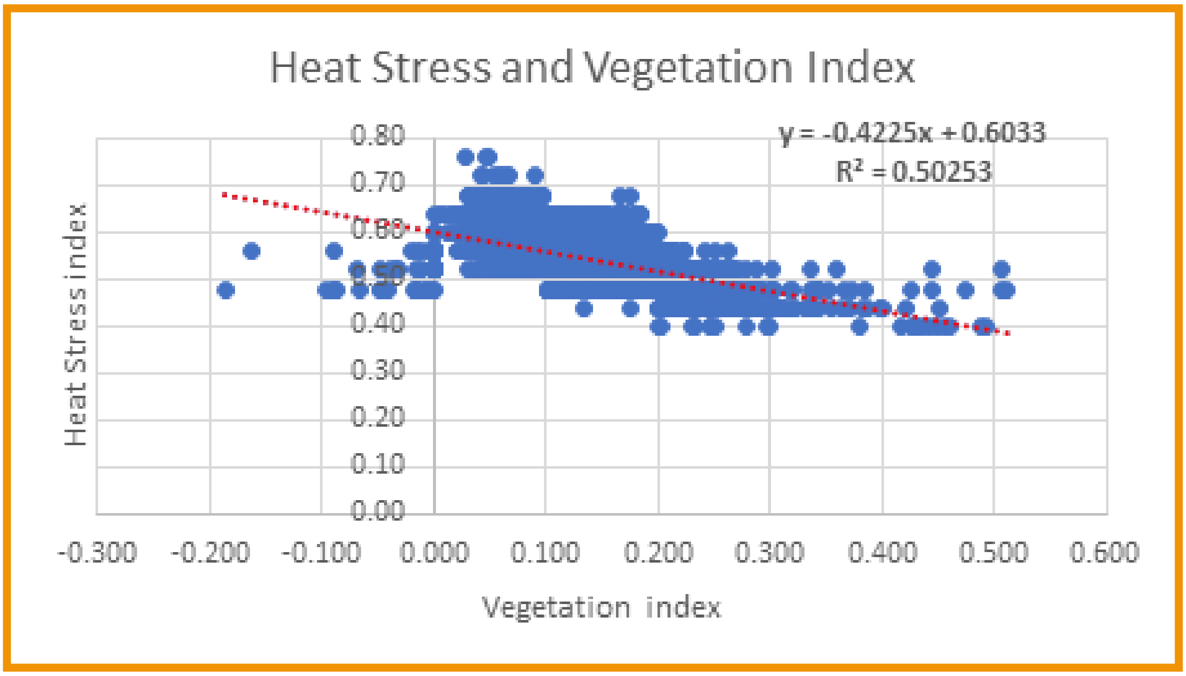


Fig 3: Spatial Correlation between Vegetation Index and Heat Stress – Bangalore 2019

7.3 Relation between Vegetation Index and Heat Stress Zones

Correlation between Vegetation and Heat Stress Zones also indicate an indirect and negative relation. However, the correlation is strong compared to water index. The relation can be modelled with the linear trendline equation of:

$y = -0.4225x + 0.6033$
$R^2 = 0.50253$

This graph indicates that there is a strong relation between vegetation index and heat zones. The absence of green areas in the city is linked with accumulation heat stress. The more the presence of green surfaces, the lesser the heat stress zones. This is understood by the negative slope. The planning implication is that in areas having more vegetation index and less heat stress, measures are to be taken to preserve the green spaces and the quality of vegetation.

7.4 Relation between Population Density and Heat Stress Zones

Correlation between Population Density and Heat Stress Zones indicates a direct and positive relation. Even though the correlation is appropriate, the equation is having a mild slope indicating a mild relation. The relation can be modelled with the linear trendline equation of:

$y = 1E\text{-}06x + 0.5345$
$R^2 = 0.48049$

This graph corroborates that there exists a relation between areas having high concentration of population and formation of heat zones. Generation of heat due to anthropogenic origins is an area of limited research but is appropriately established. Concentration of population density in cities can be linked with the planned population densities envisaged in different city zones and implemented through housing typologies permitted. Planned high

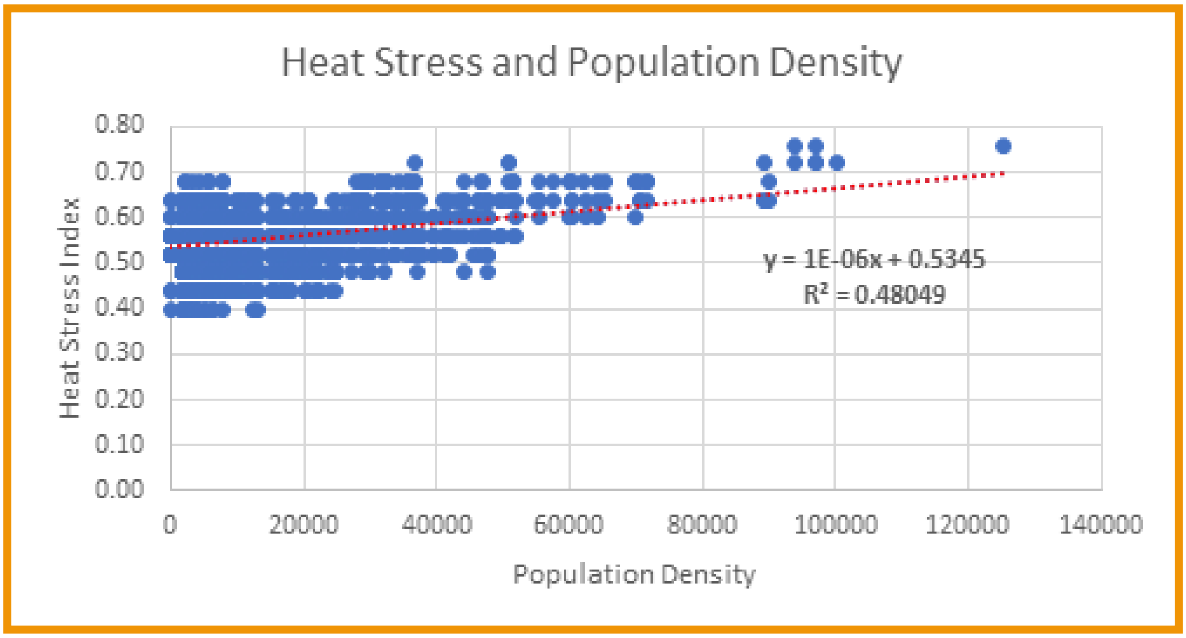


Fig 3: Spatial Correlation between Vegetation Index and Heat Stress – Bangalore 2019

population density zones are generally allowed higher FARs and height relaxations with group housing. Similarly, lower population densities are generally the plotted individual housing areas with sprawling open spaces. This gives us the direction to envisage future density patterns in tune with the heat stress zones.A

8 Inferential Discussions- Planning Implications

Several planning implications can be derived when we try to amalgamate the factors of built mass, population density, water, vegetation and actual local surface temperature with the way we see present land use pattern or plan future land use. While we often assume that heat stress is a climatic phenomenon and can only be addressed at the individual level by staying indoors, drinking more water and air conditioning, if there is affordability. However, it can be much beyond that.

Urban planners play a key role in this context, as they are mandated to define through master plans and development plans of the city, the future volume of built mass, the urban functions which the built mass shall have, the location and spate of the urban water and green areas (Imam, 2016). This influences the concentration of people that shall be residing in different zones based on available or planned infrastructure. Since there are identified spatial correlations existing at the sub-city level, as depicted in the previous sections, between heat stress and physical parameters like water, vegetation, buildings, people, there can be clear planning implications. The consequences of ignoring these combined factors can adversely impact ecosystems, land use and governance. These in turn will result in deterioration of biodiversity and soil quality, aggravation of urban heat island effects, increased pollution, flooding, water scarcity and epidemics, and consequent impacts on human health and well-being (Sudhira 2013).

Three prime planning implications are discussed below which have potential of replicability and applicability in other cities, based on the study discussed here.

A) **The Need to have Climatic Data Infrastructure as a Tenet of Planning:** Urban planning exercises of city development authorities are mostly initiated on detailed physical surveys and database creation. These are related to demand and need for different land uses, traffic movements and travel behavior, need and gap for physical infrastructure and social amenities, and social surveys that capture people's vision. There is a need to build and develop climatic data in different digital and spatial layers on aspects of temperature, water, green cover, humidity, and air quality that need to be analysed and made a part of the plan formulation process. The study framework discussed in this report suggests a simple overlay based analysis that can be replicated to arrive at heat stress zones in any city in order to decide future land use functions. Various other factors can be added to the analytical framework, like sky view factor, paved-unpaved ration, road density, plot factor, FSI, and ground coverage.

B) **Heat Stress Oriented Planned Green and Blue Index for the Future:** In urban planning, location and quantum of urban green in the form of parks and playgrounds are often based on planning standards and evolve based on anthropogenic recreational requirements. While per capita green space allocated to different parts of the city based on demography is a rational approach, there could be alternative approaches whereby heat stress zones can have different green space standards. Also, available green spaces in a city can be conserved in the heat stress zones with a spatial logic rather than the conventional approach of conservation based on ecological significance of trees. Urban water bodies could also be conserved or expanded in relation to the heat zones. Since there lies negative correlation, it can help reduce heat stress and thereby increase resilience.

C) **Heat Resilient Density Gradients for Future:** Urban planners often project population at the ward level and decide future population densities for each ward looking at the prospect of maximising population holding capacity. Higher population densities are preferred as they make the city compact and reduce sprawl. Also, there is higher municipal tax returns. However, looking at the clear direct correlation between built up mass and heat, as well as between population density and heat, it is pragmatic to include the present context of heat stress zones before we plan the future density patterns of a city. If the heat stress is beyond a particular threshold at present, that zone should have density restrictions for built mass as well as population. In other words, there could be more focus on open spaces, greenery and water bodies rather than further accelerating building activities.

Planning implications from the above findings could be ample. For example, the grids having maximum heat stress can be identified and specific planning guidelines that can reduce heat accumulation as per the relational equations derived in this study can be attempted at. In the context of India it is argued hereby that planners need a better understanding of the relationship between the UHI and land-use patterns in order to reduce the UHI and promote more sustainable urban development (Kim, 2014). While there can be many planning consequences that can be drawn when we make heat as a focal point for deciding future designs of a city, there are very few real-life examples of urban planning wherein climatic conditions like heat stress have been considered to develop city plans.

This study portrays a simple and replicable framework, which is assumed to be a small step towards making planning processes more climate resilient in the context of heat.

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