Co-funded by the Erasmus+ Programme of the European Union

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Assessing the Role of Landuse Landcover Transition in Mitigating Heat Risk

A Study on Urban Area of Dhaka North City Corporation

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Background

"Any hard-won victories over climate change on a global scale could be wiped out by the effects of uncontrolled urban heat islands" (Dutch Economist Richard Toll)

The **urban population of Bangladesh** has increased by nearly **10 times** since independence, **1/3** of which has taken place in **Dhaka city** (The Daily Sun, 2018)

The city has witnessed **a rise in temperature** of around **3 °C** in the last 20 years (The Daily Star, 2022)

The increase in annual daytime temperature in Dhaka over the last 20 years is 2.74 °C (Dewan et. al., 2021)

Green space and water bodies have been diminishing in expense of built-up areas in every decade at **a rate of 40%** since 1978 (Moniruzzaman et. al., 2021).

It is **predicted** that there will be a **13% (summer) & 20% (winter)** increase in **LST by 2030** across Dhaka Metropolitan area (Faisal et al., 2021)

Aim

*"The aim of this research is to find the **pattern** of urban growth **factors** contributing in **increase** of **SUHI** and how the **factors** can **be utilized** to **reduce** the **Heat risk**"*

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Objectives

- To identify LULC transition pattern causes highest level of surface temperature increase
- To find relative contribution of socio-economic and physical factors influencing Surface Heat intensity
- To predict location of susceptible land transformation causes rapid surface heat increase.

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Key Findings in Literature

- To achieve heat sensitive urban development, **Landuse zoning** and **Decentralization** is a key tool of **Mitigation** (Pal & Ziaul, 2017).

- **LULC** is considered as a **major driver** for **LST change**, and hence the **interrelation** between them has been a key area of **UHI research** (Suriana et. al., 2000; Ke et. al., 2014; Tran et al., 2017).

- Although **Physical factors** have dynamic **effect** on **UHI pattern** (Xiong et al., 2012), however, **Socio-economic factors** explain approximately 10 % to 20 % of the variances of UHI effect (Ying et. al., 2020).

- A high degree of **agreement** is established between **satellite retrieved** and **ground based** LST observations (Rigo et. al., 2006; Sharma & Joshi, 2014; Yuan and Bauer, 2006; Mallick et. al., 2013).

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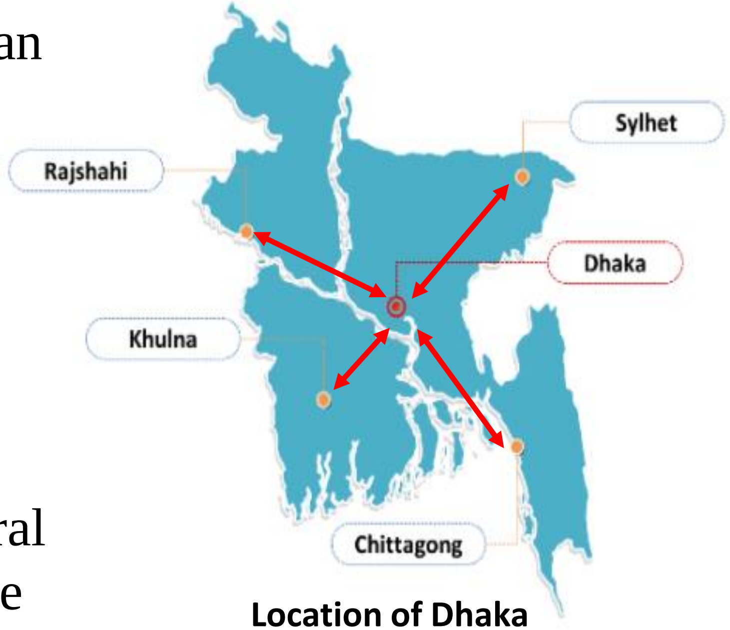
Study Area

- Dhaka is a historical **capital city** of Bangladesh with **Primacy status**

- **9th largest** Metropolitan cities in the world (UN World Cities Report, 2018)

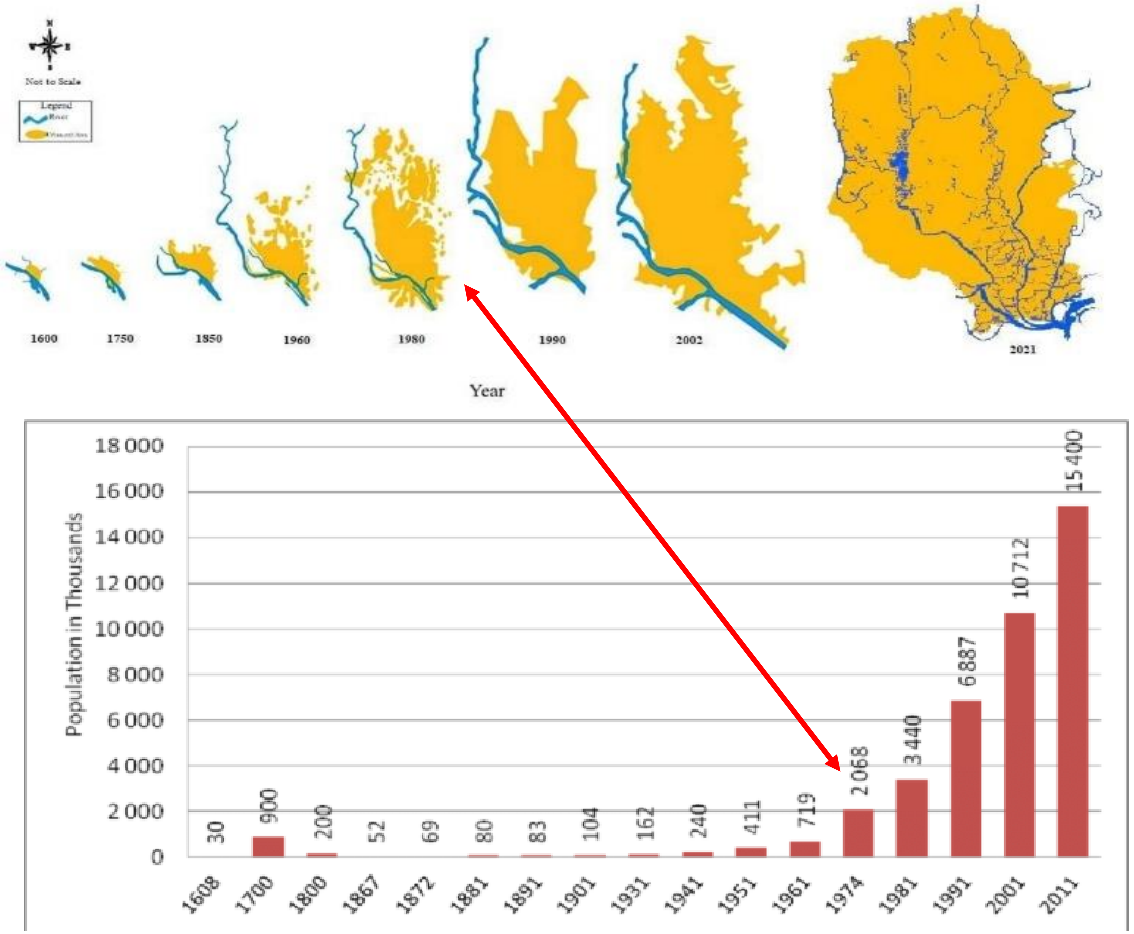
- Contributing **40%** of country’s total GDP

- Economic, Administrative, Cultural & Transport **hub** of the country



Location of Dhaka

Historical Growth of Dhaka City



Population Growth in Dhaka Megacity (1608-2011). Source: BBS 1977; 1984; 1991; 1997; 2003; Taylor 1840; D'oyly 1824; Siddiqui 2000.

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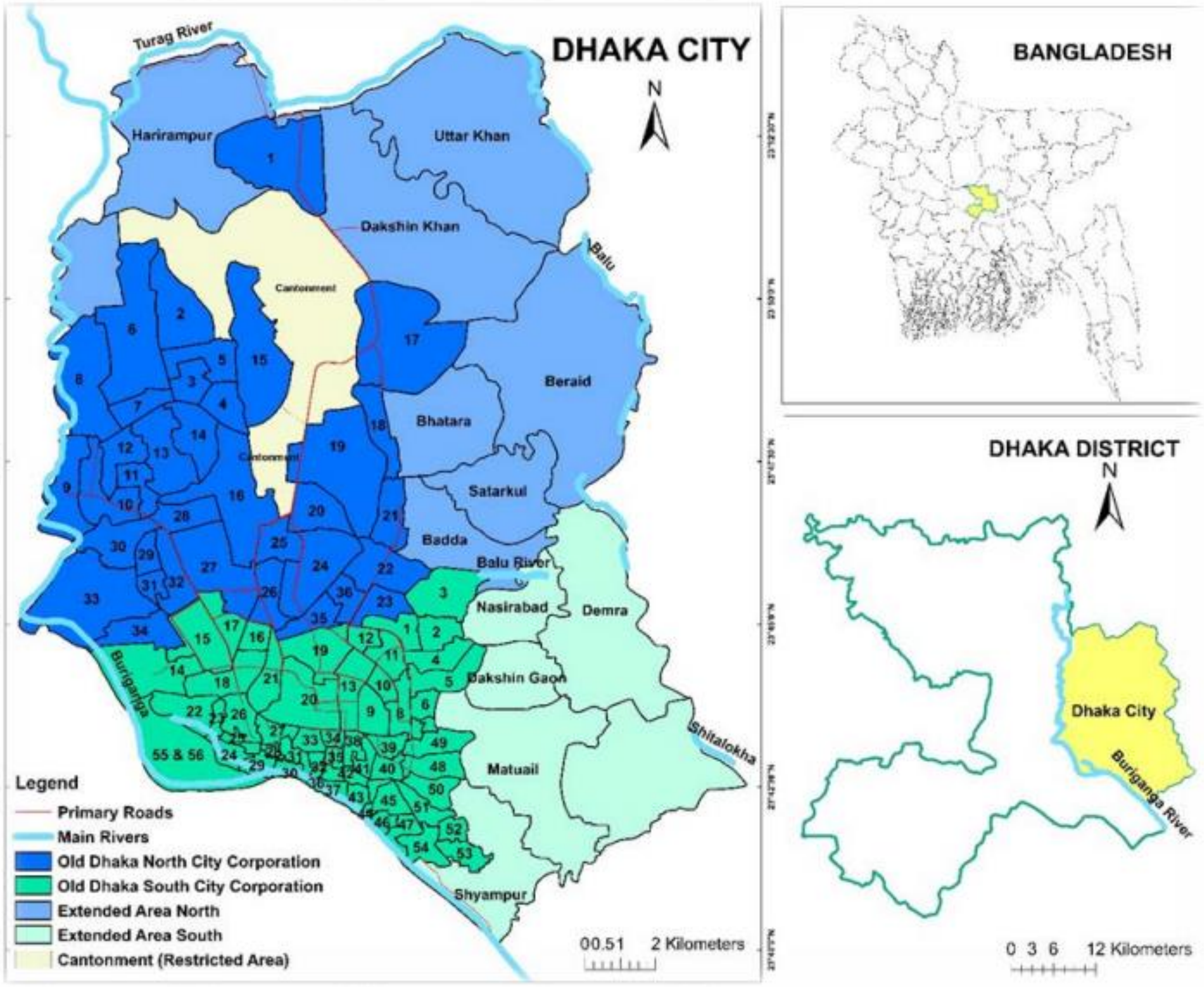
Study Area

In 2011, The **Dhaka City is divided** into two administrative area such as Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC)

DNCC was extended in 2016 and new non-urban areas have been included

This study is based on **urban areas** (blue) **of DNCC**



(SHLC, 2018)

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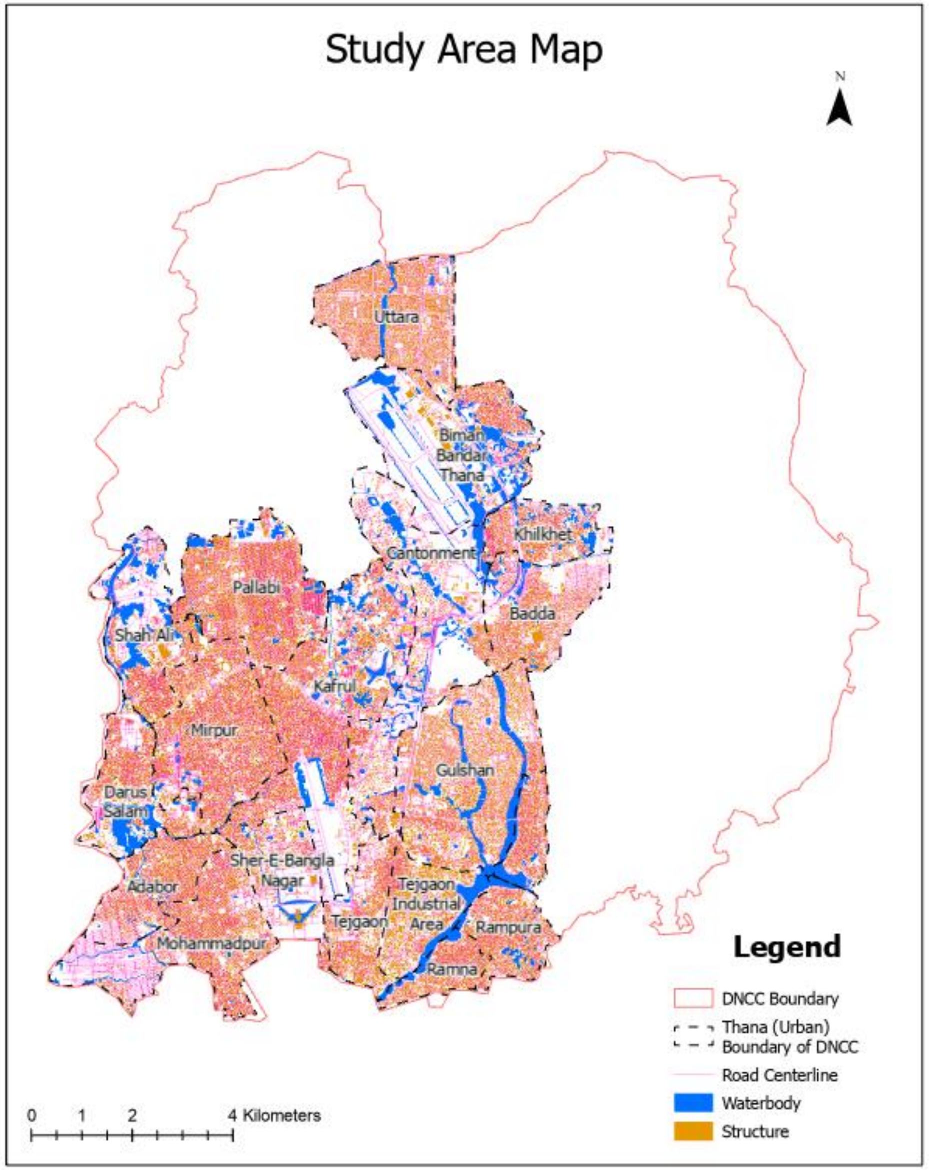
Study Area

Urban area DNCC comprises of 18 Thanas including a total of 36 wards

SL	Thana	Population Density (sq km)
1	Adabor	63747
2	Badda	15640
3	Biman Bandar Thana	687
4	Cantonment	13954
5	Darus Salam	48371
6	Gulshan	29187
7	Kafrul	53036
8	Khilkhet	16245
9	Mirpur	77940
10	Mohammadpur	43237
11	Pallabi	59863
12	Ramna	54911
13	Rampura	83925
14	Shah Ali	29997
15	Sher-E-Bangla Nagar	30915
16	Tejgaon	58368
17	Tejgaon Industrial Area	30761
18	Uttara	20101

(BBS, 2011)



(RAJUK, 2021)

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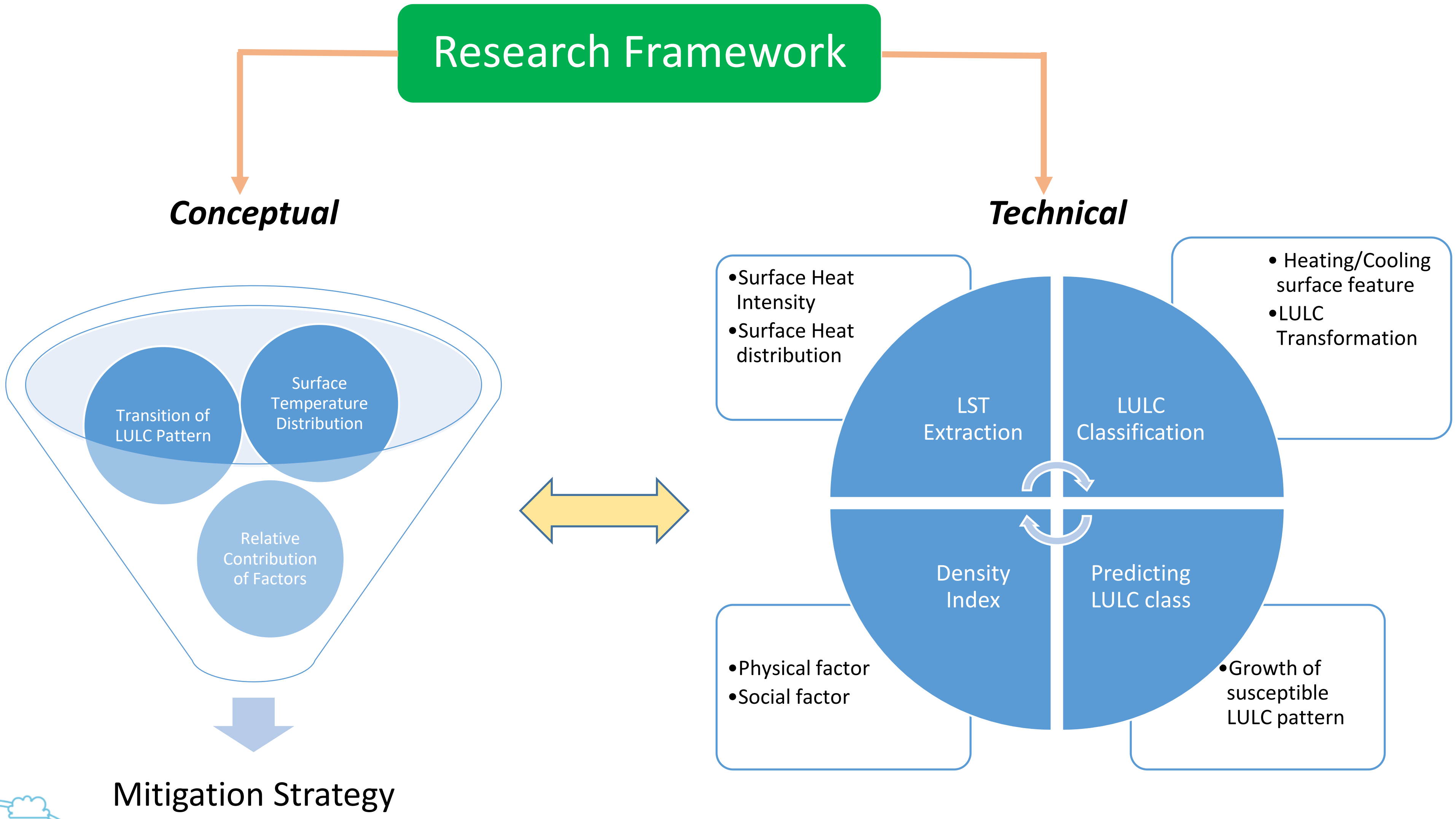
Methodology



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Methodology

Sources of Data

Theme	Data	Source
Climatic	Land Surface Temperature (LST)	Landsat 5 TM (2001, 2011) and Landsat 8 OLI (2021) of USGS
Landuse Landcover (LULC)	Built-up, Waterbody, Vegetation & Bare land class	Landsat 5 TM (2001, 2011) and Landsat 8 OLI (2021) of USGS
Physical	GIS shapefile of Building, Waterbody and Road	RAJUK (Capital Development Authority)
	Vegetation Indice (NDVI)	Landsat 8 OLI (2021) of USGS
Socio-economic	Population, Decadal Growth Rate, Building Material, Electricity consumption	Bangladesh Bureau of Statistics, 2001 & 2011
	Location of Services & Facility	RAJUK (Capital Development Authority)
Topography	Digital Elevation Model (DEM)	RAJUK (Capital Development Authority)

Methodology

Method

Land Surface Temperature (LST)

Below equation is used to determine LST for all the three-year study

(Weng, Lu, & Schubring, 2004)

$$\text{LST} = \frac{T_i}{1 + \left(\lambda \times \frac{T_i}{\rho}\right) \times \ln(\varepsilon)}$$

Ti = sensor’s brightness temperature,

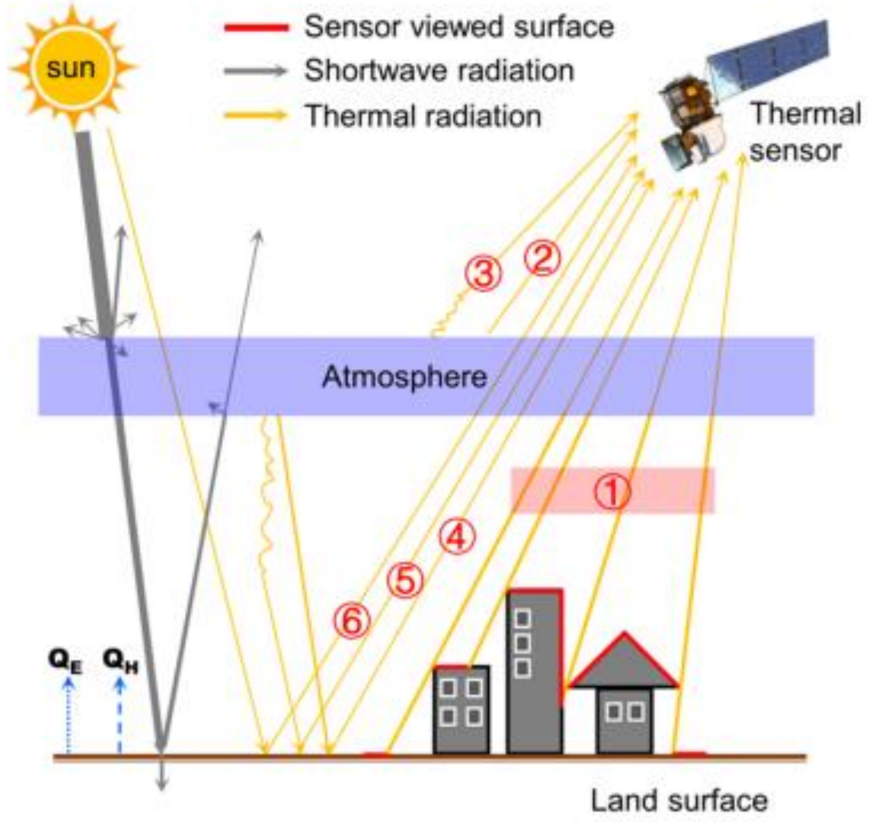
λ = emitted radiance’s wavelength,

Ɛ = spectral emissivity of the land surface,

ρ= $hc\,/\,\sigma$= 1.438 ×10 − 2 mk, where h and c indicates Plank’s constant and velocity of light respectively. σ is the Boltzmann constant.

To reduce the effect of seasonality and temporal variation, LST has been normalized and represented as an annual Normalized LST (NLST)
(Rasul et. al., 2011)

$$\text{LST}_{\text{NRS}} = \frac{(\text{LST})}{\sqrt{\sum(\text{LST})^2}}$$



(Zhou et. al., 2019)

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Methodology

Method

LULC Classification 2001-2011-2021

- Landcover classification follows **Anderson level I** classification system dividing the city into **four LULC classes** (Anderson et. al., 1976)
- **Unsupervised Classification** has been conducted using ISODATA clustering method (ERDAS Imagine Software)
- Classified based on shape, size, texture, tone and pattern of group of pixels

SL	LULC class	Description
1	Built-up area	All types of manmade structures: residential, industrial, commercial and services; transportation and utilities; mixed urban or built-up
2	Waterbody	River, permanent open water, lakes, ponds and reservoirs; Permanent and seasonal wetlands, marshy land, rills and gully, swamps
3	Vegetation	Deciduous forest, mixed forest lands, palms, conifer, scrub and others Crop fields, fallow lands and vegetable lands
4	Bare land	Exposed soils, sand fill, landfill sites, and areas of active excavation

(Mamun et. al., 2013)

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Methodology

Method

LULC Projection for 2031 & 2041

- To produce predicted map of LULC for the year of 2031 and 2041, Cellular Automata – Markov (**CA-Markov**) model has been used
- LULC maps of previous years such as 2001 and 2011 have been used as **source data** (GIS) for the model
- Using the **input parameters**, the predicted LULC map has been generated for the year of 2031 and 2041.

SL	Parameter	Description	Justification of assumption
1	Distance from new built-up area	Existing trend and location of built-up class in 2021 LULC class.	The area which is spatially closer to recently developed built-up are more potential for future built-up class.
2	Road	Existing location of major roads	There is more possibility of urban area grows which is closer to major roads
3	Surface Elevation	High and low surface of land	Urban areas tend to be developed on areas with higher surface elevation
4	Slope	Flat and uneven surface	The possibility of built-up growth higher in comparatively flat land.
5	Transition sub-model	Pattern of Transition from other(waterbody/vegetation/bare land) to built-up class	The spatial pattern of built-up growth will follow the same trend of growth as occurred in previous years unless major intervention takes place.

(Kafy et. al., 2021)

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Validation & Accuracy Assessment

Accuracy Assessment of LULC Classification

- Using **Error/Confusion Matrix,** accuracy of LULC classification has been assessed
- Above **70%** is considered as acceptable for Overall, User & Producer Accuracy
- A range between **0.40 and 0.85** is considered as acceptable for Kappa Coefficient

(Basu & Das, 2021)

$$\text{Overall accuracy} = \frac{\text{Total number of corrected classified pixels (diagonal)}}{\text{total number of reference pixels}} * 100$$

$$\text{User Accuracy} = \frac{\text{number of correctly classified pixels in each catagory (diagonal)}}{\text{total number of reference pixels in each category (row total)}} * 100$$

$$\text{Producer Accuracy} = \frac{\text{number of correctly classified pixelxs in each category (diagonal)}}{\text{total number of reference pixels in each category (column total)}} * 100$$

$$\text{Kappa Coefficient (T)} = \frac{\text{Total number of Sample*Total Number of Corrected Sample} - \sum(\text{col.tot*row tot})}{(\text{Total number of Sample})^2 - \sum(\text{col.tot*row tot})} * 100$$

Validation of LULC Projection

The projected LULC map (including four LULC class) has been validated using **Chi Square test** (Rahaman et. al., 2022; Kumar et. al., 2013)

$$X^2 = \sum (O-E)^2 / E$$

X^2 = Chi Square Value
O = Area of Classified (observed) land class
E = Area of Projected LULC class)
Level of Significance at 0.05 with Degree of Freedom of 3

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LST Validation

- The study has limitation of collecting in-situ measurement and depends on results from previous literatures regarding integrity of Landsat Satellite Thermal Sensor
- A **high degree of agreement** between the satellite retrieved surface temperature and the ground based LST observations has been established in several research (Sharma & Joshi, 2014; Yuan and Bauer, 2006; Mallick et. al., 2013)
- Although, Satellite derived long wave upward radiation of Landsat has a **bias of 1.9 Kelvin** and **RMSE of 1.2 Kelvin** (Rigo et. al., 2006)

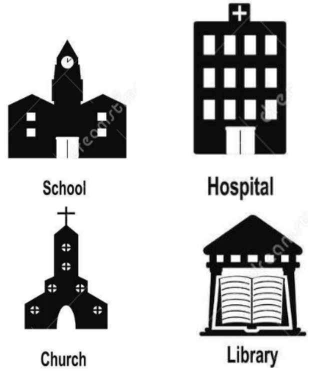
Methodology

Socio-economic Variables

Decadal Growth Rate

Population Density

Density of Community Facilities



% of Affordable Housing

Average Household (HH) Size

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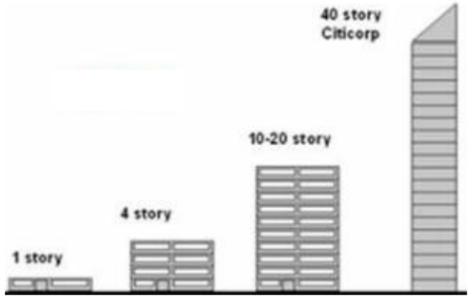
(Source: Parsaee et. al., 2019; Magli et.al, 2015; Jusuf et al., 2007; Shahmohamadi et al., 2010)

Methodology

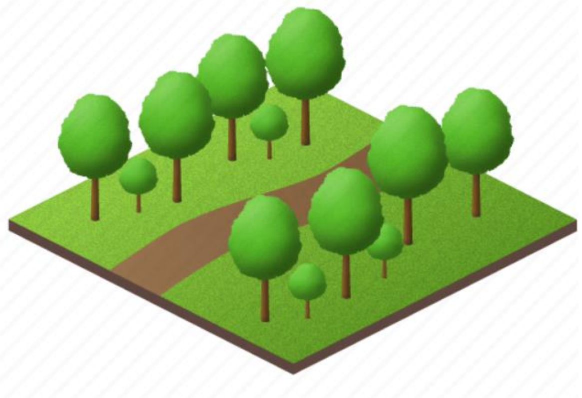
Physical Variables

Building Density

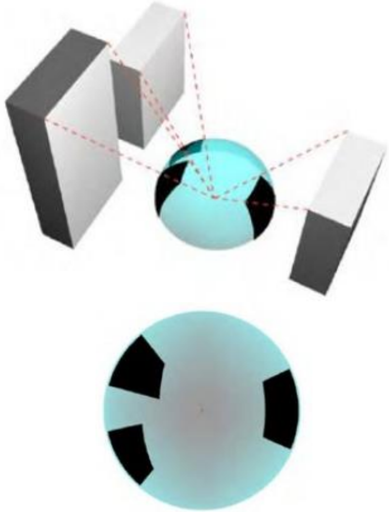


Waterbody Density

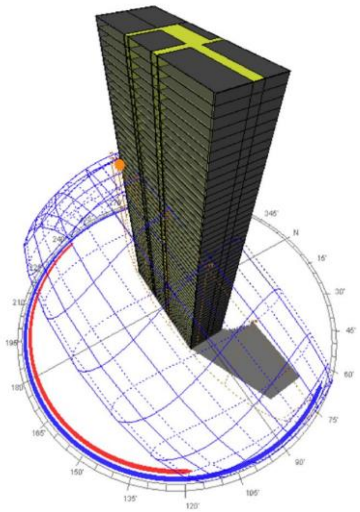
Vegetation Condition



Sky View Factor (SVF)



Building Height



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(Source: Oke, et al., 2017; Gunawardena et al., 2017; Dare, 2005)

Methodology

Method

Socio-economic & Physical Index

Socio-economic and physical index of respective Thana has been calculated using existing parameter value and weight of each variable of both factors, using below equation (Larsson, 2000)

Index of Factors, $F = \sum (W_i \times V_i)$

W_i = Weight of Variable i;

V_i = Value of Variable i

Weight has been determined by concentration ratio of correlation between mean NLST change and all the variables of socio-economic & physical factors within respective Thana.

$W_i = C_i / T_c$

(C_i = Correlation value between variable i and mean NLST change;

T_c = Total of correlation values of all variables

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Methodology

Method

Socio-economic & Physical Index

To bring all the variables into a common scale of measurement, minimum maximum standardizing method has been applied (Han et. al., 2012) ranging from 1 to 100 .

$$v_i' = \frac{v_i - min_A}{max_A - min_A}(new\_max_A - new\_min_A) + new\_min_A.$$

v’i = Transformed value,
vi = Input,
min_A = minimum value of original dataset,
max_A = maximum value of original dataset,
new_ min_A = minimum value of transformed dataset,
max_A = maximum value of transformed dataset.

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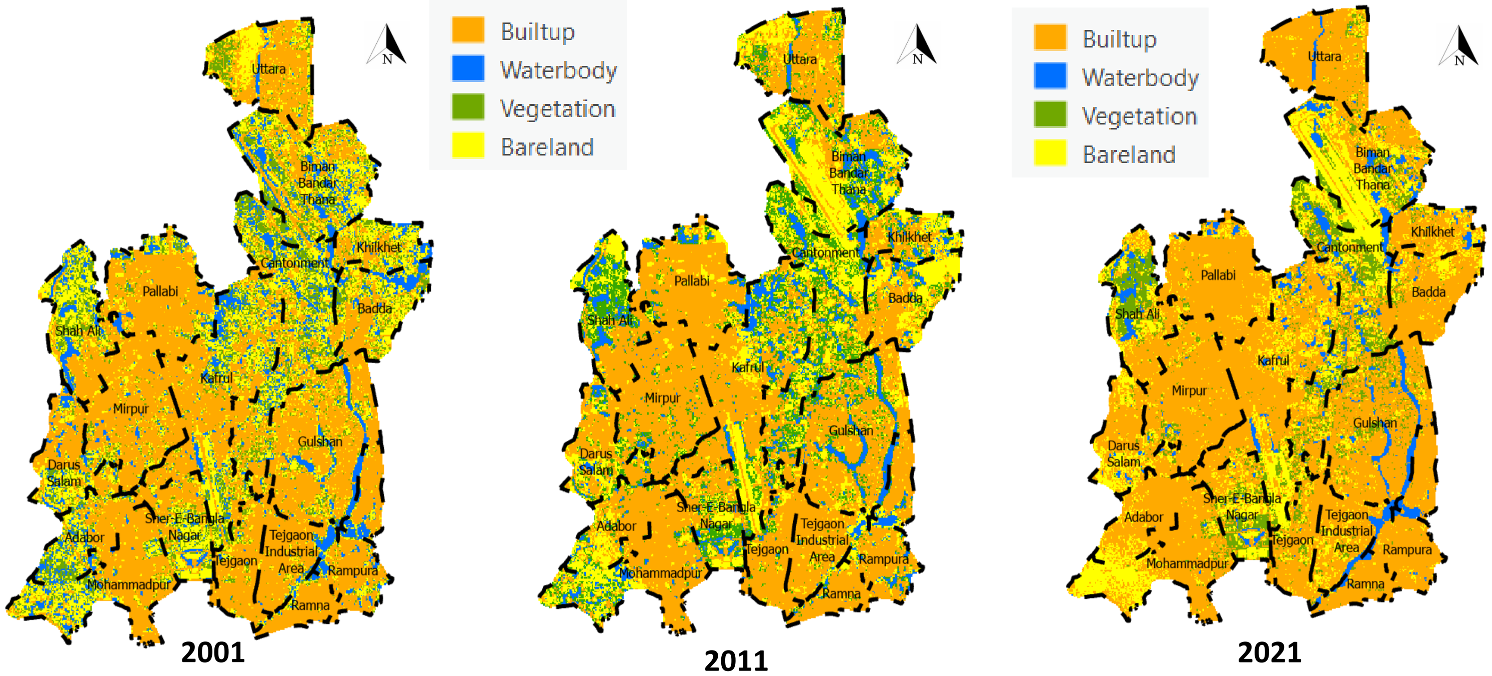
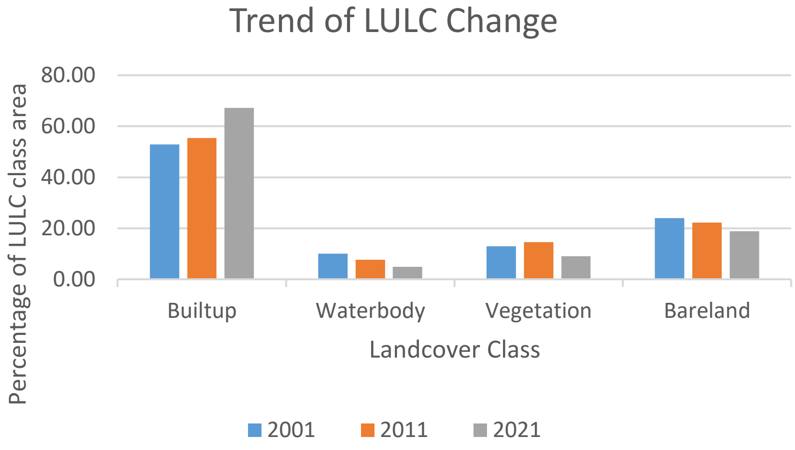
Result & Findings

LULC Transition

Spatio-temporal Transition of LULC (2001-2021)

- **Built up** class comprises of lion's share of total land with **21.13%** rate of change between 2001-2021
- **Waterbody** has **declined** more than **double** during the time period, followed by **vegetation & baren land** with a **-42.49% & -27.70%** rate of change





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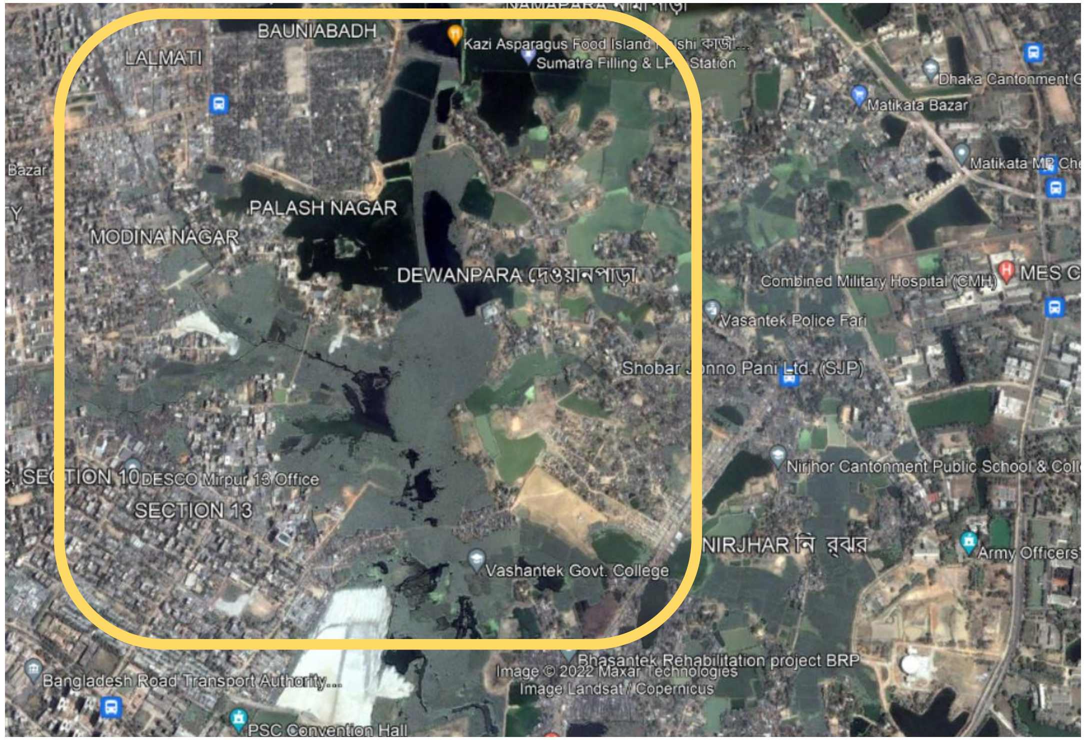
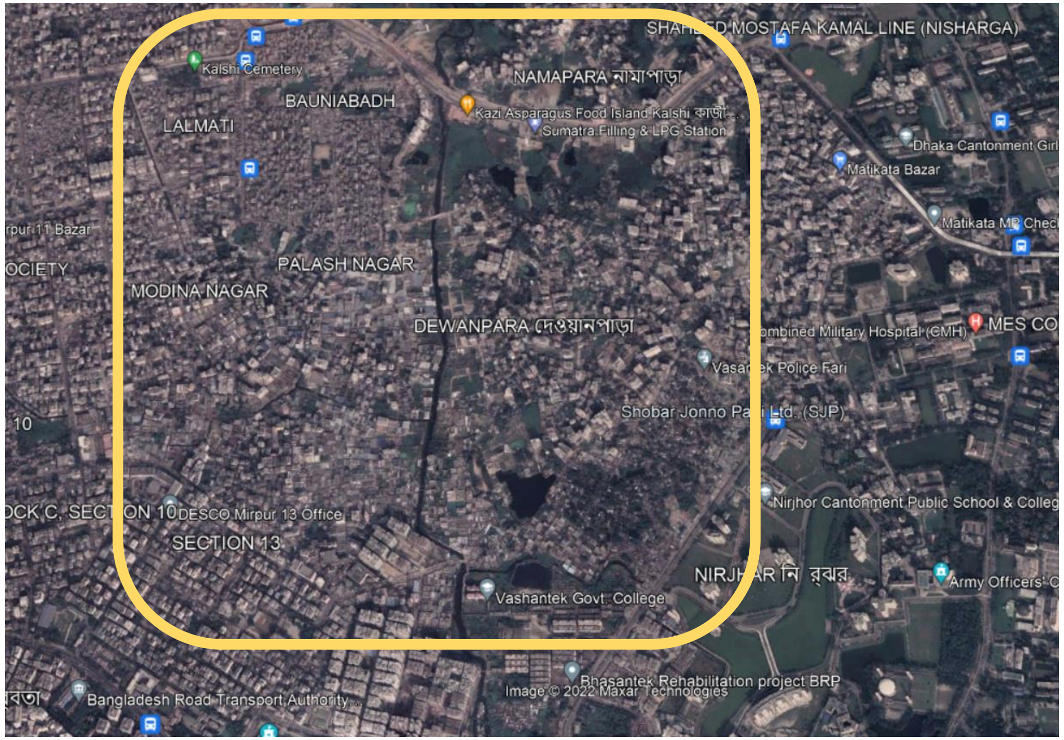
Result & Findings

LULC Transition

Waterbody replaced by built-up (2001-2021)



2001



2021

(Source: Google Earth Pro; Paul et. al., 2019; Faisal et. al., 2021; Bangla Tribune)

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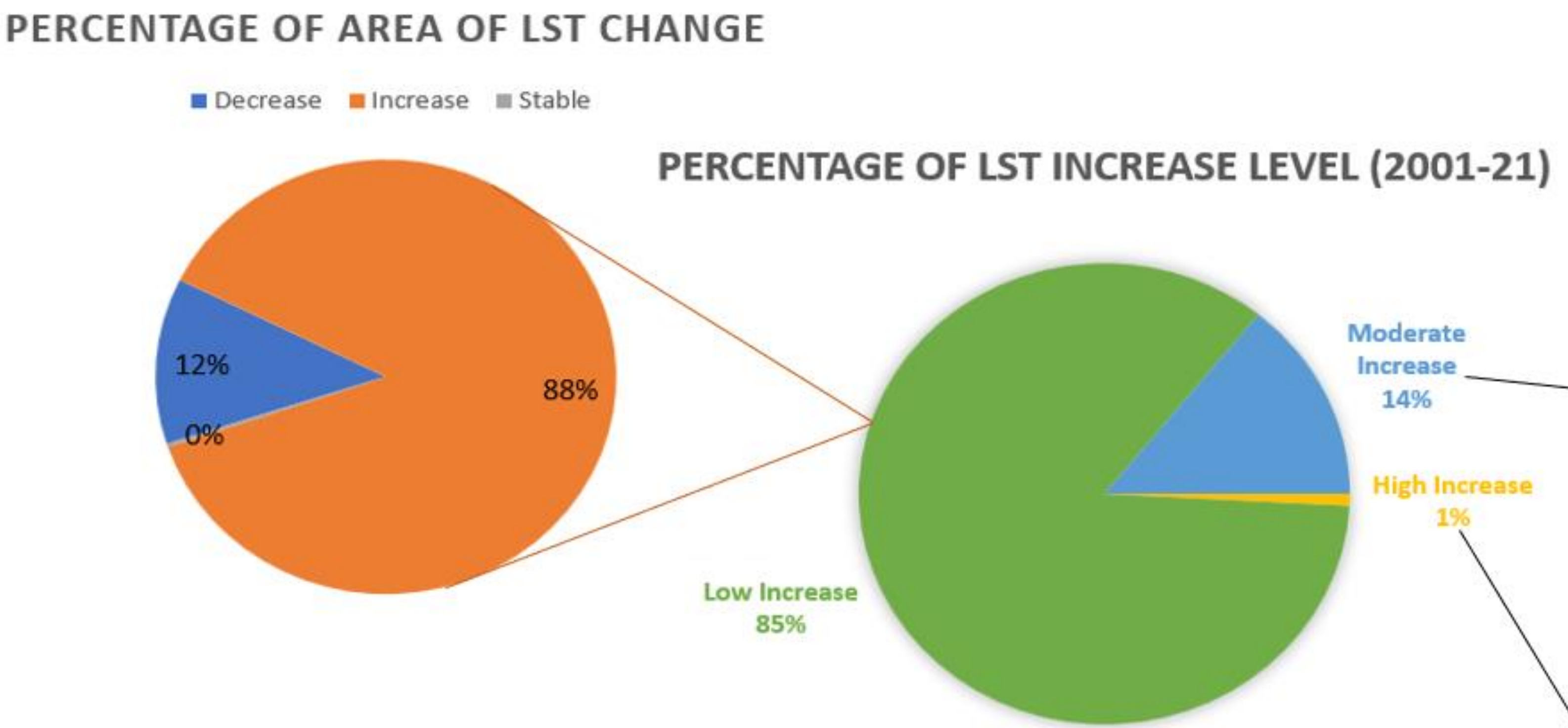
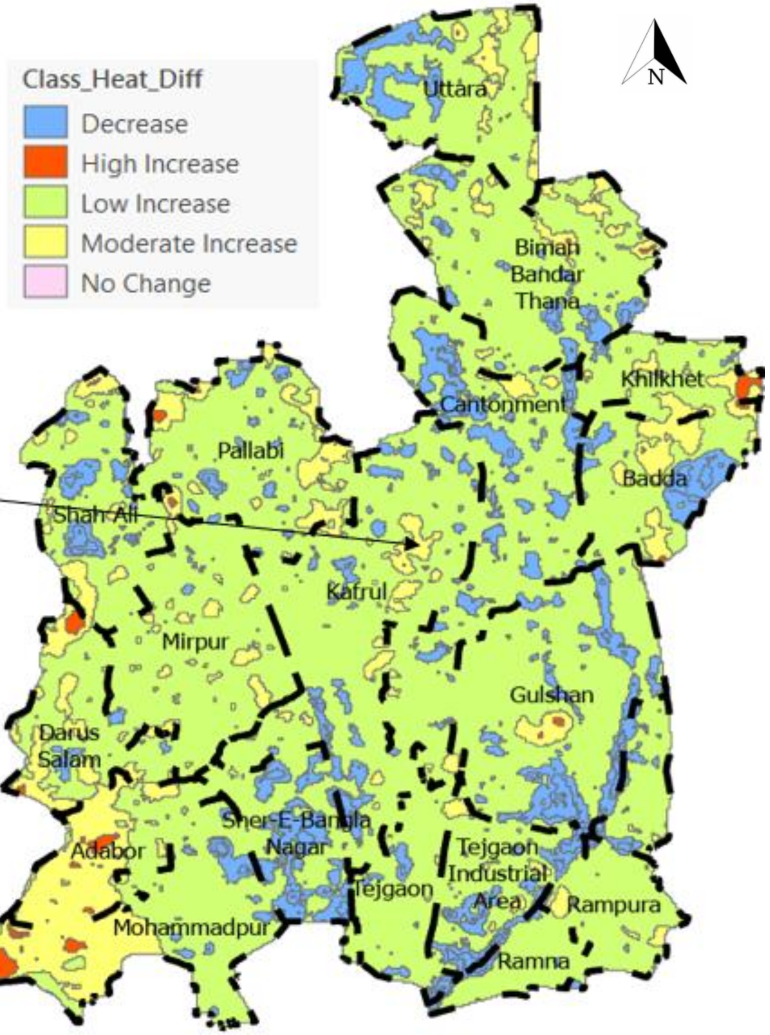
Result & Findings

Increase of Surface Temperature

Mean NLST Increase (2001-2021) and Spatial Distribution





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Result & Findings

Pattern of LULC Transition

Pattern of LULC Transition in High-moderate Heat Increase Zone

- Areas occupied by mainly built-up types consistently over the three decades has higher influence in increasing surface Temperature

- Areas where built-up class formed subsequently during both decades of 2011 and 2021, shows a cumulative increasing pattern of Surface Temperature

Transition Category	Phases of Built-up transition			Percentage of Area
	2001	2011	2021	
1st Order Urban	Built-up/ Bare land	Built-up/ Bare land	Built-up/ Bare land	54%
2nd Order Urban	Vegetation/ Waterbody	Built-up/ Bare land	Built-up/ Bare land	21%
3rd Order Urban	Vegetation/ Waterbody	Vegetation/ Waterbody	Built-up/ Bare land	12%
Other	Any	Any	Any	13%

87%

If an area is occupied with built-up/bare formation for long periods of time, it is highly susceptible to heat increase.

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Result & Findings

Relative Influence of Factors

Composite Scenario of Socio-economic & Physical Index

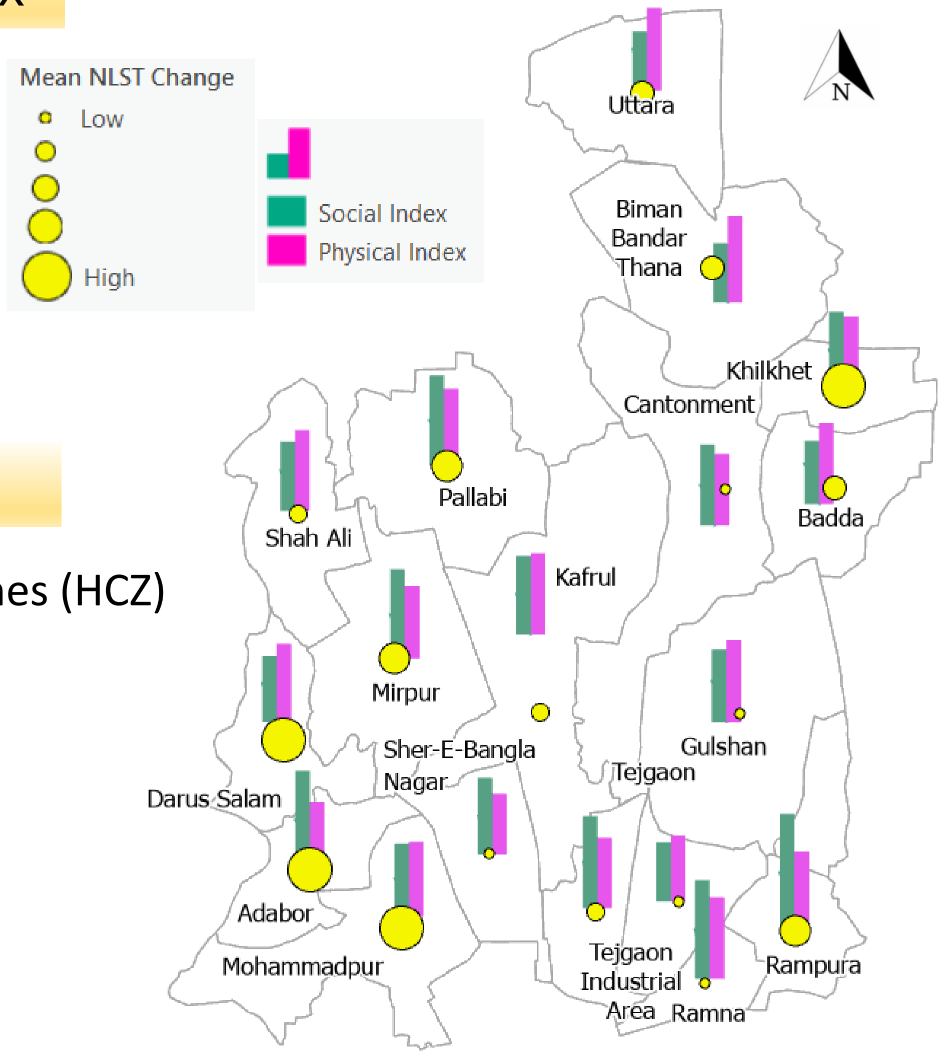
- Moran's Autocorrelation finds the city has a random socio-economic and physical pattern, **not clustered**
- Pearson's correlation shows **a weak positive correlation** (0.18)
- **Neither Intra nor Inter relationship** within and between two types of factors

Selection of Heat Center Zones

- Quartile of mean NLST change value determines Heat Center Zones (HCZ)

SL	Name of Thana	Socio-economic index	Physical index	Mean NLST change	Quartile of mean NLST change
1	Adabor	66.86	22.73	100.00	4th
2	Darus Salam	12.89	68.58	63.22	4th
3	Mohammadpur	24.91	57.02	62.06	4th
4	Khilkhet	32.08	44.27	61.19	4th

4 HCZ have been identified



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Result & Findings

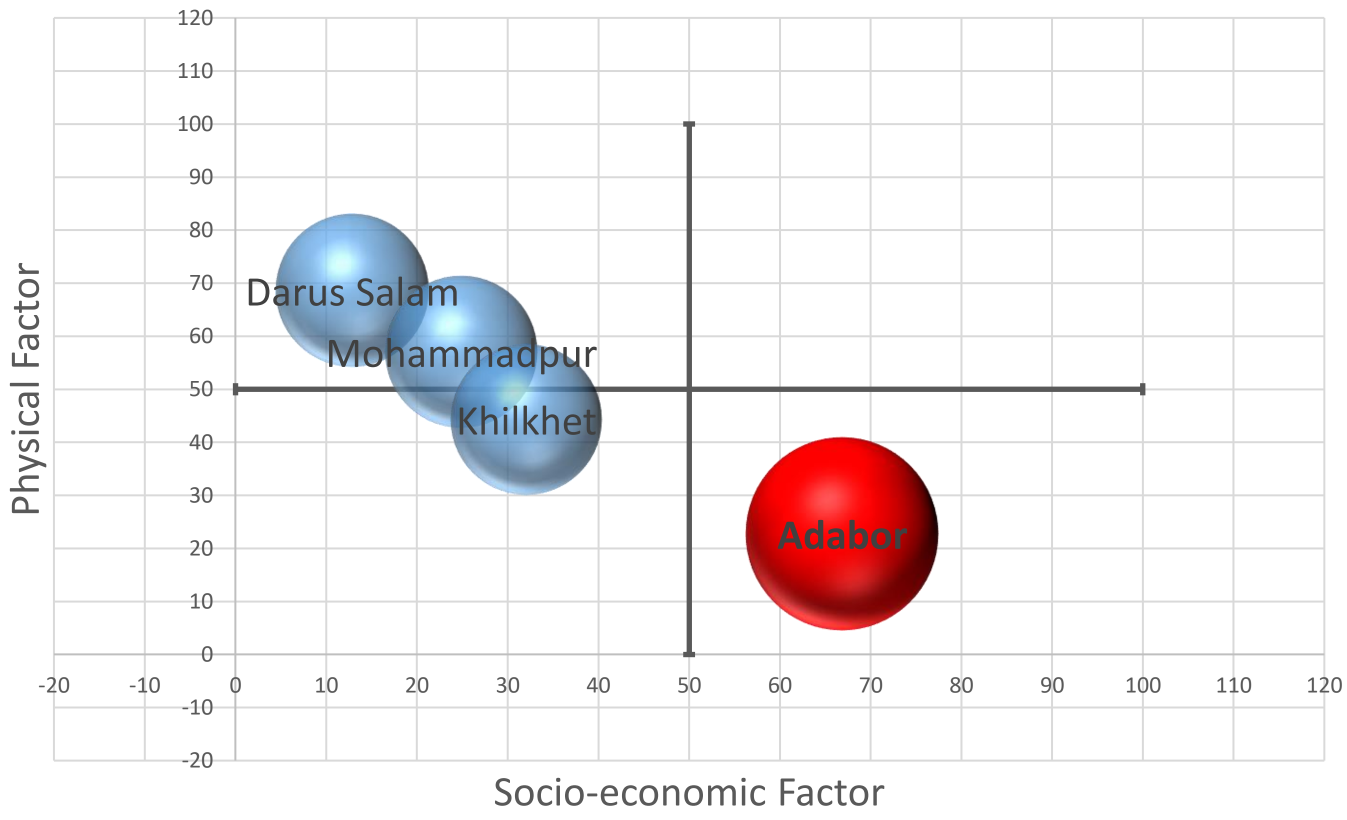
Relative Influence of Factors

Pattern of Contribution by Factors on Heat Center Zones

- Surface heat is less with simultaneous decreasing trend of socio-economic factor and increasing trend of physical factor
- Areas with less discrepancy between both factor shows comparatively less intensity of temperature increase

A balance between both factors is necessary to minimize the increase of Heat Risk

(a) Relative Importance of Socio-economic & Physical Factors



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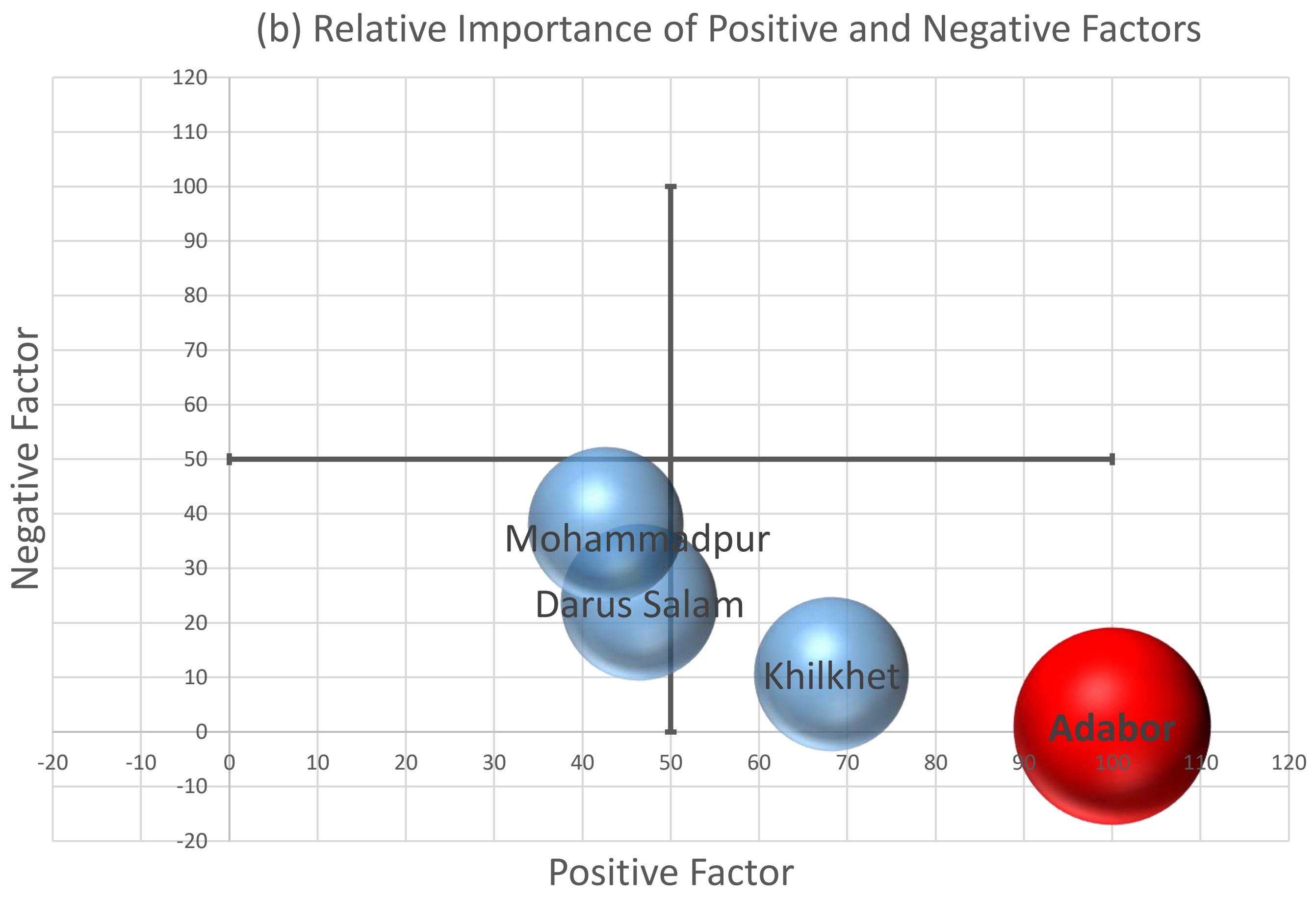
Result & Findings

Relative Influence of Factors

Pattern of Contribution by Factors on Heat Center Zones

- A gradual decrease in surface heat with increasing influence of negative factors

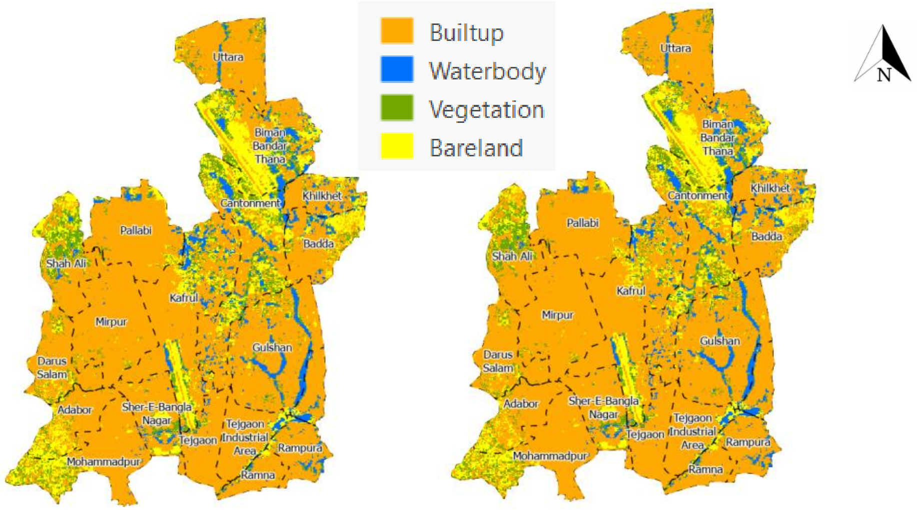
Need of Efficient Utilization of Negative Factors in reducing the surface heat intensity



Result & Findings

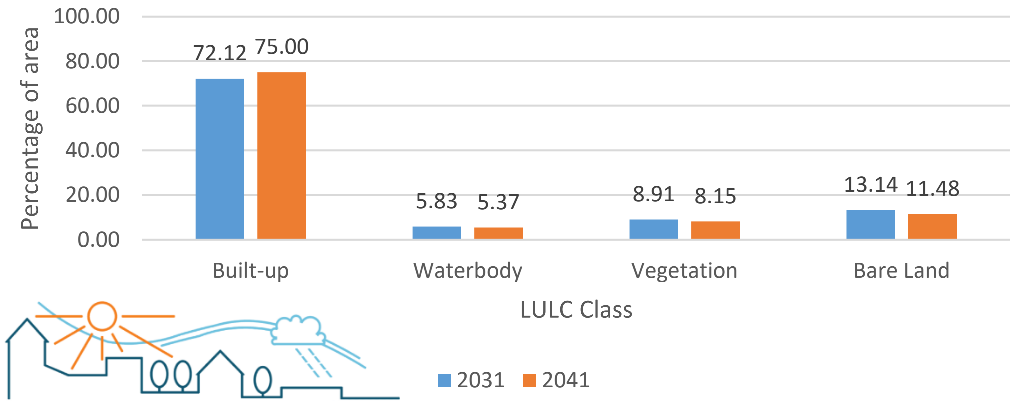
LULC Prediction

Growth of LULC Susceptible to Heat Increase

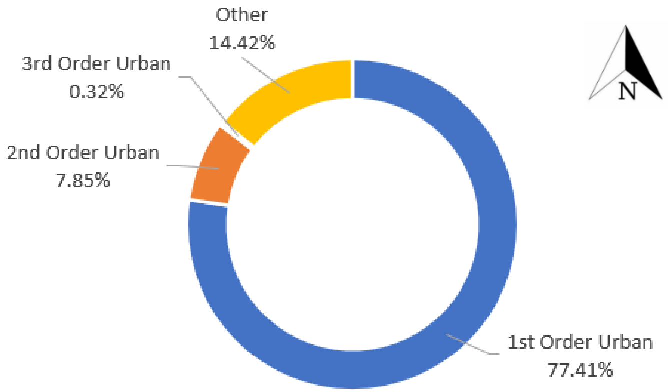


2031 **2041**

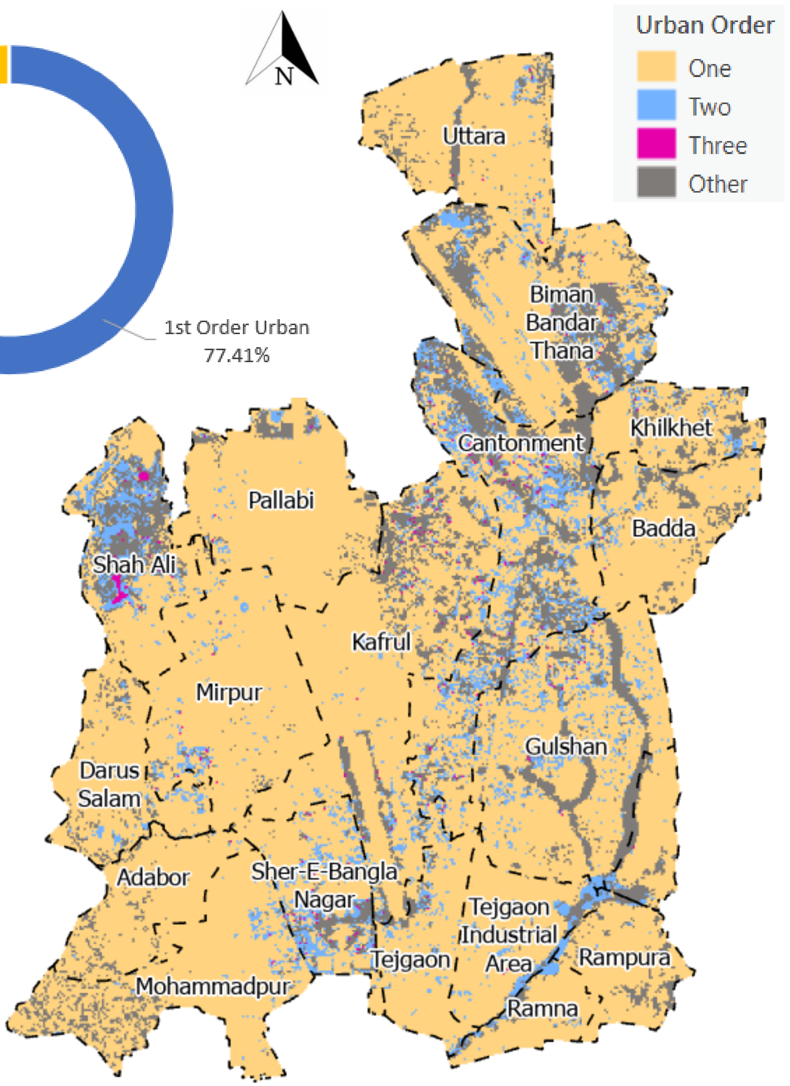
Percentage of area of LULC class in 2031 and 2041



% of Area by Urban Order Categories



Only 14.42% of land surface will be left by 2041 which does not pose risk to SUHI



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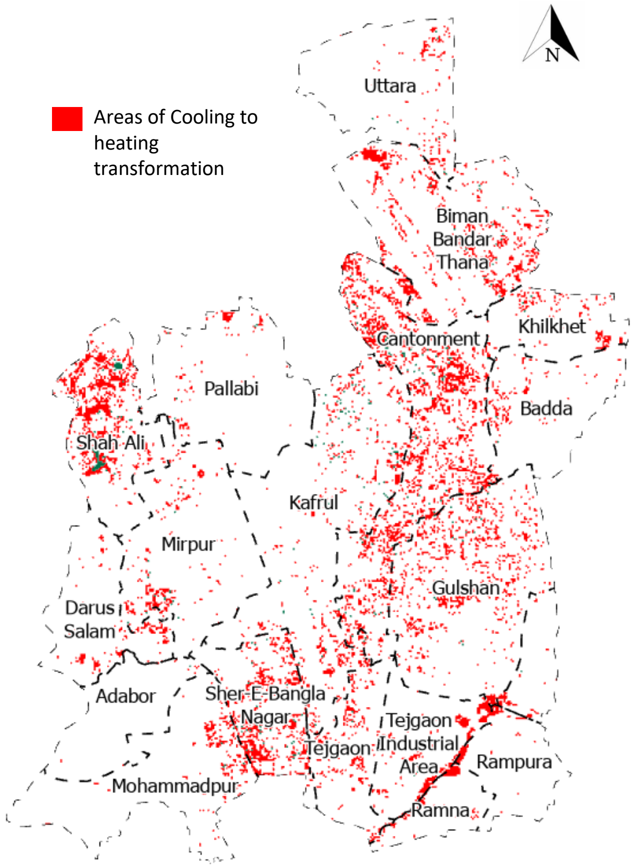
Mitigation Strategy

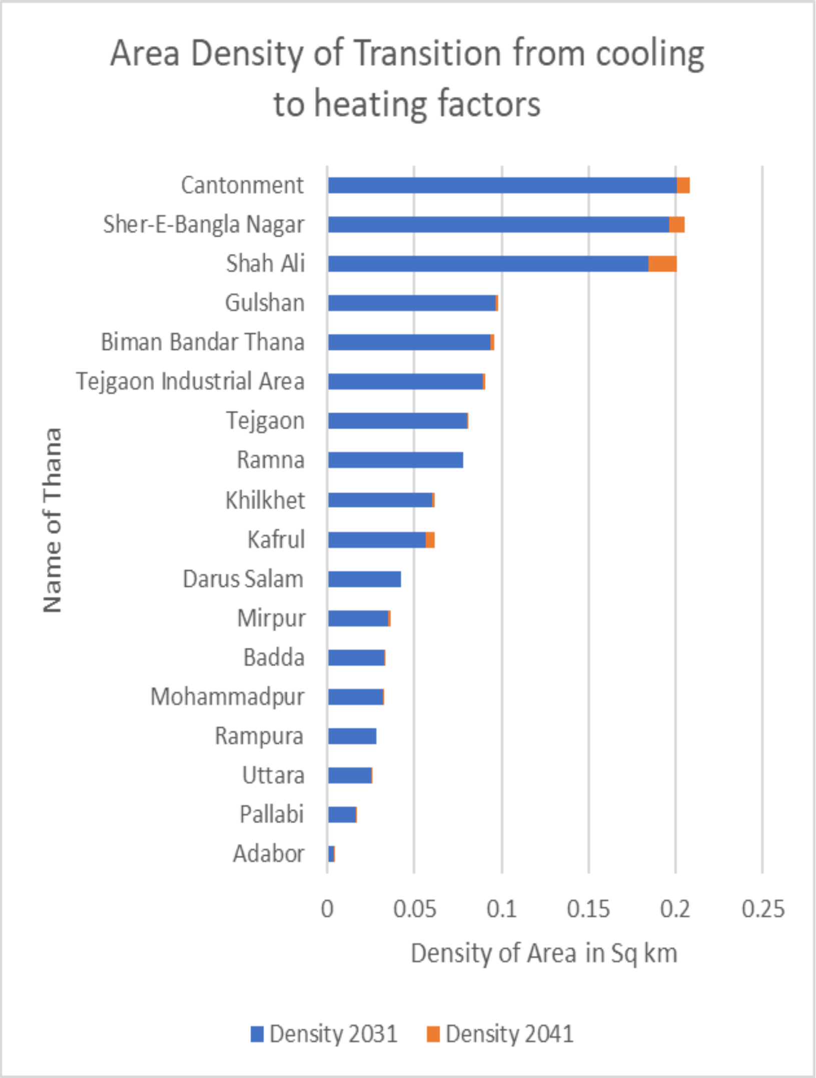
Challenges

Future Transformation of Cooling Factors by Heating Factors

- A major transformation will happen by 2031

The areas of such land transformation should be tackled immediately





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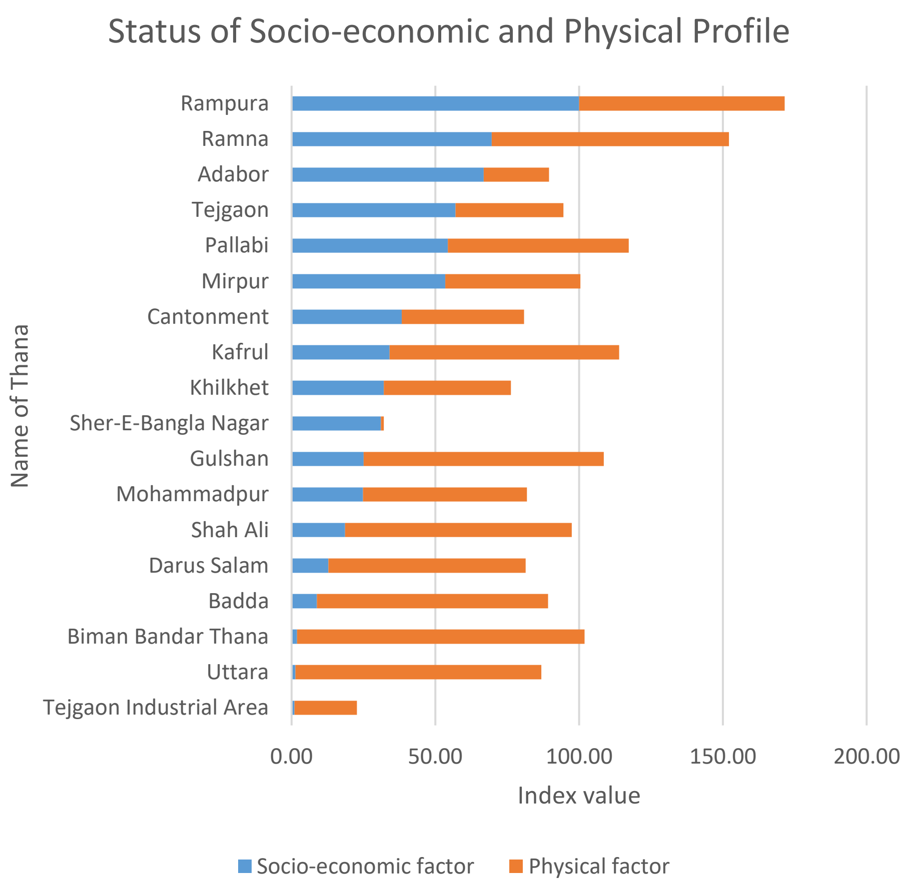
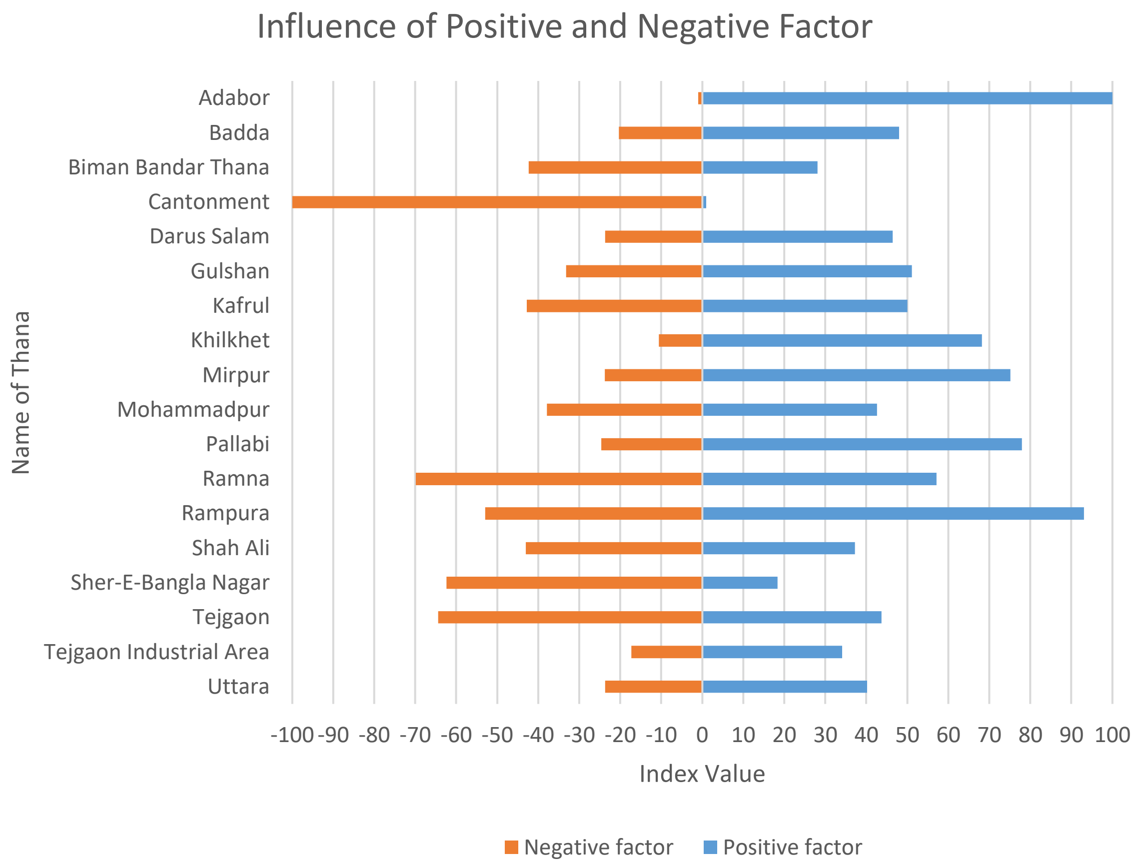
Mitigation Strategy

Challenges

Spatial Dynamics of Factor Influence





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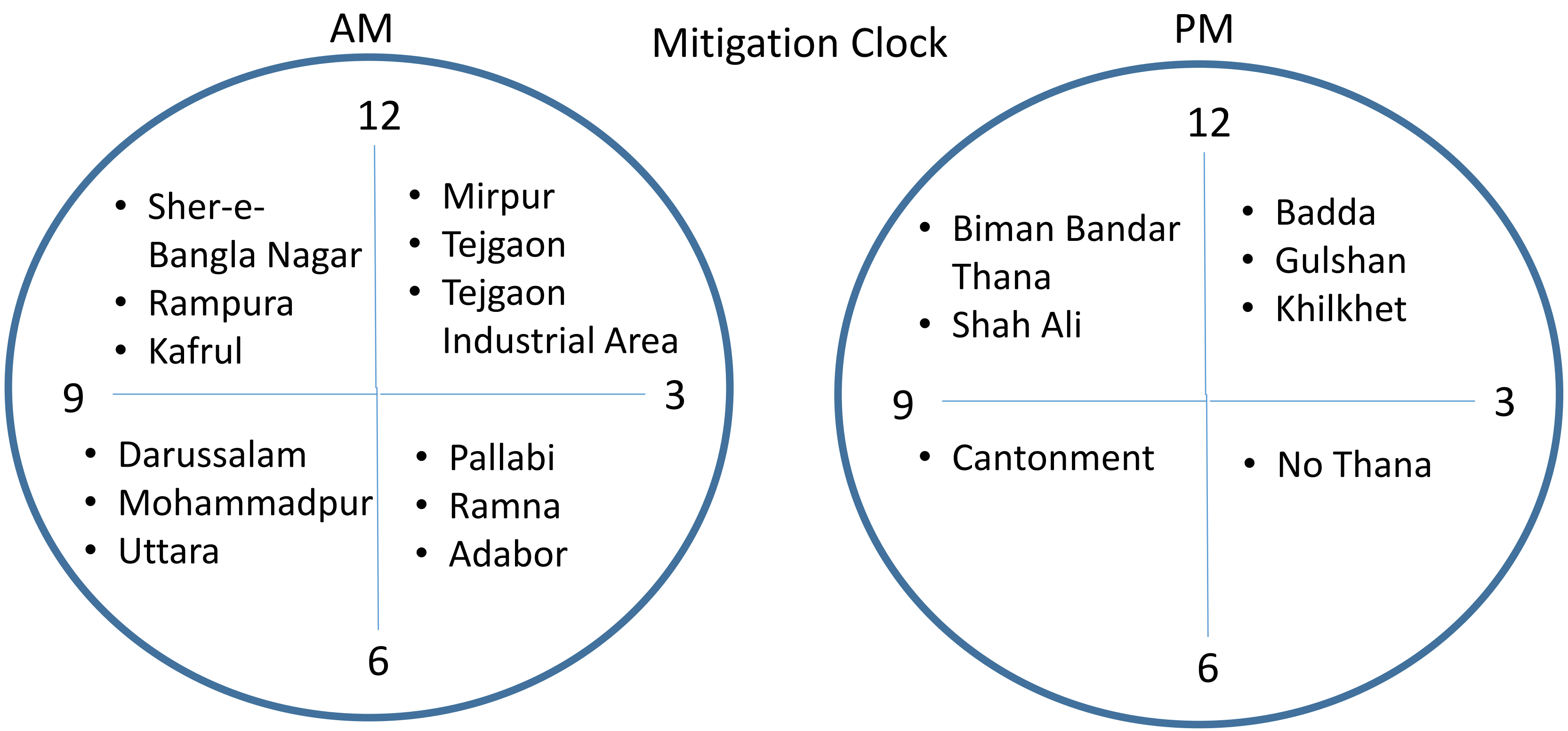
Addressing the dynamics of factors and varying level of variables

Mitigation Strategy

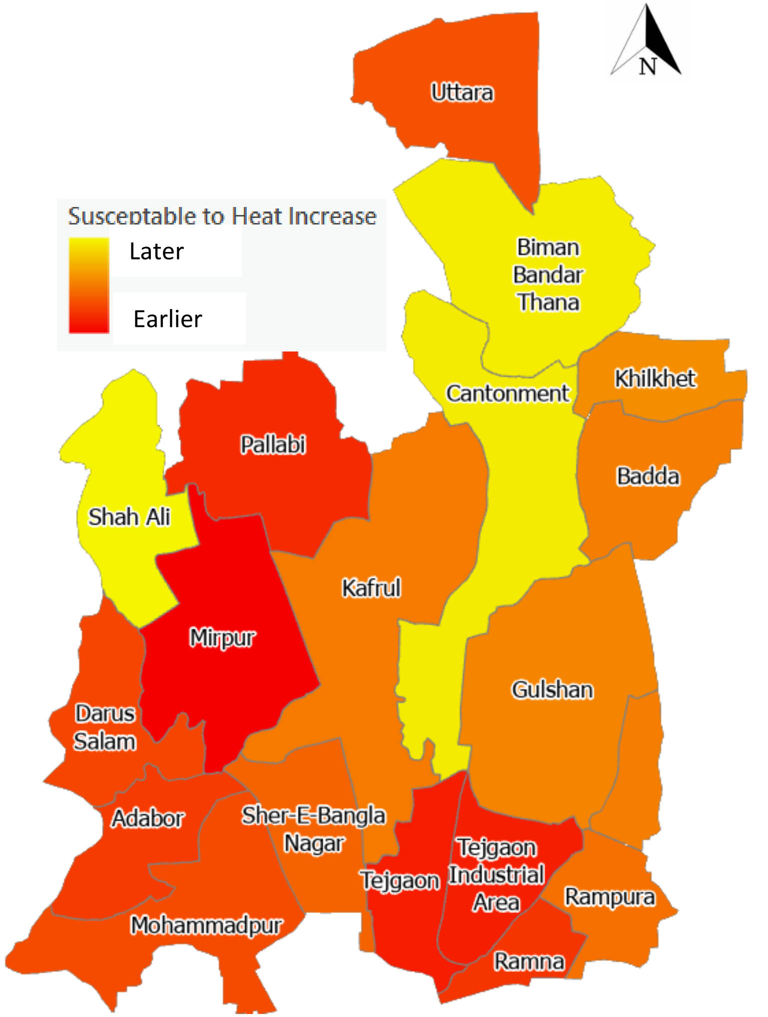
Temporal Impact of Spatial Transformation

Component 1: Priority Areas of Action

Mitigation Clock



Area Coverage Map by Transition of Urban Order



Mitigation action should be preferred to the areas with susceptibility to Heat at early stage

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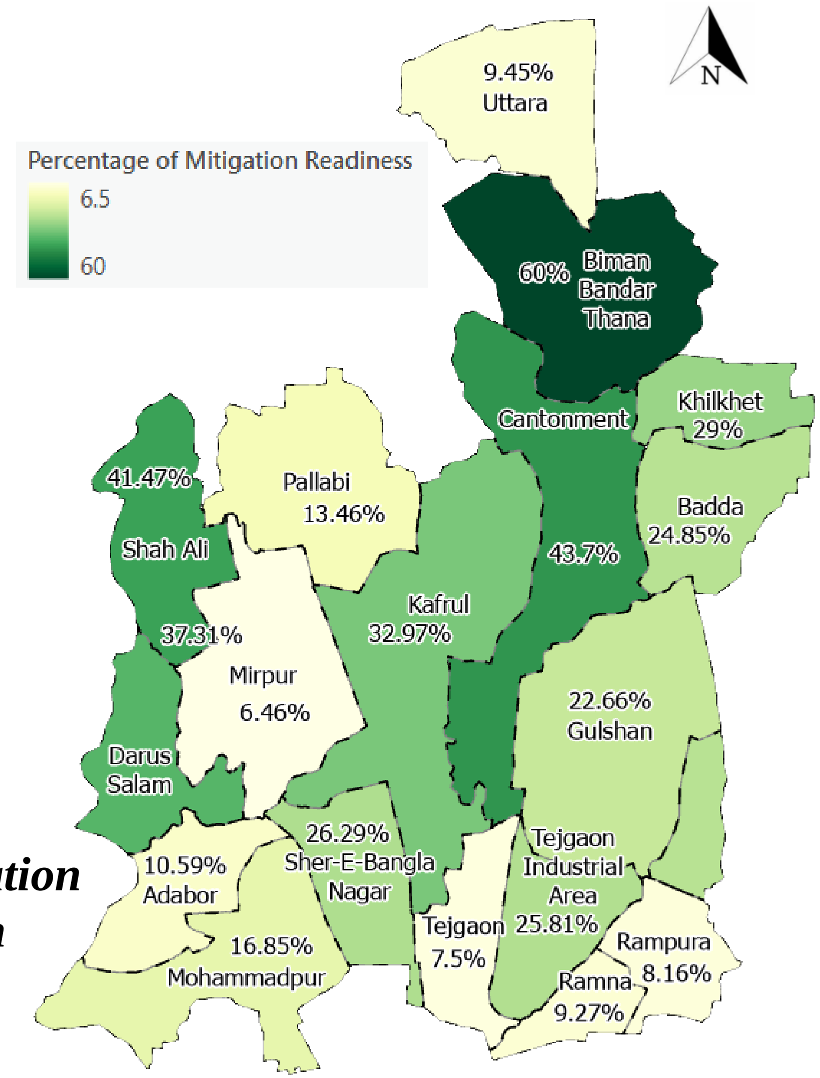
Mitigation Strategy

Heat Risk Reduction Tool

Component 2: Capacity of Resources

- The analysis finds that physical features with negative effect (leverage mitigation tools) strongly contributes to surface heat reduction
- Area specific strategies should be undertaken following either conservation or optimization of leverage mitigation resources (Waterbody, Vegetation & SVF)
- Readiness Map support decision makers by indicating level of capacity of an area to cope with further Heat Sensitive Development

Heat Mitigation Readiness Map of DNCC



A strategic utilisation of such resources as a leverage mitigation will be more effective, rather than general consideration

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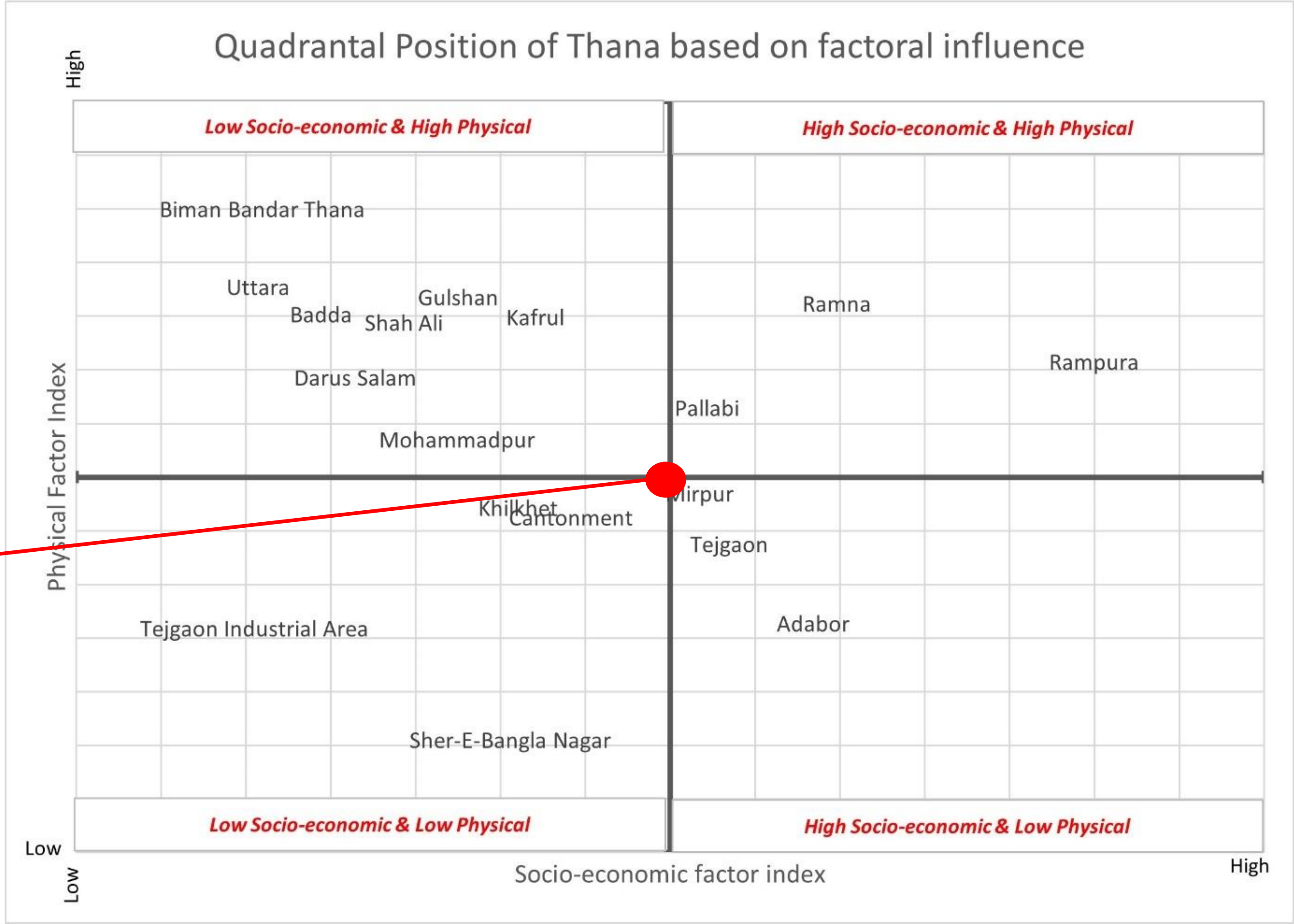
Mitigation Strategy

Sector of Strategic Focus

Component 3: Factor Oriented Strategy

Further area development strategies should be directed to the equilibrium point of physical and socio-economic sectors

Point of Sectoral Equilibrium



Practical Implication

Detail Area Plan of Dhaka (2015-2035)

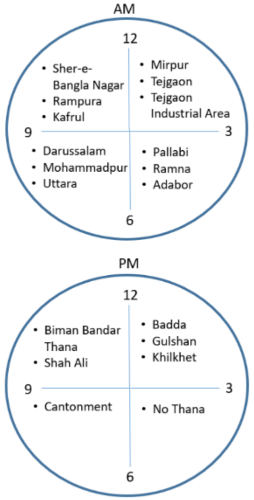
- **Section 4.5.3** of Detail Area Plan (DAP) of Dhaka promotes Heat Sensitive Landuse Plan
- The Findings and Proposed Mitigation Strategies directly support Local Government (DNCC) by providing respective **Administrative Area Profile** associated with SUHI
- This study demonstrates the need for **density zoning**, **height zoning**, **restoration of canals**, establishing **green space**

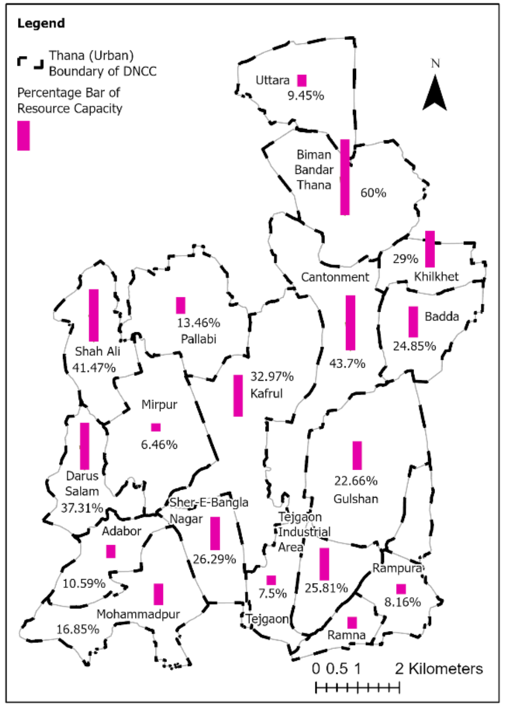
Practical Implication

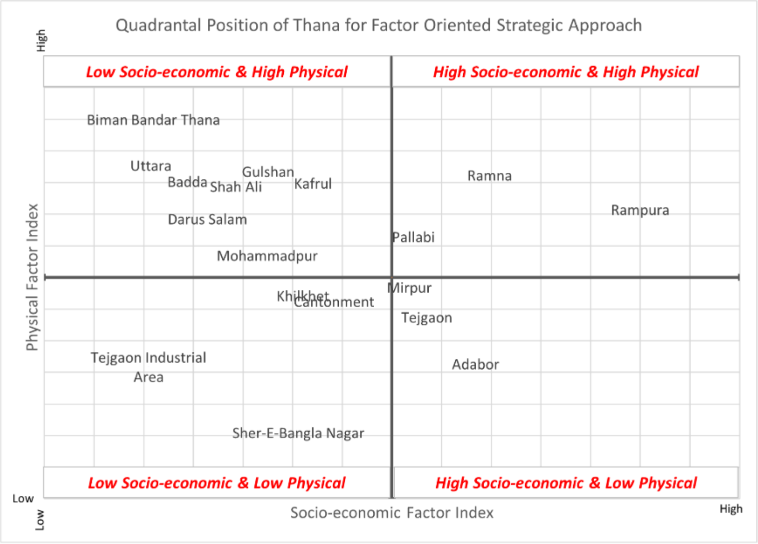
Area Wise Heat Risk Profile

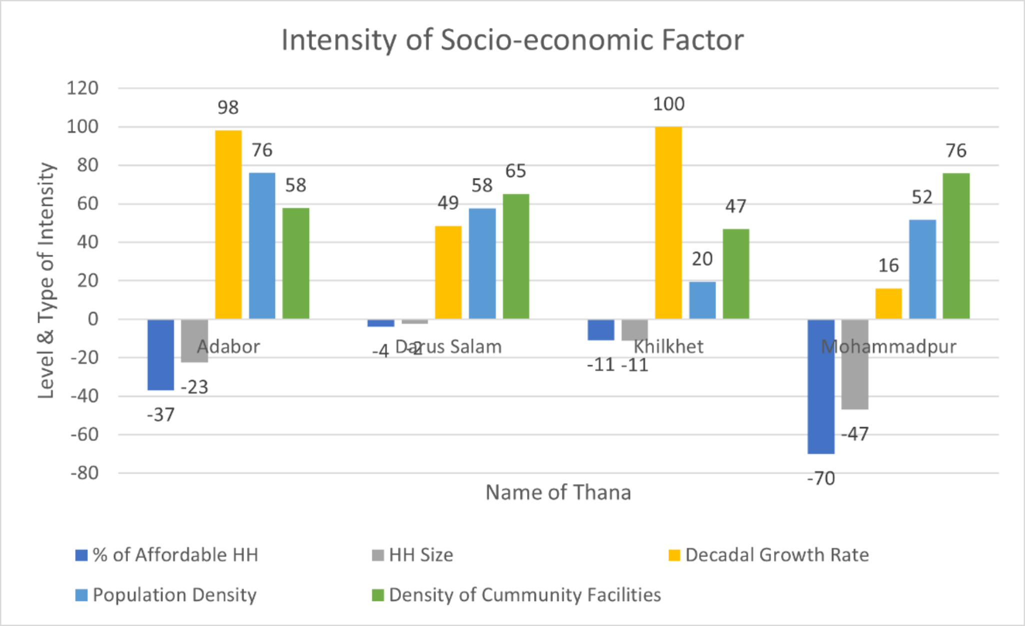
Strategic Heat Mitigation Map of DNCC Urban Area

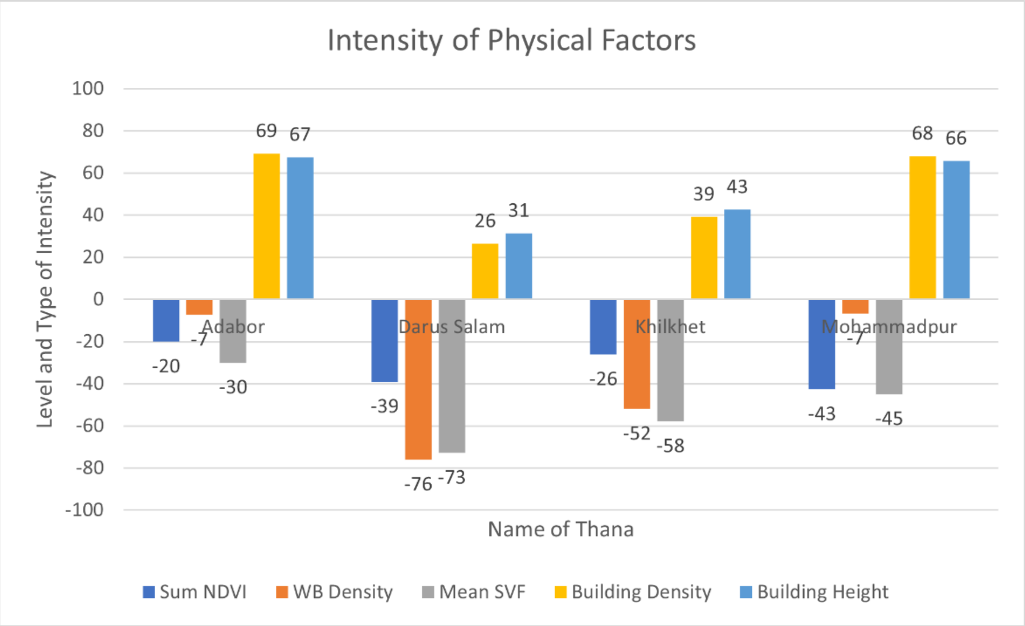
Mitigation Response Clock











Thank You

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