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Urban Heat Island Effect and Urban Density of Savar Municipality

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Abstract: This study critically examines the relationship between urbanization and Land Surface Temperature (LST) in the Savar Municipality area, employing Landsat 8 OLI + TIRS imageries and OpenStreetMap data. The Urban Heat Island (UHI) phenomenon, characterized by increased temperatures in urban areas compared to surrounding areas, has significant implications for environmental sustainability. The research objectives encompass a comprehensive analysis of UHI and urban building density using remote sensing and GIS algorithms, as well as an investigation into the correlation between UHI and urban building density within the study area.By employing advanced remote sensing techniques and GIS algorithms, this research uncovers important insights into the UHI effect and its association with urban development patterns in Savar Municipality. The analysis entails meticulous processing of satellite imagery, precise extraction of land cover information, rigorous calculation of LST values, and thorough examination of building density utilizing OpenStreetMap data. These methodologies ensure a robust and accurate assessment of the UHI phenomenon and its relation to urbanization. Point density calculation with fishnet method was used for analyzing the correlation between Urban Heat Island and the urban area building density of the study site. The highest temperature on 14th March 2014 was 31^0 C and the lowest one was 21^0 C where the maximum NDBI value was 0.137 and the minimum was -0.357. Again the highest temperature on 9th March 2018 is 29^0 C and the lowest one is 200 C where the maximum NDBI value is 0.163 and the minimum is -0.347. The highest temperature on 4th March 2022 was 30^0 C and the lowest one was 21^0 C where the maximum NDBI value was 0.156 and the minimum was -0.3897. The correlation between LST and NDVI results is negative. In some parts of the study area where the urban density is higher , the temperature is comparatively lower. It is apparent that the green cover weakens the UHI effect. The correlation analysis conducted between UHI intensity and urban building density unravels a positive relationship, establishing the significance of urbanization patterns in shaping local temperature patterns. The areas with higher building density consistently exhibit heightened UHI effects, providing crucial evidence of the role played by urban development in exacerbating heat island phenomena.

Keywords: LST, Thermal Image, LANDSAT, NDBI, UHI, Correlation, TIRS, OLI

1. Introduction

Rapid urbanization is an ongoing global phenomenon that has far-reaching implications for various aspects of human life and the environment. As cities expand and populations

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concentrate in urban areas, the urban climate undergoes significant transformations, including alterations in temperature patterns. The relationship between rapid urbanization and temperature has garnered substantial attention in recent years, as it directly impacts the well-being and quality of life for urban residents. Urban Heat Island (UHI) can be explained as the temperature alteration in urban areas compared to their rural surroundings. Different remote sensing technology can be used in studying UHI observation – MODIS, Landsat, and ASTER as well as their combined use (Kaplan et al. 2018). On the other hand, the OpenStreetMap database enhances the ability to measure and analyze the geospatial data developed by crowdsourcing and open database contributors. The UHI effect arises from the modification of land surfaces due to urban development, such as the construction of buildings, roads, and other infrastructure. These changes lead to changes in energy absorption, retention, and release, resulting in elevated temperatures in urban environments. The UHI effect is particularly pronounced during heatwaves and can exacerbate the impacts of extreme heat events on urban populations.The consequences of increased temperatures associated with rapid urbanization are multi-faceted. Firstly, higher temperatures in urban areas can contribute to heat-related health issues, such as heat stress, dehydration, and heat-related illnesses.

2. Aim and Objective

The broader aim of the research is to analyze the Landsat 8 OLI + TIRS imageries and OpenStreetMap data to identify the relationship between urbanization and Land Surface Temperature in the Savar Municipality area. The overall objectives follow:

1. To analyze the Urban Heat Island (UHI) and urban area building density using remote sensing and GIS algorithms
2. To analyze the correlation between UHI and urban area building density of the area.

3. Study Area

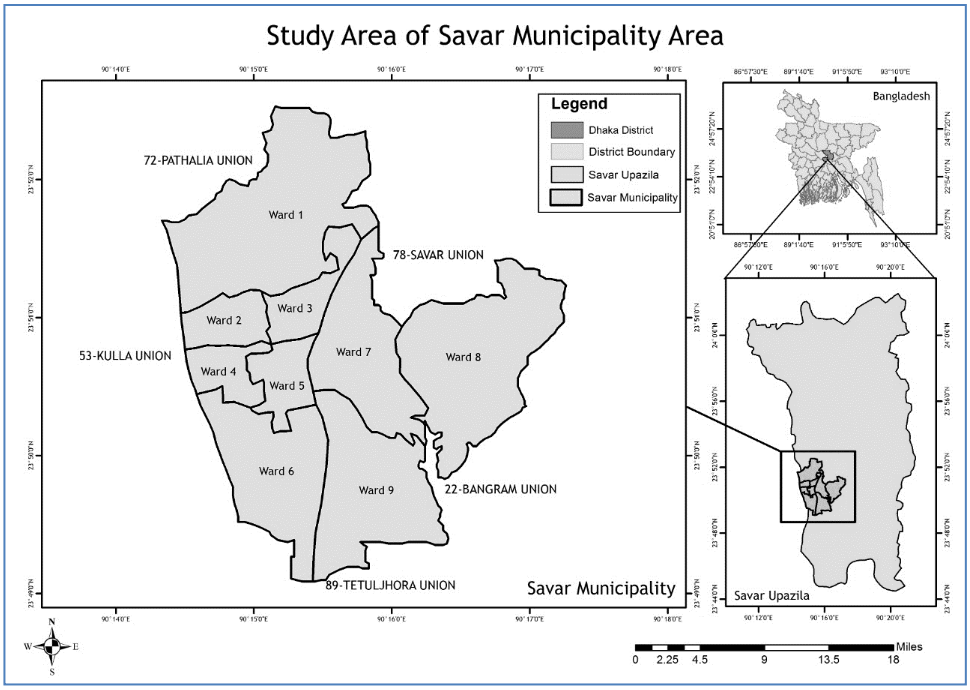
The second-largest Upazila of Dhaka district, Savar experienced rapid urbanization and industrialization in recent decades. Savar is located at the northern edge of Dhaka, between 23°44’ N and 24°12’ N latitude and between 90°11’ E and 90°22’ E longitude. Savar Municipality was our study area. The population of Savar municipality is 2,86,008 and this is one of the densely populated areas of Savar Upazila **(BBS 2011).**

Table: 1.1 Population, household, and area of the study area (Savar Municipality)

WARD NAME	AREA (acres)	HOUSEHOLD	POPULATION
Ward No-01	918	8638	34926
Ward No-02	160	5171	20255
Ward No-03	178	7861	30204
Ward No-04	140	3424	14628
Ward No-05	171	6858	28373
Ward No-06	536	12399	43545
Ward No-07	500	13192	50053
Ward No-08	789	7944	30904
Ward No-09	589	9028	33120
Total	3981	74515	286008

Source: BBS, Small area Atlas, 2017

Map: 1.1 Study Area Map (Compile by Author)



4. Data Source and Methods

Firstly this study calculates the surface temperature of the Savar municipality and then went for the correlation between NDVI & LST and later NDBI & LST. Before calculation this analysis explored the band combination of Landsat 8. Operational land imageries (OLI) and Thermal Infraredsensorsr (TIRS) comprise Landsat 8 satellite. For LST calculation, this research used band 10, band 4, and band 5 of Landsat 8. Those bands have different spatial resolutions. These are given below.

Table: 1.2: Band Designation of LANDSAT 8

Satellite Name	Band Name	Sensor	Wavelength (μm)	Spatial Resolution(m)
Landsat 8	Band 4 (Red)	Operational land imegeries (OLI)	0.64 – 0.67	30
	Band 5 (Near Infrared)	Operational land imegeries (OLI)	0.85 – 0.88	30
	Band 6 (Short Wave Infrared I)	Operational land imegeries (OLI)	1.57 – 1.65	30
	Band 10 (Thermal Infrared Sensor I)	Thermal Infrared Sensor (TIRS)	10.6 – 11.19	100

Source: USGS, 2013

i. Measuring Urban Heat Island

The study acquired Landsat 8 imageries of three different years (2014, 2018, 2022) with four years intervals from the USGS Landsat image repository. These images have been analyzed using an LST tool developed using Arc gis 10.8. The tool retrieved LST with the input of the Red (0.64 µm – 0.67 µm), NIR (0.85 µm – 0.88 µm), TIRS (10.60 µm – 11.19 µm) layers. The UHI was extracted using the following equation:

$$UHI = \mu + \frac{\sigma}{2}$$ (Schwarz et al., 2011)

Here, µ represents the LST value of the area, whereas σ represents the SD (standard deviation) of the LST. To determine the correlation between the land cover and the LST results, NDVI and NDBI are calculated. Equation two has been used to calculate the NDVI,

$$NDVI = \frac{NIR - Red}{NIR + Red}$$ (Streutker, 2003)

Furthermore, the NDBI index (Zha et al, 2003) is being calculated using the third equation noted below.

$$NDBI = \frac{MIR - NIR}{MIR + NIR}$$

a) **Conversion to Top of Atmosphere (TOA) Radiance:**

"Using the radiance rescaling factor **Thermal Infra-Red (DN)** Digital Numbers can be converted to TOA spectral radiance.

LA= ML * Qcal + AL-O_i ; LA = 0.0003342*Band 10+0.10000-0.29

Where, Lλ = TOA spectral radiance (Watts/ (m2 * sr * µm)); ML = Radiance multiplicative Band (No.); AL = Radiance Add Band (No.); Qcal = Quantized and calibrated standard product pixel values (DN); O_i = correction value for band 10 is 0.29 "

b) **Conversion to Top of Atmosphere (TOA) Brightness Temperature (BT)**

"Spectral radiance data can be converted to top of atmosphere brightness temperature using the thermal constant Values in the Metadata file. Kelvin (K) to Celsius (°C) Degrees BT = K2 / In (k1 / Lλ + 1) - 273.15 ; **BT= (1321.0789/Ln(774.8853/T0A+1))-273.15** **Where:** BT = Top of atmosphere brightness temperature (°C) ; Lλ = TOA spectral radiance (Watts/ (m2 * sr * µm))**;** K1 = K1 Constant Band (No.) **;** K2 = K2 Constant Band (No.) "

c) **Normalized Difference Vegetation Index (NDVI)**

"The Normalized Differential Vegetation Index (NOVI) is a standardized vegetation index which Calculated using Near Infra-red (Band 5) and Red (Band 4) bands. **NDVI = (NIR - RED) / (NIR + RED);** NDVI = (Band 5-Band 4)/ (Band 5-Band 4)**;** Where: RED= DN values from the RED band; NIR= DN values from the Near-Infrared band "

d) **Land Surface Emissivity (LSE)**

"Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from NDVI values. **PV = $((NDVI - NDVI_{min}) /(NDVI_{max} - NDVI_{min}))^2$** **Where :** PV = Proportion of Vegetation ; NDVI= DN values from NDVI Image; NDVI min = Minimum DN values from NDVI Image; NDVI max = Maximum DN values from NDVI Image ; E = 0.004 * PV + 0.986, **Where:** E = Land Surface

Emissivity; PV = Proportion of Vegetation; 0.986 corresponds to a correction value of the equation"

e) <u>The Land Surface Temperature (LST) Calculation</u>

"The Land Surface Temperature (LST) is the radiative temperature Which calculated using Top of atmosphere brightness temperature, Wavelength of emitted radiance, Land Surface EmissivitY.

LST = BT/ (1 + (λ * BT / c2) * ln(E))

Here,c2= 14388 µm K ; The Values of λ for Landsat 8: for Band 10 is 10.8 and for Band 11 is 12.0 ; **Where** BT = Top of atmosphere brightness temperature (£); λ. = Wavelength of emitted radiance ; E = Land Surface Emissivity c2= $h*c/s=1.4388*10^2$mK=14388mK; h= Planck's Constant=$6.626*10^{-34}$J s; s = Boltzmann constant= $1.38*10^{-23}$JK; c= velocity of light=$2.998*10^8$m/s "

The flow chart of using the algorithm has been drawn below:

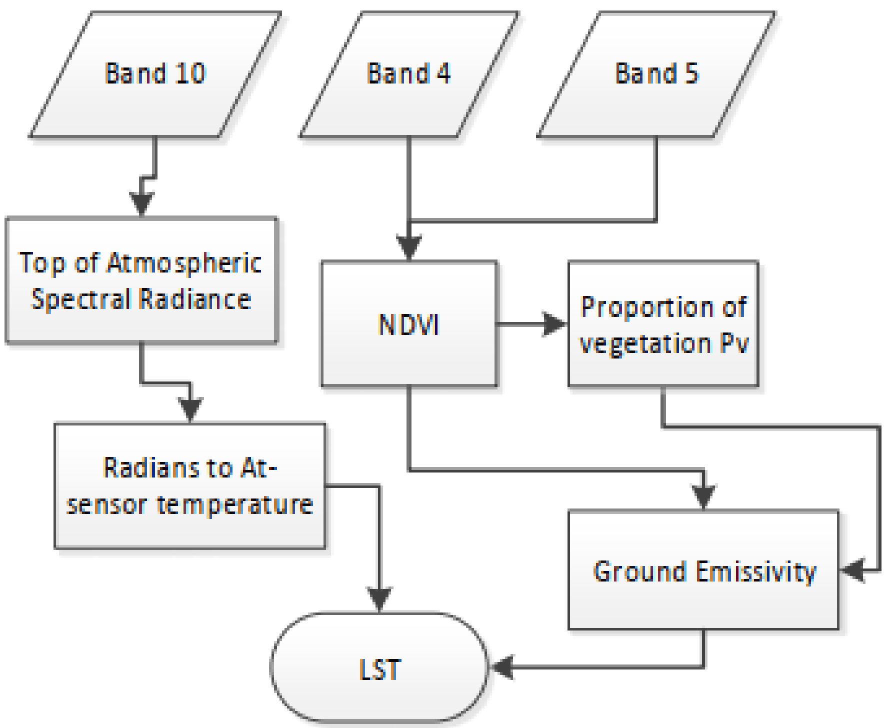


Figure 1.1: Flowchart of the LST algorithm. (Kaplan et al. 2018)

ii. Measuring Urban Build-up Density

Urban building density is essential to determine the populated area of a particular area. This study calculates the urban building density using OpenStreetMap data in the ArcGIS platform. The flowchart of this algorithm is drawn below:

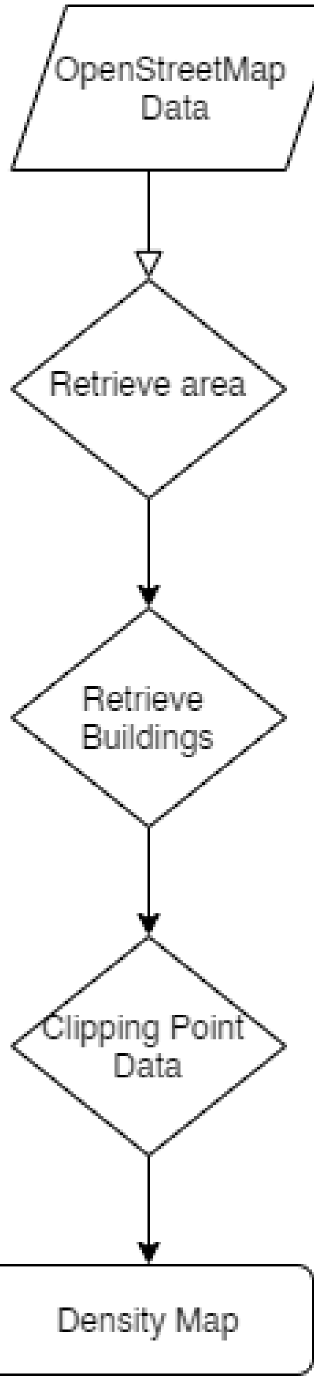


Figure 1.2: Density mapping using ArcGIS

iii. Correlationation between LST, vegetation intensity and building density

The correlation between Urban Heat Islands and Building density has been calculated by ArcGIS software. The fishnet techniques were used to get the values from the raster. After that start multi values to point conversion. Then clip the features by using AOI and open the attribute table for the creation of correlation graphs.The overall steps are given below.

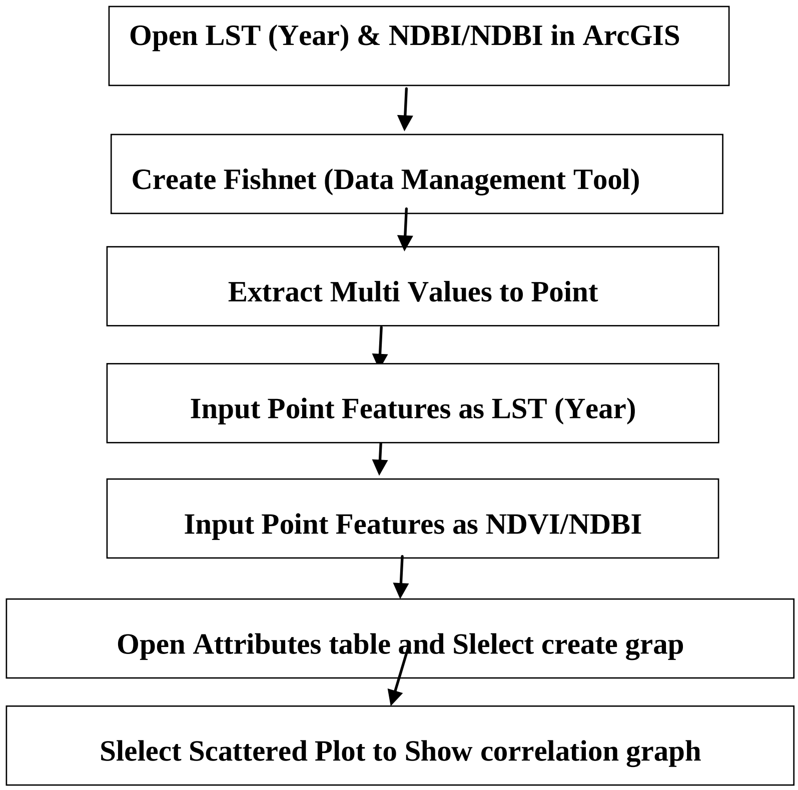


Figure 1.3: Correlation methodological steps in ArcGIS

5. Results and Discussions

5.1 Urban Heat Island of Savar Municipality

The Urban Heat Island (UHI) effect has become a significant environmental concern in rapidly urbanizing areas worldwide. It refers to the phenomenon where urban areas experience higher temperatures compared to their surrounding areas. The UHI effect is primarily caused by the modification of land surfaces due to human activities, such as the construction of buildings, roads, and other infrastructure, which alter the energy balance and thermal properties of urban environments. One such urban area experiencing significant urbanization and potential UHI effects is Savar Municipality, located in the Dhaka district of Bangladesh. Savar Municipality has witnessed rapid population growth and extensive urban development in recent years, making it an ideal case study to explore the relationship between urbanization and the UHI effect.

i. Understanding the UHI effect in Savar Municipality is crucial for several reasons. Firstly, it directly affects the well-being and comfort of the urban population, as higher temperatures can lead to heat-related health issues and increased energy demand for cooling. Secondly, the UHI effect can impact local climate patterns, including rainfall patterns and air quality, further influencing the overall urban environment. Lastly, gaining insights into the UHI effect in Savar Municipality can inform urban planners, policymakers, and stakeholders in implementing appropriate mitigation and adaptation strategies for sustainable urban development.

ii. This study investigated the UHI effect in Savar Municipality by utilizing GIS and remote sensing techniques. The integration of Geographic Information System (GIS) allows for the analysis and visualization of spatial data, while remote sensing enables the acquisition and interpretation of satellite imagery for assessing land surface temperature (LST) patterns.

iii. The objectives of this research are twofold. Firstly, to analyze the UHI effect in Savar Municipality by comparing LST values between urban and rural areas using Landsat 8 OLI + TIRS imageries. This analysis will provide insights into the magnitude and spatial extent of the UHI effect in the study area. Secondly, to investigate the relationship between the UHI effect and urban density by examining the distribution and intensity of the UHI effect in relation to different levels of urban development. By examining the UHI effect and its relationship with urban density in Savar Municipality, this research aimed to contribute to the understanding of urban climate dynamics and inform sustainable urban planning practices.

iv. In Map 1.2 the land surface temperature of the consecutive years 2014, 2018, and 2022 of Savar Municipality were analyzed using a Landsat satellite image. major changes in temperature were found at three different times. Study select 14 March 2014, 9^{th} March 2018, and 4^{th} March 2022 Landsat Images to find the difference in Temperature in the study area. After the calculation from the thermal band, the highest temperature on 14^{th} March 2014 was 31^{0} C and the lowest one was 21^{0} C. Again the highest temperature on 9^{th} March 2018 was 29^{0} C and the lowest one was 20^{0} C. Lastly the highest temperature of 4^{th} March 2022 was 30^{0} C and the lowest one was 21^{0} C.

Map 1.2: Comparative Land Surface Temperature (LST) map of Savar Municipality (2014, 2018, 2022)

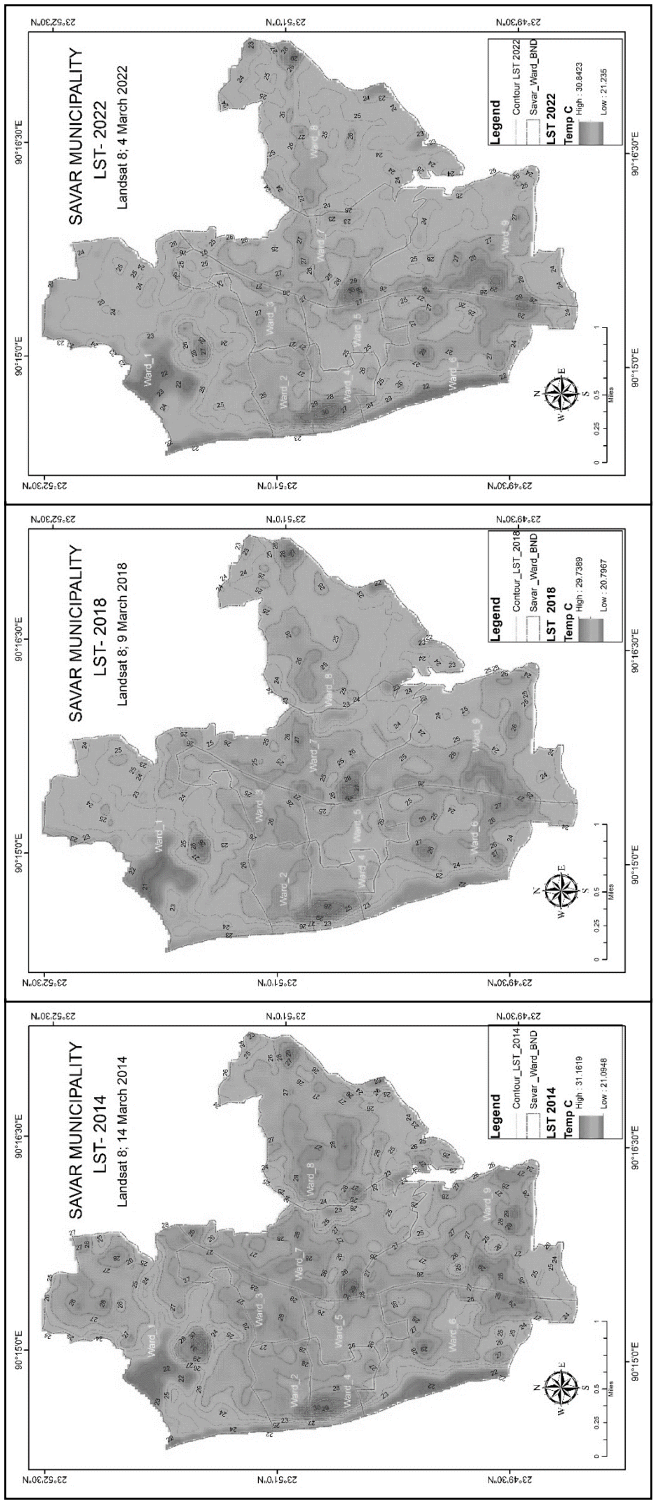


Figure 1.4: Spectral profile of some parts of Savar Municipality -2014

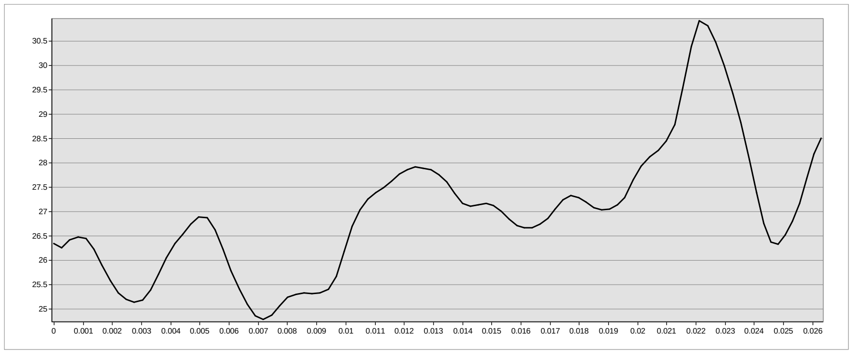


Figure 1.5: Spectral profile of some parts of Savar Municipality -2018

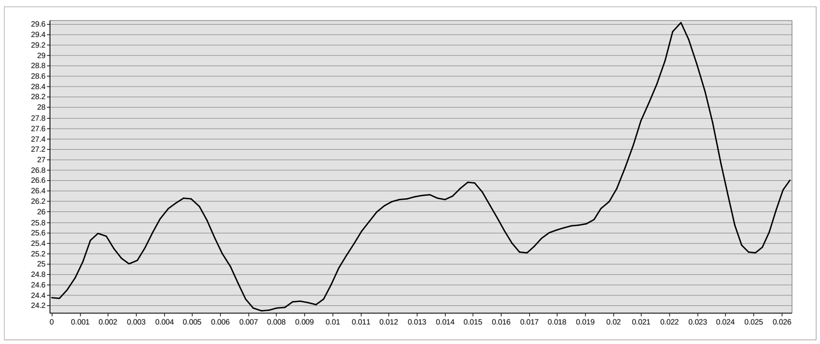
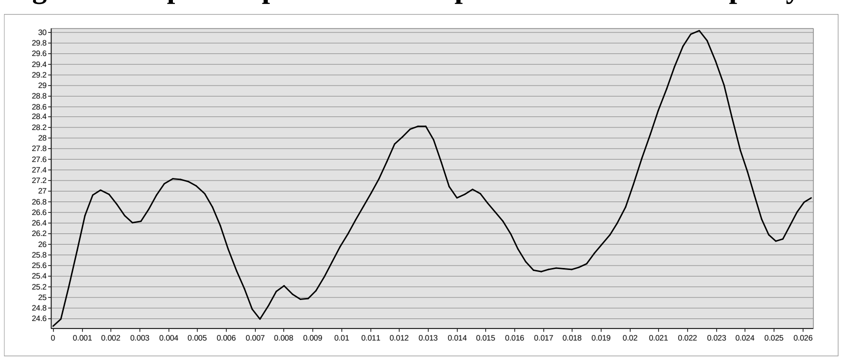
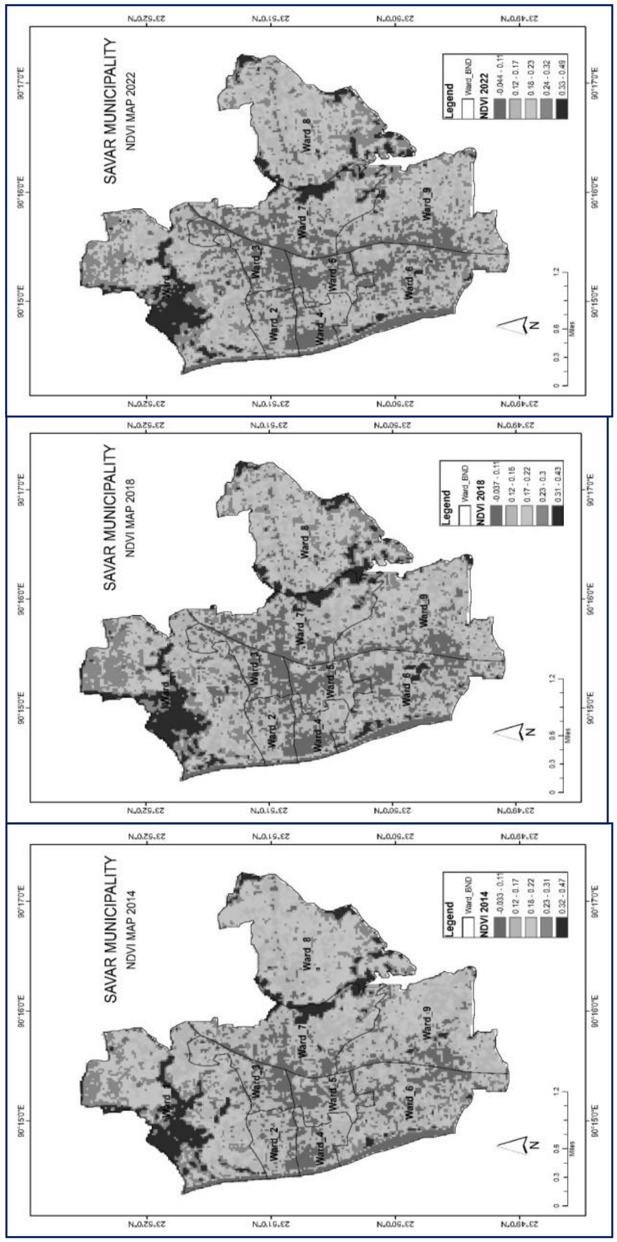


Figure 1.6: Spectral profile of some parts of Savar Municipality -2022

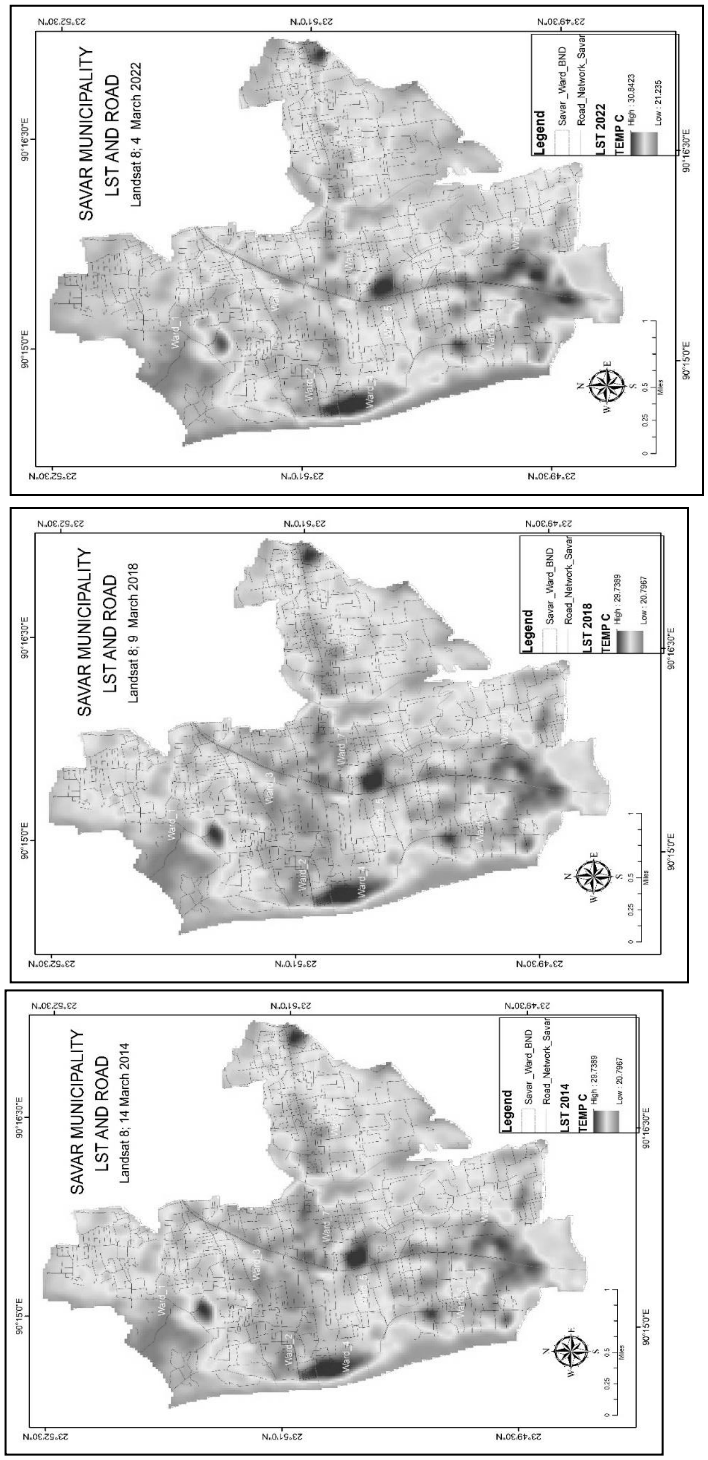


In the spectral UHI graphs, it is represented that heat is generated where vegetation is less. On the other hand, where vegetation is more, the temperature is lower. Both the three graphs' peak is almost the same. This research indicates that Vegetation and building density maintain the heat balance of any area like Savar municipality.



Map 1.3: Land Surface Temperature (LST) of three different dates of savar Municipality

In map -1.3, the Road network line has been superimposed on LST data to see the influence of road features on the increase of LST. On the map, we noticed the high-temperature area is surrounded by the road line. The conditions are almost the same in both three years of the LST map. The eastern and southern parts of the study area absorbed more temperature.



Map 1.4: Normalized difference Vegetation Index (NDVI) of Savar Municipality Area (2014, 2018, 2022)

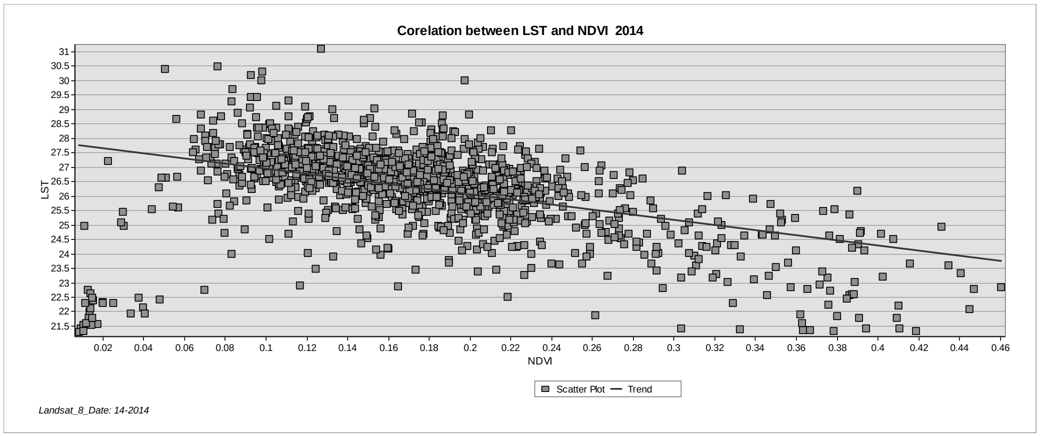


Figure 1.7: Correlation between LST 2014 and NDVI 2014

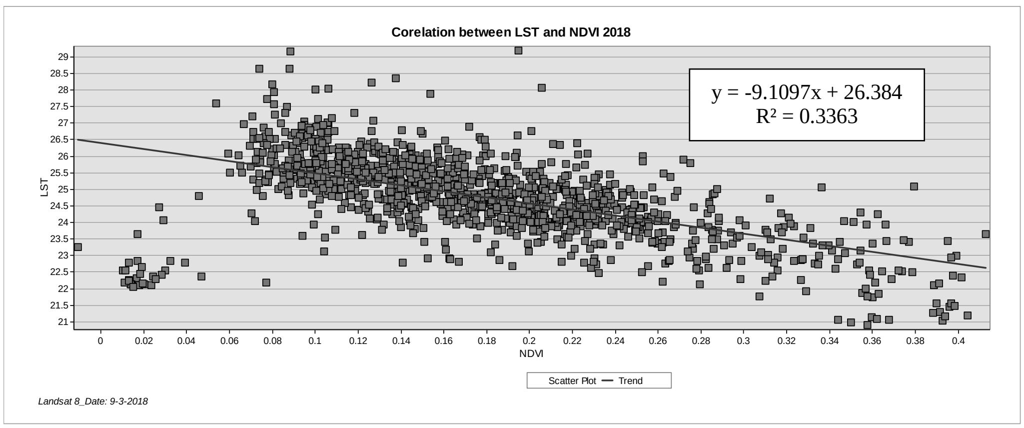


Figure 1.8: Correlation between LST 2018 and NDVI 2018

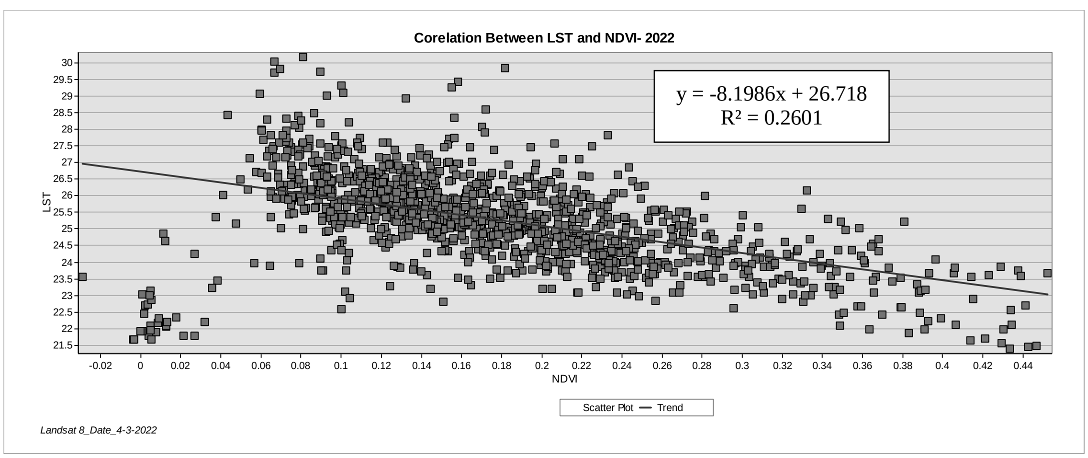


Figure 1.9 : Corelation between LST 2022 and NDVI 2022

5.2 Correlation between Land Surface Temperature and NDVI

In figure (1.7-1.9) NDVI and land surface temperature (LST) has negative correlation. With the increase in NDVI value, corresponding surface temperature in the three years getting decreased. Normalized difference vegetation index (NDVI) values are sensitive to changes in the surface temperature and those variations of NDVI may create changes in LST (Chen & Zhang, 2017) . In figure 1.8 the highest NDVI value is 0.46 and at the same point, the LST value is 23^0 C. Conversely , the lowest NDVI value is 0.02 and the LST value is 27^0 C. In this graph 1.9, study found the highest temperature is 31^0 C Where the NDVI value 0.12. High NDVI values were found in Ward-1, Ward-7, and Ward 8 of Savar Municipality. NDVI values are comparatively lower in Ward-2, Ward-3, Ward-4, Ward-5, Ward-6, and Ward-9. The LST of that area is also high than in other areas. The building density is relatively high in that area. The LST values of the 2014 Image are more than the other two sample years because of the date of capturing an image from the satellite. Due to the factory and production-based activity, the highest LST was observed in the industrial area of Savar. The surface temperature on the west side of the savar Municipality was the lowest which decrease the (UHI) effect.

Table 1.3: STATISTICAL DATA OF LST FOR THREE DATES OF SAVAR MUNICIPALITY (°C)

Image acquisition Date	**Statistical Results**			
	Minimum	Maximum	Mean	Standard Deviation
14-03-2014	21.096	31.161	26.236	1.504
09-03-2018	20.796	29.738	24.758	1.202
04-03-2022	21.236	30.842	25.254	1.358

(Compiled by Author)

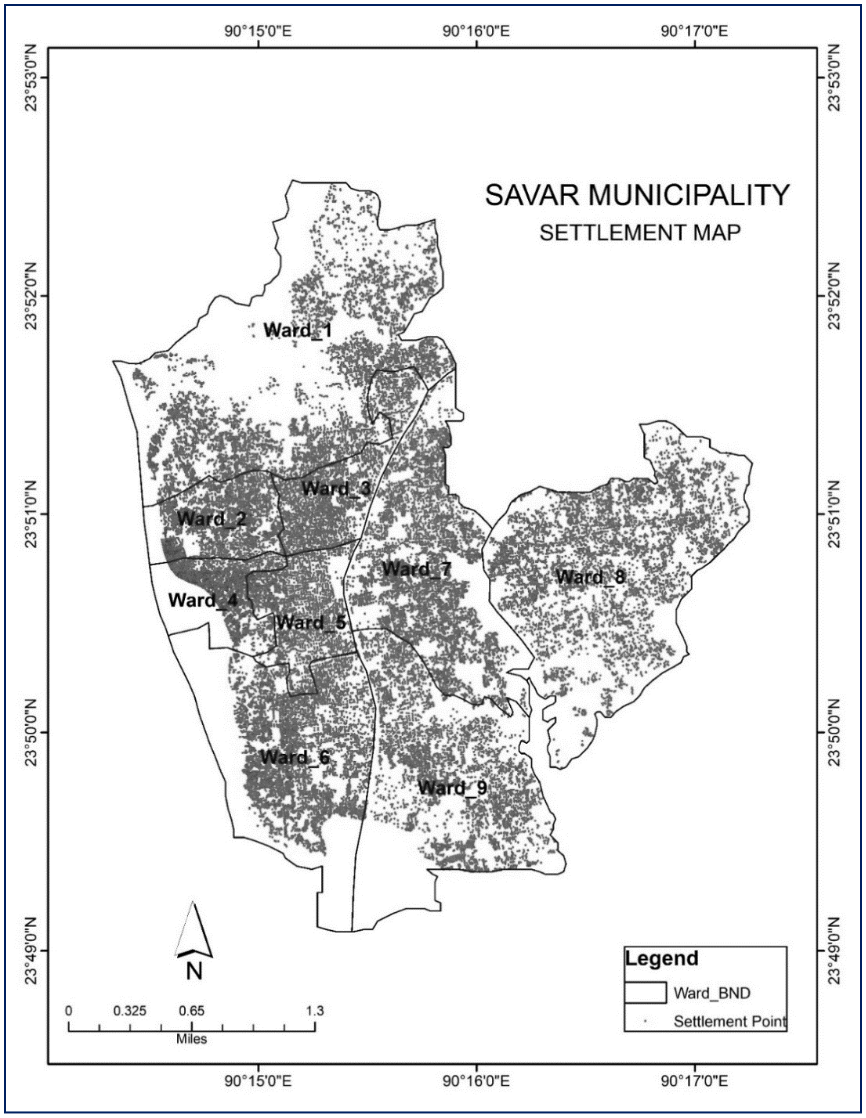
Table 1.4: NDVI DATA FOR THREE DATES OF SAVAR MUNICIPALITY (°C

Image acquisition Date	**Statistical Results**			
	Minimum	Maximum	Mean	Standard Deviation
14-03-2014	-0.033	0.472	0.177	0.075
09-03-2018	-0.036	0.429	0.177	0.076
04-03-2022	-0.043	0.491	0.176	0.076

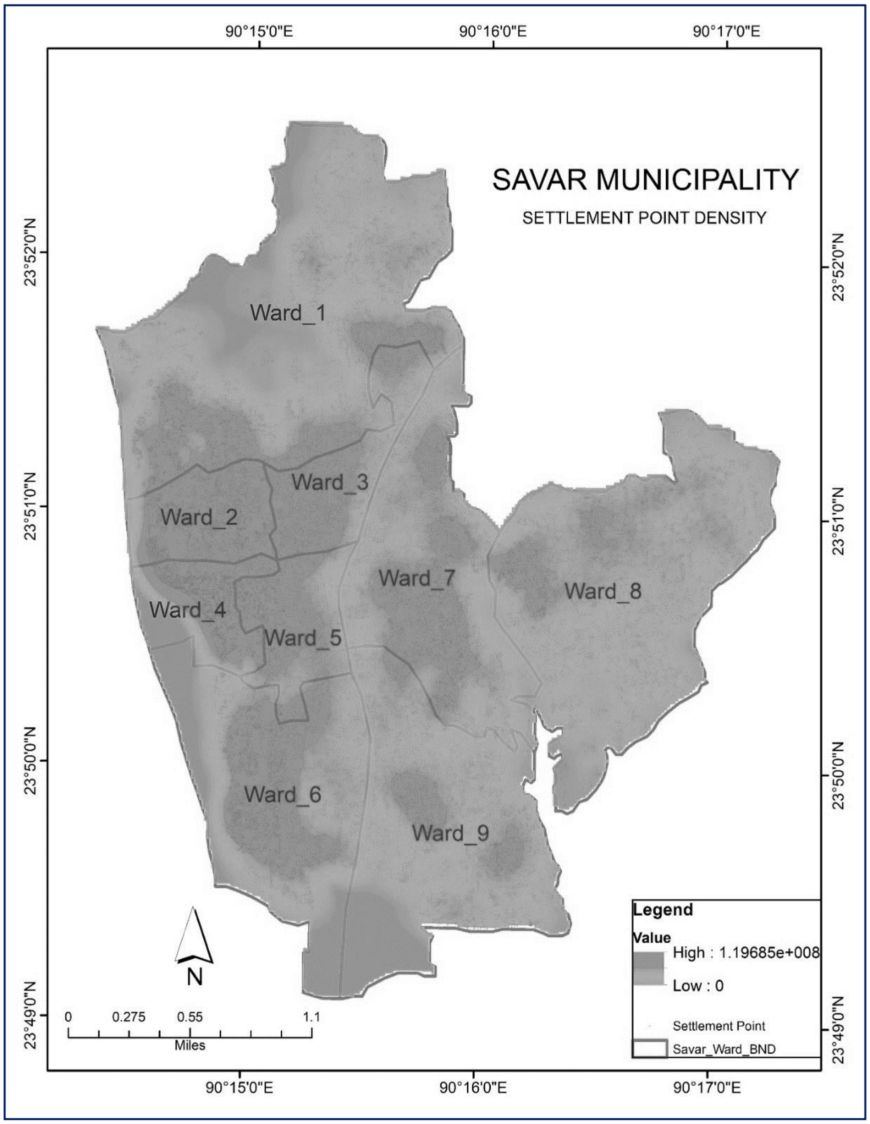
(Compiled by Author)

5.3 Building density of Savar Municipality

The Urban Heat Island effect can produce heat events, extend the duration of high temperatures, and narrow the time window for relief from high-heat exposure (Tan, J. et al., 2010). Like that Savar Municipality has a huge building density than other areas. In map 10, the settlement distribution of Savar Municipality is presented. Ward, 1,2,8,9 has less building density than other areas. The LST is also less in that particular area.

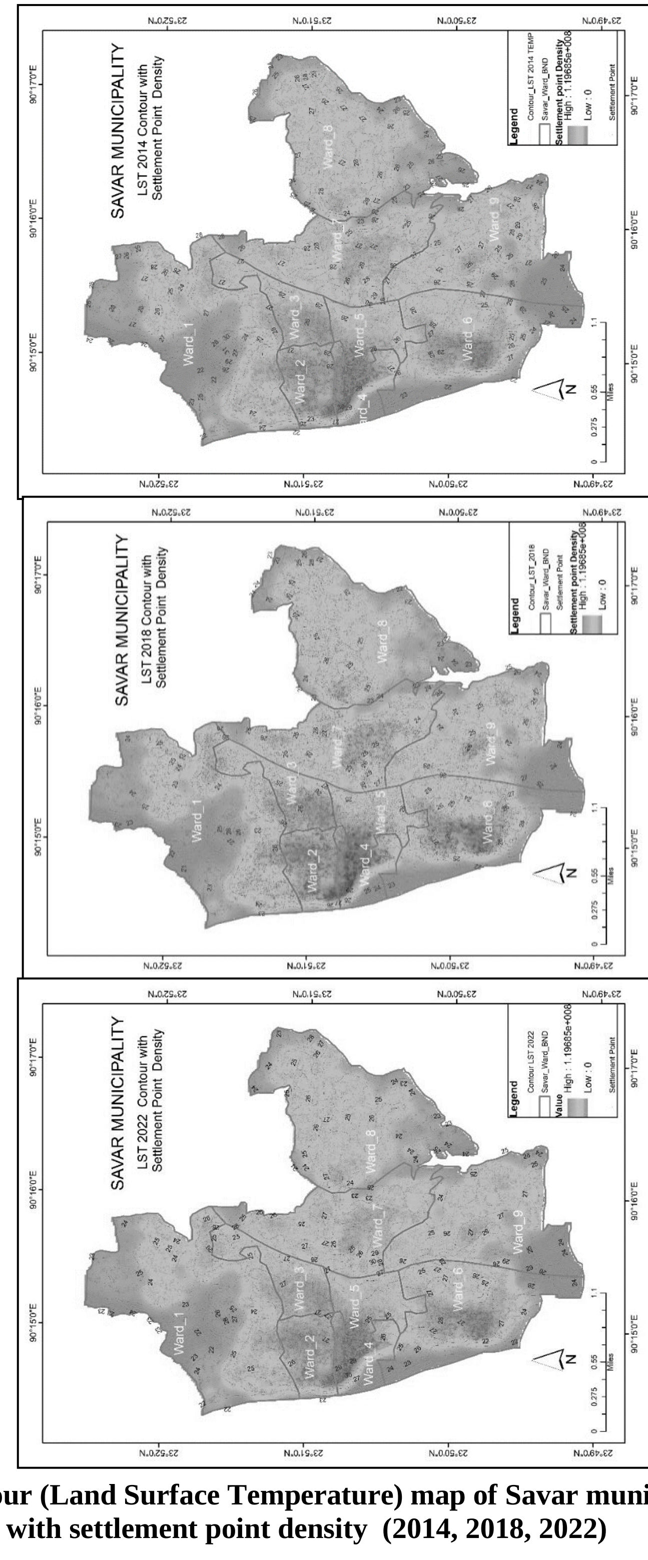


Map 1.5: Updated settlement map of Savar Municipality ,Source: (OSM Data, 2022)



Map 1.6: Point Density Settlement Map of Savar Municipality

In Map 1.6, the Settlement layer has been converted to a point. After that, analyzed the settlement point into point density to get the settlement concentration of the study area. Ward (2-6) has an increasing building concentration than other spots. These wards are located in the city hub of savar. Ward no 1,8 and 9 have less building concentra tion to the distance from the city center.



Map 1.7: Contour (Land Surface Temperature) map of Savar municipality area with settlement point density (2014, 2018, 2022)

5.4 Heat Island (UHI) and building density

Urban heat island has a strong relationship with the building density of the urban area. Guo et.al, 2020 noted that currently scholars are limited to a single factor in the exploration of surface temperature driving factors, such as population density, land use, a landscape index, a remote sensing spectral index (NDBI, NDVI, NDSI), or three-dimensional architecture.

For calculating urban building density this study used normalized difference buildup index shortly known as NDBI. Correlation methods are now being used to identify the relationship between the impact factor and Land Surface Temperature, ignoring the impacts of elements of urban properties on thermal elements (Yang et al., 2018).

Table 1.5: NDBI DATA FOR THREE DATES OF SAVAR MUNICIPALITY (°C)

Data	Statistical Results			
	Minimum	Maximum	Mean	Standard Deviation
14-03-2014	-0.357	0.137	-0.057	0.068
09-03-2018	-0.347	0.163	-0.073	0.069
04-03-2022	-0.387	0.156	-0.066	0.072

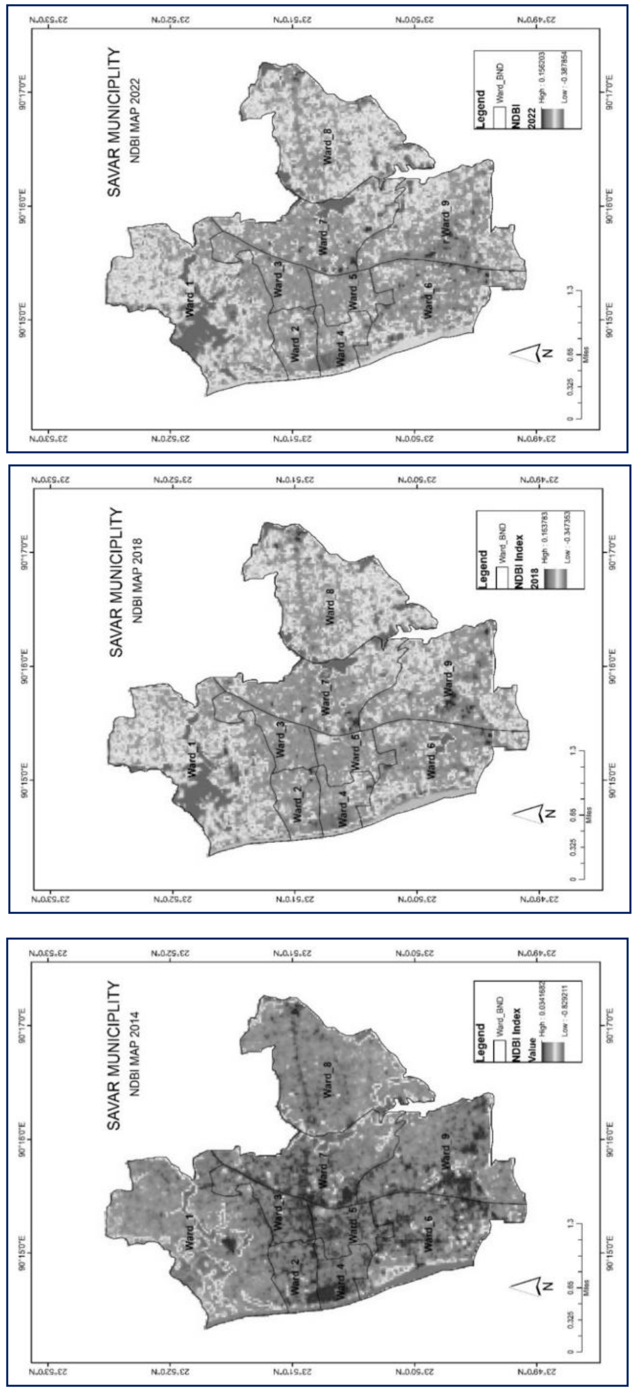
(Compiled by Author)

In table (1.5) depicted the maximum, minimum, mean, and standard deviation of NDBI values of three dates in the study area. The maximum and minimum NDBI of 14th March 2014 is 0.137 & -0.057. The mean and SD of that date are -0.057 & 0.068. The NDBI is comparatively high than the other two dates. The maximum and minimum NDBI of 9th March 2018 is 0.163 & -0.347.

i. The mean and SD of that date are -0.073 & 0.069. Again the maximum and minimum NDBI of 4th March 2022 is 0.156 & -0.387. The mean and SD of that date are -0.066 & 0.072. Due to the growing urbanization, the urban heat island has become a dominant feature of urban climate, affecting the urban dweller’s life (Guha and Govil, 2020).

ii. This study was conducted to identify the relationship between Surface temperature and the urban density including buildings and roads in the study area. For that reason buildup index is a very important component to analyze the relationship between LST and NDBI .

iii. For identifying the correlation between LST and NDBI, this study converted the raster band into a point feature and then plot it using an arc gis plotter. Here three particular image dates were assigned to create an individual graph with the trend function algorithm. The graphs are shown on the figure no 1.11 to 1.13.



Map 1.8 : Normalized Difference Build-up Index (NDBI) map of Savar municipality area (2014, 2018, 2022)

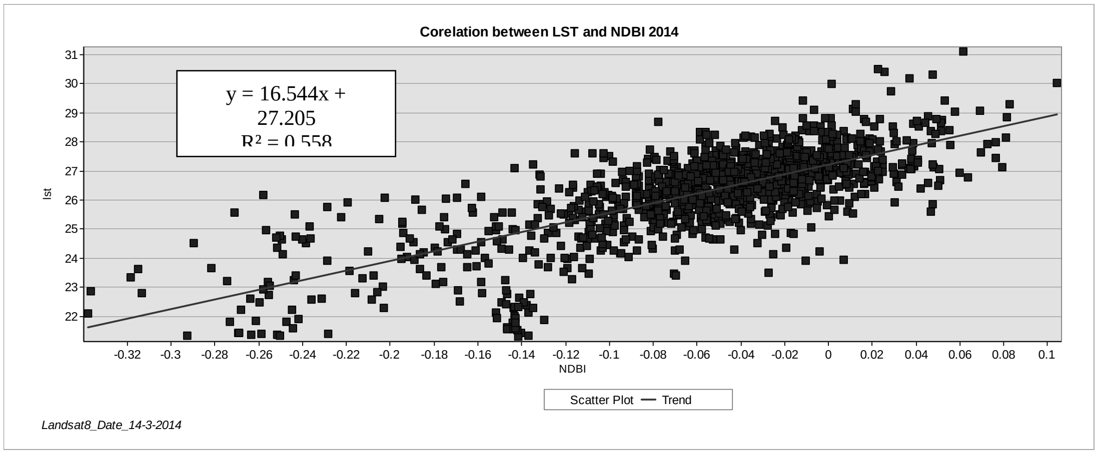


Figure 1.10: Correlation between LST 2014 and NDBI of 2014

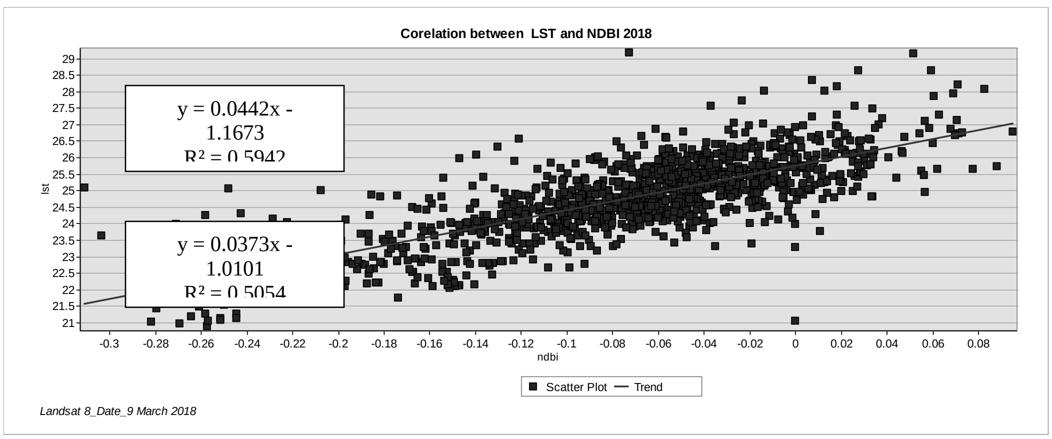


Figure 1.11: Correlation between LST 2018 and NDBI of 2018

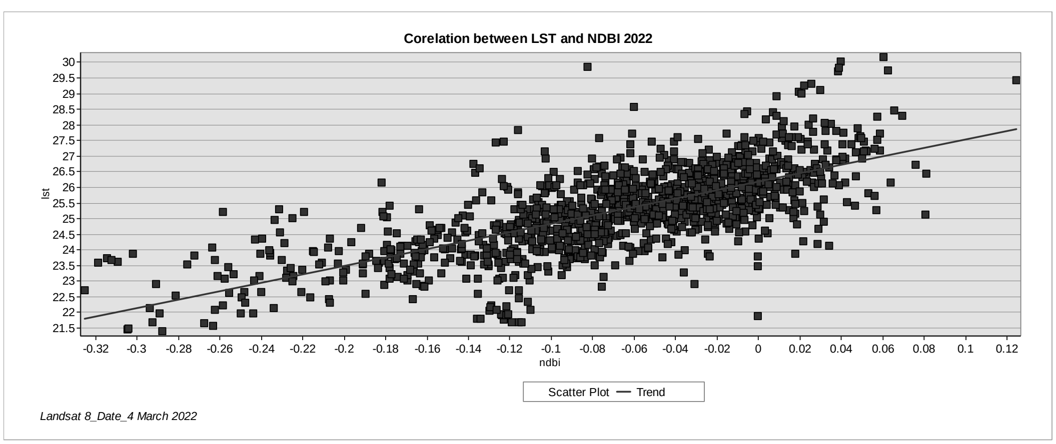


Figure 1.12: Corelation between LST 2022 and NDBI of 2022

5.5 Correlation between Land Surface Temperature and Normalized Difference Buildup Index

The strong linear relationship between the Land Surface Temperature (LST) and Normalized Difference Buildup index (NDBI) shows that urban buildup areas are responsible for most of the variation in land surface temperature dynamics. That relation has been shown in the graph (1.10- 1.12). The first graph represents the LST of 2014 and the NDBI of 2014 for the specific dates. In this graph, the increasing trend of NDBI and LST is being represented .

i. Here positive correlation exists between NDBI and LST. The maximum temperature observed in between 24^0 C to $29^{\,0}$ C where the NDBI value range was (-0.12) to (0.06). The second graph represents the correlation between the LST of 2018 and the NDBI of 2018. In this graph, the increasing trend is also shown. Here the maximum temperature observed in between 22^0 C to $27^{\,0}$ C where the NDBI value range was (-0.18) to (0.06).
ii. The last graph represents the correlation between the LST of 2022 and the NDBI of 2022. In this graph, the maximum temperature observed in between 22^0 C to $28^{\,0}$ C where the NDBI value range was (-0.14) to (0.04). Both the three graph shows the increasing trend of NDBI and LST that indicating a positive correlation. As Savar is a highly populated urban area, it was expected to affect the urban heat island in this area.
iii. In this research, It is examined that the urban heat island mostly happened in the residential and industrial zone of the study area. The surface temperature is also high in the city area where the NDBI values are high. Some places in the study areas show negative correlation between LST and NDVI, where the NDVI value is high which proved that the green cover weakens the UHI effect. At the time of analyzing the relationship between land surface temperature maps and settlement density, study found the highest value of LST is in urban areas and the lowest value is in wetlands. In the urbanized area where bare soil is very limited, LST measurements typically represent the radiometric temperatures of vegetated and non-vegetated surfaces, mainly built-up areas. The changes in the pixel may be mostly related to built-up area amounts and characteristics since vegetated surfaces vary less in temperature than city surfaces. Moreover, NDBI is highly sensitive to the settlement area. (Li Hua and Liu Qinhuo, 2008). In Map 12, Ward,1,7,8, and 6 have low NDBI values that indicate low buildup density. The LST of that particular area is also lower than in other areas.

6. Conclusion

The analysis of this study involved the utilization of remote sensing and GIS techniques, including Landsat 8 OLI + TIRS imageries and OpenStreetMap data.The results of the study indicated a clear association between urbanization and the UHI effect in Savar Municipality. The analysis of satellite imagery and land cover data revealed significant differences in LST values between urban areas and surrounding regions. The UHI effect was evident through higher LST values within urbanized zones, indicating the impact of urban development on local temperatures. This research identified the heat island of Savar municipality where urban building density is comparatively high. Mainly the central and the southern part of the study area has more building concentration with high rise building. Unavailability of the satellite image of the same dates is one of the major limitations of this study. Besides this ground temperatures data were required during the analysis but that was not available at that time. This research only used the common temperature data received from the satellite sensor. Further research could be done with analysis based on daytime and nighttime temperature. Furthermore, the investigation of urban building density using OpenStreetMap data allowed for a comprehensive assessment of the built environment. The correlation analysis revealed a positive relationship between UHI intensity and urban building density. Areas with higher building density exhibited more pronounced UHI effects, confirming the influence of urbanization patterns on local temperatures.The findings of this study have practical implications for urban planning and management in Savar Municipality. By understanding the relationship between urbanization and the UHI effect, policymakers and urban planners can develop strategies to mitigate heat island effects and promote sustainable urban development. The integration of remote sensing, GIS, and OpenStreetMap data provides valuable tools for assessing and monitoring urban heat island phenomena, enabling evidence-based decision-making. In conclusion, this research contributes to the understanding of the UHI effect and its correlation with urban building density in Savar Municipality. The utilization of remote sensing and GIS techniques, along with the analysis of Landsat 8 imageries and OpenStreetMap data, offers valuable insights into the urbanization dynamics and their impacts on local temperatures. These findings serve as a foundation for further research and provide guidance for sustainable urban planning practices to mitigate the UHI effect and promote a healthier urban environment in Savar Municipality.

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