Urban Heat Island in New York City using GIS

Introduction

Urban Heat Island (UHI) is a term used to describe a phenomenon in which metropolitan regions typically suffer much hotter temperatures than their rural surroundings.(Oke, 1982) This is mainly caused by the concentration of buildings, impermeable surfaces, and human activity in cities, which absorb and retain more heat than natural environments. The heat produced by automobiles, industrial operations, and the emission of heat from built structures are some of the factors that contribute to the high temperatures in metropolitan areas.

Geographic Information Systems (GIS) offer the opportunity for the integration of disparate datasets, such as satellite imagery, land use, and temperature data, to predict and visualise the spatial distribution of UHIs(Voogt and Oke, 2003). Researchers and urban planners can identify hotspots, examine the variables causing UHI formation, and assess the success of mitigation initiatives by employing GIS capabilities.

Background & Materials

Study Area

New York City, the most prosperous metropolis in the world, is located on the eastern coast of the USA Geographically, New York City is located between 74°00’W and 74°18’W longitude and 40°42’N and 40°51’N latitude. The Hudson River, which runs through the city to the west, and the East River, which divides Manhattan from Brooklyn and Queens, are its two primary waterways.

Data

In this study, several types of data were adopted, including Landsat 8 satellite images from USGS, Borough Boundaries from NYC Open Data, and mapPLUTO from the Department of Planning NYC. Details of the datasets were shown in the table below.

Table 1. Satellite dataset details

Satellite	Path	Row	Date	Source	Band	Application
Landsat 8	14	32	20130601	USGS	4,5,6,10	NDVI, NDBI, LST

Landsat 8	13	32	20180131	USGS	4,5,6,10	NDVI, NDBI, LST
Landsat 8	13	32	20230214	USGS	4,5,6,10	NDVI, NDBI, LST

Table 2. mapPLUTO data details

	Year	Version	Type	Application
mapPLUTO	2013	13v1	Shapefile	LULC
mapPLUTO	2018	18v1	Shapefile	LULC
mapPLUTO	2023	23v1	Shapefile	LULC

Index Clarification

A variety of factors were applied in this study, which were Normalized Difference Vegetation Index (NDVI), Proportional Vegetation Index (PVI), Brightness Temperature (BT), Error Correction (E), Top of Atmosphere (TOA), Land Surface Temperature (LST), Normalized Difference Built-up Index (NDBI), Land use and Land cover (LULC)(Faizan, 2020). They can be estimated as follows:

NDVI

The NDVI is a crucial indicator of the biomass, stress, and health of vegetation. It can be estimated by using the equation below:

$$NDVI = \frac{Band5 - Band4}{Band5 + Band4}$$

TOA

The TOA is frequently used in the context of remote sensing and climate studies to refer to measurements of solar radiation, or the Earth's energy budget, at the edge of the atmosphere before it is absorbed or scattered by the atmosphere itself. It can be estimated by using the equation below:

$$TOA = 0.0003342 * Band10 + 0.1$$

BT

In remote sensing, the BT is used to express the temperature of a radiating body, based on the assumption of blackbody. It can be estimated by using the equation below:

$$BT = (\frac{1321.0789}{\ln\left(\frac{774.8853}{TOA} + 1\right)} - 273.15$$

PVI

The PVI is a remote sensing index used to measure the density and health of vegetation on Earth's surface. It can be estimated by using the equation below:

$$PVI = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{\min}}\right)^2$$

Where $NDVI_{min}$ is the minimum value of NDVI, $NDVI_{max}$ is the maximum value of NDVI.

E

Error Correction (E) is a technique used to minimize the influence of external factors. It can be estimated by using the equation below:

$$E = 0.004 * PVI + 0.986$$

LST

The LST is the irradiative skin temperature of the soil surface, which affects how energy is distributed between the soil and the vegetation and affects the temperature of the surface air(Weng, Lu and Schubring, 2004). It can be estimated by using the equation below:

$$LST = \frac{BT}{1 + \left(0.00115 * \frac{BT}{1.4388}\right) * ln(E)}$$

NDBI

NDBI is also regarded as a significant factor and indicator of LST. It can be estimated by using the equation below:

$$NDBI = \frac{Band6 - Band5}{Band6 + Band5}$$

Methodology

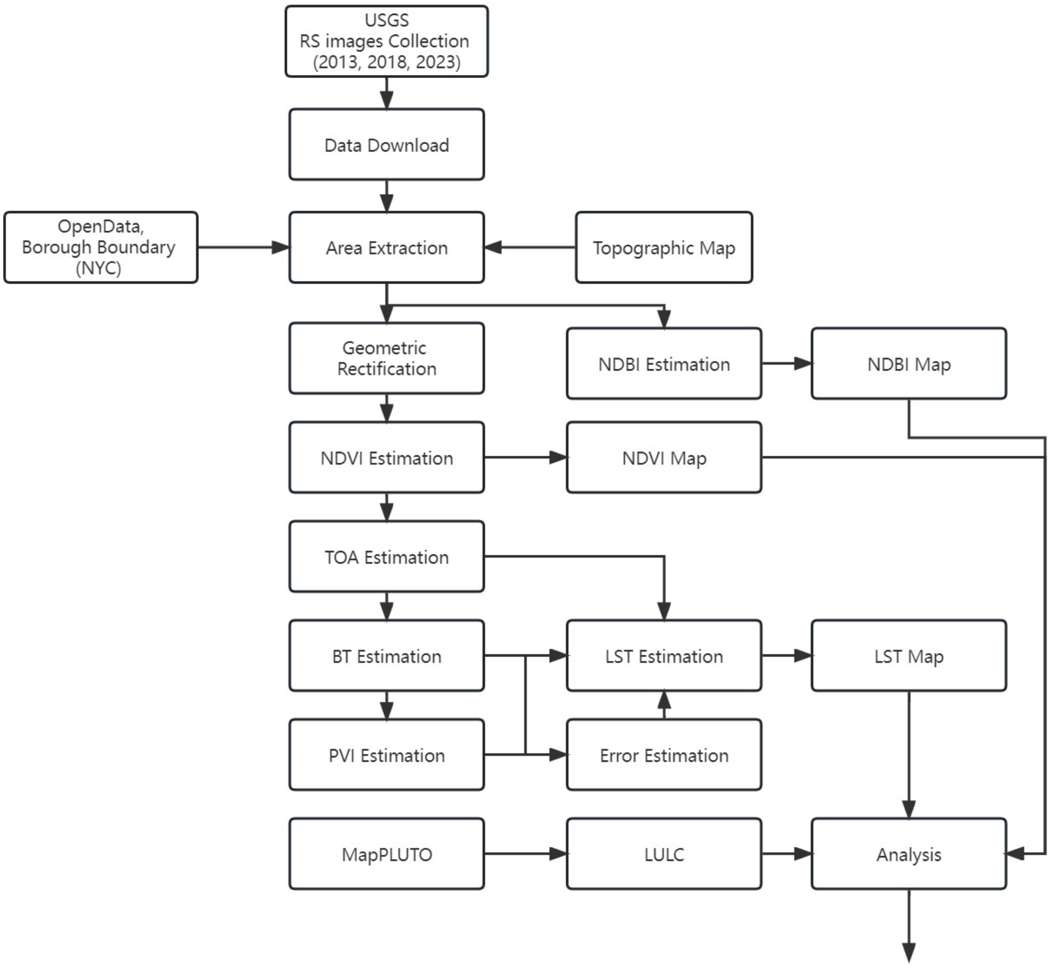

Figure 1. Workflow

Results and Discussions

NDVI

The statistical data of year 2013, 2018 and 2023 is shown in the **Table 3.**

Table 3. Statistical data about NDVI

Date	Minimum	Maximum
20130601	-0.77	0.57
20180131	-0.13	0.47
20230214	-0.16	0.50

The GIS outputs were shown as follows:

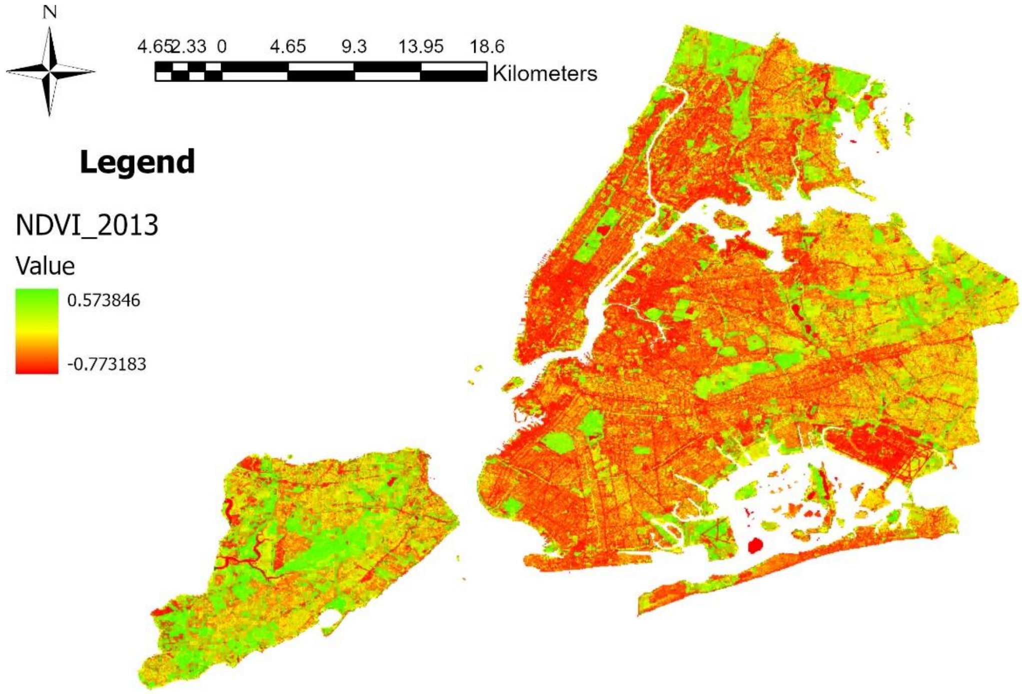

Figure 2. NDVI in year 2013

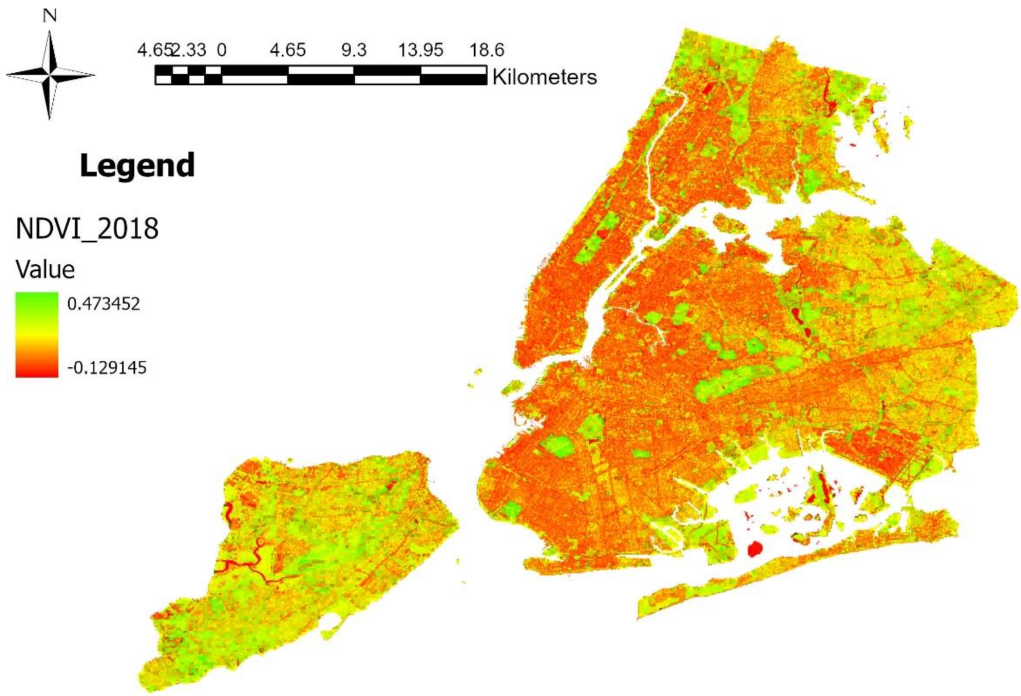

Figure 3. NDVI in year 2018

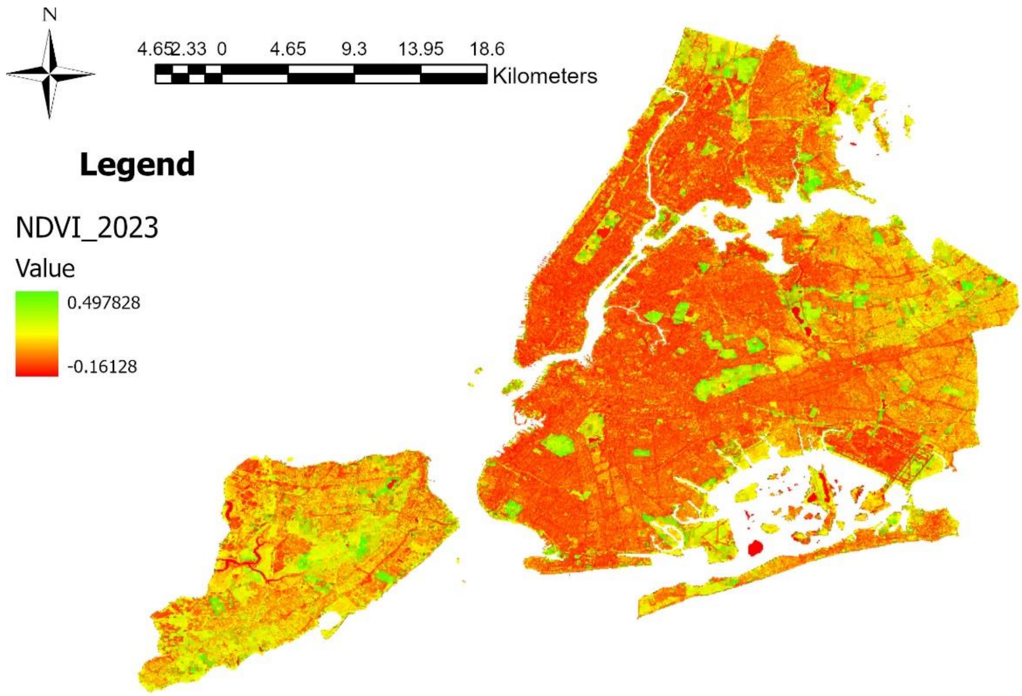

Figure 4. NDVI in year 2023

Positive values indicates areas with healthy plant cover and negative values indicates areas without vegetation cover. As shown in Figures, from year 2013 to 2023, the vegetation cover rate in New York City experienced a significant growth. However, the extent of healthy plant decreased.

LST

Table 4. Statistical data about LST

Date (F°)	Minimum	Maximum
20130601	54.69	76.92
20180131	37.19	50.84
20230214	43.61	58.19

The GIS outputs were shown as follows:

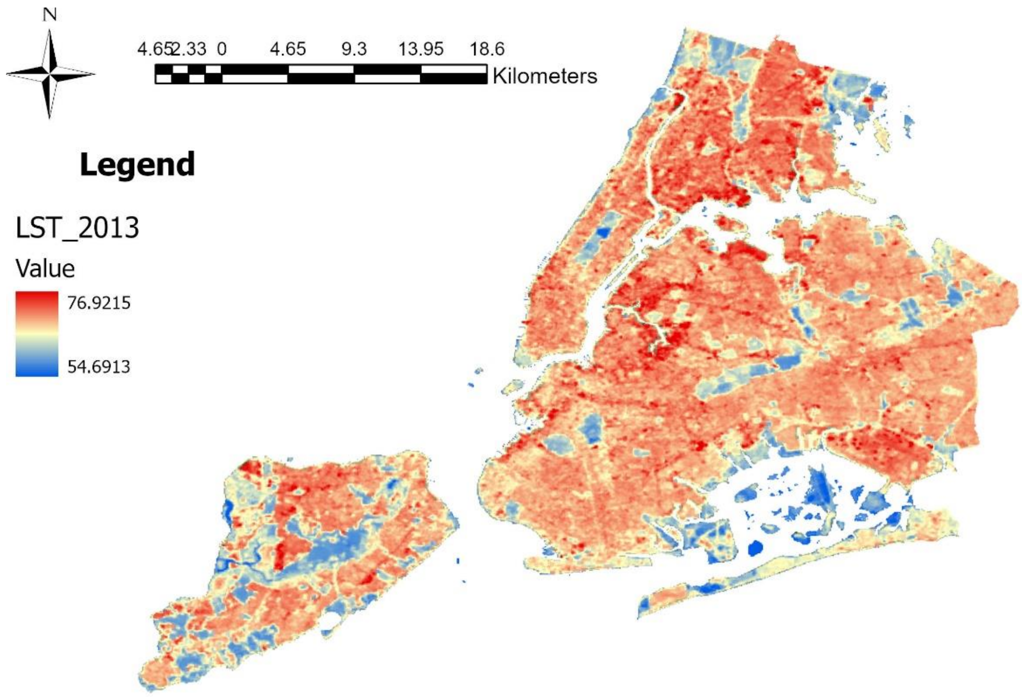

Figure 5. LST in year 2013

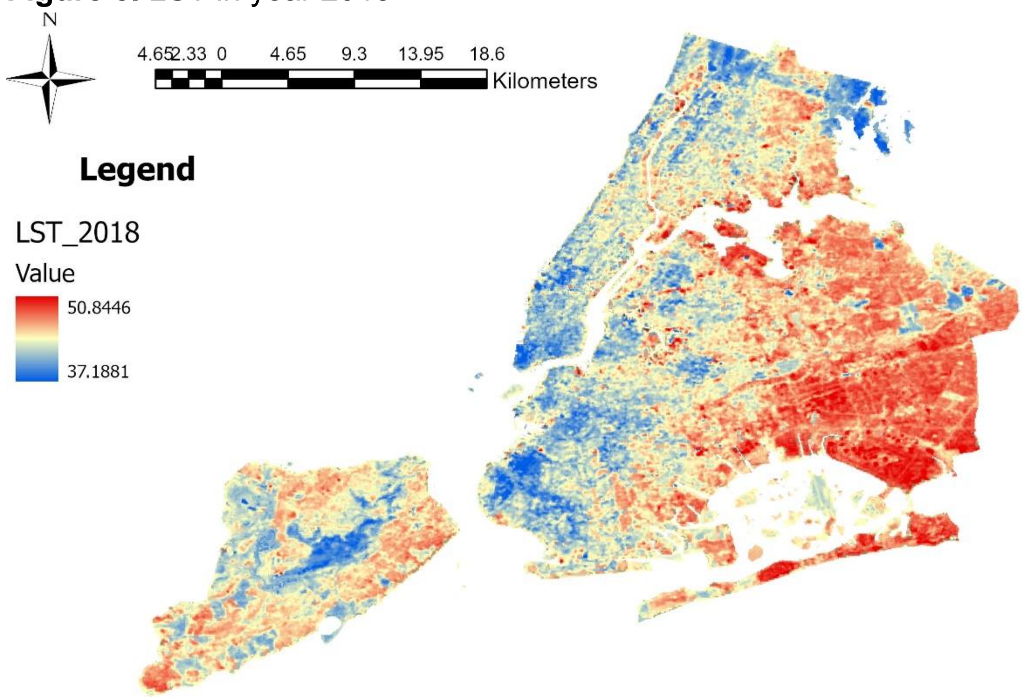

Figure 6. LST in year 2018

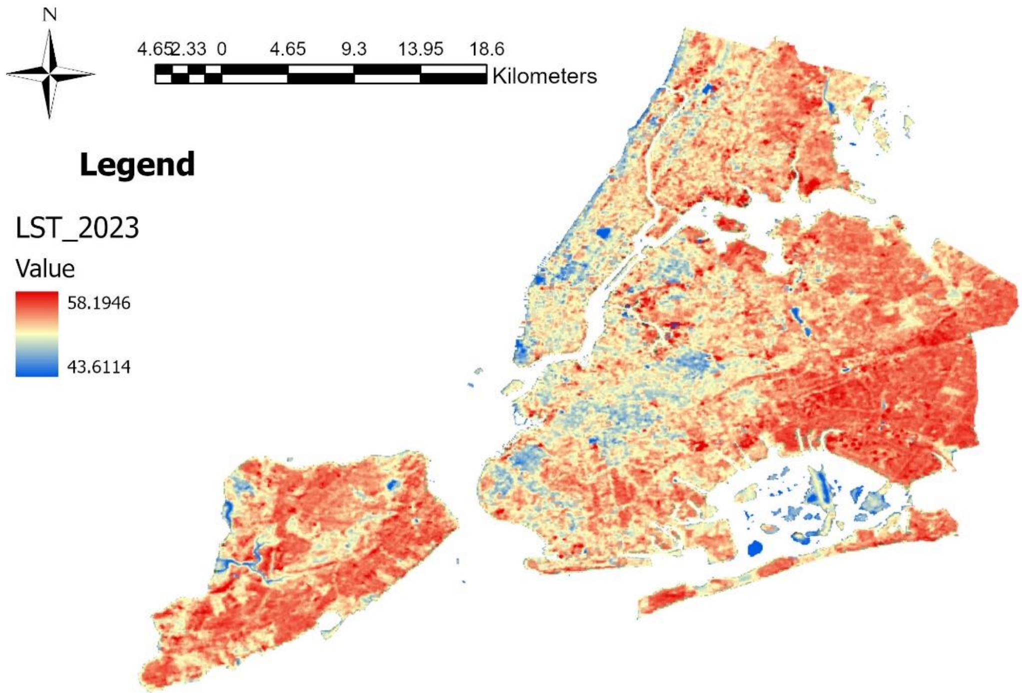

Figure 7. LST in year 2023

As shown in figures, in year 2013, the temperature was almost same throughout New York City. But in year 2018, the temperature in Manhattan and Brooklyn became much lower than other areas, that may be caused by industrial transfer.

NDBI

Table 5. Statistical data about NDBI

Date	Minimum	Maximum
20130601	-0.92	0.53
20180131	-0.56	0.72
20230214	-0.40	0.53

The GIS outputs were shown as follows:

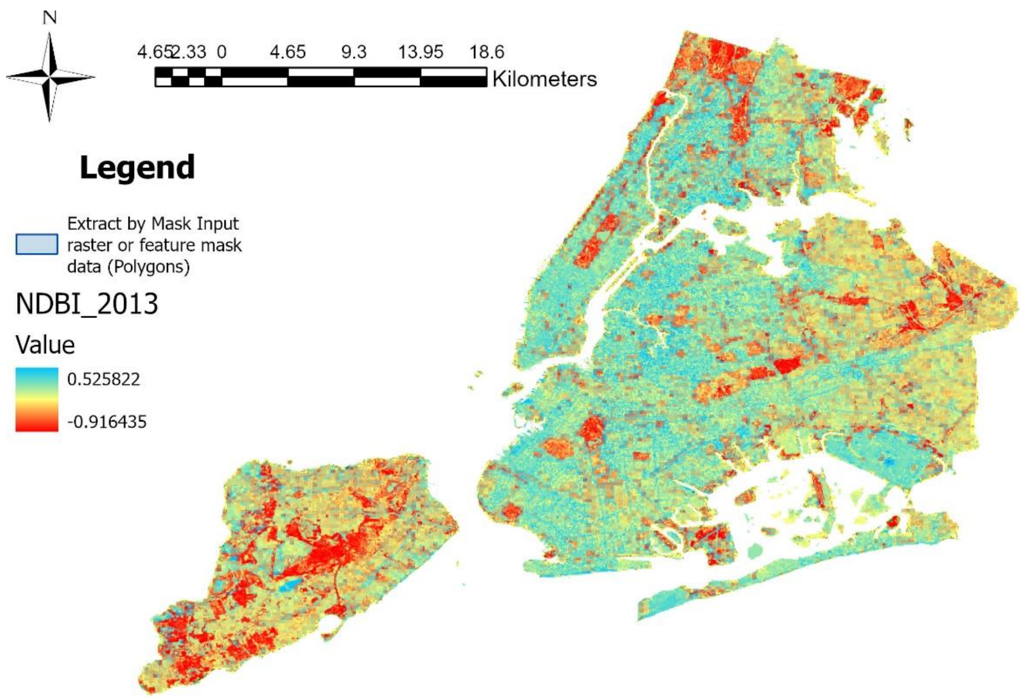

Figure 8. NDBI in year 2013

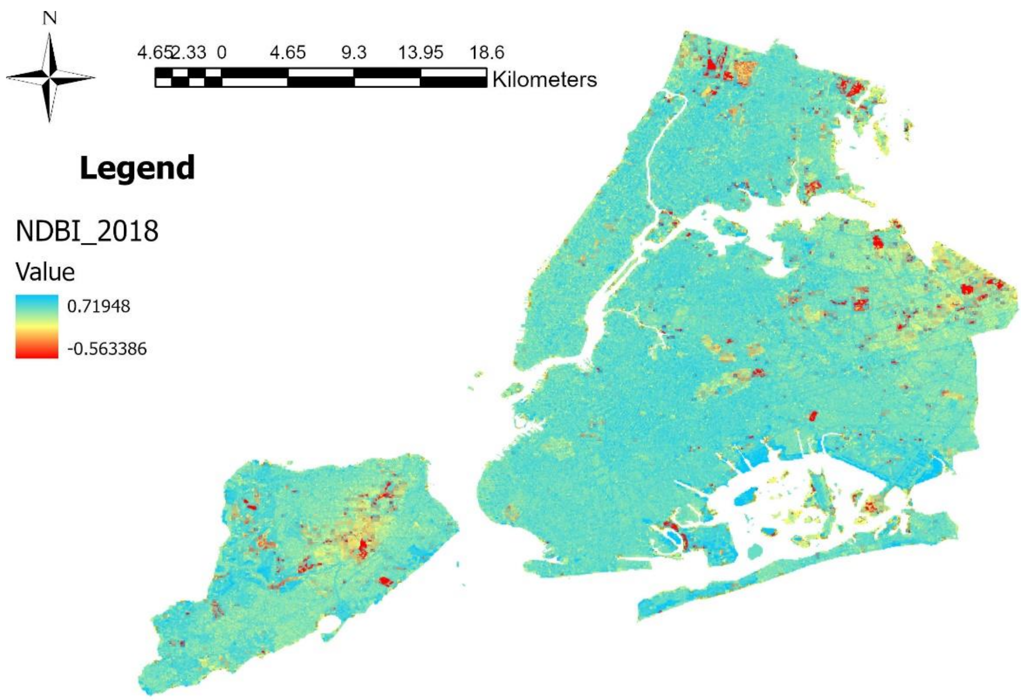

Figure 9. NDBI in year 2018

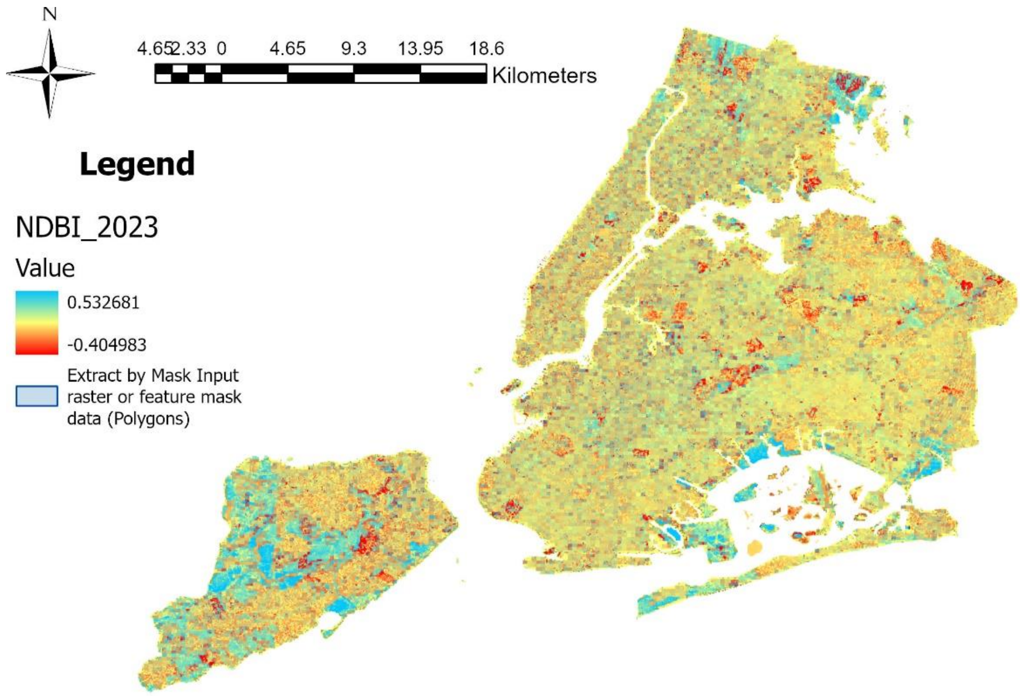

Figure 10. NDBI in year 2023

NDBI value ranges from-1 to +1. Positive values indicate heavily developed area, whereas negative values point to different types of land cover. As shown in **Figure 7.**, it can be found that a big portion of land in the Staten Island was not used for urban construction in 2013. However, until 2018, it was well developed. Possibly, the urban design here was changed.

Conclusions

In conclusion, this study used GIS to investigate the Urban Heat Island effect in New York City. We were able to observe changes in vegetation, temperature, and built-up area over time utilising indices such as NDVI, LST, and NDBI. The findings emphasise the importance of urban planning and green infrastructure in minimising the UHI effect and improving the overall urban environment for inhabitants' well-being.

References

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Oke, T.R. (1982) ‘The energetic basis of the urban heat island’, *Quarterly Journal of the Royal Meteorological Society*, 108(455), pp. 1–24. Available at: https://doi.org/10.1002/qj.49710845502.

Voogt, J.A. and Oke, T.R. (2003) ‘Thermal remote sensing of urban climates’, *Remote Sensing of Environment*, 86(3), pp. 370–384. Available at: https://doi.org/10.1016/S0034-4257(03)00079-8.

Weng, Q., Lu, D. and Schubring, J. (2004) ‘Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies’, *Remote Sensing of Environment*, 89(4), pp. 467–483. Available at: https://doi.org/10.1016/j.rse.2003.11.005.