Research Paper

Estimation of Urban Heat Islands Effect and Its Impact on Climate Change: A Remote Sensing and GIS-Based Approach in Rajshahi District.

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Abstract

In all cities around the world, the urban land surface temperature (LST) is increasing gradually. The dramatic increase in LST leads to climate change, which creates a more extended and serious urban heat island (UHI) effect. In the last few decades, massive land use/land cover (LULC) transition leads to higher LST in the city space of Rajshahi City. The dramatic decrease in greenery and water bodies and a significant increase in the urban built-up area influence UHI in Rajshahi city. This study estimates the effect of UHI using quantitative temporal, thermal GIS and remote sensing and techniques. Series of Landsat TM/OLI and ASTER images of Rajshahi collected in summer season were used to explore the variation in LST from 1998 to 2018 as well as LULC change. Also, the correlation between LST, NDBI and NDVI for the mentioned date is estimated, and the correlation coefficient is generated. The UHI effect was quantitatively defined using urban thermal field variance index (UTFVI). Results of the study indicate that there are increases in the overall LST between years 1998 and 2018. UHI phenomenon represents that total of 37.36% of the area in the study region estimated higher LST in the space of 20 years. Also, the distribution of UTFVI predominantly related to the expansion of urban built-up area during the study period. The hot spot of lower UTFVI was found in vegetation land where higher UTFVI were mainly found in the built-up areas. These higher hot spot areas are the most vulnerable to UHI effect. The findings will help the concerned authority to prepare a suitable strategy to reduce the UHI effect and improve the climate change scenario of the cities.

Keywords

Climate Change, Land use/Land cover, Land Surface Temperature, Urban Heat Island, Rajshahi District.

1. Introduction:

Climate is the most dominating factors that affect a person not only psychologically and physiologically but also hamper life behaviour and economic activities. In the case of indoors and outdoors, the climate impacts the comfort of the person significantly (Priyadarsini, 2012, Ogashawara and Bastos, 2012b). Human Settlements, as well as rapid urbanization, has significant impact on climate change. Industrial activity, road traffic, impervious pavements and so on affect significantly on atmospheric composition near urban agglomerations (Gallo et al., 1993a, Rizwan et al., 2008, Fu and Weng, 2018). In large and very populated cities, urban smog events are common characteristics where artificial cover and emitted energy are responsible for the climatic changes and actions. Therefore, Urban Heat Island (UHI) effect is the most often and common analysed phenomenon related to cites (Streutker, 2003, Poumadere et al., 2005, Gallo and Owen, 1999).

A UHI is defined as the temperature, which is warmer than its surroundings. The higher the urbanization, the higher impervious cover on surface, causes UHI effect. Natural cooling effect system has been demolished due to replacement of natural land cover with concrete, infrastructure and industrial activities, meanwhile, tall buildings and narrow streets which help to heat the air trapped between them and increases UHI effect (Speth, 2005, Poumadere et al., 2005, Weng et al., 2004). Many studies indicate that UHI has more and more severe impacts on human living environment (Weng, 2002, Weng et al., 2004, Yang et al., 2012, Ogashawara and Bastos, 2012b). Estimation indicates that more than 70% people of the world's population will live in urban areas in the next 30 years (Gallo et al., 1993b, Gaur et al., 2018, Godschalk, 2004). As a result, according to Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature will be increased around 1.4-5.8 °C by 2100 and the atmospheric carbon dioxide concentration could be twice compared to the amount of pre-industrial concentration (Rasul et al., 2015, Kafy et al., 2019a, Gaur et al., 2018, Streutker, 2002, Zhao et al., 2014). That is why the study of UHI is compulsory to manage the environment whereas remote sensing-based approach could be a better way to analyse it.

Urban Heat Island is broadly categorized into sectors such as atmospheric UHI and Surface UHI (Ogashawara and Bastos, 2012b, Randolph, 2004). This case study explores only surface UHI. The surface UHI can be measured with the help of satellite thermal remote sensing data (Poumadere et al., 2005, Streutker, 2003, Chen et al., 2006). Hence, satellite remote sensing provides a way to retrieve Land Surface Temperature (LST) by investigating thermal data. As UHI has significant dependency on LST therefore, many researchers suggest to use remote sensing data for examining most appropriate assessment of UHI (Gallo et al., 1993b, He et al., 2007, Hart and Sailor, 2009, Lai and Cheng, 2010, Bahi et al., 2016, Gaur et al., 2018, Fu and Weng, 2018, Kafy et al., 2019a).

The relation between land surface temperature changes with land use/land cover (LULC) change is investigated by many studies (Wang et al., 2010, Fabrizi et al., 2010). The comparative study between LST and LULC change allows researchers to investigate the link between UHI effect and LULC change (Fabrizi et al., 2010). There are several different types of LULC indices that have been introduced to investigate the correlation between LST and LULC changes. The commonly used indices are Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), and Normalized Difference Bareness Index (NDBaI) strongly correlate with LST (Chen et al., 2006, Liu and Zhang, 2011, Zhi-hao et al., 2011, Abutaleb et al., 2015)

The study aims to demonstrate the UHI effect by retrieving LST and LULC change indices and analysing the affecting interconnectivity among them. In case of inter-correlation, the authors analyse the correlation among LST, NDVI and NDBI which are directly incorporated with the UHI. Hence, Landsat images provide sufficient spatial and temporal resolution to investigate the changes in LULC and LST at city scale (Hart and Sailor, 2009, Roth et al., 1989, Streutker, 2003, Ahmed, 2018). Therefore, the authors considered Landsat imageries to investigate the analysis. Thus, this study utilizes Landsat images to study LST and UHI impacts in Rajshahi City area.

2. Materials and methods

2.1. Study area profile

The Rajshahi district is located in the north-west region of Bangladesh between 24°12′ to 24°42′ N latitude and 88°15′ to 88°50′ E longitude (Figure 1). Topographically, the area of Rajshahi district is almost flat with a surface elevation varies from 1 to 18 m. The area of Rajshahi district is about 2428 $km^{2,}$ and it consists of 9 Upazilas, 4 thanas, 13 Municipalities and 147 Wards. Rajshahi District predominately a tropical wet and dry climate region. The average temperature is 22-25°C and rainfall is about 1448 mm. Total land of the study area is 2422 Km^2, where agriculture, infrastructures and others constitute 394986.32 ha, 117615.42 ha and 63829.56 ha, respectively (Rajshahi Development Authority, 2008, Clemett et al., 2006, Statistics, 2013, Kafy et al., 2018). Historically Rajshahi district is known as rural agrarian community. However, after the construction of Jamuna Bridge and industrialisation, this area is significantly experiencing rapid urbanization. The rapid urbanization remarkably changed the intensity of winter and summer season during the last couple of years which is detrimental to environment, livelihood and agricultural production of this district (Kafy et al., 2019b).

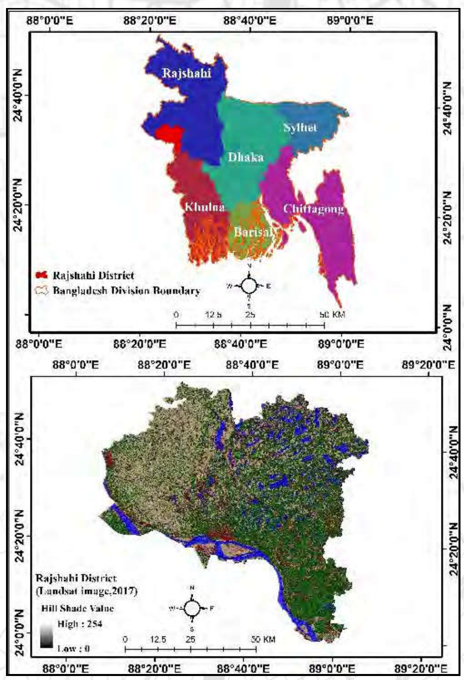

Figure 1 Location map of the study area

2.2. Methodology

2.2.1 Derivation of land surface temperature

The LST is estimated from the Digital Number (DN) values of the thermal bands (Bands 10 in Landsat 8 TIRS and Band 6 in Landsat 5 TM). At first step, spectral radiances (Lλ) of the Landsat 8 TIRS and Landsat 5 TM bands can be calculated by using the Eq. (1) and (2), respectively (Pal and Ziaul, 2017). The LST in Degree Celsius can be obtained from Lλ by using the Eq. 3 (Weng et al., 2004, Ahmed, 2018).

$$L_\lambda(Landsat\ 5\ TM) = L_{min} + \frac{L_{max} - L_{min}}{Qcal_{Max} + Qcal_{min}} \times DN \qquad (1)$$

$$L_\lambda(Landsat\ 8\ OLI) = ML \times DN + AL \qquad (2)$$

$$LST = \frac{T_B}{1+[(\lambda \times \frac{T_B}{\rho}) \times \ln(\varepsilon)]} - 273.15 \quad (3)$$

Where ML (0.0003342) is band-specific multiplicative rescaling factor, and AL (0.1) is a band-specific additive rescaling factor. The values for Landsat TM, L_{max} and L_{min} are available in the satellite header file (metadata). λ (11.5 µm) is the wavelength of emitted radiance in meters. $\rho = h \times c/_{\sigma}$ = 1.438×10^{-2} mK (where h indicates Plank's constant which is equal to 6.626×10^{-34} Js, c indicates the velocity of light, which is equivalent to 2.998×10^{8} ms^{-2} and σ is the Boltzmann constant (5.67×10^{-8} Wm^{2}k^{-4} = 1.38 ×10^{-23} JK^{-1}). ε is the land surface emissivity which is ranged between 0.97 and 0.99.

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)} \quad (4)$$

In equation 4, T_B is the satellite brightness temperature (Hart and Sailor, 2009, Rasul et al., 2015, Gaur et al., 2018, Kafy et al., 2019a), K1 and K2 are constants of band-specific thermal conversions in metadata (Landsat-5 TM: K1 is 607.7 and K2 is 1260.6 and Landsat 8 TIRS: K1 is 774.9 and K2 is 1321.07).

2.2.2 Retrieving of urban heat island (UHI):

To compare the LST of three different years, a normalisation procedure was performed in equation 5 to estimate UHI (Abutaleb et al., 2015):

$$UHI = \frac{LST - LST_m}{SD} \quad (5)$$

Here, UHI means urban heat island, LST_m represents the mean temperature of the land surface temperature, SD means standard deviation of temperature. Finally, UHI effect is described performing urban thermal field variance index (UTFVI). It can be calculated as the following equation (Liu and Zhang, 2011, Zhang et al., 2006, Ahmed, 2018):

$$UTFVI = \frac{LST - LST_m}{LST} \quad (6)$$

Considering six different ecological indices suggested by (Ahmed, 2018, Zhi-hao et al., 2011, Chen et al., 2006) UTFVI was divided into six levels.

Table 1 Threshold values of UTFVI

UHI Phenomenon		UTFVI	Ecological Evaluation Index
None	Low	<0	Excellent
Weak		0 – 0.005	Good
Middle	Moderate	0.005 – 0.01	Normal
Strong		0.01 – 0.015	Bad
Stronger	High	0.015 – 0.02	Worse
Strongest		>0.02	Worst

2.2.3 Classification and retrieving of LULC

The land-use types were divided into four broad categories which are water bodies, built-up areas, vegetation cover and bare land. The training areas are determined, and the maximum likelihood supervised classification (MLSC) algorithm was used for the image classification. The accuracy assessment of land use classification (overall accuracy, Kappa coefficient, and accuracy validation) was applied. The detail MLSC method was described in the previous study (Kafy et al., 2019b, Kafy et al., 2018) . For accuracy assessment, randomly 350 points were selected for evaluating each classified map using Google Earth images.

3 Result and Discussion

3.2 LULC change analysis

In this present scenario urbanization is the most vital and active forces that derive LULC cover changes and impact climate warming (Mosammam et al., 2017, Hu, 2007). Four local factors (Waterbody, build-up, vegetation, bare soil) have been generated to carry out the objective of the study area. Figure 2 retrieved LULC of the study area. From this figure, it can be easily perceived that a large number of water bodies disappear in 2008 and 2018 from the year 1998 which transform into either vegetation or build-up area. A significant portion of bare soil (alluvion) also appears in 2018 that was remain in water body (river) in 1998. Decreasing vegetation cover and increase in concrete impervious surface modifies thermal process in urban regions, thus creating 2^{o}C to 4^{o}C warmer regimes than rural areas (Ogashawara and Bastos, 2012a, Pal and Ziaul, 2017).

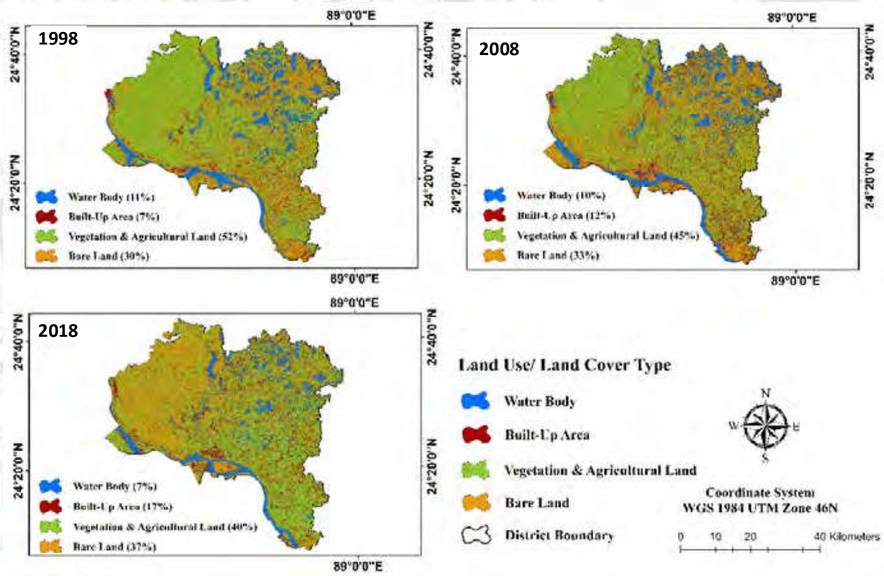

Figure 2 Classified LULC types of the study area

Form Table 2 it easily emphasised that the vegetation area was 50.8% in 1998 and in 2008 it changes about 3.9 % and in 2018 it's about 4.03% to other LULC types. This reduction generates extra 6^{o}C mean temperature (see figure 2) at build-up area as urban area expansion. From the table below it can clearly perceive the condition of bare soil LULC type. In 2008 this type of LULC decreased to 0.5 % and transformed towards either vegetation or build-up area. Again in 2018 this type of LULC increased to 4%. It means the alluvion condition on the bank of Mighty Padma

Table 2 Percentage of Area under different LULC in different periods.

	Area (Km^2)				
Name	**1998**	**2008**	**Changes in % (2008-1998)**	**2018**	**Changes in % (2018-2008)**
Water Body	301.9	272.3	-1.2	269.2	-0.13
Build Up Area	178.2	316.9	5.7	320.1	0.13
Vegetation	1232.5	1137.2	-3.9	1039.5	-4.03
Bare Soil	709.8	696.2	-0.5	793.8	4.03

3.3 LST distribution in the study area

Figure 3 and 4 indicate a spatial pattern and area distribution of LST in three phases, e.g. 1998, 2008 and 2018. In all maps, bright reddish tone highlights higher temperature and bluish tone low LST. These spatial patterns of LST concentration and temporal shift LST pattern highlights rapid change of LULC classes.

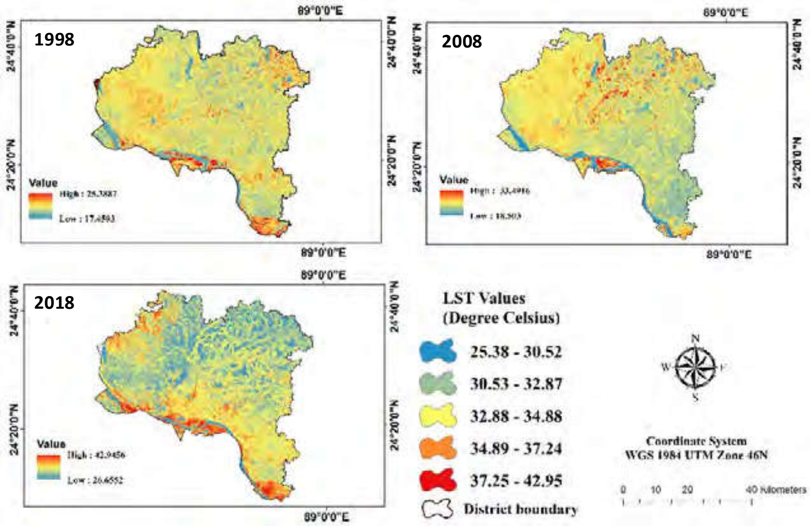

Figure 3 LST distribution in the study area

Usually, LST was confined within the range of 17–25^0 C during 1998, 18-33^0 C during 2008 and 26-42^0 C during 2018. Out of total area (2428 km^2), 40.28% area represents temperature from 28 - 30^0 C in 1998 followed by 44.05% area in 2008. Core urban area is sensitive to high temperature. From 1998 to 2018 the temperature was heaved up to, and 37.63% area was faced 37-39^0 C temperature in the year 2018. This growth is entirely arithmetic, but more realistic temperature growth calculated using spatial average indicates that about 17^0 C LST has increased since 1998–2018. The northeastern part of the study area exhibits lowering in temperature due to higher vegetation and agricultural land whereas the southwestern part exhibits the rise in LST due to rapid urban expansion and declining of water bodies as well as vegetation cover.

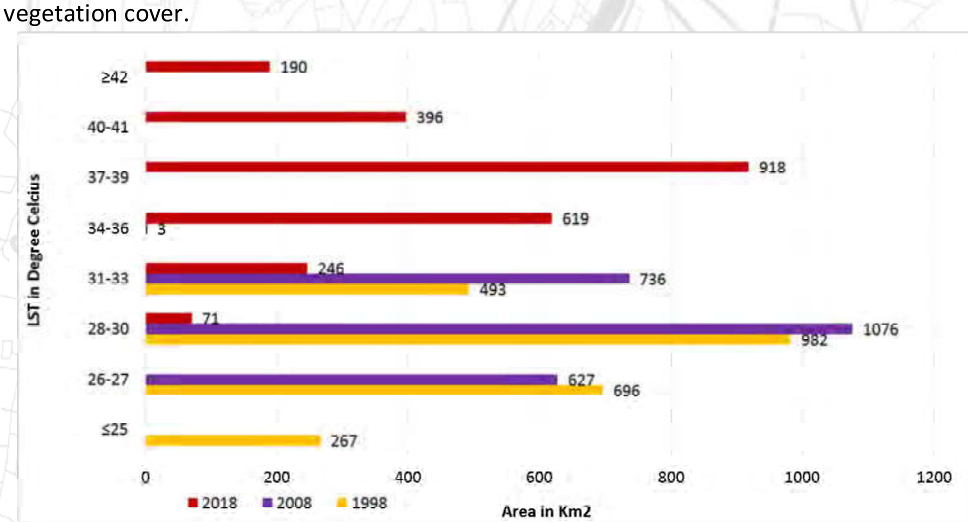

Figure 4 Area wise LST distribution

3.4 LULC change and its association with LST distribution

Statistical analysis was conducted in order to estimate the association between LST and LULC. Using a lot of different methods, many authors documented this association (Ahmed, 2018, Pal and Ziaul, 2017). Figure 5 represents the LULC wise LST distribution for 1998,2008 and 2018. From the figure it was found that urban core area with dominant built-up land experienced 24^{0}C in 1998, 33^{0}C in 2008, and 41^{0}C LST in 2018 respectively. Also, high LST recorded 24^{0}C, 31^{0}C and 40^{0}C for bare soil in three different years. Associate with the built-up area and bare land other two land use (water bodies and vegetation & agricultural land) recorded the lowest temperature ranging from < 19^{0}C - <33^{0}C. The minimum temperature recorded for water bodies (19^{0}C,21 ^{0}C and 30^{0}C) followed by vegetation & agricultural land (21^{0}C,23 ^{0}C and 33^{0}C) in three different years. Following that, the maximum temperature recorded for the year 1998 in bare land (24^{0}C) and 2008 and 2018 in built-up areas (33^{0}C & 41^{0}C).

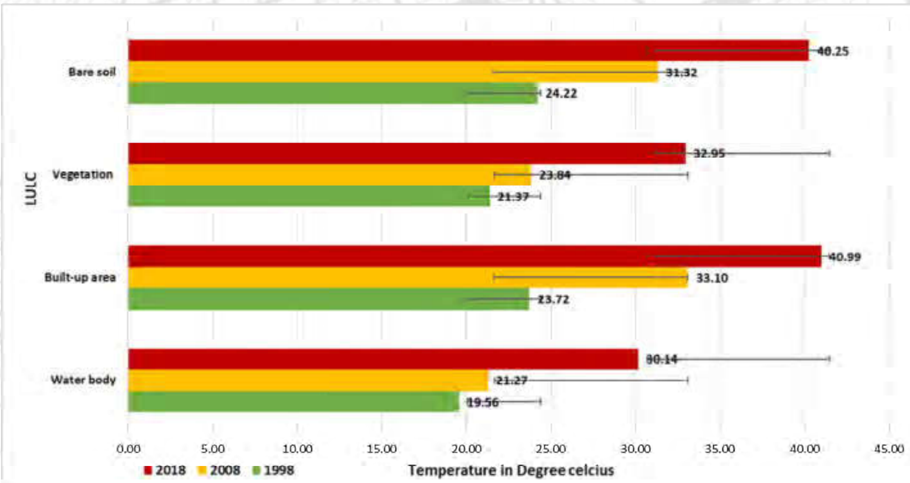

Figure 5: LST distribution for each LULC types for 1998, 2008 and 2018.

3.5 UHI effect estimation:

The present research was paid attention to the ecological evaluation phenomenon that is influenced through the UHI. To retrieve the UHI effect, Urban Thermal Field Variance Index (UTFVI) was performed (Figure 6). As much of terrain in Rajshahi district is agricultural land to orchard especially mango, litchi and betel leaf. Less than 20% terrain was brought out under development. Most of the remaining undeveloped parcels were either vegetation or bare soil. Therefore, during 1998 UTFVI shows excellent ecological evaluation index. Only 30% land shows worst index. Due to scatter and leapfrog development in Rajshahi district, the urban expansion occurred to southeast side of the district during 2018. This concentrate and haphazard urban development lead beyond the control and to the demoted eco-environment situation with worst evaluation index. During 2018 the upper side of Rajshahi district shows excellent evaluation index due to the implementation of several projects by Barind Multipurpose Development Authority (BMDA). From 1996 to 2006 BMDA implemented eco-system management project, under which 5.55 lakhs afforestation, 43 excavation of pond, 16.50 Km canal excavation, 11 cross dam construction, 430 mini ditch excavation, 9 eco-village establishment, and 1 mini eco-park establishment has been initiated. The output has come into visible in 2018 (BMDA, 2006).

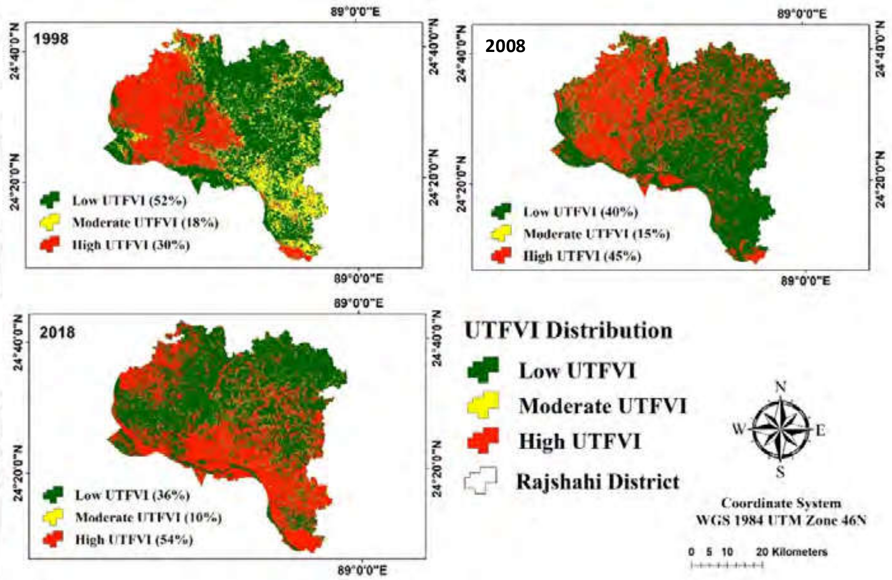

Figure 6 The UTFVI classification map of ecological evaluation in Rajshahi District

4 Conclusion

Based on the Landsat images of 1998, 2008, and 2018, we examined the trend of LULC and LST changes and fluctuation of UHI in Rajshahi district, Bangladesh. From the results, it was found that the built-up area was increased from 1998 to 2018 about 165 km^2, where 188 km^2 vegetation areas were lost. LST shows a rapidly growing trend in city areas, while in regions occupied by water bodies and vegetation shows a decreasing trend. In the last 20 years, LST was increased about 17^0 C, and 37.63% area was faced 37-39^0 C temperature in the year 2018. Important to mention is that rapid urbanization is the crucial driving process of LULC and LST changes and subsequent rise of UTFVI.54% of the study area was faced high UTFVI effect in 2018 which is only 30% and 45% in 1998 and 2008 respectively. Without implementing a radical decentralisation strategy, it is difficult to prevent the rise of UTFVI. A massive increase in UHI can damage the human health and components of the ecosystem. The local government, urban planners and environmental engineers of Rajshahi can consider the rapid urban growth and the formation of UHI based on the results in this study. The results also give the updated and improved understanding for the urban planners in developing an inclusive climate resilience policy to make a city more sustainable.

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