Research Paper

Using Geographic Information System and Remote Sensing Techniques in Environmental Management: A case study in Cumilla City Corporation

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Abstract

Geographic Information System (GIS) and Remote sensing (RS) play a crucial role in land use/land cover (LULC) estimation, environmental planning and management. Effective management of the environment plays a crucial role in maintaining a sustainable ecosystem and biodiversity. Cumilla City Corporation (CCC), located in the southern region of Bangladesh, faces rapid urban growth and as a result, massive LULC conversation takes place, which creates a negative impact on the environment. The aim of this study is to estimates the different LULC indexes such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Built-up Index (NDBI) and Normalized Difference Bare Soil Index (NDBSI) to measure the environmental condition in CCC area. NDVI and NDWI value give an estimation of the proportion of vegetation and water bodies while NDBI and NDBSI indicate the ratio of built-up area and bare land in the study area. Three Landsat satellite images (Landsat 4–5 TM for 1998 & 2008, and Landsat OLI for 2018) were used to estimate the different LULC indexes using GIS and RS techniques. All the indexes were calculated using Near-Infrared, Short Wave Infrared, Red, Green, and Blue bands. The result suggests that rapid and moderate increase in NDBI and NDBSI value, and a significant decrease in NDVI and NDWI value, respectively. The built-up area replaces almost 21% of vegetation land and 3% of water bodies in the last 20 years. The study provides an appropriate solution in decision making for making cities sustainable and environmental friendly using GIS and RS technologies.

Keywords

LULC, Landsat Images, Environmental management, Cumilla City Corporation (CCC)

1. Introduction:

The use of remotely-sensed data has been widespread in natural resource mapping as well as environmental processes modelling, managing and monitoring in recent years (Ahmed, 2018, Weng and Larson, 2005, Wu et al., 2000). Remotely sensed data is now frequently available from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions which can be applied in multiple fields (Melesse et al., 2007). It has become a great source of data as a scene cover larger area with a lot of spectral information (Faisal and Khan, 2018). Besides, maximum remote sensing works have been focused on environmental management issues over the past decades with the advancement of availability of high-resolution images (Melesse et al., 2007).

The urban landscape is a component of the environment which characteristically a complex mixture of roads, buildings, parking lots, garden, cemetery, soil, water, and so on. To create the spatial complexity of ecological systems, each urban surface exhibits a unique thermal, radiative and moisture properties, and relates to their surrounding site environment (Oke, 1982). For better understanding of the dynamics of patterns, processes and interaction in heterogeneous landscapes, ability to accurately enumerate the spatial pattern of the landscape and its temporal changes is obvious(Wu et al., 2000). For identifying the dynamic changes, it is necessary (1) to define the components by having a standardized method, and (2) to conduct a map in repetitive and consistent ways and so the model of urban morphology could be globally developed and monitored (Ridd, 1995).

Furthermore, to identify the dynamic urban morphology, some mathematical indices have been invented which are globally accepted and widely used (Gandhi et al., 2015, Mishra and Prasad, 2015, Yengoh et al., 2015). Hence, there are many vegetation indices for detecting the worth condition of vegetation cover, vegetation structure and leaf distribution using satellite images (Zhao et al., 2014). The most popular and widely applied vegetation index is termed as Normalized Difference Vegetation Index (NDVI) which is relied on the red and near-infrared band combination (Gascon et al., 2016).

Additionally, in the assessment of water resources, the monitoring of water bodies extraction has become a necessary task. To do so, Normalized difference water index (NDWI) is an index that was developed by McFeeters to delineate the water features using satellite images (McFeeters, 1996). Generally, to describe water features while reducing the appearance of vegetation and soil features, the NDWI uses near-infrared (NIR) and middle infrared (MIR) radiation (Gao, 1996, McFeeters, 1996).

Moreover, urbanization is one of the most critical land cover change factors as it increases the loss of agricultural lands by converting it to urban areas (Morawitz et al., 2006, Pu et al., 2006). Information on the urban built-up area is needed to detect land use/land cover changes (LULC) (Singh et al., 2017). For detecting dynamics of urban built-up area, Normalized Difference Built-up Index (NDBI) index is widely used (Zha et al., 2003).

Normalized Difference Bare Soil Index (NDBSI) is a useful index which is built by Zhao & Chen (2005) for distinguishing bare-soil from similarly built-up and vegetation using satellite images. The index relies on a strong reflection of TIR radiation and near-total absorption of middle infrared (MIR) wavelengths by bare-soil (Chen et al., 2006; Morawitz et al., 2006).

In this study, using a combined approach of Remote Sensing and GIS technologies, four different necessary environmental components such as vegetation, waterbody, built-up land and bare soil are monitored, and their extent of changes are evaluated. Thus, the study can give a complete environmental profile to manage ecological components and ensure environment sustainability in Cumilla City Corporation area.

2. Materials and Methods

2.1. Study area

Cumilla district is bounded by Brahmanbaria District in north, by Feni and Noakhali Districts in south, by Narayanganj District, Munshiganj and by Chandpur Districts in west and Tripura State of India in the east. It lies between 23°02' and 23°48' north latitudes and between 90°38' and 91°22' eastern longitudes. The total area of the district is 3146.30 Km^2 (1214.79

sq. miles) with an estimated population of 5387288 people (Statistics, 2011, Kafy and Ferdous, 2018). Cumilla City Corporation was established on the 10th of July 2011 (Statistics, 2011). The Cumilla City Corporation is situated on the bank of Gumti River. The city is also known as the hub of road communication of the eastern part of Bangladesh. The Cumilla City Corporation area has not uniform topographical features. The location of Cumilla City Corporation area is shown in Figure 1. The area experiences mixed type of topography. Also, the land of the area is not flat rather undulated. The elevation of city's area varies from 9.29 m to 16.58 m (Corporation, 2017). The city corporation area includes hilly tracks with brown, light brown and dark brown granular sandy silts or clayey silts. The soil condition of the city is very acidic and hard. Also, soaking condition of soil is ranged from very high to moderately good. Besides, the area has a condition of high to medium risk of flash floods and erosions (Department, 2014).

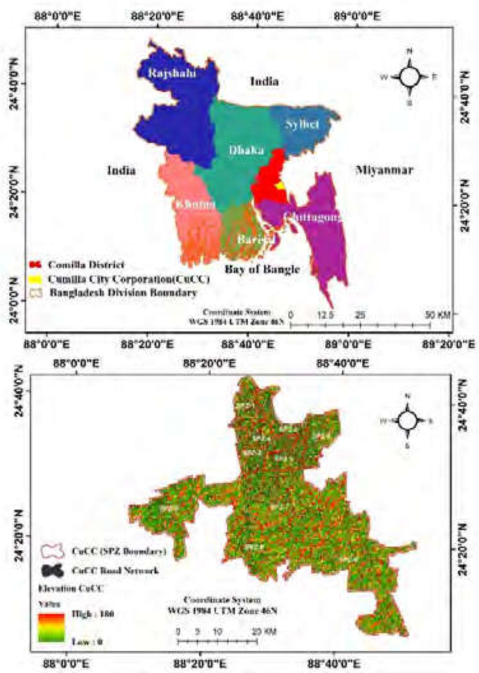

Figure 1 Location map of the Cumilla City Corporation

2.2. Methodology

In order to identify the environmental changes of the study area, three Landsat satellite images (Landsat 4–5 TM for 1998 & 2008, and Landsat OLI for 2018) were used. Environmental assessment can be done by analysing different indices such as NDVI, NDWI, NDBI and NDBSI using satellite images. As mentioned earlier, Landsat images are used to determine the index in different periods. The sequential methods of determining the value of indices are given as follows.

2.2.1 Determination of Normalized Difference Vegetation Index (NDVI):

The calculation procedure of NDVI is based on the red band and near-infrared (NIR) bands. According to Gascon et al., 2016 and Yengoh et al.,2015 the formula of calculating NDVI is given as below equation (1) (Gascon et al., 2016, Yengoh et al., 2015).

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

For Landsat (4-5) images, band 3 and band 4 are the RED and NIR bands, respectively. Additionally, in the case of Landsat 8 images, band 4 and band 5 are RED and NIR bands, respectively.

2.2.2 Determination of Normalized Difference Water Index (NDWI):

NDWI relies on near-infrared (NIR) and Short-wave Infrared (SWIR) bands. The formula of delineating water features while reducing the appearance of vegetation and soil features in terms as NDWI is given as equation (2) (Abutaleb et al., 2015).

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

For Landsat (4-5) images, band 4 and band 5 are the NIR and SWIR bands, respectively. Also, in the case of Landsat 8 images, band 5 and band 6 are the NIR and SWIR bands, respectively.

2.2.3 Determination of Normalized Difference Built-up Index (NDBI):

For determining the built-up scenario of an area NDBI is used. It also relies on near-infrared (NIR), and Short-wave Infrared (SWIR) bands as same as NDWI but equation is different. The formula of retrieving NDBI is given as the following equation (3) (Rouse Jr et al., 1974).

$$NDWI = \frac{SWIR - NIR}{SWIR + NIR} \quad (3)$$

In the case of Landsat (4-5) images, band 4 and band 5 are the NIR and SWIR bands, respectively. In, addition, for Landsat 8 images, band 5 and band 6 are the NIR and SWIR bands, respectively.

2.2.3 Determination of Normalized Difference Bareness Index (NDBSI):

NDBSI is a function of Red, Blue, near-infrared (NIR) and Short-wave Infrared (SWIR) bands to delineate bare soil from environmental morphology. The following equation (4) describes the formula for determining NDBSI (Mfondoum et al., 2016).

$$NDBSI = \frac{(RED + SWIR) - (NIR + BLUE)}{(RED + SWIR) + (NIR + BLUE)} \quad (4)$$

In the case of Landsat (4-5) images, band 1, band 3, band 4 and band 5 are the Blue, Red, NIR and SWIR, respectively. Also, for Landsat 8 images, band 2, band 4, band 5 and band 6 are the Blue, Red, NIR and SWIR, respectively.

3. Result and discussion

3.1. Normalized difference vegetation index (NDVI)

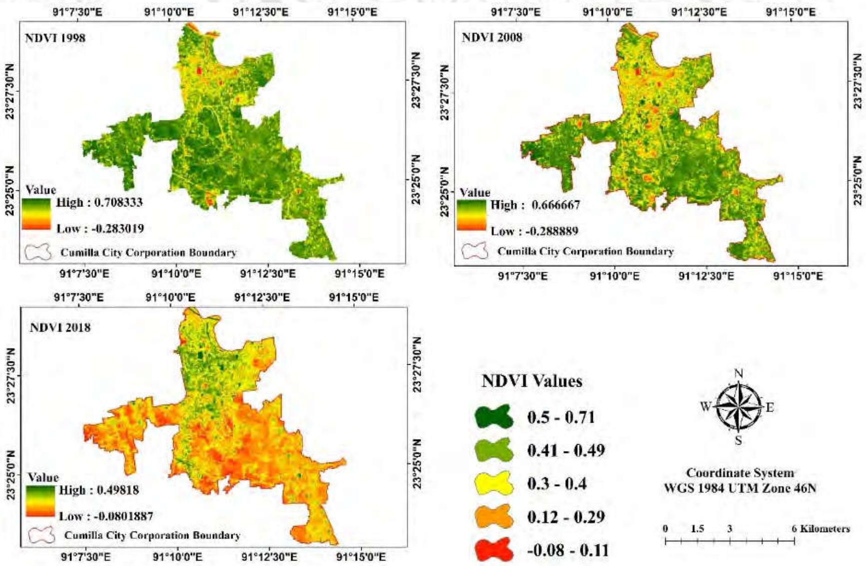

Figure 2 NDVI distribution of study area in different year

Based on the radiation absorption by the red spectral area chlorophyll and reflectance of it near the spectral area of infrared, the variation of NDVI values are observed. The similarity of the vegetation in an area is represented by the values of NDVI which is confined between -1 to +1. A higher value represents dense vegetation, and the lower value represents lower or no vegetation. Visually it can be said that a remarkable decrease in vegetation area eventuated in 2018 comparing to 1998 & 2018. Dense vegetation was observed in 2008.

3.2. Normalized difference vegetation index (NDWI)

Mapping of water bodies can be performed using NDWI based on spectral band green and near-infrared by which turbidity variations, as well as vegetation in the water and vice versa, can be visualised. Similar to NDVI its values also vary from -1 to +1. Values adjacent to +1 represents waterbody and -1 as well as near to it represents dry land. From visual representation it is obtained a gradual reduction of waterbody took place from 1998 to 2018. The area containing water is found higher in 1998 and lower in 2018.

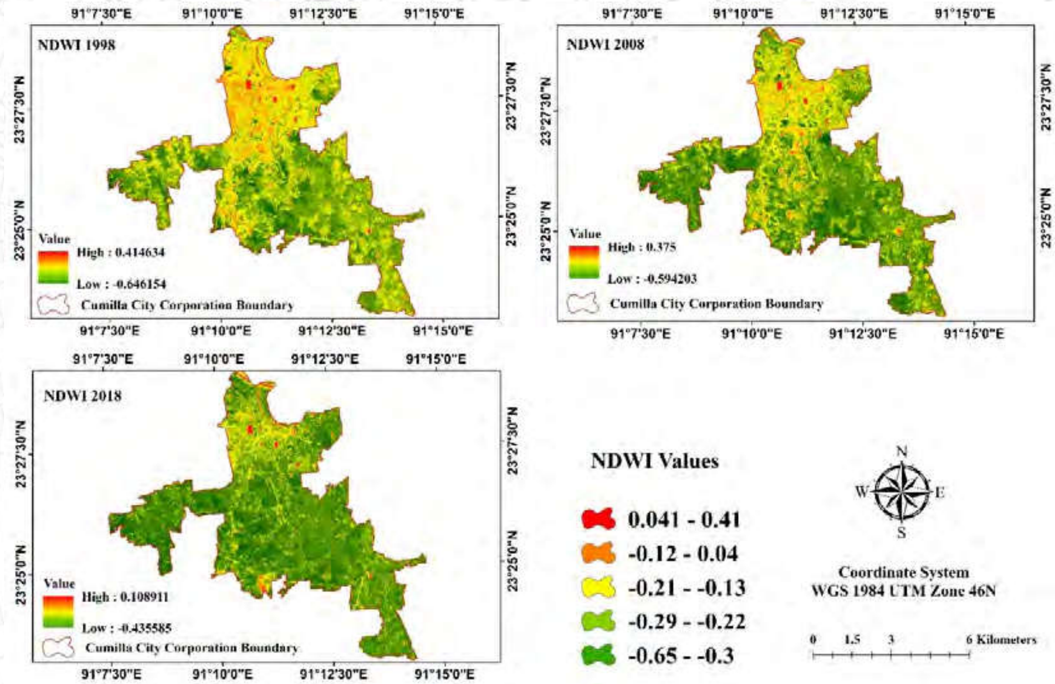

Figure 3 NDWI distribution of study area in different year

3.3. Normalized difference bare soil index (NDBSI)

Bare soil accommodated area can be derived performing NDBSI which use spectral band red, blue, middle infrared and near-infrared to determine its value. Values close to -1 represents the bare soil land areas, and +1 represents the others landscape elements such as forest, waterbody, cropland etc. form the visual representation it can be said that there is a decrease of land covered with bare soil in 2018 compared to the year 1998 & 2008.

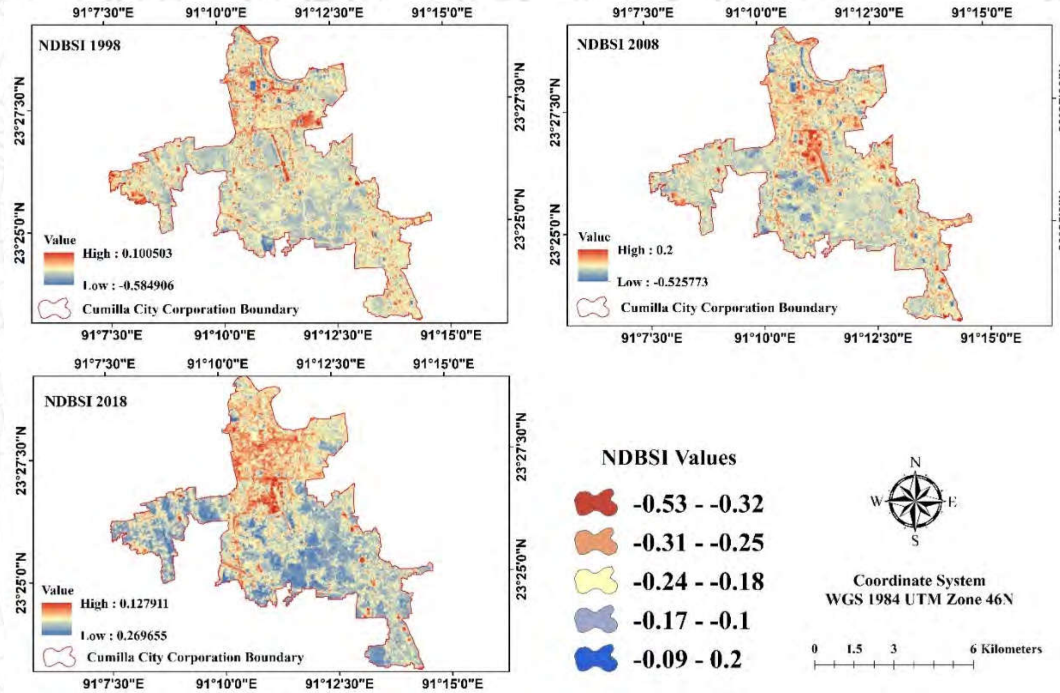

Figure 4 NDBSI distribution of study area in different year

3.4. Normalized difference built-up index (NDBI)

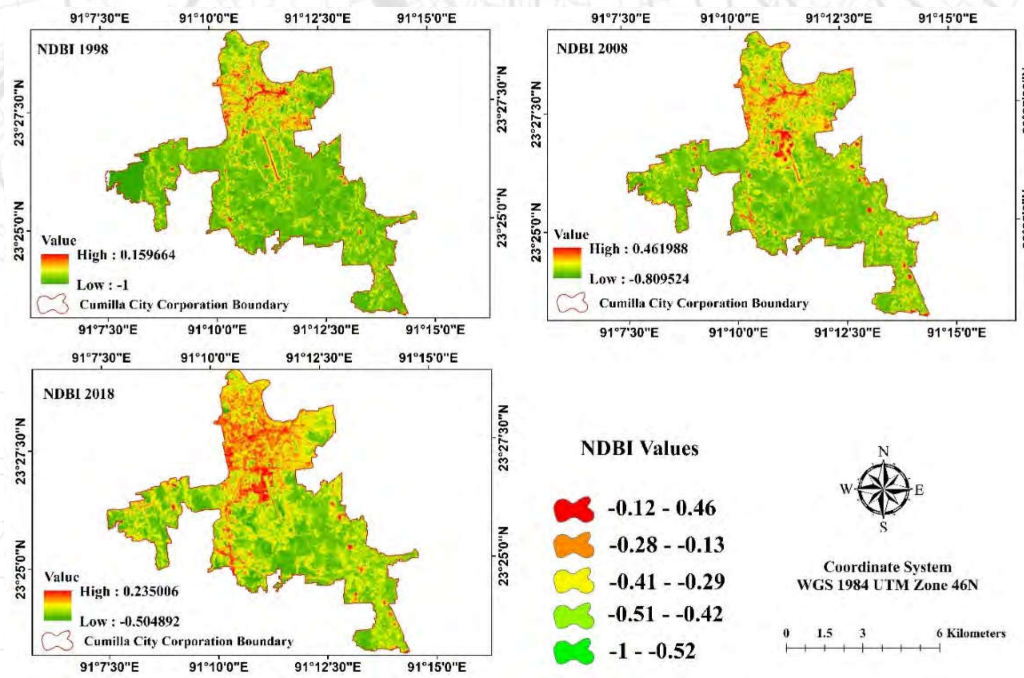

Figure 5 NDBI distribution of study area in different year

The use of NDBI in majorly in human settlement along with few essentials of land areas such as roads, dams, canals etc. mapping. Spectral band middle infrared and near-infrared is used for deriving the value of NDBI. Values close to +1 represents the land areas which have covered with buildings and -1 represents the other natural elements of environments such as forest, waterbody, cropland etc. In contrast with NDVI and NDWI, an increase of built-up area is observed gradually from 1998 to 2018. This radical change has a significant impact on environment.

3.5. Correlation matrix of land use indexes

Land use matrixes of different years are analyzed from correlation viewpoint. The best correlation is found between NDVI & NDWI and NDBI & NDBSI, respectively for the year 1998 & 2008. Also, in 2008, the correlation between NDBI & NDWI is too high. For the year 2018, best correlation is estimated for NDVI & NDWI with NDBSI & NDBI respectively. Correlation values ranges from 0 to ±1 where ±1 represents fully correlated (positively or negatively), and 0 represents not correlated. Table 1, 2, 3 shows the correlation values of different index for 1998, 2008 and 2018 respectively. It is found from the values that correlation between NDVI and NDWI is always higher than other in every year. In 2018 this value is obtained 1 which illustrates maximum correlation. Nevertheless, values between these matrixes in other two years are also higher than 0.9. In 2018 the maximum number of high correlation values are observed between two indexes.

Table 1 Correlation matrix between NDVI, NDWI, NDBSI and NDBI for the year 1998

	1998			
	NDVI	NDWI	NDBSI	NDBI
NDVI	1	-	-	-
NDWI	**0.92256**	1	-	-
NDBSI	-0.35203	0.0278	1	-
NDBI	-0.54452	-0.29322	**0.91202**	1

Table 2 Correlation matrix between NDVI, NDWI, NDBSI and NDBI for the year 2008

	2008			
	NDVI	NDWI	NDBSI	NDBI
NDVI	1	-	-	-
NDWI	**0.96282**	1	-	-
NDBSI	-0.37514	0.16799	1	-
NDBI	**-0.71393**	**-0.57866**	**0.83359**	1

Table 3 Correlation matrix between NDVI, NDWI, NDBSI and NDBI for the year 2018

	2018			
	NDVI	NDWI	NDBSI	NDBI
NDVI	1	-	-	-
NDWI	1	1	-	-
NDBSI	**-0.99035**	**-0.99035**	1	-
NDBI	**-0.8438**	**-0.8438**	0.77486	1

3.6. Changes in land use indexes and their impact on LULC

The rapid increase in NDBI and NDBSAI and a significant decrease in NDVI contributes to rapid LULC change and thus create a negative impact on urban environment. Figure 6 illustrates the LULC change for increase and decrease in land use indexes. Increase in the NDBI value significantly increase the urban built-up area from 15.95 %(1998) to 28.14 %(2018). The increase is almost doubled in the space of 20 years, and these increases accelerate by damaging the vegetation area and water bodies. 21% vegetation cover area and 3% water bodies were replaced by built-up and bare land area. The significant increase also noticeable in bare land (11%) because of increase in NDBSI value. Higher NDBI and

NDBSI reduce green space in the study area and will create ecological imbalance and environmental problems in Cumilla city corporation area in the near future.

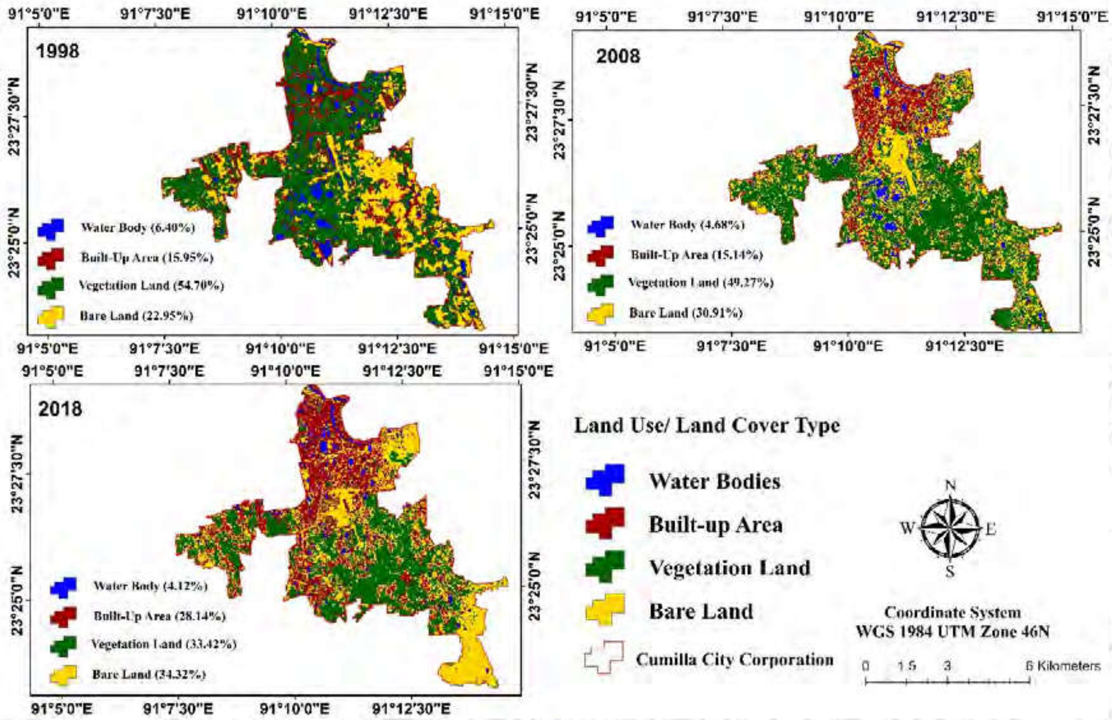

Figure 6 LULC change in the study area due to the increase and decrease in land use indexes

4. Conclusion

This paper investigated the changes in land use indexes (NDVI, NDWI, NDBI and NDBSI) and identified the impacts of those changes in the urban environment using GIS and RS techniques. A strong positive correlation was found in NDVI & NDWI and NDBI & NDBSI. A strong negative correlation was noticed between NDBI & NDVI and NDBSI & NDWI because of rapid replacement of vegetation cover and water bodies by speedy built-up and bare land expansion. Later those bare land converted to urban built-up area. With the help of those land-use indexes, these study also estimate the LULC change in Cumilla city corporation area to identify the impacts on urban environment. The LULC change indicates that urban built-up area was almost doubled and the urban expansion mainly replaced the vegetation cover area. Using Landsat-45TM and Landsat 8 OLI images, this study successfully demonstrates that NDVI is an accurate indicator of vegetation cover where NDBI indicates rapid urban growth. The study provides an appropriate solution in decision making and helps urban planners, engineers and environmentalist for building cities ecologically sustainable and environmental friendly using GIS and RS technologies.

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