EVALUATING THE IMPACT OF CLIMATE CHANGE ON THE URBAN ENVIRONMENT USING GEOSPATIAL TECHNOLOGIES IN BHUBANESWAR, INDIA

Pritipadmaja*, R. D. Garg

Geomatics Engineering Group, Department of Civil Engineering, Indian Institute of Technology Roorkee -

pritipadmaja@ce.iitr.ac.in

Commission IV, WG IV/9

KEY WORDS: LULC, LULC changes, Urbanisation, LST, NDVI and Google Earth Engine.

ABSTRACT:

Fast population growth is a significant contributor to worldwide land scarcity and has a long-term impact on the environment and climate. Rapid urbanisation along with industrialisation contributed to land transformation across the globe. Understanding, monitoring, and mitigating the environmental impacts of urbanisation are critical for sustainable development. Also, Rapid urbanisation has contributed significantly to regional and global temperature. Land surface temperature (LST) has long been regarded as a critical physical metric for analysing regional and global climate change and its effects on many ecosystems. Remote sensing is an effective method for monitoring and quantifying urbanisation and assessing its impact on regional heating. This paper examines the combined impact of land use and land cover (LULC) change and climatic variability in Bhubaneswar city using remote sensing, geographic information system and google earth engine. Images from the Landsat were utilised to prepare the LULC, LST and NDVI layer for 2001, 2010 and 2020. The random forest method of supervised classification was employed to estimate the LULC. According to this study, the impact of urbanisation shows that the built-up areas in Bhubaneswar City have increased by over 70% at the cost of agricultural land and vegetation cover. The finding also indicates the urban area has been expanded around 12 percent where LST has increased by 4˚C in the last two decades. As a result, continuous monitoring of LULC dynamics is required to guide sustainable land-use decisions that promote environmental protection and economic development in this region. A multi-temporal environmental analysis of the region is critical for future environmental planning, such as the restoration of damaged areas, to be more effective and efficient. This study, thus, would be helpful for the administrators, urban planners, and policymakers for proper planning and sustainable development of Bhubaneswar City.

1. INTRODUCTION

Unplanned urbanisation, industrialisation, technological development and associated rapid population growth have contributed to an increase in global land scarcity (Umezaki et al., 2020) and have obvious negative impacts on the regional environment (Kurucu & Chiristina, 2008). Urbanisation is a significant aspect of monitoring human activities, the physical landscape transformation, industrialisation, transportation accessibility, air quality impacts and the impacts on the environmental components such as vegetation, land and water bodies (Kedia et al., 2021), (Halder & Bandyopadhyay, 2021). Human and natural activities are primarily responsible for land use and land cover (LULC) change, making this an essential study issue concerns the human and natural environment interaction, global climate change and sustainability (Lambin et al., 2003), (Teixeira et al., 2014) (Pricope et al., 2019), (Das et al., 2021). The land transformation has both manmade and natural causes, and its impact on the regional environment is essential to comprehending the relationship between society and the environment (Rahaman et al., 2020). LULC changes in an area are determined by social, political and economic aspects (Alam et al., 2020). Studies related to LULC changes are vital for urban planners, researchers, administrators and policy makers to better understanding the changing situation and develop appropriate plans for such locations (Halder & Bandyopadhyay, 2021).

To determine the LULC change analysis for the present, past and future, advance technologies like Remote sensing and Geographic Information Systems (GIS) can be very useful (M. Li et al., 2014). The satellite images are used to identify the land transformations in the earth surface and to monitor the earth surface changes with many of application (L. Li et al., 2020), (Halder & Bandyopadhyay, 2021).

With the rise in urban population, majority of the changes in LULC have been substantial. A rapidly expanding Indian city in the state of Odisha is Bhubaneswar which is also experiencing issues related to urbanisation (Thandar, 2012). Several previous studies have used remote sensing and GIS techniques to analyse LULC change arising from urbanisation (Mohanty, 1994), (Ramesh, 1995), (Thandar, 2012b), (Chettry & Surawar, 2020) and few studies focused on urban sprawl and modelling them (Brueckner, 2003), (Gupta et al., 2015), (das Chatterjee et al., 2016), (Mishra et al., 2019). Others have studied the impact of urbanisation and LULC changes on LST using these advance techniques (Swain et al., 2017), (Anasuya et al., 2019), (Das et al., 2021). But so far, none of these studies have considered how changes in LULC may impact the range of environmental indicators that this study is focusing.

Urbanisation leads to extensive LULC changes with intendent negative impacts on a wide range of environmental indicators, such as LST, and NDVI. Ultimately, such processes are unsustainable and eventuate a decrease in overall environmental health in a region (Rahaman et al., 2020). Researchers have looked into the different environmental impacts of LULC in many ways, such as remote sensing assessments of surface changes using, for example, LST, NDVI, NDBI and NDWI (Baeza & Paruelo, 2014), (Rahaman et al., 2020). LST is a significant determinant of the biophysical processes of land

* Corresponding author

systems (Mohamed, 2021), (Halder et al., 2021) while NDVI is a dimensionless variable whose index provides details about the vegetation vigor. Vegetation is a major part of land cover and effects on climate change. This implies that NDVI can be used as an indicator for urban climate studies (Mumina & Mundia, 2014). The majority urban climate research focuses on LST and NDVI since the areas with high NDVI are signified by low LST values (negative correlation)(Yuan & Bauer, 2007). There are several factors that affects relationship between NDVI and LST, making it quite complex (Dhumal et al., 2021). This study aims to evaluate the dynamic impacts of LULC changes and the relationship between a various range of environmental variables like LST and NDVI using remotely sensed data for 20 years. Landsat data has been widely used to detect the changes in LULC, which offers continual worldwide coverage with a moderate spatial resolution (Gao & Zhang, 2009). Thermal bands from the Landsat series were used to determine the thermal variation and LST with the help of air temperature and water vapours (Halder et al., 2021). Here, Landsat data is used to map LULC, LST and NDVI. To better understand the nature of urban dynamicity, dynamic progress of LULC changes, NDVI, and LST, Bhubaneswar, the capital city in Odisha, has been selected as a study area for this study. This study can be considered a strategic guide for urban planners, researchers, administrators and policy makers to achieve sustainable city planning and balance urbanisation and protecting the environment.

2. STUDY AREA

Bhubaneswar is a smart city situated in eastern India. This city serves as the capital city of Odisha, which is located in the Khordha district. It stretches between 20˚5'N to 20˚26'N in latitudes and from 85˚30'E to 85˚59'E in longitudes (Figure 1). The planning for this city began on 13th April 1948. The city has emerged as one of the country's fastest-growing urban agglomerations. It is developed from the centre to its surrounding area. Bhubaneswar is often called the Temple City of India for its numerous temples. It has been a place of religious and cultural efflorescence through the ages and today the city reflects a unique harmony between antiquity and urbanity (Thandar, 2012a). The city lies in the Eastern Coastal Plains region and forms an undulating hilly topography with an average elevation of 45 meters above the mean sea level. Daya and Kuakhai rivers flows in southern and eastern directions of this city, respectively. It is divided into two major parts, namely eastern lowland and western upland. Soil of Bhubaneswar is mostly hard red lateritic soil in the north and western part. The eastern and southern part consists of alluvial soil which is very good for agricultural activity. The climate is humid and tropical here. The vegetation of Bhubaneswar city and its surroundings is categorised as tropical moist deciduous (mixed type).

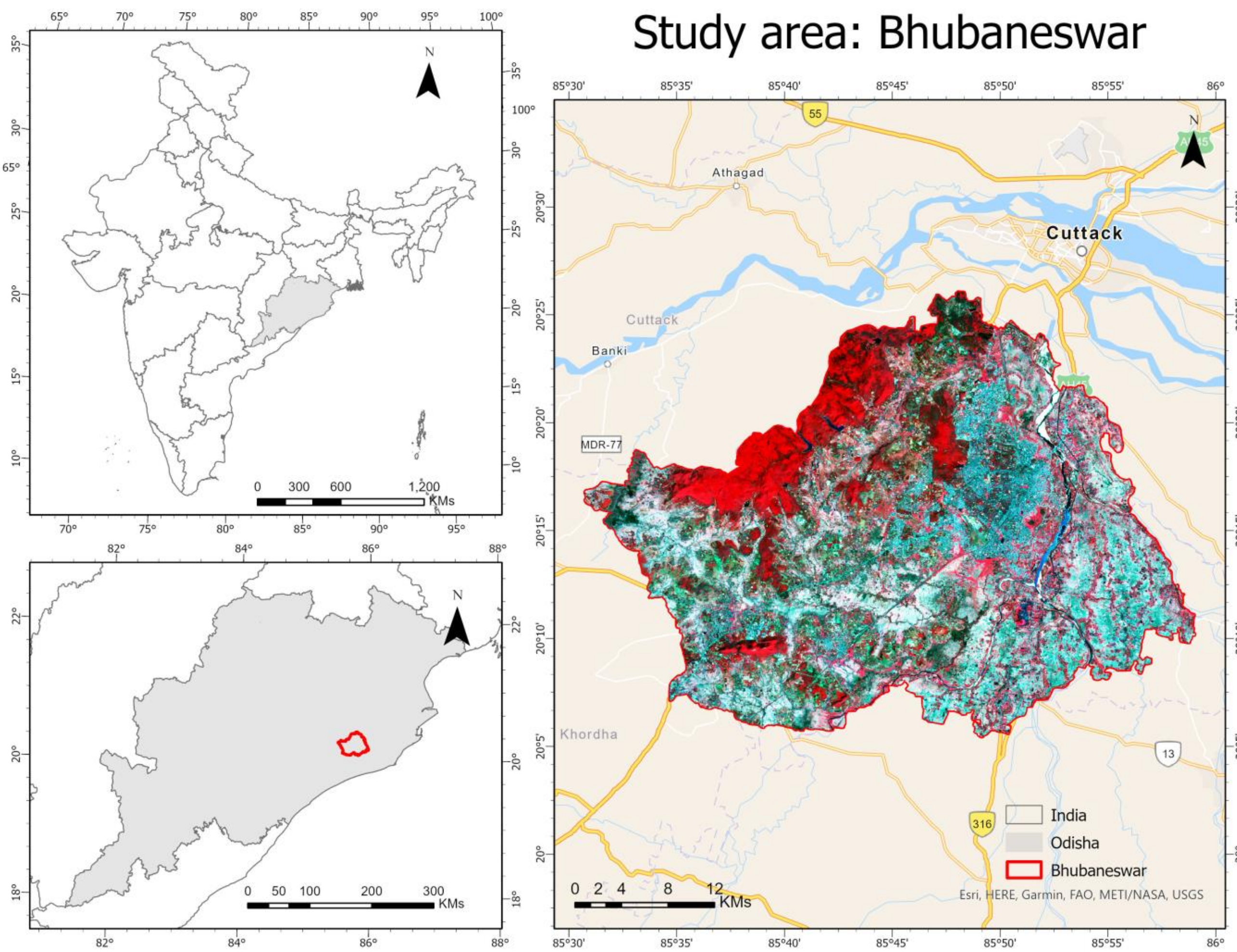

Figure 1. Location map of the study area

3. METHODS

3.1 Image pre-processing:

Google Earth Engine (GEE) uses Google's computing infrastructure to facilitate a fast analysis platform (Zurqani et al., 2018). It is a geospatial processing tool for extensive environmental analysis and interpretation (Saravanan, 2021). Landsat imagery that had already been pre-processed were available through GEE which were used for LULC changes assessment across the study area. GEE provides online access to archived Landsat data as a collection of the USGS (Huang et al., 2010). Cloud-computing technology in the GEE platform (https://earthengine.google.org/) was used for processing all of the Landsat data. GEE provides an alternate way for accessing multiple images in their collection using the function *ee.ImageCollection()*. This study used Landsat top-of-atmosphere (TOA) reflectance data for the years 2001, 2010 and 2020 for classification.

3.2 LULC Mapping:

A commonly used machine learning approach for supervised classification is Random Forest (RF). It is a decision tree-based classifier consisting of a set of decision trees, with each tree trained based on a randomly selected subset of the total training samples (Rodriguez-Galiano et al., 2012). For this study, the RF approach is used for the urban land cover classification of Bhubaneswar. A training data set consisted of 70 percent randomly selected observations, while the remaining 30 percent of the observations were used in the validation data set. The training dataset was used to improve the supervised classifier algorithm, whereas the validation dataset was used in the accuracy assessment of the produced LULC classification maps.

3.3 Accuracy Assessment:

Accuracy assessment is a fundamental aspect of any kind of satellite data classification. The classification accuracy can be reported by obtaining a confusion matrix using the function ee.ConfusionMatrix on GEE. This matrix provides information about the reliability of the classification results. It also includes overall accuracy, Kappa statistic, user accuracy and producer accuracy for training and validation samples. For further analysis, the image is exported in the GeoTIFF format.

3.4 Environmental Indicators:

NDVI

The amount of green vegetation cover was evaluated by quantification of the red and near-infrared bands. As a result, a standard method known as the NDVI was used to estimate vegetation cover. The formula that is used to calculate NDVI is as follows:

$$NDVI = (NIR - R) / (NIR + R)$$

Where R= Red Band, NIR= Near-Infrared Band and NDVI= Normalized Difference Vegetation Index.

It is possible to gain useful information about the green vegetation present in each pixel by using the NDVI raster image. Therefore, it is also used to determine the emissivity values.

Proportional Vegetation:

The Pv represents the pixel's emissivity and vegetation present within a pixel. The following formula determines it:

$$Pv = \{(NDVI - NDVImin) / (NDVImax - NDVImin)\}2$$

where Pv = Vegetation Proportion, NDVI= Normalized Difference Vegetation Index, NDVImax= Maximum value of NDVI and NDVImin= Minimum value of NDVI.

Land Surface Emissivity:

Using NDVI and Pv as input raster images, (Sobrino et al., 2004) have derived a formula to determine emissivity. The Land Surface Emissivity was derived from the following formula:

$$\varepsilon TM = 0.004Pv + 0.986$$

where ƐTM= Land Surface Emissivity and Pv= Vegetation Proportion.

Conversion of DN to Radiance:

From the thermal band, radiance values were obtained by converting DNs. For calculation of radiance, values gain, and bias, method was used.

$$L\lambda = 0.05518 * (\text{thermal band}) + 1.2378$$

where 0.05518 and 1.2378 = constant.

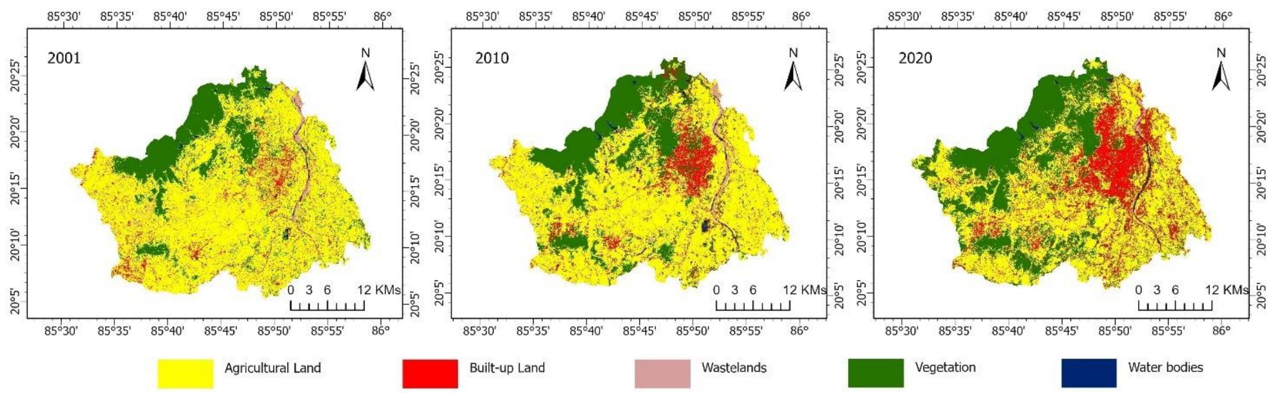

Figure 2. Land use / Land cover classification pattern in 2001, 2010 and 2020

Computation of Land Surface Temperature:

Based on radiance and emissivity raster values, land surface temperature was calculated:

$$T(K)= \{[K2/\log ((k1* \varepsilon TM6)/ (L\lambda)+1)]\} – 273$$

where K1 = 607.76 and K2 = 1260.56 (K1 and K2 are Calibration constants), Lλ = Spectral radiance and ƐTM6= Emissivity.

4. RESULTS AND DISCUSSION

4.1 Land cover Land use Classification and its accuracy:

The study area is classified into five major LU/LC classes encompassing built-up land, water bodies, vegetation, agricultural land and wastelands (Table 1). Figure 2 displays the LULC Classification of Bhubaneswar for the study period of 2001, 2010 and 2020.

Land use/ Land cover Classes	Features Description
1. Built-up Land	Residential, commercial and services, industrial, recreational, transportation, communication and utilities, educational institutes, cantonments, reclaimed land, slum areas, quarrying/mining area
2. Water Bodies	River/Stream, Reservoirs, Lakes, Ponds, Canals/Drains
3. Vegetation	Evergreen forest, deciduous Forest Land, Mixed Forest Land, Shrub/degraded vegetation
4. Agricultural Land	Crop Land, Plantations, and fallow Land
5. Wastelands	Rock outcrop, sandy area, water logged area, and undulating land with or without scrub, gullied/ravenous land, salt affected area

Based on SAC Technical Report 1999: SAC/RESA/TR-3/July 1999

Table 1. Land use / Land cover classification schema used in the study

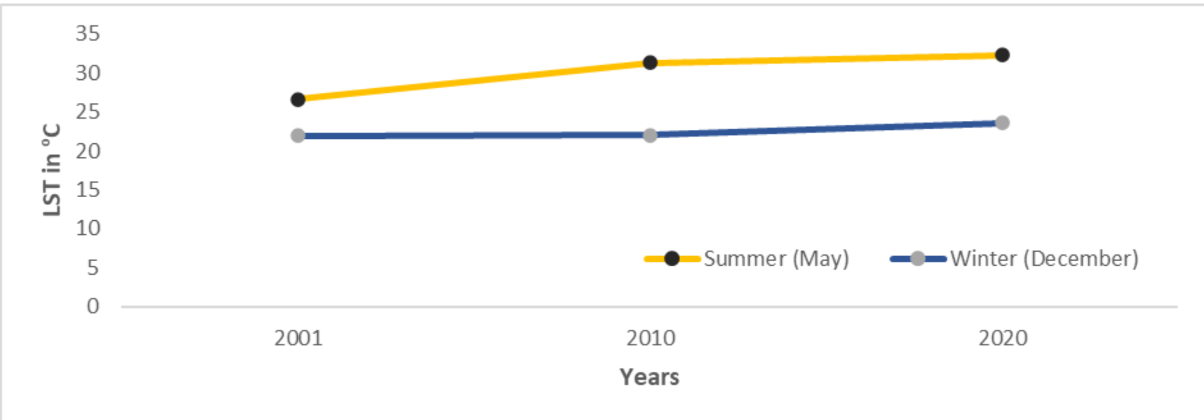

Figure 3. Trends in LST during 2001, 2010 and 2020 over the study area for summer (May) and winter (Dec.)

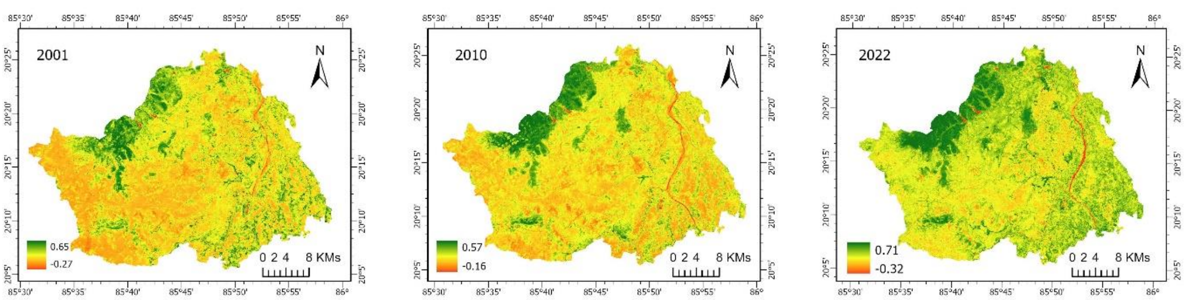

Figure 4. NDVI Spatial distribution from 2001 to 2020

2001	**Confusion Matrix**					**PA**	**CA**
	Built-up land	**Water bodies**	**Vegetation**	**Agricultural land**	**Wastelands**		
Built-up land	93	2	0	16	4	0.809	0.744
Water bodies	2	153	0	0	0	0.987	0.987
Vegetation	2	0	4942	7	0	0.998	0.999
Agricultural land	25	0	5	2405	6	0.985	0.989
Wastelands	3	0	0	4	275	0.975	0.965
OA	0.990						
KS	0.990						
2010	**Confusion Matrix**					**PA**	**CA**
	Built-up land	**Water bodies**	**Vegetation**	**Agricultural land**	**Wastelands**		
Built-up land	180	3	0	3	0	0.968	0.978
Water bodies	2	630	0	0	0	0.997	0.994
Vegetation	0	0	5098	0	0	1	0.999
Agricultural land	2	1	2	465	1	0.987	0.989
Wastelands	0	0	0	2	1333	0.996	0.999
OA	0.998						
KS	0.998						
2020	**Confusion Matrix**					**PA**	**CA**
	Built-up land	**Water bodies**	**Vegetation**	**Agricultural land**	**Wastelands**		
Built-up land	536	0	8	9	0	0.969	0.967
Water bodies	0	268	0	0	0	1	1
Vegetation	5	0	6463	8	0	0.998	0.998
Agricultural land	12	0	4	452	0	0.966	0.964
Wastelands	1	0	0	0	80	0.988	1
OA	0.994						
KS	0.994						

Table 2. Confusion matrix for RF classification for 2001, 2010 and 2020

Class code	**Land use & Land cover**	**Absolute area cover (sq. km)**						**LULC Changes (%)**		
		2000		2010		2020		2001-10	2010-22	2001-22
		Area	%	Area	%	Area	%			
1	**Built-up area**	74.22	6.33	106.46	9.07	215.29	18.24	2.75	9.16	11.91
2	**Water bodies**	8.16	0.70	15.67	1.34	7.20	0.61	0.64	-0.72	-0.09
3	**Vegetation**	238.55	20.33	292.89	24.96	382.7	32.42	4.63	7.46	12.09
4	**Agricultural land**	825.51	70.36	724.83	61.78	566.75	48.01	-8.58	-13.77	-22.35
5	**Wastelands**	26.84	2.29	33.39	2.85	8.47	0.72	0.56	-2.13	-1.57

Table 3. Area under different LULC in Bhubaneswar from 2001 to 2022

The supervised classification results using the RF machine learning method for the years 2001, 2010 and 2020 are presented in Figure 2. RF classifier performed well with high overall accuracy and Kappa statistic based on the training samples. The same overall accuracy and Kappa statistic values of 0.990, 0.998 and 0.994 for 2001, 2010 and 2020 were observed, respectively. The classification accuracy based on the sampling points is also satisfying, as shown in Figure 2. Referring to the confusion matrix (Table 2), the misclassification rate is quite low.

4.2 Changes in Land cover Land use:

Figure 3 shows LULC of Bhubaneswar for the years 2001, 2010 and 2020 which is further studied for the analysis of LULC changes. Additionally, table 3 shows the percentage cover of every class type during the study years. During the study period, the greatest decline was found for agricultural land.

The urban area (red pixels) has grown and intensified during the study years as seen in the figure 2. From the initial rectangular shape, it seems that the city has expanded outwards from the center, mostly towards north, northwest, and southwest directions along major transportation routes. During the recent years, the urban growth has sprawled. This could be attributed to the availability of ample fallow land around, which facilitated the sprawl. Also, in the subsequent years, expansion of urban structures close to the city center has been intensifying the already-urbanised areas (Figure 2).

4.3 LST Analysis:

Figure 3 presents the LST trends for winter (December) in the lower panel and summer (May) seasons in the lower panel for the study years respectively. It is clearly seen in the figure 3 that mean LST value of the study area is rising with increasing urbanisation. The result also reveals that mean LST for summer season increased from 4˚C between 2001 and 2021. In general, the findings signify that the most significant rise in LST is associated with the construction of buildings and urban infrastructure in the past 20 years. As opposed to that, the lowest increase in LST is associated with water bodies and vegetation cover.

4.4 NDVI Analysis:

Figure 4 provides an informative visual depiction of the spatial distribution of NDVI within Bhubaneswar for the study years 2001, 2010 and 2020 and a related statistical summary is given in Table 4. NDVI analysis showed both negative and positive values. The highest NDVI value has been observed in the North, and North Western portions of the city, where vegetation is extensive and LST is comparably minimal.

	NDVI (min)	NDVI (max)	NDVI (mean)	Standard Deviation
2001	-0.28	0.65	0.12	0.12
2010	-0.16	0.57	0.13	0.13
2020	-0.32	0.71	0.20	0.19

Table 4 Summary statistics for NDVI for Bhubaneswar (2001- 2000)

5. CONCLUSION

Remote sensing and GIS techniques are widely used to assess land dynamics. This study is to map, monitor and analyse land use and land cover change and urban expansion over Bhubaneswar, Odisha in India. Multitemporal Landsat data were used to analyse the extent of LULC changes in the study area and its impacts on NDVI and LST. 2001, 2010 and 2020 Landsat imageries were used for this land dynamics assessment. Agricultural land (including croplands and fallow lands) is converted into built-up land due to anthropogenic activities. Maximum growth has occurred towards the north, northwest and southwest directions along major transportation routes. This rapid urbanisation has impacted the urban environment of Bhubaneswar. In the last two decades, the urban area has been expanded by around 12 percent, where 4˚C has increased LST. The findings also suggest that planners and policymakers in Bhubaneswar should be concerned about future urban growth and develop a strategic plan for environmentally friendly constriction and green building to reduce the urban microclimate warming effect. This study can be considered a comprehensive guide for urban planners, researchers, administrators and policymakers to better understand the changing environment and develop appropriate plans for Bhubaneswar.

ACKNOWLEDGEMENT

I acknowledge the support of the Indian Institute of Technology Roorkee in the form of International Travel Grant, which enabled me to attend this conference.

REFERENCES

Alam, A., Bhat, M. S., & Maheen, M. (2020). Using Landsat satellite data for assessing the land use and land cover change in Kashmir valley. *GeoJournal*, *85*(6), 1529–1543. https://doi.org/10.1007/s10708-019-10037-x

Anasuya, B., Swain, D., & Vinoj, V. (2019). Rapid urbanisation and associated impacts on land surface temperature changes over Bhubaneswar Urban District, India. *Environmental Monitoring and Assessment*, *191*. https://doi.org/10.1007/s10661-019-7699-2

Baeza, S., & Paruelo, J. M. (2014). *Land Use / Land Cover Change (2000 – 2014) in the Rio de la Plata Grasslands : An Analysis Based on MODIS NDVI Time Series*. 1–22.

Brueckner, J. K. (2003). U Rban S Prawl. *International Regional Science Review*, *23*(2), 160–171.

Chettry, V., & Surawar, M. (2020). Urban sprawl assessment in Raipur and Bhubaneswar urban agglomerations from 1991 to 2018 using geoinformatics. *Arabian Journal of Geosciences*, *13*(14). https://doi.org/10.1007/s12517-020-05693-0 das Chatterjee, N., Chatterjee, S., & Khan, A. (2016). Spatial modeling of urban sprawl around Greater Bhubaneswar city, India. *Modeling Earth Systems and Environment*, *2*(1). https://doi.org/10.1007/s40808-015-0065-7

Das, T., Jana, A., Mandal, B., & Sutradhar, A. (2021). S patio-temporal pattern of land use and land cover and its effects on land surface temperature using remote sensing and GIS techniques: a case study of Bhubaneswar city, Eastern India (1991–2021). In *GeoJournal* (Vol. 0123456789). Springer Netherlands. https://doi.org/10.1007/s10708-021-10541-z

Dhumal, S., Tanaji, P. P., Ajit, V., & Vishnu, D. S. (2021). *Urban weather assessment using LST, NDBI and NDVI of Kolhapur city, Maharashtra* (Vol. 14, Issue 4). https://www.researchgate.net/publication/350399343

Gao, Y., & Zhang, W. (2009). LULC classification and topographic correction of Landsat-7 ETM+ Imagery in the Yangjia river Watershed: The influence of DEM resolution. *Sensors*, *9*(3), 1980–1995. https://doi.org/10.3390/s90301980

Gupta, A., Swain, S., & Kumari, M. (2015). *"A GEOINFORMATIC APPROACH TO STUDY URBAN AGGLOMERATION OF BHUBANESWAR CITY (ODISHA)."*

Halder, B., & Bandyopadhyay, J. (2021). Evaluating the impact of climate change on urban environment using geospatial technologies in the planning area of Bilaspur, India. *Environmental Challenges*, *5*(May), 100286. https://doi.org/10.1016/j.envc.2021.100286

Halder, B., Bandyopadhyay, J., & Banik, P. (2021). Evaluation of the Climate Change Impact on Urban Heat Island Based on Land Surface Temperature and Geospatial Indicators. *International Journal of Environmental Research*, *15*(5), 819–835. https://doi.org/10.1007/s41742-021-00356-8

Huang, C., Goward, S. N., Masek, J. G., Thomas, N., Zhu, Z., & Vogelmann, J. E. (2010). An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks. *Remote Sensing of Environment*, *114*(1), 183–198. https://doi.org/10.1016/j.rse.2009.08.017

Kedia, S., Bhakare, S. P., Dwivedi, A. K., Islam, S., & Kaginalkar, A. (2021). Estimates of change in surface meteorology and urban heat island over northwest India: Impact of urbanisation. *Urban Climate*, *36*(February), 100782. https://doi.org/10.1016/j.uclim.2021.100782

Kurucu, Y., & Chiristina, N. K. (2008). Monitoring the impacts of urbanisation and industrialisation on the agricultural land and environment of the Torbali, Izmir region, Turkey. *Environmental Monitoring and Assessment*, *136*(1–3), 289–297. https://doi.org/10.1007/s10661-007-9684-4

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*, 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Li, L., Zhou, X., Chen, L., Chen, L., Zhang, Y., & Liu, Y. (2020). Estimating urban vegetation biomass from sentinel-2A image data. *Forests*, *11*(2), 1–24. https://doi.org/10.3390/f11020125

Li, M., Zang, S., Zhang, B., Li, S., & Wu, C. (2014). A review of remote sensing image classification techniques: The role of Spatio-contextual information. *European Journal of Remote Sensing*, *47*(1), 389–411. https://doi.org/10.5721/EuJRS20144723

Mishra, S. P., Nayak, S. P., Mishra, S., Siddique, M., & Sethi, K. C. (2019). GIS and auto desk modeling for satellite cities around Bhubaneswar. *International Journal of Innovative Technology and Exploring Engineering*, *8*(11), 297–306. https://doi.org/10.35940/ijitee.K1328.0981119

Mohamed, M. A. (2021). Spatiotemporal impacts of urban land use/land cover changes on land surface temperature: A comparative study of damascus and aleppo (syria). *Atmosphere*, *12*(8). https://doi.org/10.3390/atmos12081037

Mohanty, R. R. (1994). Analysis of urban landuse change using sequential aerial photographs and spot data: An example of north Bhubaneswar, Orissa. *Journal of the Indian Society of Remote Sensing*, *22*(4), 225–235. https://doi.org/10.1007/BF03026522

Mumina, J. M., & Mundia, C. N. (2014). Dynamism of Land use Changes on Surface Temperature in Kenya : A Case Study of Nairobi City. *International Journal of Science and Research*, *3*(4), 38–41.

Pricope, N. G., Mapes, K. L., & Woodward, K. D. (2019). Remote sensing of human-environment interactions in global change research: A review of advances, challenges and future directions. *Remote Sensing*, *11*(23). https://doi.org/10.3390/rs11232783

Rahaman, S., Kumar, P., Chen, R., Meadows, M. E., & Singh, R. B. (2020). Remote Sensing Assessment of the Impact of Land Use and Land Cover Change on the Environment of Barddhaman District, West Bengal, India. *Frontiers in Environmental Science*, *8*(August), 1–15. https://doi.org/10.3389/fenvs.2020.00127

Ramesh, B. (1995). Residential area evaluation using GIS technique: A case study - Part of Bhubaneswar city. *Journal of the Indian Society of Remote Sensing*, *23*(2), 65–76. https://doi.org/10.1007/BF03007974

Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., & Rigol-Sanchez, J. P. (2012). An assessment of the effectiveness of a random forest classifier for land-cover classification. *ISPRS Journal of Photogrammetry and Remote Sensing*, *67*(1), 93–104. https://doi.org/10.1016/j.isprsjprs.2011.11.002

Saravanan, S. (2021). *Assessment of Land Use And Land Cover Change Detection And Prediction Using Remote Sensing And CA Markov In The Northern Coastal Districts of Tamil Nadu, India Devanantham abijith National Institute of Technology Tiruchirappalli*. https://doi.org/10.21203/rs.3.rs-576976/v1

Shetty, A., Umesh, P., & Shetty, A. (n.d.). *Application of Google Earth Engine to Evaluate the Signatures of Land-Use/Land-Cover Change on Land Surface Temperature Variation*.

Sobrino, J. A., Jiménez-Muñoz, J. C., & Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5.

Remote Sensing of Environment, *90*(4), 434–440. https://doi.org/10.1016/j.rse.2004.02.003

Swain, D., Roberts, G. J., Dash, J., Lekshmi, K., Vinoj, V., & Tripathy, S. (2017). Impact of Rapid Urbanization on the City of Bhubaneswar, India. *Proceedings of the National Academy of Sciences India Section A - Physical Sciences*, *87*(4), 845–853. https://doi.org/10.1007/s40010-017-0453-7

Teixeira, Z., Teixeira, H., & Marques, J. C. (2014). Systematic processes of land use/land cover change to identify relevant driving forces: Implications on water quality. *Science of the Total Environment*, *470–471*, 1320–1335. https://doi.org/10.1016/j.scitotenv.2013.10.098

Thandar, S. (2012a). Analysis of Spatio-temporal Changes of Urban Land Use Using Remote Sensing and GIS: A Case Study of Bhubaneswar City, Odisha. In *Dagon University Research Journal* (Vol. 4).

Thandar, S. (2012b). Analysis of Spatio-temporal Changes of Urban Land Use Using Remote Sensing and GIS: A Case Study of Bhubaneswar City, Odisha. *Dagon University Research Journal*, *4*(1989), 19–29.

Umezaki, A. S., Ribeiro, F. N. D., de Oliveira, A. P., Soares, J., & de Miranda, R. M. (2020). Numerical characterization of spatial and temporal evolution of summer urban heat island intensity in São Paulo, Brazil. *Urban Climate*, *32*(March), 100615. https://doi.org/10.1016/j.uclim.2020.100615

Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalised difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment*, *106*(3), 375–386. https://doi.org/10.1016/j.rse.2006.09.003

Zurqani, H. A., Post, C. J., Mikhailova, E. A., Schlautman, M. A., & Sharp, J. L. (2018). Geospatial analysis of land use change in the Savannah River Basin using Google Earth Engine. *International Journal of Applied Earth Observation and Geoinformation*, *69*, 175–185. https://doi.org/10.1016/j.jag.2017.12.006