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Investigating the effects of land cover land use change on surface temperature using Landsat satellite images

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Abstract

Global and local population growth and the rapid increase in urbanization affect nature negatively by the destruction on forests and natural lands. An additional problem can be considered as the increment of the land surface temperatures due to the heat island phenomenon. Thus, long-term monitoring of rapidly developing cities is important. In this study, Izmir, which ranks 3rd among the big cities of the country, was chosen to monitor the long-term effects of urbanization. For this purpose, a 20-year period from 2020 to the past has been examined with Landsat images. As a first step, historical land cover – land use maps were produced from satellite images using the Random Forest algorithm in the Google Earth Engine platform. Secondly, the urban thermal field variance index (UTFVI) was calculated from thermal bands of Landsat images to examine the effect of urban heat islands and their relation to urbanization progress. Results of these analyses indicated that both cities faced urbanization at the expense of forest and semi-natural area loss in this 20-year period, which is well correlated with an increase in the UTFVI values. Moreover, the increase in UTFVI values on already urbanized regions proposed that the intensity of the urban areas also increased.

1. Introduction

Rapid and uncontrolled urbanization is one of the most important factors affecting the habitat, climate and ecosystem. This unpredictable increase in urbanization, unplanned industrialization, excessive destruction of forested or green areas, and climate changes have a vital negative impact on the health of people living in cities (Çelik et al., 2019).

Remote sensing data and analysis based on these data are frequently used in order to see the degree of this negative impact, to manage the environment and to take precautions. The groundbreaking advances in satellite systems in recent years have positively affected the remote sensing discipline, and it is seen that satellite image-based approaches are increasingly used in the monitoring and evaluation of environmental disasters or climate events such as climate change, drought, flood, earthquake, fire, urban heat island, etc.

According to Oke (1982), urban heat island (UHI) formation occurs when the urban atmosphere is warmer than the surrounding rural areas. The main causes of this formation are roof surfaces, which are characterized as impermeable surfaces, and light absorbing surfaces covered with dark materials such as concrete and asphalt. These types of surfaces re-radiate the solar energy they absorb into the environment and reflect it poorly. This leads to an increase in urban temperatures not only during the day but also after the sun sets (US EPA, 2014).

In general, atmospheric heat islands are measured by networks of weather stations with air temperature sensors, while urban heat islands are determined by land surface temperature (LST). There are many different methods in the literature for calculating the LST. The most preferred of these methods are: Split window method (Sobrino et al, 1996), temperature/emissivity separation algorithm (Gillespie et al, 1998), mono window algorithm (Qin et al, 2001) and single channel method (Jiménez-Muñoz and Sobrino, 2003).

Several studies investigated the effects of urbanization on the urban heat islands in different cities of Türkiye (Kaya et al. 2012; Şekertekin et al. 2015; Ünal et al. 2019). However there no studies focused on this effect in Izmir city yet to our knowledge and very few studies correlated the relationship between urbanization

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and thermal field variance index (UTFVI) (Cevik Degerli et al., 2023).

This study focuses on the long-term land cover (LC) change analysis of Izmir city by use of LC classification results belonging to 2000 – 2009 and 2020 and correlate the findings with the changes in UHI conditions by use of UTFVI.

2. Method

The methodology of this study is consisting of two stages that are land cover mapping with use of Landsat images and random forest algorithm, LST derivation from thermal bands and urban thermal field variance index calculation respectively.

2.1. Land cover mapping

This study uses random forest (RF), one of the most current machine-learning based classifier, for land cover classification. It can be considered as a pixel-based algorithm since it analyzes pixels individually rather than taking them as a group like object-based approaches. Algorithm uses decision trees, which identify the classes of training data and determine which class the test data will be included in based on the results obtained from the training data (Erdem et al., 2018).

The classification schema was constructed according to CORINE LULC Level 1 class definitions. Algorithm is fed with around 800 samples for training and tested with around 200 test points for each year.

2.2. UTFVI retrieval

Zhang et al. (2006) UTFVI as a way to identify locations affected by UHI. Formula UTFVI is displayed in Eq. 1.

$$UTFVI = \frac{T_s - T_m}{T_s} \quad (1)$$

where, Ts represents the LST of the pixel and Tm represents the average LST of the region. Higher values of this index show higher affect of UHI on the region. To calculate this index, first the LST was derived from the thermal bands of Landsat images similar with the procedure provided in Celik et al., (2019) study.

3. Results

The LC classification results for the three dates are provided in Fig. 1. According to accuracy assessment results, overall accuracies achieved 95%, 92% and 97%, while kappa values were observed as 0.93, 0.89, and 0,96 for the 2000, 2009 and 2011 dates respectively.

To perform a detailed LC change analysis, images from two different dates were combined to create a change image and the changing areas were identified from this change image. To create this change image, the pixel values of the previous year's LC map were multiplied by 10 and summed with the new dated image. The aim here is to generate new classes on a pixel basis. These classes are the combination of the transformations of the five classes used in the study (Table 1 and Table 2).

Between 2000 and 2009, there is an increase of 252.87 km^2 in the area of the city. 190.87 km^2 of the transformed areas is attributed to agriculture. It is followed by barren areas with 36 km^2 and forest areas with 26 km^2 as a result of excessive destruction. When the change areas between 2009-2020 are analyzed, the results show an increase in urban areas. The reason for this is the conversion of 122 km^2 from forest, about 5 km2 from wetlands, 85 km^2 from barren areas and finally 100 km^2 from agricultural areas to urban.

When the UTFVI maps are investigated, it can be asserted that the density and distribution of the extreme UHI Effect class (≥ 0.02) has increased in line with the increase in urbanization (Figure 2).

Table 1. Areal statistics of classes with change matrix for 2000 – 2009 period.

		2009 (sqkm)					
		Forest	Water	Urban	Bareland	Agriculture	Total
2000 (sqkm)	Forest	5782.67	5.30	43.55	45.99	807.70	6685.21
	Water	22.75	171.45	2.58	0.40	14.58	211.77
	Urban	54.28	5.06	266.89	17.67	238.80	582.70
	Bareland	34.22	2.57	24.22	12.28	33.57	106.85
	Agriculture	1308.46	8.39	297.98	69.36	2802.07	4486.25
	Total	7202.37	192.79	635.21	145.69	3896.72	

Table 2. Areal statistics of classes with change matrix for 2009 – 2020 period.

		2020 (sqkm)					
		Forest	Water	Urban	Bareland	Agriculture	Total
2009 (sqkm)	Forest	6262.53	24.95	88.46	31.39	828.82	7236.15
	Water	10.39	177.16	4.44	2.49	3.97	198.45
	Urban	44.19	4.03	326.03	27.13	235.40	636.78
	Bareland	54.92	0.59	28.20	13.33	48.64	145.68
	Agriculture	1234.31	7.58	300.44	47.34	2329.97	3919.63
	Total	7606.33	214.32	747.56	121.68	3446.80	

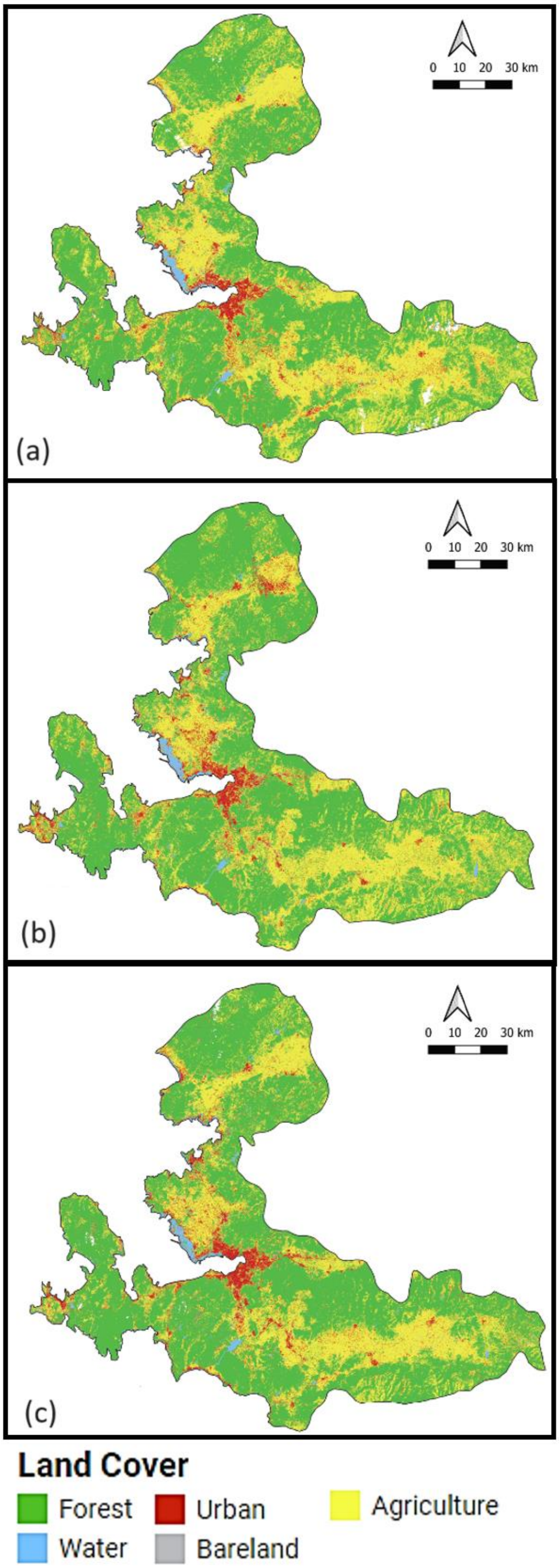

Figure 1. Land cover maps of Izmir city for (a) 2000, (b) 2009 and (c) 2020

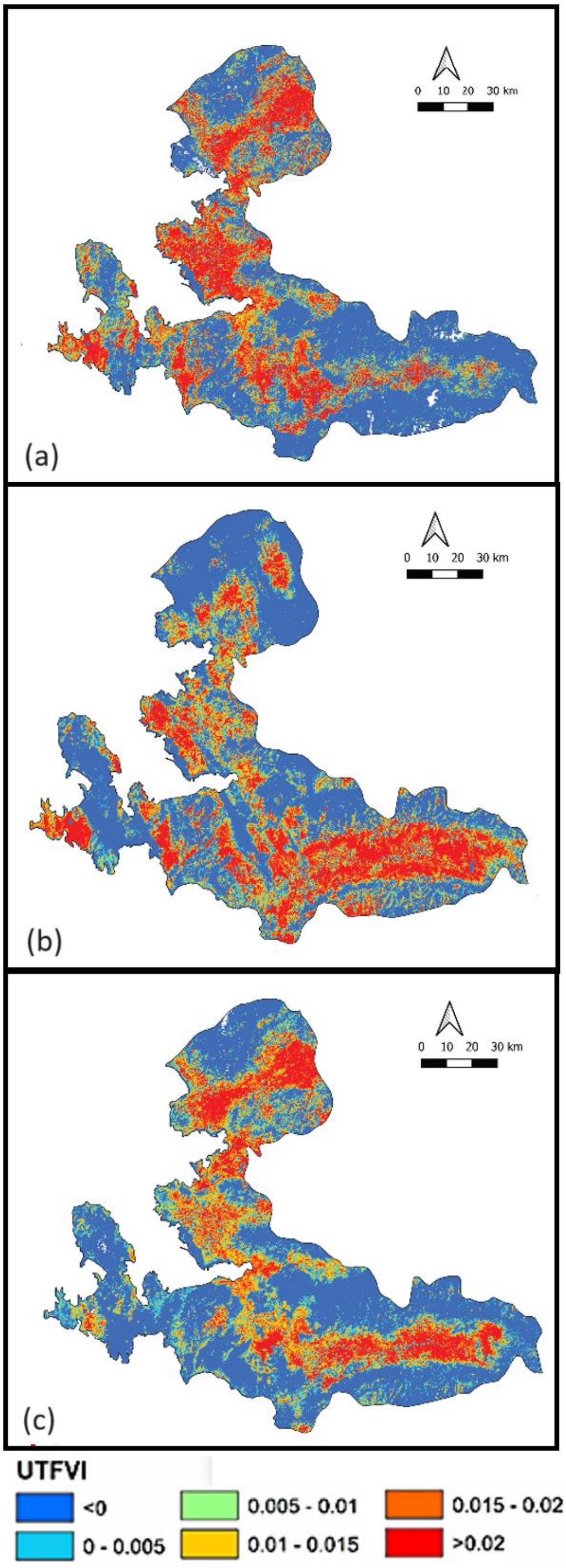

Figure 2. UTFVI maps of Izmir city for (a) 2000, (b) 2009 and (c) 2020.

4. Discussion

Especially in Izmir province, the reflectance values of roofs and the reflectance values of wasteland are mixed, making it very difficult to differentiate in LC classification. Again, in the same province, it was difficult to distinguish between forest and agricultural areas since there is not much difference in reflectance values between them and the transition between climates is smooth. As a solution, by calculating indices on Landsat images, these confused classes can be separated more easily. The higher spatial resolution Sentinel-2 satellite and its Red Edge bands can be useful for differentiation.

Moreover, this study used single image in spring for each year, which raise ambiguities due to seasonal affects both for LC and LST mapping. It is recommended to include multitemporal image set per year to improve the accuracy of findings.

5. Conclusion

This study focused on examining the LC changes in Izmir city of Türkiye for a 20-year period and investigated the effects of urbanization on UHI. Results provided that city continuously urbanized with the expense of destruction in natural lands. When UTFVI maps are examined, it is seen that the UHI effect occurs in urban centers where urbanization is high. Since it is known that human health and future will be negatively affected in places where this effect is intense, it is recommended by the competent authorities to increase afforestation efforts in these areas and to give more space to green lands. If UHI maps are used as a data source to help the preparation of urban plans, especially in metropolitan areas, it will be possible to make climate-sensitive modeling. Thus, urbanization can be ensured with urban land plans made with minimum damage to nature and rural ecosystems.

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