Urban Heat Island Effect Detection in the Al ‘Ain Region in 2000 and 2019

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The study evaluates the extent of land use, land cover, and land surface temperature change between August 2000 and August 2019 in the Al ‘Ain region in the southeast of the United Arab Emirates using Landsat satellite images. The satellite imageries have been classified by both unsupervised and supervised classification methods using ENVI software. In an unsupervised technique, the ISODATA clustering algorithm will be used for the classification. The resulting image will be used as a reference and for understanding the distribution of pixels with different digital numbers. In the supervised classification method, the maximum likelihood algorithm will classify the image based on the region of interest (training sets) provided by the user based on the field knowledge. Changes in land use/ land cover between 2000 and 2019 were quantified using post-classification analysis in a geographic information system. Followed by atmospheric correction and LST retrieval. The results have shown a dramatic change in land cover and an obvious increase in land surface temperature over the 19 years' study period. The composition of land use/ landcover features significantly influences the magnitude of land surface temperature, and the percent cover of the urban area had an unexpected inverse effect. In contrast, the percent of vegetation is the most fundamental factor in reducing land surface temperature. Using the topical approach, the researchers suggest that the leadership can directly minimize the urban heat island effect in Al ‘Ain city by keeping the cooling effects of urban greenery.

Keywords: Al ‘Ain city, UAE, land use/ land cover, land surface temperature, Landsat, urban heat island

Introduction

The United Arab Emirates (UAE) is a federation of seven emirates located on the southeastern shore of the Arabian Gulf. The capital city of the UAE is the Abu Dhabi city. Abu Dhabi Emirate has the largest area of about 84% of the total area of the country. The Emirate consists of three main regions: Abu Dhabi Region, The Eastern region (Al ‘Ain), and the Western Region (Al Dhafra.). The estimated population of the Emirate was approximately 2,908,173 in the middle of 2016, according to Abu Dhabi Statistics Centre. The annual population growth rate was 5.6% from 2010 to 2016. Over recent decades, a significant transformation in economic growth has been witnessed in Abu Dhabi. The Emirate is working hard to shift its economy from being primarily petroleum-based to focusing on investment in infrastructure, tourism, transport, health, and education, in line with Abu Dhabi's 2030 vision (UAE Government Portal, 2020). This paper will focus on the Al 'Ain Region of Abu Dhabi Emirate. It is one of the fastest developing urban regions in the UAE. Monitoring the earth's surface from space using satellite imagery is currently unequivocal for understanding the effect of human activities on the environment. The objective of this study is to derive land use/ land cover classification maps for the Al 'Ain region in 2000 and 2019, to investigate the urban heat island effects in terms of the variation in land surface temperature in the Al 'Ain region for the same period, and to establish the spatial relationship between land use and land cover (LULC) and land surface temperature (LST).

Literature Review

The evaluation of changes in both natural areas and man-made structures is important in decision-making processes (Jensen and Cowen 1999). The re-molding of the landscape affects people's quality of life and the environment in urban areas. The process of urbanization affects the climate, leading to a variety in temperature compared to other land cover areas.

The surfaces of the urban communities and their spatial pattern can influence temperature; the relationship between land surface temperature (LST), vegetation coverage, and the percent of impervious surface areas in an urbanized environment gives an additional value to understanding urban growth and related surface temperature. Previous studies demonstrated how the existence of vegetation will reduce temperature, while urban areas tend to increase it (Yuan and Bauer 2007).

One of the environmental outcomes of urbanization is the urban heat island (UHI) effect (Oke 1982), where high-density built-up areas trap the heat causing city centers to be up to 10° C warmer than surrounding rural areas. It is important to take into account that the existence of vegetation in the suburbs is exceptionally uncommon in desert areas and that the sand is the primary reflecting surface. In countries that have a desert climate, such as the UAE, it has been seen that the urban areas can generally be cooler than the surrounding rural area, which is inconsistent with the UHI effect standard (Xian and Crane 2005; Hartz et al. 2006).

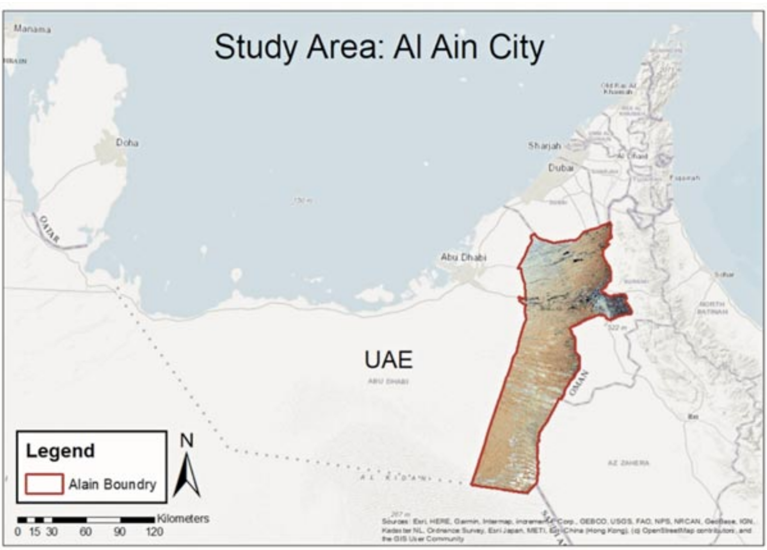
The United Arab Emirates (UAE) has witnessed significant urban transformation since its founding in 1971. Urban expansion in terms of massive infrastructures, such as new residential areas, roads, airports, and sophisticated transportation systems, is a noticeable change. Major terrain changes and disturbances, such as urbanization, are among the leading causes of global climate change. Urban heat islands within urban areas are 3.5°C to 4.5°C warmer than surrounding rural areas (UHIs). As a result, urban expansion in the UAE was predicted to follow a similar pattern, with the country's contribution to global climate change expected to be significant. Unexpected results appeared from analyses of multi-temporal (1988-2017) land surface temperature (LST) data gathered from Landsat satellite datasets over Al 'Ain urban city in the UAE. The overall LST in the study region decreased by 3°C to 5°C due to the urbanization of desert surfaces. This was linked to the expansion of green spaces in newly created urban areas, date plantation expansion, and possibly a cooling of the previously desert surface. As a result, the UHI effect in desert surfaces converted to urban areas was not effectively proven (Al Blooshi et al. 2020).

Investigative studies on the relationship between LST and vegetation cover in arid urban environments are limited. For that reason, this work aims to give a clear idea of this scenario by investigating the relationship between land use/ land cover and LST trends in the desert environment of Al 'Ain region (UAE).

Study Area

Al 'Ain is one of the largest cities in the Abu Dhabi Emirate. It is situated at the following latitude and longitude coordinates 24.207500, 55.744720. The examination zone will cover the whole Al 'Ain region as shown in Figure 1 below.

FIGURE 1
Administrative Boundary of Al 'Ain Region



Al ʻAin city is a part of an oasis located in the northeastern fringes of Al Ruba Al Khali (Empty Quarter) desert in the Arabian Peninsula. It is famous as the garden city of UAE due to the accessibility of groundwater and plantation of many palm trees gardens.

The city evolved rapidly in the 1970s due to investment in oil and gas revenues. The rapid economic growth resulted in an extensive jump in urbanization. Since 1971 after establishment of the United Arab Emirates, the choice of Al ʻAin city as a cultural center by establishing the first and largest governmental university (UAEU) there has attracted large numbers of expatriate and migrant guest workers whose presence has dramatically changed the geography of the oasis. The need for expatriate and migrant guest workers coincided with the recent economic boom, which was fuelled by immense oil revenues. The government invested in colossal projects aimed at building the country's infrastructure (Elessawy 2021).

Consequently, Al ʻAin city and other large urban centers in the United Arab Emirates witnessed a great boom in population and in urban development which continue unabated. Its population has been growing significantly at an average annual rate of 4.1% during the last two decades. The total population of the city has grown rapidly by 1000% over the last 42 years. According to the first census conducted in 1975, the total population of Al ʻAin city was 45,677 inhabitants, which increased in 2021 to 622,675Inhabitants (World Population Review 2022). Better understanding of its urban development patterns is required for the feasible arranging of its resources, for example, urban planning, management of water and land resources, service allocation, market analysis, and so forth. Accordingly, remote sensing and GIS are used to monitor the urban growth rate.

Data and Methodology

Landsat series of satellites have provided space-based moderate-resolution remote sensing data continuously for more than four decades. From July 23, 1972, in total, eight series of Landsat satellites were launched for Earth Observation (EO) purposes. Landsat 6 was the only satellite that failed to achieve orbit. The rest of the satellites have provided a unique resource for global change research and applications in agriculture, cartography, geology, forestry, regional planning, surveillance, and education over the last four decades. In this study, two images for each Landsat series of 5 and 8 were utilized for LULC classification and LST retrieval. The study area years of Landsat data are 2000 and 2019, and only clear-sky images were considered. Landsat data can be downloaded through the United States Geological Survey (USGS) 'Earth Explorer' website free of charge (Sekertekin and Bonafoni 2020).

Landsat 5 TM has six reflective bands: visible, near-infrared, and short-wavelength infrared with 30-m spatial resolution and one band in the TIR region (Band 6). The thermal band has a native spatial resolution of 120-m, but it is delivered by USGS at 30-m after cubic convolution resampling. On the other hand, Landsat 8 OLI sensor has nine reflective bands with 30-m spatial resolution, and Landsat 8 TIRS sensor has two bands in the TIR region (band 10 and band 11). These thermal bands have a 100-m native spatial resolution but are resampled and published by USGS at 30 m (Sekertekin and Bonafoni 2020).

Land Use / Land Cover Classification

A summary of the data used in the land use/ land cover classification and their sources can be found in Table 1 below.

TABLE1
Summary of data used in the study

Data type	Data product	Data source	Data specification
Satellite data	• Landsat 5 and Landsat 8	•https://earthexplorer.usgs .gov	•30m spatial resolution image
Ancillary data	• Shapefile of the study area	• Al ʻAin City Municipality	•Shapefile for Al Ain city boundary
Sample	• Ground truthing point	• Google Earth	•Land cover field data

The satellite imagery has been classified by both unsupervised and supervised classification methods using ENVI software. In an unsupervised technique, the ISODATA clustering algorithm will be used for the classification. The resulting image will be used as a reference and for understanding the distribution of pixels with different digital numbers. In the supervised classification method, the maximum likelihood algorithm will classify the image based on the region of interest (training sets) provided by the user based on his field knowledge. The region of interest given by the operator guides the software as to what types of pixels are to be selected for certain land use/ land cover types. Finally, the classification will be able to derive the land use/ land cover image of the area. Five classes, namely water, vegetation, urban, light soil, and dark soil are identified in the study area.

Vegetation Indices

The spectral vegetation indices (VIs) are mathematical expressions of different spectral bands, mostly in the visible and near-infrared regions of the electromagnetic spectrum, which give the composite property of leaf chlorophyll, leaf area, and optical measures of canopy greenness and canopy architecture. In this paper, the Normalized Difference Vegetation

Index (NDVI) was utilized. The NDVI can be assessed utilizing equation 1.

$$NDVI = (NIR-RED)/(NIR+RED) \quad (1)$$

The RED and NIR represent the spectral reflectance estimations gained in the red (visible) and near-infrared ranges. The estimation of vegetation indices, field data, and expert knowledge empowered us to comprehend and classify the raster image. The higher estimation of vegetation index demonstrates a green area, while lower estimation is separated among different classes, for example, urban, soil, and water bodies (Liaqat and Chowdhury 2017).

Land Surface Temperature

For Landsat 5 images, a first conversion has been performed from DN to at-sensor radiance, followed by the generation of Top-Of-Atmosphere (TOA) reflectance values and at-sensor brightness temperature values for thermal band 6. The atmospheric composition has been considered directly in the LST retrieval, performed with the Single Channel Method. This methodology is effective under the assumption of unity emissivity and using pre-launch calibration constants listed in Table 2 below. To estimate the vegetation cover, Normalized Difference Vegetation Index (NDVI) values have been calculated through Near Infrared (band 4) and Red (band 3). To summarize, Figure 2 illustrates the approach methodology for measuring the LST of Landsat 5(Sekertekin and Bonafoni 2020).

TABLE 2
Thermal band calibration constants of Landsat 5

	Constant 1- K1 watts/(meter squared * ster * μm)	Constant 2 - K2 Kelvin
Landsat 5	607.76	1260.56

The land surface temperature of Landsat 8 satellite imagery can be retrieved following the steps in Figure 3. In this paper, the thermal band (band 10) was used to estimate brightness temperature and red (band 4) with near-infrared (band 5) were used for calculating the NDVI. The metadata of Landsat 8 images used in the algorithm is presented in Table 3 (Avdan and Jovanovska, 2016).

TABLE 3
Thermal band calibration constants of Landsat 8

	Constant 1- K1 watts/(meter squared * ster * μm)	Constant 2 - K2 Kelvin
Landsat 8	1321.08	777.89

FIGURE 2
The methodology for measuring LST of Landsat 5

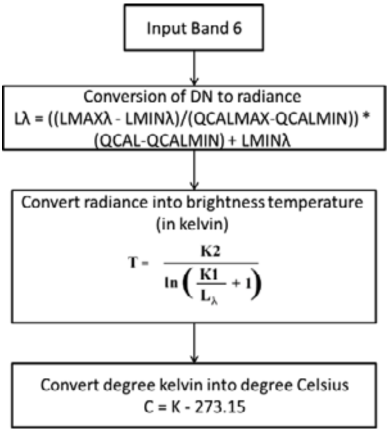
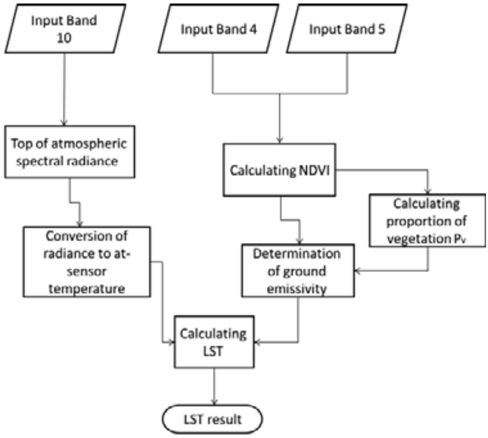


FIGURE 3
The methodology for measuring LST of Landsat 8



Results and Discussions

Accuracy assessment is considered a basic element in land use and land cover classification. The reliability of land use and land cover classification profoundly relies upon data quality, processing, and classification techniques. In this paper, an error matrix was created with the assistance of Google earth data to check the accuracy level of classified maps. The user and producer accuracy of the classified map are shown in Table 4.

In 2000, the overall accuracy of 60% with a Kappa coefficient of 0.50 is shown in Table 4. Higher values are observed in vegetation and water areas whereas urban areas exhibited a lower accuracy. The accuracy assessment table for the 2000 image shows that due to constraints of spatial resolution in Landsat 5 imagery, it is difficult to classify the urban and light soil with very high accuracy. The presence of sand in urban areas was found difficult to distinguish, which results in an underestimation of urban areas. These constraints could be minimized by using high-resolution images. On the other hand, in 2019 the overall accuracy was 85% with a Kappa coefficient of 0.81. Higher accuracy is observed in most of the classes. The ground-truthing points from Google Earth help to give a good classified map of Al 'Ain city in 2019 in comparison to 2000, which had a very low resolution on Google Earth.

The LULC classification of the Al 'Ain region for the years 2000 and 2019, respectively is shown in Figure 4. Five LULC classes were developed. The supervised classification technique, more specifically the maximum likelihood algorithm, was applied to the Landsat images.

The LULC results showed that the total area of Al 'Ain is 13,443 km^2.

TABLE 4
The accuracy of LULC classification in Al Ain city in 2000 and 2019.

LULC Class	2000 Classification		2019 Classification	
	User accuracy (%)	Producer accuracy (%)	User accuracy (%)	Producer accuracy (%)
Vegetation	100	100	90.56604	100
Water	100	100	100	94.73684
Urban Area	15.15	10	87.7551	86
Light Soil	25.88	44	63.76812	88
Dark Soil	100	64	100	58
Overall Accuracy	0.597345133 ≈ 60%		0.847457627 ≈ 85%	
Kappa Coefficient	0.490940594 ≈ 0.50		0.808795067 ≈ 0.81	

The land use and land cover changes in the study area are shown in Table 5. The results showed that soil both light and dark occupied the major portion of the region in both years. In 2000, the estimated vegetation area was 140.9553 km² whereas in 2019 it was 639.3564 km², an increase of 77.95%. The urban area increased from 97.7895 km² in 2000 to 258.9903 km² in 2019, an increase of 62.24%.

As shown in Figure 4, it can be seen that the urban area in Al ‘Ain is concentrated in the center of the city in 2000, especially in the southern part of the city center district. Whereas in 2019, we can note that the urban area in Al ‘Ain is growing in the western and southwestern direc-

Figure 4
Al ‘Ain LULC Classes for the Year 2000 and 2019

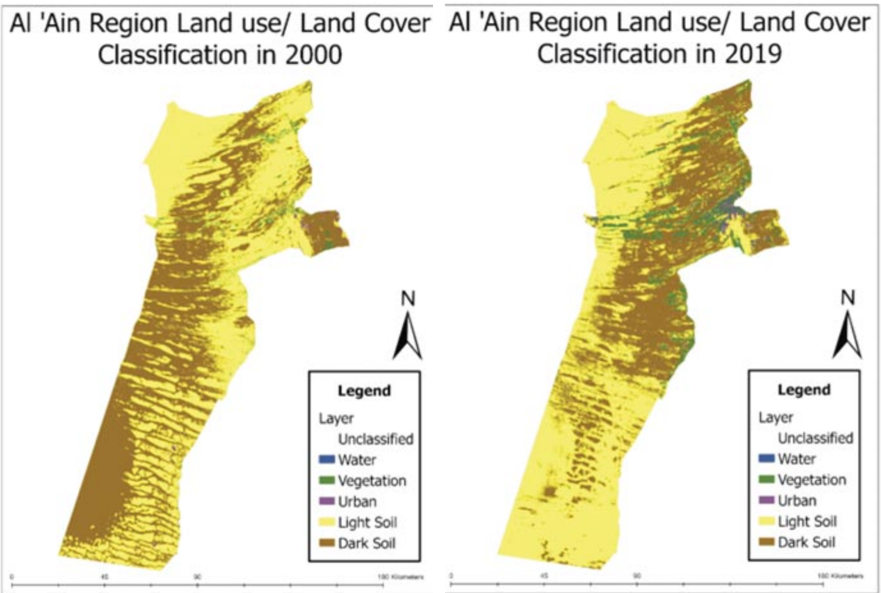


TABLE 5
Land use and land cover changes in Al ʻAin from 2000 to 2019

Land use/ land cover class	Estimated Area in 2000 in km²	Estimated Area in 2019 in km²	Change %
Vegetation	140.9553	639.3564	77.95356393
Water	0.0351	0.1413	75.15923567
Urban Area	97.7895	258.9903	62.24202219
Light Soil	6586.394	7316.0343	9.973166747
Dark Soil	6618.649	5228.6094	-26.58526376

tion, which is basically because of the development of Al ʻAin-Abu Dhabi Road networks, beside the easy access to water and electricity facilities in that area. Likewise, significant development of the urban area in the northeastern direction can be additionally noticed.

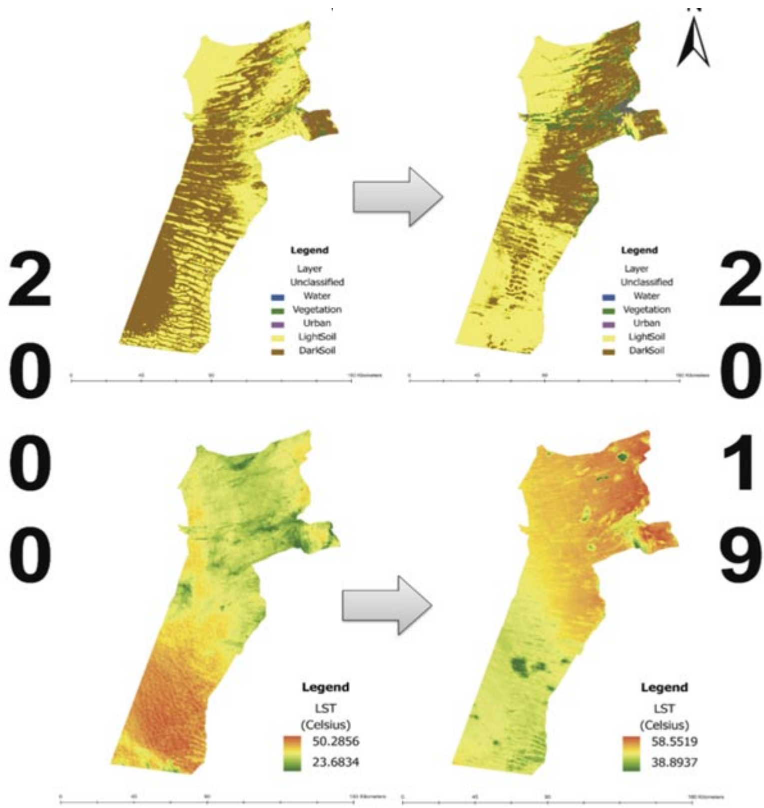
The mean values of land surface temperature (LST) by land use/ land cover class in 2000 and 2019 are calculated and presented in Table 6. The high temperature exhibited by the dark soil land cover class in 2019 (54.77 C°) could be attributed to the hot desert climate that Al ʻAin experiences. The weather is characterized by long, scorching, moderately humid, and dry summers. Vegetated areas are cooler in both years compared to the urban areas due to the greater prevalence of the cooling effect. There has been a 14.3 C° increase in mean urban LST, which is explained by the dramatic increase in population growth. Note that this increase in urban LST indicates that the urban landscape drives climatic conditions within its vicinity.

TABLE 6
Mean land surface temperature in degrees Celsius by land use/ land cover class

Land use/ land cover class	Mean Temperature in 2000 at C°	Mean Temperature in 2019 at C°	ΔT
Vegetation	29.07275391	44.09735119	15.0246
Water	28.971939	42.94099011	13.96905
Urban Area	35.84219361	50.14897415	14.30678
Light Soil	38.14717103	52.07624261	13.92907
Dark Soil	44.72337342	54.77441845	10.05105

The visual results of the land use/ land cover classification as well as corresponding land surface temperature estimation are illustrated in Figure 5. Note that there is an obvious increase in urban areas in 2019. The intensified use of air conditioning during the summer months should also be considered a factor that increases the ambient temperature (Sasidharan et al. 2009). This increase is compatible with Saaroni and Ziv who reported that the UHI effect increases the temperature in an arid city summer that experienced urbanization and an increase in population (Saaroni and Ziv 2010). In comparison, Al 'Ain's temperature increased between 2000 and 2019 (Figure 5). It is considered high because of the higher rates of population increase and urban expansion which led to the inverse urban heat island phenomena. The concept means that due to urbanization and human activities, the urban area transfers the heat to its surrounding areas. We should not forget the hot arid climate associated with the sand land cover in the Al 'Ain region.

Figure 5
Land use/ land cover and land surface temperature maps of Al 'Ain City for 2000 and 2019



The previous studies indicate that different types of land use/ land cover significantly influence LST and that increase in vegetation cover greatly reduces land surface temperature caused by urban heat islands. In this regard, LST can provide important acumens for urban design and management, wherein the local climatological influence of UHI can be controlled by balancing the comparative quantities of different land cover features (particularly vegetation) and improving their spatial arrangements.

Conclusion

In this study, a preliminary characterization has been conducted of the extent of land use/ land cover, and surface temperature change in the Al 'Ain region between 2000 and 2019 using Landsat ETM+ imagery. The accuracy of the land cover classification was 60% and 85% for the 2000 and 2019 land cover maps, respectively. The applied methodology was successful in analyzing the spatial dynamics of land use/ land cover change and associated changes in the urban heat island effect. The study has implications for urban design and spatial planning in other rapidly expanding arid cities in the region. The results suggest that the composition of land use/ land cover features influences the magnitude of land surface temperature. Most cities around the world suffer from urban heat islands, which is an outcome of the process of urbanization. In Al 'Ain, however, urbanization has led to an inverse urban heat island effect as emphasized previously in the results. The percent cover of the sand area has the most substantial effect. In contrast, the percent of vegetation is the most fundamental factor in reducing land surface temperature. We suggest that the leadership can directly minimize the urban heat island effect in the Al 'Ain region by preserving the cooling effects of urban greenery. Change detection techniques in remote sensing are suitable instruments for monitoring quickly growing cities such as Al 'Ain, and the 2008 Landsat open data policy from the United States Geological Survey (USGS) started another era for utilizing time-series imagery for that purpose (Roy et al. 2010). The free accessibility of three decades of Landsat data gives a priceless understanding of the dynamics of urbanization and its impacts on the environment. On a broader scale, the world's urban population is projected to reach 9.3 billion by 2050 (United Nations 2010). Making local climatic effects caused by urban environments is a significant contributor to global climate change.

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