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The role of land use changes on the formation and spatial changes of thermal islands (A case study in Ahvaz city, Iran)

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A B S T R A C T

In this study, 7 images of OLI and EMT sensors of Landsat 7 and 8 satellites and multi-time images of TM sensor satellite 5 have been used. These images cover the period from 1987 to 2018 (31-year period); after applying processing to satellite imagery, land use layers were prepared by supervised classification method. Then, using the thermal equations and the center algorithm, the similarity of the surface temperature of the earth for the periods of 1978, 2000, and 2018 was calculated for the study area in four stages. Results indicate that barren lands in 1987 had the largest area with 437 km and the use of irrigated land had the least area withkm^2. Studies have also shown that from 2000 to 2018, due to the increase in urban population and migration to this city and the expansion of housing construction, residential use has gradually increased to an area of 446 km^2 and the amount of land use in barren lands has decreased to 431 square kilometers. Survey of temperature with temperature changes showed that in 1987, the temperature in barren land uses reached a maximum temperature of 48 C° outside the suburbs, and from 2000 to 2018, land use in the northwest and west of the metropolis reached 56 to 70C°. Examination of the results shows that during the study year, due to population growth and the growing trend of residential use in the metropolis due to the replacement of buildings, the Cement and Asphalt Organization will absorb these levels more than they reflect the sun and has increased the temperature in urban areas. This application is considered as the creator of the thermal island for the metropolis.

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1. Introduction

Cities often experience specific climatic conditions, called urban climates, which are characterized by differences in the variables of the city (air temperature, humidity, wind speed, amount of precipitation) with the less dense areas around it. Earth temperature is one of the key parameters in physical, chemical, and biological control in land processes and is an important factor for studying urban climate (Khandelwal, 2017). Earth's surface temperature is an important parameter that can represent changes at the land level, which have recently been highlighted in many regional studies, such as global climate change, hydrological and agricultural processes, the use and coverage of urban land, and soil moisture surveys (Razistine, 2014).

The term thermal island was first coined by Howard about a century ago, in 1833 (Solk, 2004). Thermal remote sensing data is a unique source for defining a surface heat island that is associated with the thermal island of the urban canopy. Data from synoptic meteorological stations have long-term resolution and long-term coverage but it lacks spatial details. Thermal remote sensing data can have a general overview of the entire city and is of particular importance for a detailed study of the city's climate (Weng, 2009). Roth et al., (1989), used surface temperature patterns with a variety of terrestrial uses, they used AVHRR data to assess the intensity of the thermal island (Gallo et al., 1993). They compared plant indices and land surface temperatures obtained from AVHRR with the minimum air temperature observed in urban and rural areas.

In this study, it was found that the plant indices obtained from satellite data have a linear relationship with the difference between urban and rural temperatures. However, all of these studies showed that the 1.1-kilometer resolution of AVHRR data was only suitable for imaging the temperature of the city on a macro scale, and was not suitable for determining a significant and accurate relationship between the values of the extracted images and measurements on the earth. Evaluation of the effects of urban development on the thermal islands of Guangzhou (Weng and Yang, 2004) by using Landsat 7 sensor images showed that the expansion of urban structures has strengthened the effect of thermal islands with a magnitude of 0.2 to 4.7 degrees Celsius (Xiao and Moody, 2005). They examined the relationship between land use change and land cover with the pattern of land surface temperature in a delta called Pearl River in Guangdong Province in southern China using Landsat 7 and 8 satellite images (TM, RTM). The results showed that the scattering of thermal islands in urban areas was distributed with a pattern that was directly related to the distribution of the pattern of land cover. Jivang et al., 2010 calculated the Land Surface Temperature (LST) index to obtain the effects of land use changes in the city, and it was found that drastic land use land use changes lead to thermal islands. Urban thermal islands and their impact on heat waves and human health in Shanghai, China is a study conducted by Ta et al., (2010). The results showed that different sites (downtown) experienced different degrees of warming. The study of the combined and physical effects of urban research conducted by Song and Wu (2016) in Wisconsin, USA shows the unquestionable role of impermeable surfaces in the diversity of thermal islands in urban areas. In this regard, considering the importance of work, it can be said that there is an important need to pay attention to the temperature of the earth's surface and land use changes, which will be discussed in this research. Nam Van et al., (2017) have performed a study entitled Diagnosing and Predicting Urban Development in the Hanoi Region (Vietnam) Using the Spot-5 Satellite Model and the Markov Chain Model. The main purpose of this study is to diagnose and predict the development of Hanoi, a typical city in Vietnam. For this purpose, Spot-5 satellite images were first used in 2003, 2007 and 2011 to classify the four stages of earth cover, open water, vegetation, elliptical, and residential. The results showed that the impenetrable surfaces of Hanoi will increase by 8.27% and 14.09% of the total study area in 2019 and 2027, respectively. The results of this study provide valuable information for local city planners in urban planning and development. Lamchin et al., (2016) examined land use changes and desertification in Mongolia by remote sensing technique. The results of this study did not show any relationship between the Albedo level of vegetation index or TGSI index, but revealed a large relationship between TGSI and Albedo levels. The high correlation between the TGSI and Albedo indices was also significant in desertification-free areas. Sohl and Claggety, 2013 have performed a study on a protected area in southern Spain using the Markov CA chain model; these researchers were able to demonstrate land use changes in the past and future. In another study by Wang using Markov's CA chain model, Japanese land use changes were modeled for the years 2015-2042.

2. Material and Methods

2.1. Study Area

Ahvaz is located in the geographical area of 30' 31° north latitude and 65' 48° east longitude, in the plain part of Khuzestan and with a height of 12 meters above sea surface. The city of Ahvaz, with an area of 18650 hectares, is considered as one of the largest cities in Iran (the third largest city in Iran). This city is the capital of Khuzestan province, one of the eight metropolises of Iran, and is located in the central part of Ahvaz city. The existence of large industrial factories and administrative and industrial facilities of the National Iranian Drilling Company has made Ahvaz one of the most important industrial centers in Iran, and this has led many immigrants to Ahvaz. A large part of Khuzestan province is a plain and the city of Ahvaz is located in the plain part, but the severe shortage of vegetation has caused the heat and dryness of Ahvaz and has placed it in the category of the hottest regions of Iran. In winter, the temperature drops to 5 degrees

Celsius and in summer it rises to 50 degrees Celsius (Fig. 1).

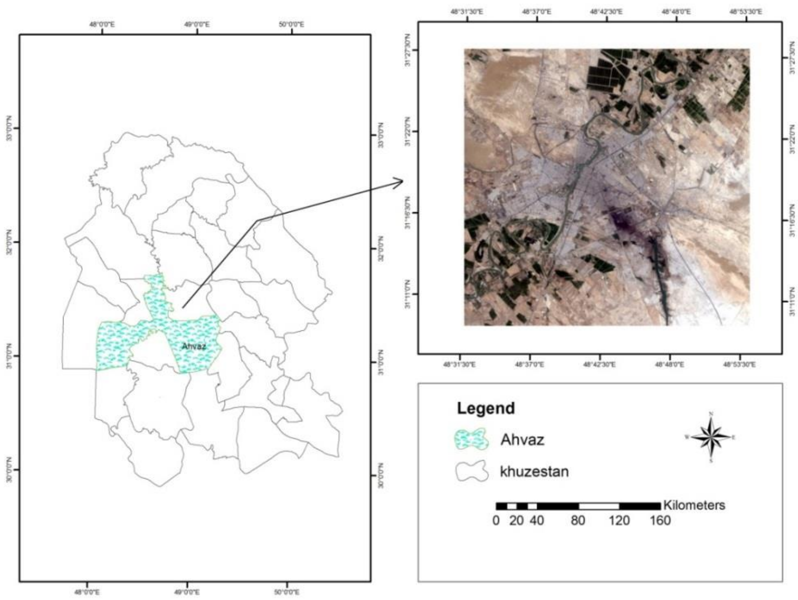

Fig. 1. Geographical location of the study area

In this research, 7 images from OLI and EMT sensors of Landsat satellite and multi-time image of TM sensor of Landsat 5 satellite have been used. These images cover the period from 1987 to 2018 (31-year period); Due to the intense heat in the summer months a series of pre-processing and geometric and radiometric corrections were applied to the images to reduce and eliminate the errors related to the images. Then, the supervised method was used to classify the information. In this method, training samples were used to classify pixels. A center similarity algorithm was used to classify and monitoring, which in fact evaluates and analyzes each unknown pixel based on the variance and covariance of that spectral reaction, assuming that the data distribution of each class is based on the normal distribution around the average pixel of that class. Finally, the Kappa method was used to validate and classify the model. Algorithmic calculation of the earth's surface temperature that is used in this study to obtain the earth's surface temperature, is based on the satellite sensor lighting temperature. This lighting temperature was performed in two stages: A) Converting the digital value of band 10 to spectral variance using relation (1), B) Converting spectral variance to sensor lighting temperature in Kelvin.

Lsat=(DN-1) × UCC (1)

Where, Lsat is sensor radiation energy, DN is digital number (numerical value of each pixel in original images), and UCC is unit conversion coefficient. This coefficient varies for each ASTER band and depends on the intensity of the sensor Gain. A metadata image file was used to determine the Gain sensor.

After calculating the radiant energy, the temperature of the earth's surface was determined using inverse Eq. 2.

$$\beta_\lambda(T) = \frac{C_1}{C_2\lambda^5(e\lambda T-1)} \quad (2)$$

(C1=1/19104 × 10-16wm) 2 (3)

(C2=1/43879 × 10-2mk) (4)

$$T = \frac{C^2}{\lambda . LN\left[\frac{C^1}{\lambda^5 B_\lambda(T)}+1\right]} \quad (5)$$

2. 1. Finding the Brightness Temperature

Thermal bandwidth data can be converted from spectral variance in the sensor to brightness temperature. The brightness temperature of the earth is assumed to be a black object (emissivity) and includes the effects of the atmosphere (absorption and radiation). The brightness temperature is calculated using the sensor calibration coefficient from Eq. 6.

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda+1})} \quad (6)$$

Here, T is the effective brightness temperature in the sensor in Kelvin, K_1 is the calibration coefficient ($w/m^2 srnm$), K_2 is the calibration coefficient 2 in Kelvin, and L is the spectral variance in the sensor (Alavi Panah et al., 2015). Table 1 shows the coefficients K_1 and K_2 for the used types of sensors.

Table 1. K_1 and K_2 coefficients for different types of sensors

Sensor	K1	K2
MSS	671.6	1284.3
TM	607.7	1260.5
ETM	666.09	1282.7
OLI	7740.8	1321.07

2. 2. Calculation of Vegetation

In this study, Eq. 7 was used to calculate the Normalized Difference Vegetation Index (NDVI).
In this Eq. NIR is a near-infrared band and RED is a red band.

2. 3. Surface Fault Calculation

In vegetation, surface faulting can be calculated according to the density of vegetation, the value of which is obtained from Eq. 8.

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (7)$$

$$C \begin{cases} 0.99 \text{ Vegetation} > 0.5 \\ 0.97 \text{ Vegetation} > 0.2 \\ \epsilon = \epsilon \text{ Vegetation} * PV + \epsilon * (1 - PV) = 0.004 * PV + 0.986 \text{ if } 0.2 <= \text{Vegetation} <= 0.5 \end{cases}$$

$$PV = \frac{\text{Most vegetation} - \text{Lowest vegetation}}{\text{Most vegetation} + \text{Lowest vegetation}} \qquad (8)$$

In this Eq., PV is the percentage of vegetation (Khosravi et al., 2017).

2. 4. Image Classification

Sensor image classification in remote sensing is one of the most important parts of satellite data interpretation. By using the supervised classification method and introducing the spectral signs of vegetation, residential and barren by applying the most similar algorithms, the supervised classification was done by dividing the four stages to urban, barren, vegetation, and water classes.
The first step in classifying the probability calculation P (xlwi) is to use the n-dimensional multi-variative density function in Eq. 9.

$$P(xlwi) = (2x)^{-\frac{f}{2}} |\Sigma_i|^{-\frac{1}{2}} (x - mi) + \Sigma^{-1} (x - mi) \qquad (9)$$

Here, Σ_i is the covariance matrix of wi-class and mi is an average vector. F is the number of bands and // is the thermal symbol.

2. 5. Image Validation

Assessing the accuracy of classification results is the final part of a classification process. For this reason, Kappa coefficient method was used to evaluate the accuracy of classified maps. It is based on the following equation.

$$kappa = \frac{P_0 - P_C}{1 - P_C} * 100$$

P_0: Correctly observed
P_C: Expected agreement

3. Results and discussion

3. 1. Investigating Land Use Changes

A study of land use changes from 1987 to 2018 in Ahvaz showed that in 1987, the Bayer land class had the largest area with 437 and the water use class with 174 had the lowest area. According to the research findings, until 2000, the water use index still has the lowest area and the largest area compared to 1987 with 207 km, and the residential use had reached the maximum area with 431 km.

A survey conducted for 2018 showed that residential use of the study area has the highest area with 446 and the water floor still has the lowest area of 262 km. Land use survey for Ahvaz city showed that from 1987 to 2018, residential areas are the most expanded due to population growth and urbanization. This expansion has been such that in 1987, residential uses were scattered in the urban areas of Ahvaz. The use of vegetation in the northeast has expanded in the areas of Seyed Amer, Khorbanieh Bozorg, Sheiban, Taleghani town, and in the southwestern part of Ahvaz in the area of Ome Nomeyr. This vegetation has been in the same area for years in the study area, and before 2000 to 2018, it was a scattered state and gradually shrunk and spread throughout the city. It is a sign of population growth and expansion in these areas (Fig. 2).

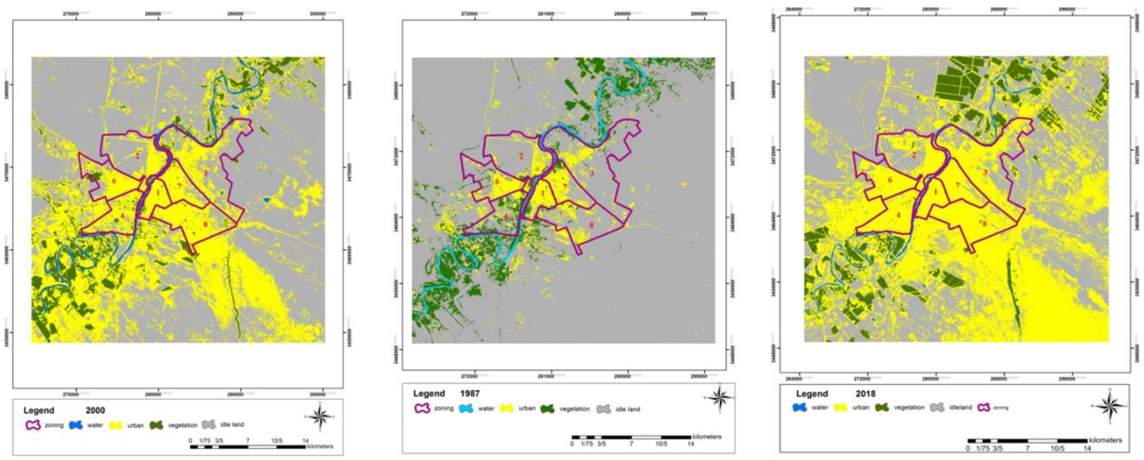

Fig. 2. Investigation of land use changes in Ahvaz during the statistical period 1987 to 2018

3. 2. Temperature Investigating

An examination of the temperature findings in fig. 3 for 1987 showed that the temperature is divided into 5 classes. The lowest temperature range is 27-35 degrees Celsius in the Karun River area and the highest area and temperature range is mostly outside the zoning of Ahvaz city (of course, except in the 2nd urban area). Studies also show that the temperature in Ahvaz is balanced due to the amount of heat absorption and storage by the Karun River. This thermal equilibrium is clearly displayed around it. With the distance from the river to the plains, the use of barren lands intensifies the temperature. Investigating temperature findings for the 2000s Like the 1987s, not much has changed (of course, this may be due to the fact that the number of years of study is 28 years, the resolution of climate change in the region should be 30 years or more). These temperature changes are mostly in the range of 42 to 45 degrees Celsius, which is more widespread than in 1987 and has reduced the intensity of the temperature, and is most widespread outside the city. Lower temperatures are below the average temperature of 25 to 41 degrees Celsius around the Karun River and the urban area. Studies have also shown that the highest recorded temperature is outside the city, due to barren lands and plains around the study area. Temperature study from 2000 to 2018 shows its different temperature changes from previous years. These changes were indicative of an increase in temperature relative to the observation years. A study of this finding showed that the largest class, 48.63 to 76.31, has expanded to urban zoning. These values have even affected the Karun River, which has been a factor in urban climate change and increased its temperature (although this should not be due to declining water levels in the Karun River) (Fig. 3).

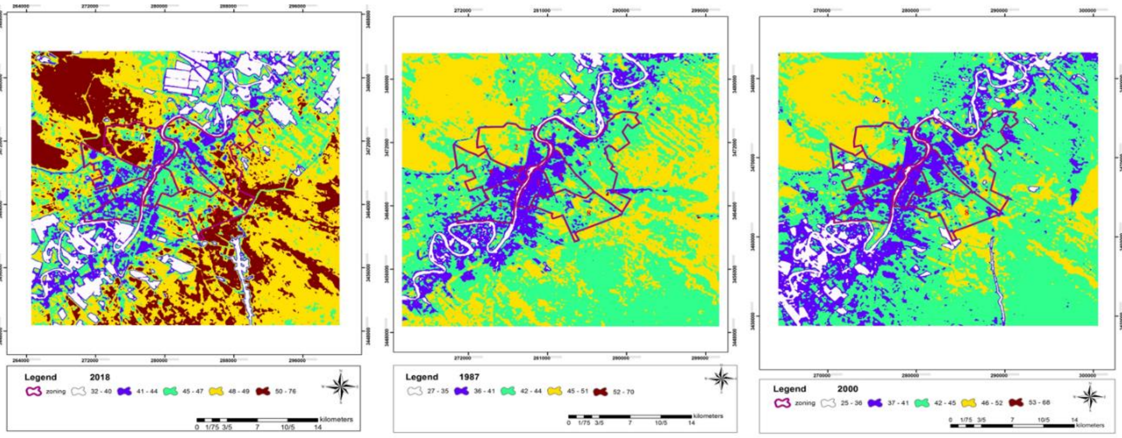

Fig. 3. Investigation of temperature changes in Ahvaz during the statistical period 1987 to 2018

3. 3. The Relationship between Temperature and Land Use

A study of the relationship between lines with the same temperature and land use for 1987 showed that most temperature lines are for wastelands and barren lands. Due to the lack of moisture, these lands become very hot during the day and cause the temperature to rise to 48 degrees Celsius (plains and deserts of this city). The findings also show that vegetation in the northeast and southwest is moderately cooled for the city, so that the temperature in this land use reaches a minimum of 32 degrees Celsius. For residential uses that are most prevalent in urban areas, the average temperature reaches 40 degrees Celsius. This use acts as an intermediate island (Fig. 4, 1987).

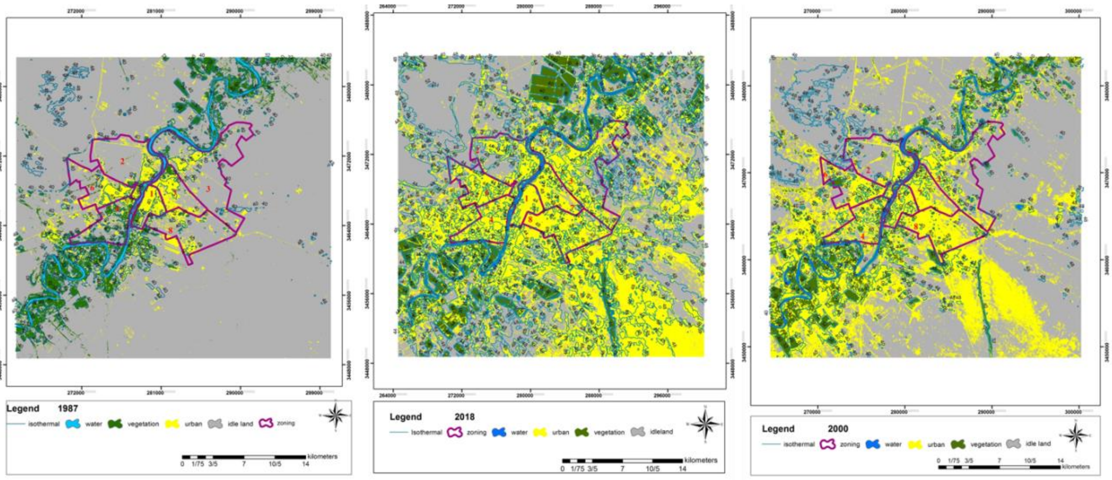

Fig. 4. Relationship between temperature and land use in Ahvaz metropolis during the statistical period 1987 to 2018

An examination of the adaptability of land use to temperature from 1987 to 2000 shows the expansion of temperature in the northwest and west of the city. The temperature for these geographical directions in some areas has reached 56 degrees Celsius, which has increased compared to previous years. Of course, in most areas it is the same as 48 degrees Celsius, and this expansion is related to some areas and barren lands. In general, residential areas continue to be a heat factor; so that the temperature in these areas reaches 40 degrees Celsius (Figure, 4, 1987). The findings also showed that the adaptability of temperature to land use has expanded in all urban and non-urban areas. In terms of temperature, the expansion of temperature for these years shows that the temperature has increased in situations where there is residential use, and this increase in temperature is no longer different from barren lands. In previous years, the use of barren land had the highest increase in temperature. From the justification of the thermal islands, according to the differences between urban areas and adjacent areas, it is clear that the characteristics of each of these environments have caused the formation of a specific microclimate. Cities have destroyed this microclimate by increasing the urban population and the process of urbanization, creating a new microclimate. Thermal islands are the result of the effects of the urban process on the climate. In this phenomenon, urban areas with the expansion of urbanization, population growth (increase in residential use) from 1987 to 2018 compared to rural and adjacent areas have the highest temperature (Fig. 4, 2000, 2018).

3. 4. Model Accuracy Classification Parameter

In this study, in order to accurately classify the parameters and calculate the kappa coefficient for each of the images, it was randomly selected and the kappa coefficient for each classification was calculated. An examination of the findings of Table 2 showed that the accuracy of the images in 2018 using the Kappa coefficient is much higher than in 1987 and 2000.

Table 2. Kappa coefficient and accuracy of image classification

Classification Accuracy	Kappa Coefficient	Number of Points	Year
0.94	0.93	170	1987
0.88	0.86	213	2000
0.96	0.96	365	2018

4. Conclusion

Research has shown that most articles have focused on land use change or thermal islands, but have not studied the role of land use and its changes in the formation of thermal islands over a 31-year period. In this study, the newest and most scientific remote sensing algorithms have been used, first using Landsat satellite images to examine the relationship between land use change and surface temperature, then to predict land use change using the Kappa Markov model. The study of research showed the results for urban and suburban areas of Ahvaz city from 1987 to 2018. At first, the city of Ahvaz had the most land use. With the increase in population and the process of urbanization, barren lands have gradually disappeared and given way to residential use. The expansion and intensity of these uses has been mostly in the east and west directions of the city (due to the Karun river in the northeast, southwest direction). Examination of land use results and temperature relationship reveals that in the year of study in urban areas, residential areas were replaced due to population growth, construction, cement organization, and asphalt organization. These levels will absorb more sunlight than they reflect, raising temperatures in urban areas and creating a special climate for the region. The results also showed that the Karun River and the vegetation within the river water range act as a moderator and cooler for the city. In case of lack of attention and planning for the management of this river, the temperature of Ahvaz will be catastrophic for both the urban areas (with the expansion of residential and community areas) and the suburban areas, the barren lands and the plain and desert state of the city. It will detrimentally affect people's health, energy consumption, and air quality.

References

Gallo, K.P., McNab, A.L., Karl, T.R., Brown, J.F., Hood, J.J. & Tarpley, J.D., 1993. The use of NOAA AVHRR data for assessment of the urban heat island effect. *Journal of Applied Meteorology*, 32(5), p. 899-908.

Jiang, J. & Tian, G., 2010. Analysis of the impact of land use/land cover change on land surface temperature with remote sensing. *Procedia Environmental Sciences*, 2, p. 571-575.

Khandelwal, S., Goyal, R., Kaul, N. & Mathew, A., 2017. Assessment of land surface temperature variation due to change in elevation of area surrounding Jaipur, India. The Egyptian. *Journal of Remote Sensing and Space Science*, 21(1), p.87-94.

Liu, L. & Zhang, Y., 2011. Urban heat island analysis using the Landsat TM data and ASTER data: A case study in Hong Kong. *Remote Sensing*, 3(7), p. 1535-1552.

Matson, M., Mcclain, E.P., McGinnis Jr, D.F. & Pritchard, J.A., 1978. Satellite detection of urban heat islands. *Monthly Weather Review*, 106(12), p. 1725-1734.

Ning, J., 2011. Influence of coastal land use change to land surface temperature. *Energy Procedia*, (11), p.3999-4004.

Rozenstein, O., Qin, Z., Derimian, Y. and Karnieli, A., 2014. Derivation of land surface temperature for Landsat-8 TIRS using a split window algorithm. *Sensors*, *14*(4), p.5768-5780.

Roth, M., Oke, T.R. & Emery, W.J., 1989. Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International Journal of Remote Sensing*, 10(11), p. 1699-1720.

Song, Y. & Wu, C., 2016. Examining the impact of urban biophysical composition and neighboring environment on surface urban heat island effect. *Advances in Space Research,* 57(1), p. 96-109.

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F. & Chen, H., 2010. The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, 54(1), p. 75-84.

Yuan, F. and Bauer, M.E., 2007. Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of environment*, *106*(3), p.375-386.

Weng, Q. & Yang, S., 2004. Managing the adverse thermal effects of urban development in a densely populated Chinese city. *Journal of Environmental Management*, 70(2), p. 145-156.

Weng, Q., 2009. Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. *ISPRS Journal of Photogrammetry and Remote Sensing*, 64(4), p. 335-344.