

COMPREHENSIVE ANALYSIS OF URBAN THERMAL ENVIRONMENT — A CASE STUDY OF Qingdao, CHINA

Yu Liu^{1, *}, Jianwei Qi¹, Guanghui Wang¹, Jie Wang¹

¹ Land Satellite Remote Sensing Application Center, MNR, Beijing 10048, China-867532660@qq.com

Commission III, WG III/1

KEY WORDS: Spatial Planning of National Land, Thermal Environment, Qingdao

ABSTRACT:

The thermal environment is an important part of spatial planning of national land. It can be inverted by thermal infrared remote sensing image data. Qingdao is an important coastal city in China which is effected by the urban heat island. The driving factors of urban thermal environment in Qingdao are analysed by using Landsat 8 OLI/TIRS images, DMSP/OLS data, ZY-3 images, statistical data et al. Firstly, the urban heat island information in different periods are retrieved by Landsat8 TIRS by the surface temperature. On this basis, the coupling analysis of the characteristics of vegetation cover, water, land use type, night light, urban impervious surface, transportation, change density and other factors that related to spatial planning of national land and the change of thermal environment is completed from two dimensions of time and space. At the same time, according to the spatial distribution of the heat island evolution, with the aim of improving the thermal environment and optimizing the urban spatial layout of Qingdao, the paper puts forward reasonable suggestions and improvement strategies, and provides basic reference data for the development of urban heat island governance and land development and utilization.

1. INTRODUCTION

Land surface temperature (LST) plays an important role in the energy exchange between the earth's surface and atmosphere, and is a key parameter for the analysis of regional and global surface processes and the simulation of climate change (Song T, 2015a). According to the 2013 climate change report of the United Nations Intergovernmental Panel on climate change, the average temperature of the earth's surface has been warming continuously every ten years in the past three decades. Global warming has become a major trend of climate change in the 21st century, which will lead to the rise of sea level and the increase of extreme weather, affecting the global ecosystem. Satellite remote sensing has become one of the main technical means for the formulation and implementation supervision of land spatial planning because of its high spatial, temporal and spectral resolution, as well as its advantages of immediacy, dynamic, accuracy, objectivity and comprehensiveness. Since 2016, Qingdao has actively explored the application of satellite remote sensing in land and resources monitoring and supervision, and urban thermal environment research is an important part of it. It lays a foundation for the dynamic monitoring and evaluation of the implementation of the overall planning of land and space. The traditional monitoring method is to evaluate the real-time data provided by the ground meteorological station. However, due to the small number of monitoring points, the accuracy and breadth can not meet the needs of large-scale regional observation (Stewart, 2011a), which affects the objective analysis of the spatial distribution characteristics of urban heat field. By using the thermal infrared data, the urban thermal environment, especially the information extraction of urban heat island, can be quickly and widely realized. On this basis, remote sensing technology and geographic information system technology are used to interpret surface information. This paper analyzes the temporal and spatial variation characteristics of urban surface thermal environment,

explores the formation mechanism of urban surface thermal environment, and conducts research on mitigation of urban surface heat island effect. At the same time, it provides reference data for improving the urban living environment and optimizing the urban spatial layout.

2. STUDY AREA AND DATA

2.1 Overview

Qingdao is located on the southeast of Shandong Peninsula, between east longitude 119 ° 30 ' - 121 ° 00 ' and north latitude 35 ° 35 ' - 37 ° 09 ' , with mild and humid climate, abundant rainfall and pleasant climate. Qingdao is the main node of the New Asia Europe continental bridge economic corridor and the strategic fulcrum of maritime cooperation, under the jurisdiction of 6 municipal districts and 4 county-level cities

2.2 Data sources and pre-process

We choose the good quality landsat8 OLI/TIRS, DMSP/OLS data, ZY-3 images data in August of 2017-2019 as research data. Landsat-8 OLI/TIRS data is used for land surface temperature retrieval, classification, specific target information extraction and others. ZY-3 and another satellite image data are used for detecting the change information. DMSP/OLS data is used for reflecting the social development.

In order to present real and objective land surface situation, reduce errors that caused by data, pre-processes like radiometric calibration, atmospheric correction, ortho-rectification, geometric correction, image mosaic and image clip has been done.

* Corresponding author

3. METHODS

Make full use of the sensitivity of thermal infrared band to heat, the land surface temperature can be extracted by using single channel algorithm. From the radiation transfer equation, thermal infrared radiation equation that satellite sensor received can be written as below (Yu L,2018a):

$$L_{\lambda} = [\epsilon B(T_s) + (1 - \epsilon)L_d]\tau + L_{\uparrow} \quad (1)$$

where ϵ = land surface emissivity
 T_s = radiation brightness temperature
 $B(T_s)$ = blackbody radiation brightness
 τ = transmittance that atmospheric in thermal infrared band

L_{\uparrow} = atmospheric upward radiance
 L_{\downarrow} = atmospheric downward radiance

From the Planck function, land surface radiation brightness temperature:

$$T_s = \frac{K_2}{\ln(K_1 B(T_s) + 1)} \quad (2)$$

For landsat8, thermal infrared band band10, $K_1 = 774.89$ W/(m²·μm·sr), $K_2 = 1321.08$ K (Hanqiu X, 2015a). Artis (Artis D A,1982a) think radiation brightness temperature is the temperature of blackbody, and most of the things in nature are not blackbody, thus emissivity should be used for correction to make it land surface temperature:

$$T = \frac{T_s}{(1 + (\lambda T / \rho) \ln \epsilon)} \quad (3)$$

where T = land surface temperature
 T_s = radiation brightness temperature
 $\lambda = 11.5\mu\text{m}$
 $\rho = 0.01438\text{mk}$
 ϵ = emission

In order to highlight comparability and relativity, it is necessary to normalize the surface temperature. As a result, the map of heat island intensity is formed.

$$H = \frac{t - t_{\min}}{t_{\max} - t_{\min}} \quad (4)$$

where H = Heat island intensity
 t = The surface temperature
 t_{\max} = The maximum surface temperature
 t_{\min} = The minimum surface temperature

The value of H is between 0 and 1. According to H value, the temperature is divided into 4 grades by density division method, which are low temperature region, middle temperature region, high temperature region and higher temperature region.

With the remote sensing image as the data source, the normalized difference vegetation index (NDVI), the fractional vegetation cover (FCV), the normalized difference impervious surface index (NDISI), the modified normalized difference water index (MNDWI) and land use information extraction are realized by using band calculation, supervised classification and other algorithms.

$$FVC = \frac{NDVI - NDVI_s}{NDVI_v - NDVI_s} \quad (5)$$

where $NDVI$ = The vegetation index

$NDVI_s$ = The minimum value of vegetation index in bare land

$NDVI_v$ = The maximum value of vegetation index in vegetation cover area

$$NDISI = \frac{TIR - \frac{Green + NIR + MIR}{3}}{TIR + \frac{Green + NIR + MIR}{3}} \quad (6)$$

$$MNDWI = \frac{Green - MIR}{Green + MIR} \quad (7)$$

TIR is the emissivity of the thermal infrared band. $Green$ is the reflectance of the green band. MIR and NIR are the reflectance of mid-infrared band and near-infrared band.

According to the statistical data such as the relevant annuals, the population density data, road network and other data are standardized; On this basis, based on the analysis of the temporal and spatial distribution characteristics of urban thermal environment and the influencing factors of urban thermal anomaly, the urban thermal environment monitoring and comprehensive analysis model is established and some suggestions for the mitigation and improvement of urban thermal environment are put forward. The technology roadmap is shown in Figure 1.

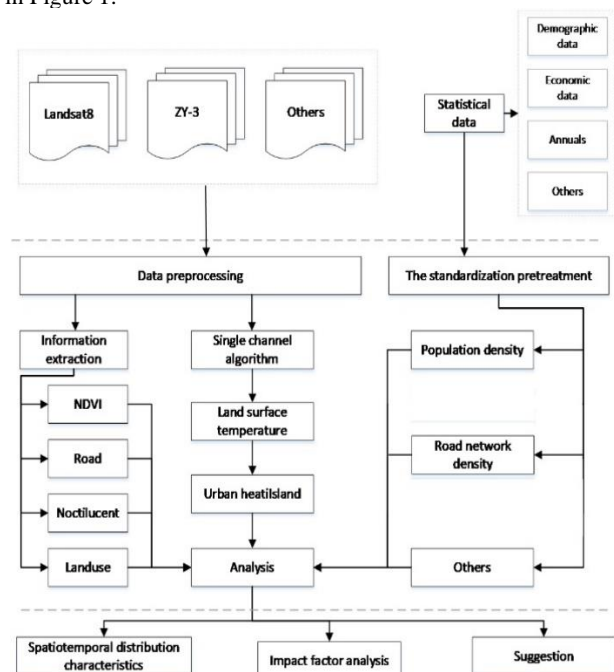


Figure 1. The technology roadmap

4. RESULT

In order to study the temporal and spatial variation of the surface temperature, the sequence Landsat 8 image data is used to realize the inversion of the surface temperature in 2017, 2018, 2019. The results are shown in Figure2. Compared with MODIS standard temperature products, the average absolute difference is 2.4k. The urban heat island is mainly concentrated in the urban area of Qingdao, the south of Jimo, the middle of Jiaozhou, the middle of Jiaonan, and the east of Huangdao. In the past tree years, the urban heat island has an increasing trend.

Furthermore, in order to study the relationship between surface temperature and vegetation cover, traffic, land use and other factors can be analysed by random sampling. 100 points are randomly generated for correlation analysis. Therefore, heat

island intensity, FCV, MNDWI, road network density map, NDISI, change density, night light data and surface coverage

classification map are generated by using remote sensing image and statistical data. The results are shown in Figure3.

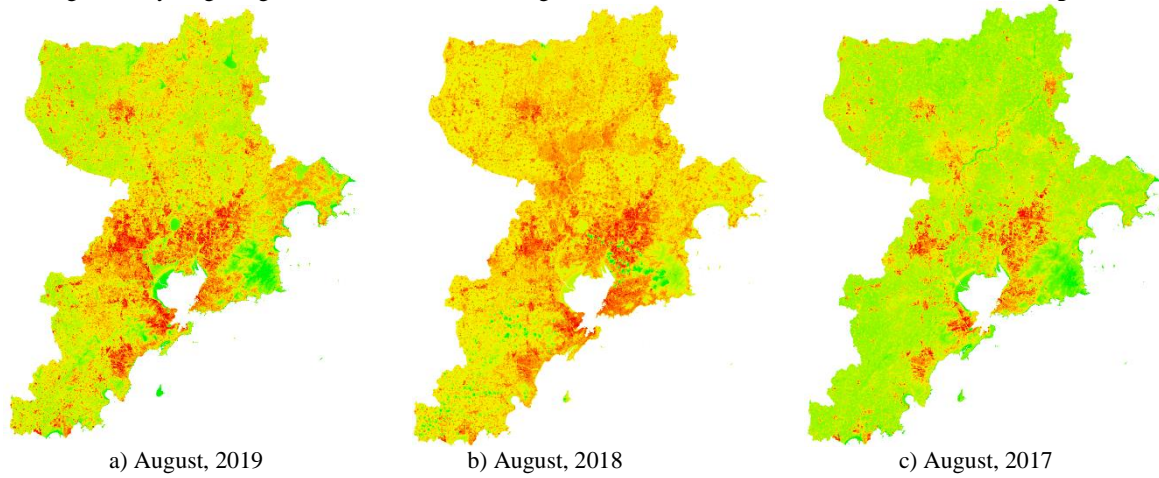
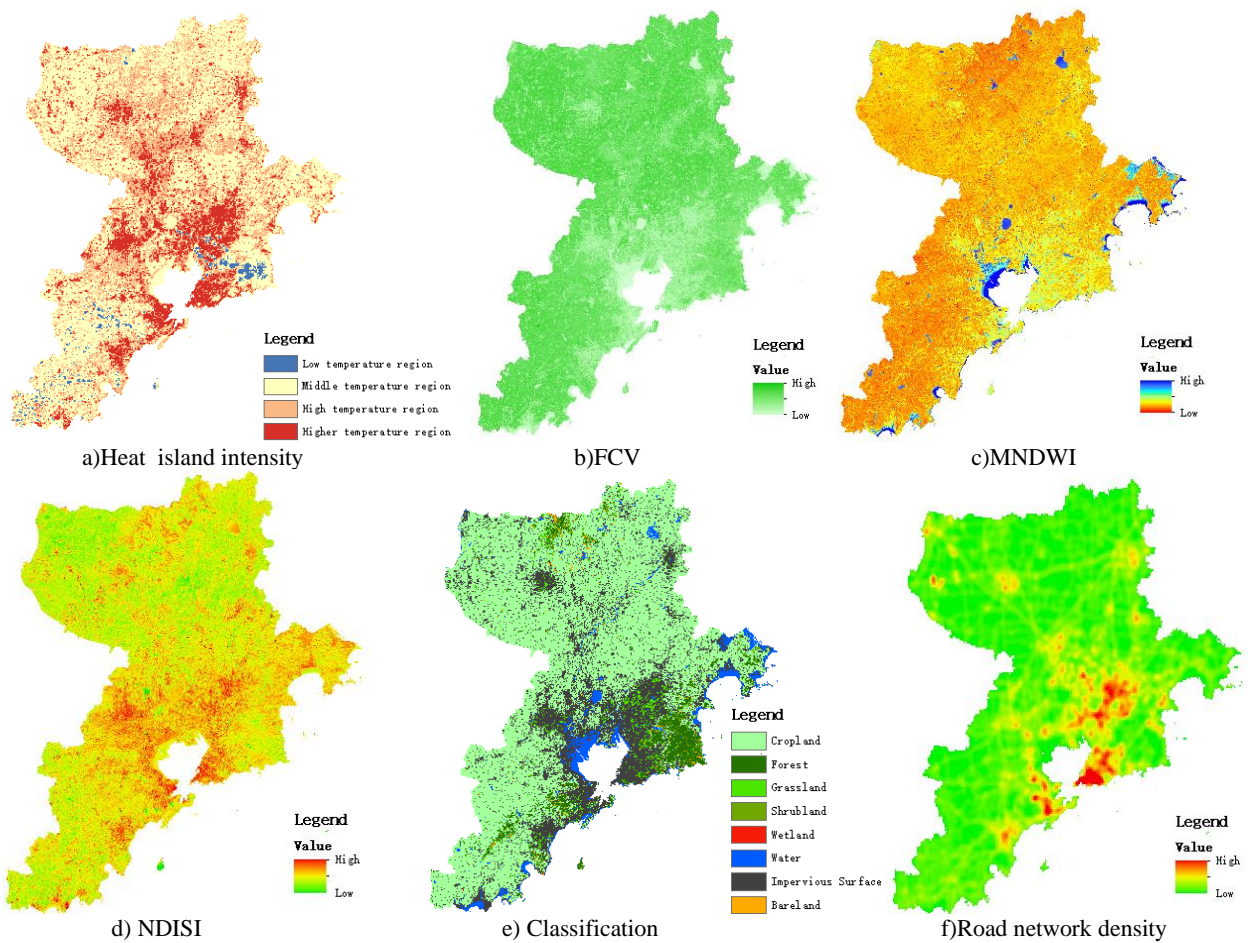


Figure 2. Inversion results of surface temperature in Qingdao



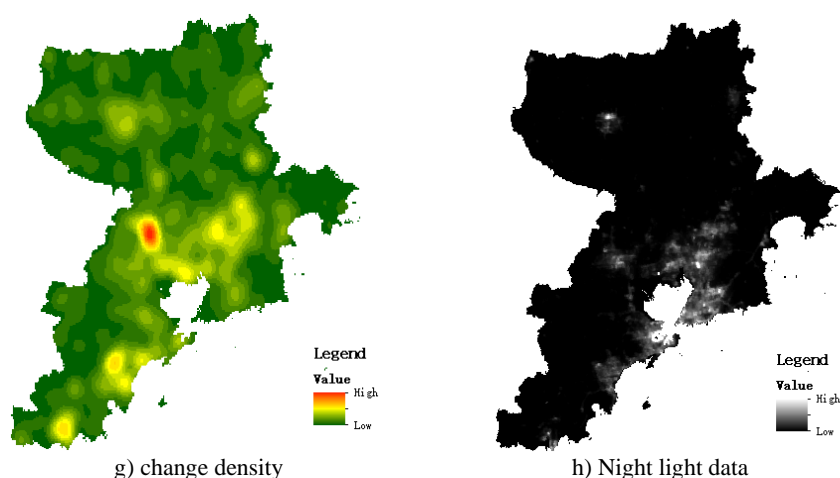


Figure 3. Inversion results of other factors

5. DISCUSSION

As a whole, the temperature difference between urban and rural areas in Qingdao is obvious, with urban as the core and suburban towns scattered around. The high and low temperature mutation areas are basically the same as the built-up areas which can be seen on the Figure3.(a) and Figure3.(e). Based on the comparative analysis of surface temperature in different years, the change of heat island in Qingdao was obtained. It can be seen that the area of heat island in Qingdao is expanding, taking the old urban area as the center and gradually surrounding the new urban area. The number of heat islands increases, and the distribution changes from local aggregation to uniform distribution. The main reason is that the urbanization level of Qingdao is constantly improving, and the urban population and energy consumption are constantly increasing.

In order to analyse the driving factors of thermal environment in Qingdao, this study considers two aspects: natural and human. According to the classification map of surface cover in Figure3.(e), it can be seen that the water body is in a low temperature area, the cultivated land and grassland are mainly in the medium temperature area, and the impervious surface with the city as the main body is mainly in the high temperature area. Industrial land is significantly higher than commercial land and residential land. The medium and low temperature areas are mostly in the suburb, water area and green space of the city, which can produce cold air. It needs to be planned reasonably. The hot island area and the cold air generation area can be used as the basis for air duct division to improve the living environment and optimize the blue-green space of the city.

In addition to the influence of factors such as the north subtropical monsoon climate, there are many factors influencing the heat island effect, most of which are carried by human beings. Night lighting data can represent the population density and social and economic situation. So, we get it by the DMSP/OLS data. The change information of the surface cover can reflect the state of human activities. We extract the monthly change information from 2017 to 2019, and use the kernel to generate the change density map, as shown in Figure 3(g). According to the trend line of change density in Figure 4., it can be seen that the LST of Qingdao is increasing with the increasing of the overall change density. This phenomenon can also have corresponding feedback on the night light data, and the heat island and night light area are highly coincident which is shown in Figure 5.

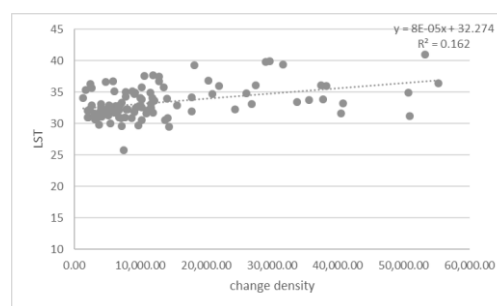


Figure 4. LST-Change density

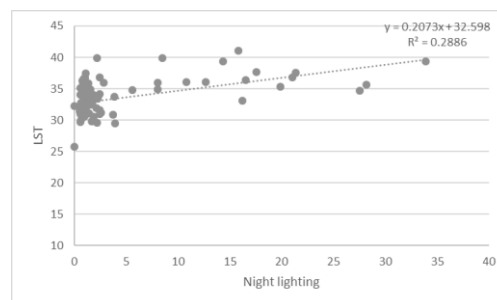


Figure 5. LST-Night lighting

People's migration and aggregation are mostly related to traffic factors. Roads connect different towns and regions, which to a certain extent accelerates the formation of heat island. The distribution of heat island in Qingdao coincides with that in places with high density of road network, which indicates that the relationship between heat island and road is positive. The same conclusion can be drawn from the results of regression analysis in Figure 6.

Through overlay analysis between rules between different intervals found that the population aggregation, change pattern and heat island effect in Jiaozhou are more intensive, but the corresponding road density is not high. It is suggested that the later planning should focus on road construction.

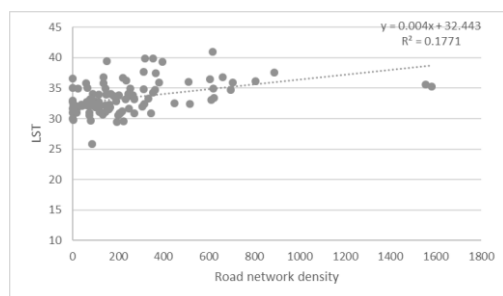


Figure 6. LST-Road network density

Combined LST, FCV, MNDWI, NDISI overlay analysis results in Figure 7., Figure 7., and Figure 9., it can be found that the LST has a negative correlation with FCV and NNDWI. On the contrary, LST is positively correlated with the NDISI. The heat island effect can be alleviated by the vegetation and the water to a certain extent. The blue-green space is an effective way to alleviate the heat island effect. Impervious surface is the main forming area of heat island and it can be obtained by NDISI which is shown in Figure 3(d). The increasing impervious surface and the decreasing natural ecological surface are the primary contributing factors to the formation of urban heat island. Therefore, reducing the impervious surface, increasing vegetation and water body, and building the urban "blue-green space" are the key measures to slow down the heat island effect.

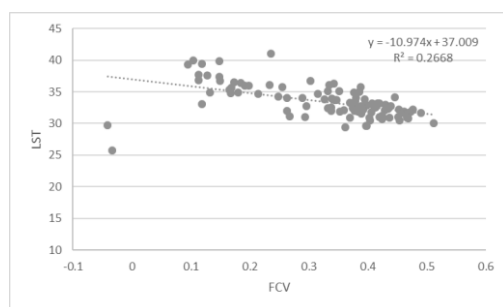


Figure 7. LST-FCV

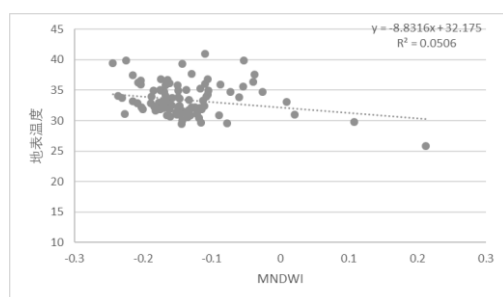


Figure 8. LST-MNDWI

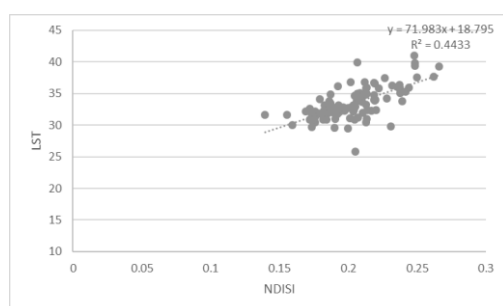


Figure 9. LST-NDISI

6. CONCLUSIONS

In this paper, based on the inversion of urban surface temperature and the extraction of heat islands, from the two dimensions of time and space, the coupling analysis of vegetation cover, water, land use type, night light, urban impervious surface, transportation, change density and other factors with the causes and changes of urban thermal environment is completed. According to the spatial distribution of the evolution of heat island, in order to improve the urban thermal environment and optimize the urban spatial layout, reasonable suggestions and improvement strategies are put forward. Furthermore, it serves for land spatial planning and provides basic reference data for improving urban spatial pattern and optimizing urban "blue and green space".

7. ACKNOWLEDGEMENT

This work was financially supported by the National Key Research and Development Program of China (no.2016YFB0501403) and the Major Program of China's High-Resolution Earth Observation System (no. AH1601)

REFERENCES

- Song T, Duan Z, Liu J, et al, 2015. Comparison of four algorithms to retrieve land surface temperature using Landsat 8 satellite. *Yaogan Xuebao/Journal of Remote Sensing*, 19(3), pp.451-464.
- LUBER G, MCGEEHIN M., 2008. Climate change and extreme heat events. *American Journal of Preventive Medicine*, 35(5), pp. 429-435.
- Stewart, Iain D, 2011. A systematic review and scientific critique of methodology in modern urban heat island literature. *International Journal of Climatology*, 31(2), pp. 200-217.
- Yu L, Qian L, Wenfeng F, et al, 2018. Coupling Analysis of Heat Island Effects, Vegetation Coverage and Urban Flood in Wuhan. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-3, 1173-1177. doi.org/10.5194/isprs-archives-XLII-3-1173-2018.
- Hanqiu X, 2015. Retrieval of the reflectance and land surface temperature of the newly-launched Landsat 8 satellite. *Chinese Journal of Geophysics*, 58(3), pp.741-747.
- Artis D A, Carnahan W H., 1982. Survey of emissive variability in thermography of urban areas. *Remote Sensing of Environment*, 12, pp.313-329.
- Miaomiao L, Bingfang W, Changzhen Y, et al, 2004. Estimation of vegetation fraction in the upper basin of Miyun Reservoir by remote sensing. *Resources Science*, 26(4), pp.153-159.
- Estoque R C, Murayama Y, 2015. Classification and change detection of built-up lands from Landsat-7 ETM+ and Landsat-8 OLI/TIRS imageries: A comparative assessment of various spectral indices. *Ecological Indicators*, 56, pp. 205-217.