Diurnal Temperature Cycle Analysis in Various Land types and Comparison with MODIS Land Surface Temperature

Mehdi Gholamnia*[1], Mehrnoosh Ghadimi[2], Masomeh Moghbel[2], Reza Khandan[3]

[1] **Department of Civil Engineering, Sanandaj Branch, Islamic Azad University, Sanandaj, Iran**
mehdi_gholamnia@ut.ac.ir

[2] **Department of Geomorphology, Faculty of Geography, University of Tehran, Tehran, Iran**
{ghadimi, moghbel}@ut.ac.ir

[3]**Department of Remote Sensing and GIS, Faculty of Geography, University of Tehran, Tehran, Iran**
rs.reza_khandan@ut.ac.ir

(Received: March 2021, Accepted: December 2021)

Abstract

Land Surface Temperature (LST), as a key parameter in environmental interactions, has been studied in several researches. Urban thermal condition depends on land cover types that composed of different materials with various thermal properties. In this study we analyzed diurnal temperature of vegetation, stone, water, cement, asphalt, and soil land cover types (LCT), as main components of urban structure. The Diurnal Temperature Cycle (DTC) method used to model daily behavior of different material temperatures by application of precise sensors at a weather station in Tehran, of Iran. Then, comparisons between maximum diurnal temperatures of LCT with LST at the day and night time of MODIS were conducted. Result showed that in warm days the discrepancies between materials were larger and soil, asphalt, and cement had higher temperatures than stone, vegetation, and water. Also, water had little fluctuations and some phase shift to reach maximum amplitude. Also, time series of MODIS LST in the study area were extracted and compared with maximum diurnal temperature of different LCT. Maximum correlation was estimated between Terra daytime LST and T_{max} of soil and cement material with 0.948 values for R^2 and 2.89 and 4.2 °C for RMSE.

Keywords: Maximum temperature, Urban, MODIS, LST, diurnal, land cover

* Corresponding Author

1. Introduction

Thermal comfort in urban areas has been changed due to climate change and rapid urbanization especially in megacities (Dugord et al. 2014; Harlan and Ruddell 2011; Jenerette et al. 2016). In order to improve the quality of urban life more researches about urban climate have been conducted during recent decades (Hu and Brunsell 2015; Huang and Cadenasso 2016). A key parameter in study of Urban Heat Islan (UHI) is Land surface temperature (LST) which is based on the received emission from surface (mainly) to satellite remote sensing sensors. LST is an important parameter in urban environment that controls energy exchange and thermodynamic processes from different land covers with the atmosphere. LST has an important role in urban climatology, global environmental change and human-environment interactions (Polydoros et al. 2018).

LST is retrieved at the time of satellite over passes. Therefore, it is not possible to analyze the Diurnal Temperature Cycle (DTC) by polar orbit satellites, on urban land covers, which is used to study of UHI during 24 hours a day in urban planning and evaluating the high and low diurnal temperature cycles in a city. Geostationary satellite with high temporal resolution from 5 (GOES) min to 30 (like MSG SEVIRI) (Chang et al. 2021). However, the spatial resolution in this satellite is poor (almost 5 Km) and lowest resolution belongs to GOES -16 (2km) which does not have coverage over Iran. The solution could be mathematical modeling of the LST based on discrete satellite observations(Chang et al. 2021; Hong et al. 2018; Mathew et al. 2018a; Sharifnezhadazizi et al. 2019). Therefore, it would be possible to analyze in details the portion of each land cover in UHI (Mathew et al. 2018a)and also it can be used as a measure for analyzing of land cover changes irrespective of other available methods(Pramanik and Punia 2020). The proposed DTC modeling's need at least four observations in a day to build the model (Lu and Zhou 2021). The Moderate Resolution Imaging Spectroradiometer (MODIS) provide such minimum temporal resolution (geostationary platforms provide more observations in a day). Since it has higher spatial resolution (1 Km), it is possible to use it for DTC modeling in urban studies (Lu et al. 2020; Mathew et al. 2018a; Mathew et al. 2018b). Tehran city is capital of Iran and the most populated city of the country and has been faced with unfolding expansion in recent decades. This expansion caused that the land use changes and the natural covers be replaced with artificial and man-made structures. Based on the researches by (Amanollahi et al. 2012; Karimi et al. 2017; Tayyebi et al. 2018), the LST and air temperatures are rising in Tehran city due to high population, surrounded by mountain ranges, topography and density of built-up area (Shahmohamadi et al. 2009).

Regarding the importance of remote sensing data application in evaluating the effect of urban development and land use and land cover (LULC) changes on LST in urban areas, the main objectives of this study are:1) evaluating the diurnal LST cycle in the city using diurnal modeling, 2) calibration and verification of the estimated LST modeling in contrast with ground observations ,3) recognition of the thermal behavior of different land covers in urban areas and 4) recognition of the areas with the highest potential for UHI formation due to LST. Section 2 explains the study area and the details of LST data from MODIS and ground sensors. Section 3 explores the mathematical modeling applied for construction of DTC based on four MODIS observations. Section 4 highlights the results for different land covers and section 5 provides the discussion and conclusions.

2. Study area and Data

2.1 Study area

Tehran city is located in north of Iran and surrounded by Alborz Mountain ranges in north and east, also south of Tehran is covered by Varamin plain. Fig. 1 represents different land covers of Tehran with their area and location. As can be seen, the built-up areas occupy the largest area of the city (Fig,1b). Since the construction of these areas is mainly by man-made materials (Fig, 1c), naturally, the expansion of these surfaces can have a significant effect on land surface temperature (LST).

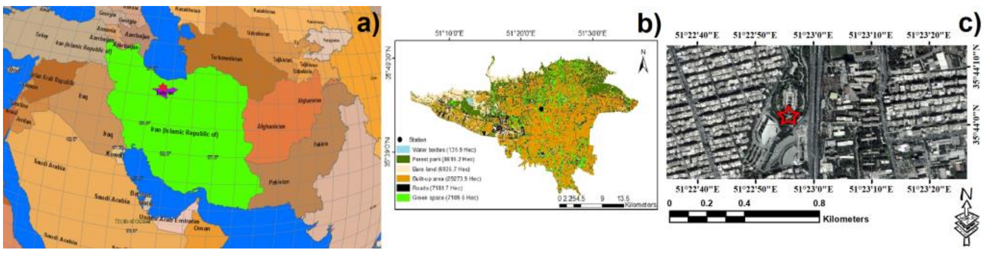

Figure1. Study area position (by using Google earth images)

2.2 Data

2.2.1 In-situ Data

In order to conduct field surveys and LST measurements of different urban land covers including grass, stone, water, cement, asphalt, and soil, as main components of urban structure, three LUFFT OPUS 2-channel data loggers with six calibrated PT100 sensors were used. Sensors were located on the surface and LST was recorded in 10 minutes intervals. Table (1) shows valid data collection from 44694 observations for each land cover type, during 01-Nov-2011 to 30-Aug-2013 at 279 days (table 1). Fig.2 indicates how to install the sensors and the location of the field measurements in Geophysics Weather Station in north of the Tehran with 35° 44.029'N and 51° 22.927'E location.

Table 1. Number of temperature measurements for each land cover type.

Land Cover Type	No observation
Vegetation (grass)	44686
Stone	44682
Water	43202
Cement	44682
Asphalt	44681
Soil	44681

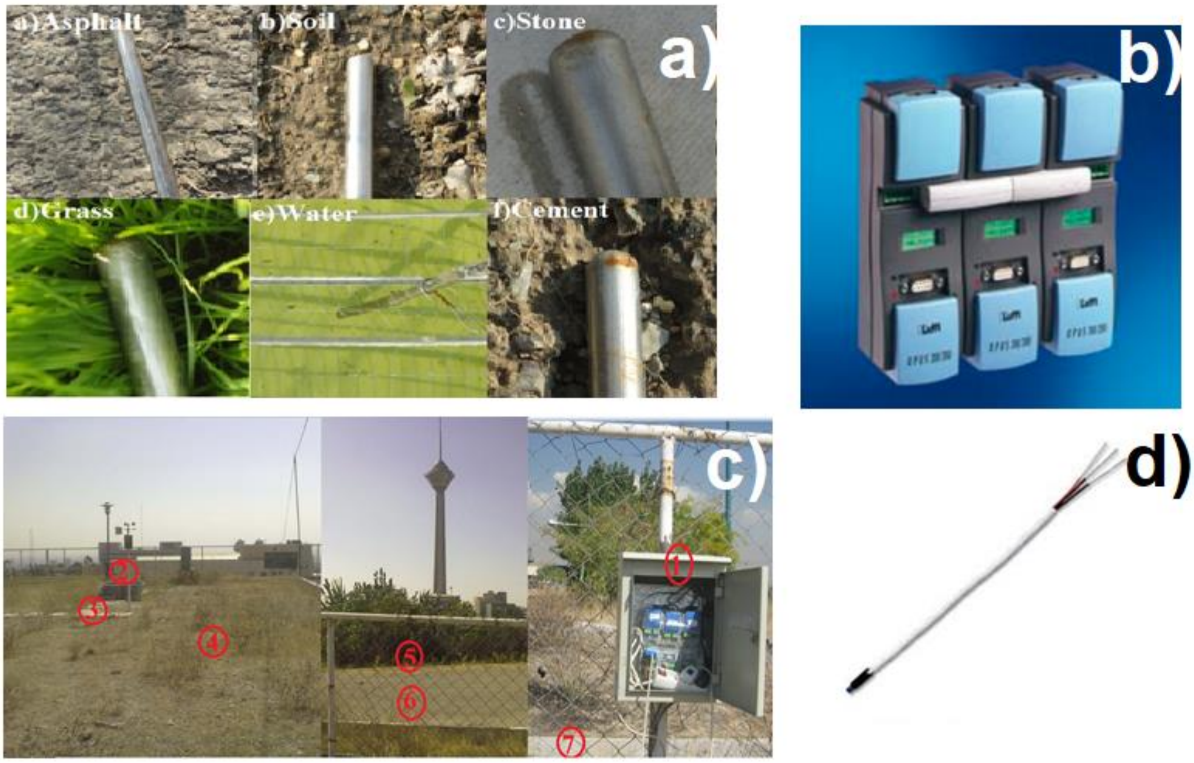

Figure2. Location and installation of the sensors and data loggers on different land covers in Geophysics weather station of Tehran (a, c). (1) data loggers, (2) water sensor, (3) stone sensor, (4) soil sensor, (5) grass sensor, (6) Asphalt sensor, (7) Cement Sensor. (b) OPUS200/300 Data Loggers, (d) PT100 Sensor.

2.2.2 MODIS LST

The MODIS LST data which used in this study collected from both Aqua and Terra platform, MOD11A2 and MYD11A2 product, with 1-km nominal resolution. The MODIS LSTs computed by day and night split window algorithm from 31 and 32 thermal infrared channels (Wan and Dozier 1996), that considered the zenith angles effect and clear sky conditions (Wan 2009; Wan and Dozier 1996).

3. Methodology

3.1 DTC modeling

The Diurnal Temperature Cycle that introduced by Johnson and Fitzpatrick (1977), composed of two part functions with some unknown coefficients that are determined empirically. Duan et al. (2012) compared six diurnal models for modeling daily LST. Gholamnia et al. (2017) developed a new model for daily variations of air temperature cycle which modified versions of (Göttsche and Olesen 2001) DTC modeling. In this study we used two part functions based on (Göttsche and Olesen 2001) where its parameters were described in (Duan et al. 2012).

$$T_{DTC}(t) = \begin{cases} T_{min} + (T_{max} - T_{min}) \cos\left(\frac{\pi}{\omega}(t - t_m)\right) & t \le t_s (2) \\ T_{min} + \left[(T_{max} - T_{min}) \cos\left(\frac{\pi}{\omega}(t_s - t_m)\right)\right] e^{\frac{(t - t_s)}{k}} & t > t_s (2) \end{cases} \quad (1)$$

$$k = \frac{\omega}{\pi}\tan^{-1}\left(\frac{\pi}{\omega}(t_s - t_m)\right) \quad (2)$$

$$\omega = \frac{2}{15}\arccos(-\tan\varphi \tan\delta) \quad (3)$$

$$\delta = 23.45 \sin\left(\frac{360}{365}(284 + DOY)\right) \quad (4)$$

$T_{DTC}(t)$ is a two-part function of DTC model. T_{max} and T_{min} are the maximum and minimum daily temperatures. t_m is the time that temperature reaches its maximum values. t_s is turning point of DTC model which first part of model was finished and second part of it starts. K is attenuation coefficient that be obtained by first derivative of two-part DTC model. ω is day duration and is computed by astronomical relation. δ is solar declination and DOY is day of year. The free parameters of model are T_{min}, T_{max} , t_s , and t_m that are estimated by Levenberg–Marquardt minimization method (Kanzow et al. 2002).

3.2 Processing

The DTC modeling of six land surface types were done by using E.q (1 to 5). Then, free parameters of the DTC (T_{min}, T_{max}, t_s, and t_m) were estimated by Levenberg–Marquardt minimization. Characterization for each free parameter at various land types were investigated. MODIS LST time series for Aqua and Terra at day and night time for the study area for different land covers were extracted. Correlation between MODIS LSTs with maximum and minimum temperature (T_{max} and T_{min}) for different land type were analyzed, in next step. The Root Mean Square Error (RMSE) and coefficient of determination (R^2) were calculated to test the result of DTC modeling and relationship with MODIS LSTs.

4. Result

4.1 Land cover type DTC model

Temperature measurements for each land cover, collected based on six calibrated PT100 sensors, were arranged based on day of year. DTC model for each daily observation was constructed according to Eq. 1 to 5. Fig 3 showed the DTC model for 18th of the Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, and Nov for 2013 in each land cover type. As shown in the Fig1, the noise effect is quietly obvious in some months (i.e., Fig 3 c, d, i), the DTC model acceptably estimated the diurnal behavior of observation over day and night time. Also, as the Fig 3 presents the water temperature (blue color) had less undulation than other land cover types and lower range of diurnal variation. Asphalt and soil temperature have higher temperature ranges and are more sensitive to environmental variation. Building of DTC model and estimation its free parameters depend on the behavior of daily temperature observations. For example, in Fig (3a), water temperature observation, DTC model was not carefully constructed. Table (2) presented the number of complete constructed DTC model for each land cover type.

Fig 4 demonstrates the maximum temperature 〖(T〗_max) measured at the midday by the estimation of the DTC model parameters for each land cover type. The bare soil and asphalt with near 73 and 72(_" " ^"o")"C" have the maximum measured temperature. Also, water about 49.5 (_" " ^"o")"C" has the lowest values of T_max. Vegetation has more fluctuations in T_max over the year in comparison to other ones. Plot of the values of the RMSE and coefficient of determination with respect to the Day of Year (DOY) for the DTC model were shown at the Fig 5. Since water had lower fluctuations (Fig 4), it had the lowest RMSE among others (Fig 5, a). Also, T_max time of water occurred with some phase shift to in relation other materials. Due to uncorrected DTC modeling, some lower values of "R" ^"2" appear in Fig (5, b) which happen in winter season.

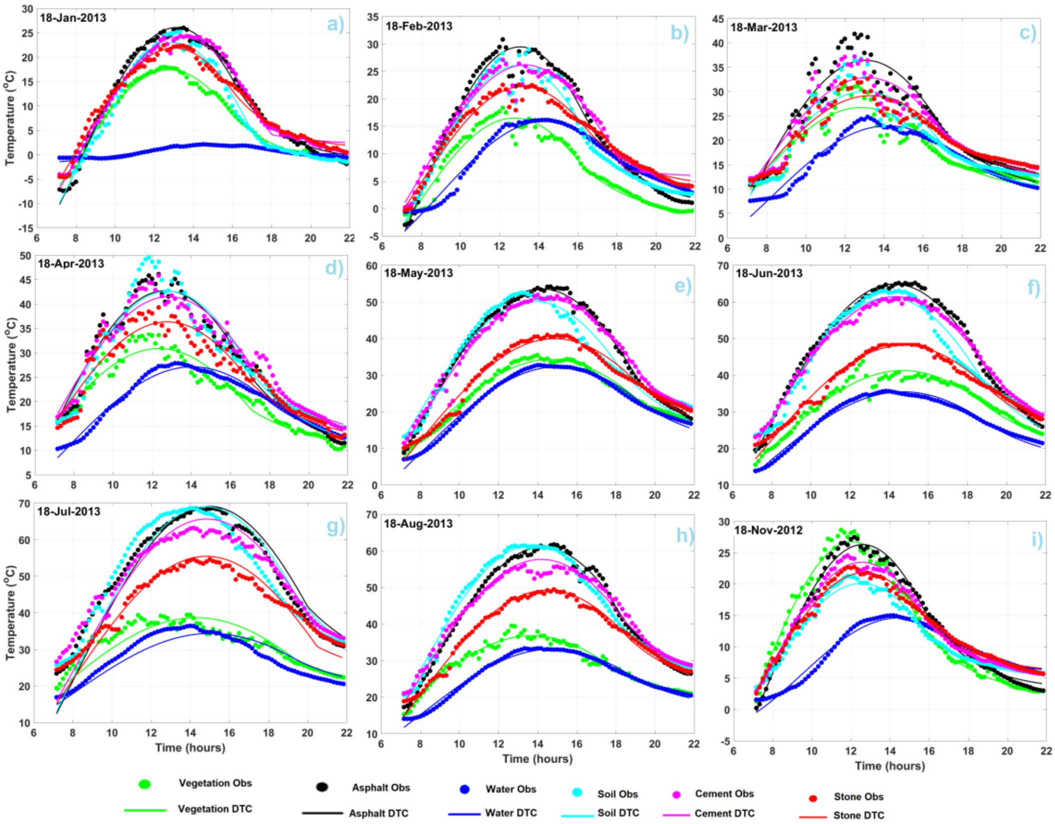

Figure 3 Diurnal temperature for different material in 18th Jan (a), Feb (b), Mar (c), Apr (d), May (e), Jun (f), Jul (g), Aug (h), and Nov (i). vegetation (green), asphalt (black), water (blue), soil (cyan), cement (Purple), and stone (red)

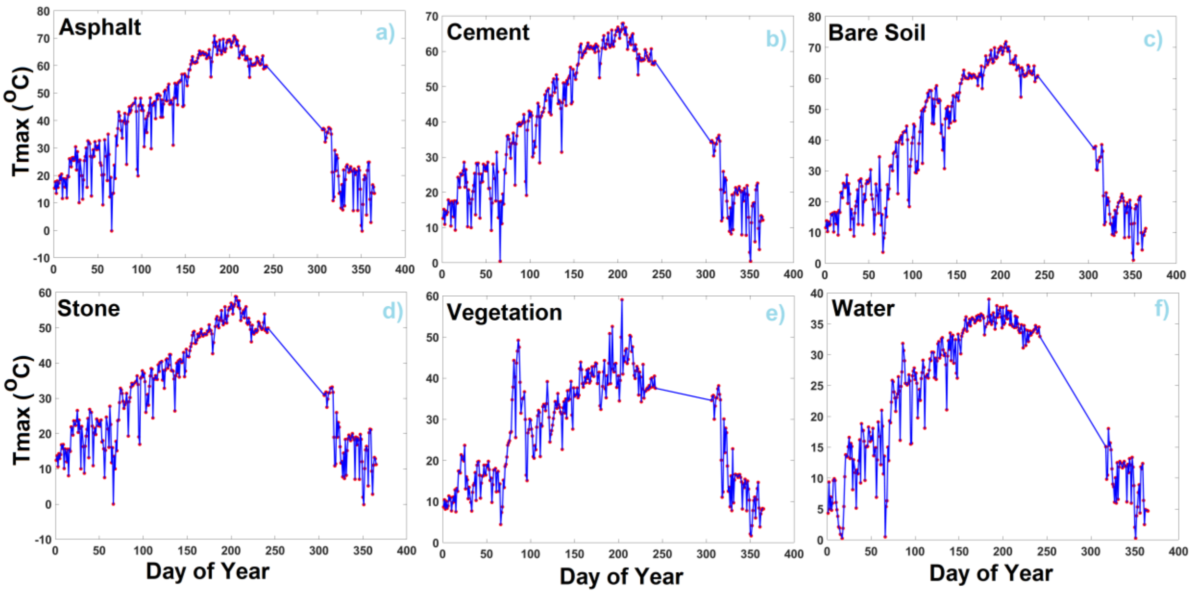

Figure 4 Maximum Asphalt (a), temperature (Tmax) of Cement (b), bare soil (c), Stone (d), Vegetation (e), and Water (f) which estimated by DTC model during day of 2013 year.

Table 2. Number of complete constructed DTC for each land cover type.

Land Cover Type	No DTC
Vegetation (grass)	238
Stone	179
Water	78
Cement	189
Asphalt	181
Soil	275

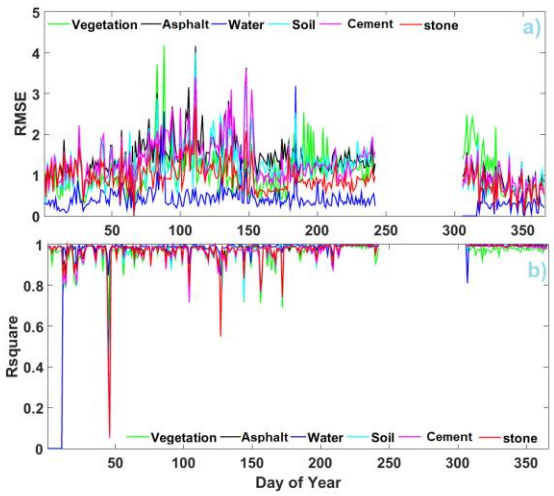

Figure 5. RMSE and R^2 of diurnal temperature modeling for different materials for day of year. Vegetation (green), asphalt (black), water (blue), soil (cyan), cement (purple), and stone (red)

4.2 Maximum temperature modeling with MODIS LST

Figure 6 shows the scatterplot of the MODIS LST data with estimated T_{max} parameters of the DTC modeling. As shown in Figure (6), MOD_D LST values and maximum temperature of cement and stone have higher correlations and lower values of RMSE, 0.947 and 0.923 in R^2 and 2.89 and 2.53 °C RMSE. For MOD_N LST, 0.929 of R^2 for soil and 3.17 °C for RMSE of water are noticeable values. Comparisons between the values of R^2 and RMSE of MOD_D and MYD_D LST shows that MOD_D had almost higher correlation and lower RMSE with T_{max} than MYD_D LSTs (Fig 6). Also, the values of R^2 and RMSE between MOD_N and MYD_N LSTs with T_{max} of different materials has similar result. It should be considered that although water maximum temperature and MODIS LST had lower correlations, it had lower values of RMSEs.

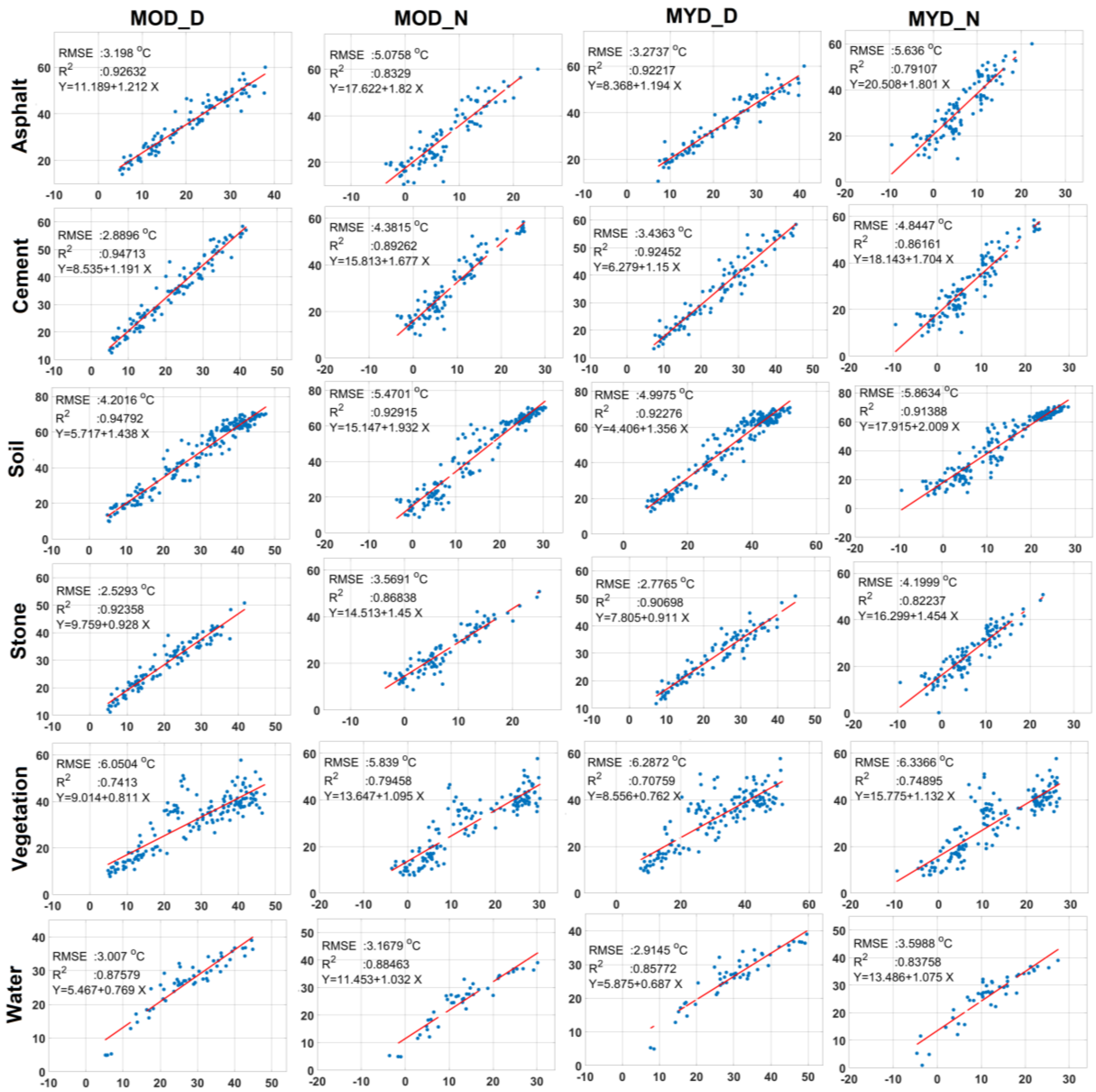

Figure 6 Scatterplots between MODIS LST and maximum DTC of the various land type

5. Discussion and Conclusion

The DTC model for six land cover types in Tehran urban region were analyzed in this study. Asphalt and bare soil had higher Maximum temperature than others that could be related to their heat capacity. This study showed that DTC model could be more useful for analyzing the thermal behavior of different materials and land cover types. Also, maximum temperature for each diurnal measurement was estimated and compared with MODIS day and night LSTs. Results showed that MODIS LST on Terra platform has higher correlations with T_{max} than Aqua LSTs. Among four daily LST observations, MOD_D has higher correlation with six LUTs. Water with high thermal capacity, has lower fluctuations and some time lag to reach T_{max} values, and is more suitable for DTC modeling. By considering the site location which is covered by building and impervious surfaces, MODIS LST is mostly related to maximum temperature of hard covers like asphalt, stone and cement. This study could be expanded to other land cover types and some mathematical models can be developed to investigate the relationship between LST and DTC parameters.

Reference

[1] Amanollahi, J., Abdullah, A.M., Ramli, M.F., & Pirasteh, S. (2012). Land surface temperature assessment in semi-arid residential area of Tehran, Iran using Landsat imagery. World Appl. Sci. J, 20, 319-326

[2] Chang, Y., Xiao, J., Li, X., Frolking, S., Zhou, D., Schneider, A., Weng, Q., Yu, P., Wang, X., & Li, X. (2021). Exploring diurnal cycles of surface urban heat island intensity in Boston with land surface temperature data derived from GOES-R geostationary satellites. Science of The Total Environment, 763, 144224

[3] Duan, S.-B., Li, Z.-L., Wang, N., Wu, H., & Tang, B.-H. (2012). Evaluation of six land-surface diurnal temperature cycle models using clear-sky in situ and satellite data. Remote Sensing of Environment, 124, 15-25

[4] Dugord, P.-A., Lauf, S., Schuster, C., & Kleinschmit, B. (2014). Land use patterns, temperature distribution, and potential heat stress risk–the case study Berlin, Germany. Computers, Environment and Urban Systems, 48, 86-98

[5] Gholamnia, M., Alavipanah, S.K., Darvishi Boloorani, A., Hamzeh, S., & Kiavarz, M. (2017). Diurnal Air Temperature Modeling Based on the Land Surface Temperature. Remote Sensing, 9, 915

[6] Göttsche, F.-M., & Olesen, F.S. (2001). Modelling of diurnal cycles of brightness temperature extracted from METEOSAT data. Remote Sensing of Environment, 76, 337-348

[7] Harlan, S.L., & Ruddell, D.M. (2011). Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. Current opinion in environmental sustainability, 3, 126-134

[8] Hong, F., Zhan, W., Göttsche, F.-M., Liu, Z., Zhou, J., Huang, F., Lai, J., & Li, M. (2018). Comprehensive assessment of four-parameter diurnal land surface temperature cycle models under clear-sky. ISPRS Journal of Photogrammetry and Remote Sensing, 142, 190-204

[9] Hu, L., & Brunsell, N.A. (2015). A new perspective to assess the urban heat island through remotely sensed atmospheric profiles. Remote Sensing of Environment, 158, 393-406

[10] Huang, G., & Cadenasso, M. (2016). People, landscape, and urban heat island: dynamics among neighborhood social conditions, land cover and surface temperatures. Landscape Ecology, 31, 2507-2515

[11] Jenerette, G.D., Harlan, S.L., Buyantuev, A., Stefanov, W.L., Declet-Barreto, J., Ruddell, B.L., Myint, S.W., Kaplan, S., & Li, X. (2016). Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA. Landscape Ecology, 31, 745-760

[12] Johnson, M., & Fitzpatrick, E. (1977). A comparison of two methods of estimating a mean diurnal temperature curve during the daylight hours. Theoretical and Applied Climatology, 25, 251-263

[13] Kanzow, C., Fukushima, M., & Yamashita, N. (2002). Levenberg-Marquardt methods for constrained nonlinear equations with strong local convergence properties. Citeseer

[14] Karimi, A., Pahlavani, P., & Bigdeli, B. (2017). LAND USE ANALYSIS ON LAND SURFACE TEMPERATURE IN URBAN AREAS USING A GEOGRAPHICALLY WEIGHTED REGRESSION AND LANDSAT 8 IMAGERY, A CASE STUDY: TEHRAN, IRAN. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42

[15] Lu, L., & Zhou, X. (2021). A Four-Parameter Model for Estimating Diurnal Temperature Cycle From MODIS Land Surface Temperature Product. Journal of Geophysical Research: Atmospheres, 126, e2020JD033855

[16] Lu, Y., Wu, P., Ma, X., Yang, H., & Wu, Y. (2020). Monitoring seasonal and diurnal surface urban heat islands variations using Landsat-scale data in Hefei, China, 2000–2017. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 13, 6410-6423

[17] Mathew, A., Khandelwal, S., & Kaul, N. (2018a). Analysis of diurnal surface temperature variations for the assessment of surface urban heat island effect over Indian cities. Energy and Buildings, 159, 271-295

[18] Mathew, A., Khandelwal, S., Kaul, N., & Chauhan, S. (2018b). Analyzing the diurnal variations of land surface temperatures for surface urban heat island studies: Is time of observation of remote sensing data important? Sustainable cities and society, 40, 194-213

[19] Polydoros, A., Mavrakou, T., & Cartalis, C. (2018). Quantifying the trends in land surface temperature and surface urban heat island intensity in mediterranean cities in view of smart urbanization. Urban Science, 2, 16

[20] Pramanik, S., & Punia, M. (2020). Land use/land cover change and surface urban heat island intensity: source–sink landscape-based study in Delhi, India. Environment, Development and Sustainability, 22, 7331-7356

[21] Shahmohamadi, P., Ani, A., Abdullah, N., Maulud, K., Tahir, M., & Nor, M. (2009). The Conceptual Framework on Formation of Urban Heat Island in Tehran Metropolitan, Iran: A Focus on Urbanization Factor. European Journal of Scientific Research

[22] Sharifnezhadazizi, Z., Norouzi, H., Prakash, S., Beale, C., & Khanbilvardi, R. (2019). A global analysis of land surface temperature diurnal cycle using MODIS observations. Journal of Applied Meteorology and Climatology, 58, 1279-1291

[23] Tayyebi, A., Shafizadeh-Moghadam, H., & Tayyebi, A.H. (2018). Analyzing long-term spatio-temporal patterns of land surface temperature in response to rapid urbanization in the mega-city of Tehran. Land Use Policy, 71, 459-469

[24] Wan, Z. (2009). MODIS Land Surface Temperature Products Users' Guide. In

[25] Wan, Z., & Dozier, J. (1996). A generalized split-window algorithm for retrieving land-surface temperature from space. IEEE Transactions on Geoscience and Remote Sensing, 34, 892-905.