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Master's Thesis:

Reduction of Urban Heat Island effects in the dry climate of Tehran, Iran

submitted by:

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Abstract

City infrastructure elements like buildings and roads often increase the air temperature of cities comparing to the rural areas. The surfaces of such elements absorb solar energy during the day and transfer it back to the surrounding atmosphere as heat, which increase the surface and air temperature and cause the phenomenon called Urban Heat Islands (UHI). Several mitigation strategies have been introduced to reduce the adverse effects of UHI, such as adding green spaces, installing cool or green roofs, employing green facades, increasing shading elements, using high albedo building materials, and finally management the building energy efficiency. Among these strategies, adding green elements such as trees and vegetation is one of the most effective solutions. However, this approach would be costly in an arid region with a dry climate due to the challenge of maintenance. Cities in these regions face water shortage which is a big concern in creating sustainable green spaces.

In this study, we have selected the city of Tehran, the capital of Iran (western Asia), as our case study. Having a dry climate and a considerable developing rate, the city has faced sustainable challenges such as UHIs in its 22 districts. In this thesis, we present an approach to locate regions where locally adapted green spaces can minimize the detrimental effects of UHIs. To do that, we employ remote sensing observations from the Landsat 8 satellite mission on the Land Surface Temperature (LST) within 2013—2019 and the Normalized Difference Vegetation Index (NDVI) within 2020 of the city together with the GIS-based statistics of the green areas. Using the aforementioned data, we estimate the cooling extent of the parks which enable us to evaluate and classify them in terms of cooling impact and vegetation density. From our analysis, the four districts namely 6, 8, 14, and 17 lack sufficient green areas and are more prone to suffer from UHIs. These regions carry low capita in urban parks, high mean LST, and insufficient cooling extents from the green areas. The addition of more green spaces and the improvement of existing green infrastructure are top priorities in these four critical districts. Also, 14 districts in Tehran have capita of urban area less than 10 m^2 includes urban parks with high LST, and low NDVI, which need improvement in vegetation. Only the four districts namely 1, 4, 19, and 22 have the sufficient urban parks per capita. However, just in district one the urban parks are capable of reduction of temperature, and the parks in other three districts have high mean LST during summer months. In the final step, based on the literature, a short list of native, dominant, and drought-resistant plant species is recommended.

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1. Introduction

1-1. What is Urban Heat Island?

Definition of Urban Heat Island

Urban areas are characterized by dense and massive structures, high population, high energy consumption, and low green spaces (Busato, Lazzarin R., & Noro, 2014). In the cities, buildings, roads, and other infrastructure make the urban areas warmer than the surrounding rural areas. The building and road surfaces absorb the solar energy during the day and give it back as heat to the atmosphere, which raises the air temperature and forms the so-called urban heat island (UHI) effect (Oke, The energetic basis of the urban heat island, 1982). The elevated temperature in urban areas differs due to the time, location, geographical, meteorological features, and structure of the cities (Shahmohamadi, Cubasch, Sodoudi, & Che-Ani, 2012). In general, the loss of vegetation and green spaces in the cities, energy absorption by the building materials, and dense and high-rise urban forms cause the urban heat island (EPA, 2008). A comparison of air temperature from urban stations and rural stations at the same time can show the urban heat island in an urban area as compared to the rural counterpart (Arnfield, 2003).

Surface temperature and air temperature define two different types of surface and atmospheric urban heat islands. Surface urban heat island is related to the increase of surface temperature, and it forms in the canopy layer of an urban area- the layer between where people live to the top of trees and buildings (Schwarz, Lautenbach, & Seppelt, 2011). The surface urban heat island is at the highest level during the hottest hours of a warm day, which can differ about 10 to 15˚C in daytime and 5 to 10 ˚C in nighttime compared to the rural area (Voogt & Oke, 2003). However, the surface temperature of shaded or moist surfaces stays close to the air temperature (EPA, 2008).

Atmospheric urban heat island forms by the elevated air temperature in an urban area. The annual mean rise in air temperature in big cities is about 1 to 3˚C (Oke, 1997). Atmospheric urban heat island happens in the boundary layer of the cities from top of the urban surfaces to about 1.5 km far from the surface (Oke, The energetic basis of the urban heat island, 1982) where the trapped heat in an urban has no more effect on the atmosphere (EPA, 2008).

Figure 1 shows the difference of air and surface temperature through an urban section. During the day, the surface temperature rises more than the air temperature due to the absorption of the sun radiation to the urban materials (Voogt & & Oke, 1997). The air temperature increases more during the night because of the absorbed heat released from the urban structure. Also, the figure shows that the vegetation and water bodies have lower surface temperatures during the days, and the dense urban structure has the highest raise of the surface and air temperature (EPA, 2008).

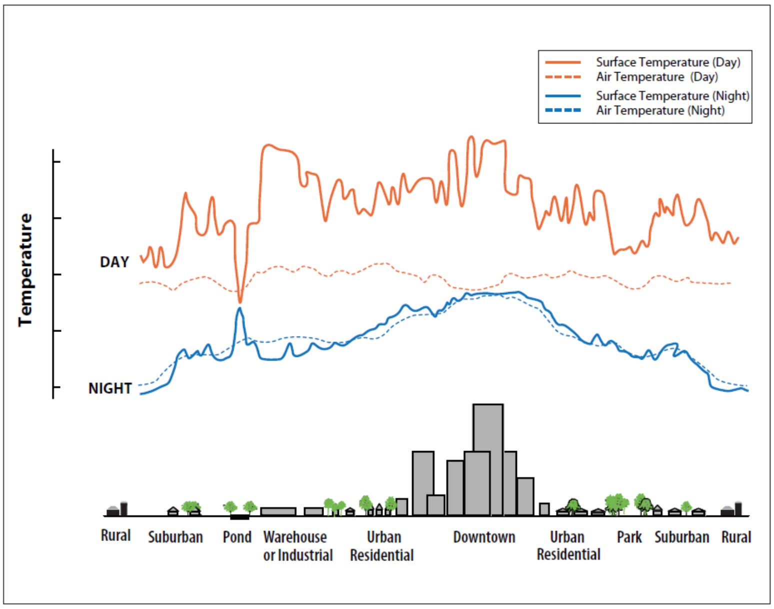


Figure 1. Difference of air and surface temperature through urban and rural area
Source: (EPA, 2008), chapter 01, page:4

Mitigation of the UHI in the cities is one of the main concerning issues. As urban heat island can cause the heat stress in the urban areas and rise in human mortality (Shahmohamadi, Che-Ania, Etessamb, Mauludc, & Tawila, 2011). Also, urban heat island increases the energy consumption to cool the buildings, and the generation of more electrical power during hot days add more pollution to the air (Alexandri, 2006). Besides, in high temperature, the emission of the ground-level Ozone rises and photochemical reactions of the air pollution form smog in the cities, which aggravate the air pollution in big cities (EPA, 2008) (Shahmohamadi, Che-Ania, Etessamb, Mauludc, & Tawila, 2011).

Reasons of Urban Heat Island

Urban areas are growing around the world. Based on the World Bank data, more than 50 percent of the world population is living in cities (United Nations Population Division, 2018). So, one of the main reasons behind the increase in urban heat island is the expansion and densification of the cities with a higher population.

Growing cities intervene in the green and vegetated lands and cover the grounds with impervious materials. Loss of vegetation for roads, buildings, sidewalks, and parking lots expands the surface, which can absorb more sun's energy and give it back to the atmosphere and increase the air and surface temperature. Also, as Figure 2 shows, less green and permeable surfaces reduce the evapotranspiration and moisture to cool the air (EPA, 2008).

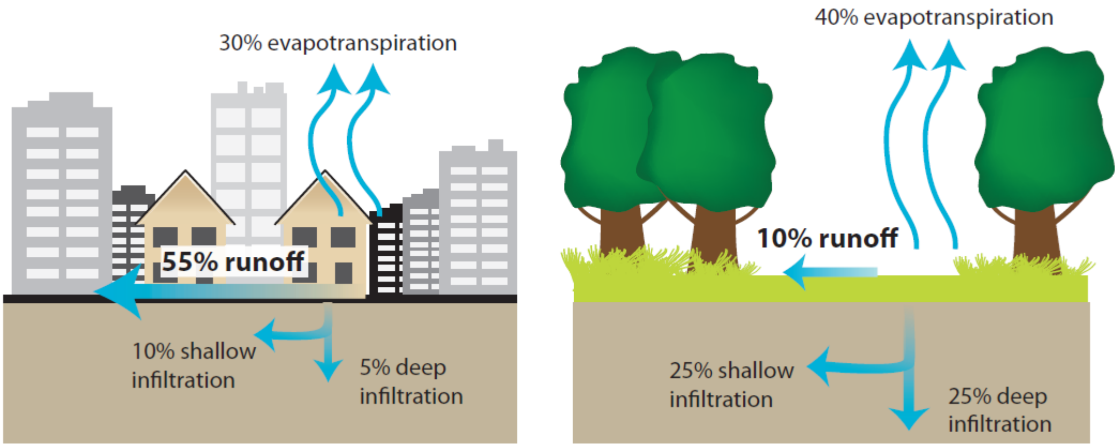


Figure 2. Less evapotranspiration due to more impervious surfaces in urban area
Source: (EPA, 2008), chapter 01, page: 7

Materials of urban structures can absorb more sun's energy in comparison to rural and green areas. Solar energy includes three range of solar rays: 5 percent of UV spectrum, 43 percent of visible light, and 52 percent of infrared. Infrared rays are the spectrum which is absorbed in urban materials as heat and increase the temperature (EPA, 2008) (Phelan, et al., 2015).

The shape of the urban structures influences the number and area of surfaces exposes to the sun. The building's height and spacing between them affect the wind direction and velocity and also the reflectance of the sun radiation. High buildings and tight urban corridors can trap the sun's energy between the buildings and obstruct the sun's reflection to the atmosphere, which increases the heat and temperature, especially during the night in urban areas (EPA, 2008) (Sailor & Fan., 2002).

Also, human activities produce heat in urban areas such as transportation, industrial activities, buildings energy consumption, and other infrastructure activities (EPA, 2008) (Munn, 2002). So, cities with a high population and density have larger risk of the urban heat island. The concentration of active land uses like, industrial and commercial in the urban area produce more anthropogenic heat (Che-Ani, et al., 2009). Also, the formation of urban heat islands in cities causes higher anthropogenic heat, as in the summer, air-conditioning consumes more energy in buildings. In the same way, the increase of power generation by fossil fuels adds more pollution to the urban environment (Che-Ani, et al., 2009) (Santamouris M. , 2007).

Moreover, the climate and geographical location of a city are critical factors in the formation of the urban heat island. Climate parameters such as temperature, wind speed or wind direction, humidity, precipitation, and so on highly correlate to the geographical feature of a location like distance from the sea, altitude, direction of slope, and topography can affect the urban climate (Givoni, 1998). Climate features such as wind and sky cloud cover directly influence urban heat island. More sun's radiation can reach the urban surfaces in clear sky days, and the trapped warm air in the city cannot move by calm wind (EPA, 2008). Topography affects the wind speed and wind direction through the city. For instance, air can be trapped in a city surrounded by mountains. Also, large water bodies near or in the cities can change the air temperature and create breezes through the cities. So, geographical location and terrains of the city can significantly influence the formation of the urban heat islands (EPA, 2008).

Special features of Urban Heat Island in hot and dry climate

Mostly, urban areas in arid regions during the summer shows less temperature difference to rural areas in comparison to regions with moderate climate (Agharabi, 2014). Open fields and bare natural lands in rural areas in a hot and dry climate are covered with shrubs and dispersed vegetation, which is less capable of protecting the land surface from the sun radiation. Also, due to low heat capacity and conductivity of barren soils, they are heated faster by sun radiation. So, the difference in the temperature between the urban areas to bare lands in a dry climate could not be an informative scale to measure the urban heat island intensity (Haashemi, Weng, Darvishi, & Alavipanah, 2016). But in any case, in the hot and dry climate, the temperature in urban areas rises due to massive urban structure and forms urban heat stress.

The temperature of urban surfaces increase quickly in a hot and dry climate temperature during the summer days, but the heat reflects slowly to the atmosphere during the nighttime (Johansson, 2006) (Dialesandro, Wheeler, & Abunnasr, 2019). In the research by Haashemi et. al. shows that during the night higher temperature is detected in semi-arid cities compared to rural areas. Because, the barren rural lands have lower thermal capacity and cool faster than urban areas, also anthropogenic heat is provided during the night. In addition, high rise buildings in the city prevent the heat to reflect from the surfaces to the atmosphere, and also block the ventilation through the city (Haashemi, Weng, Darvishi, & Alavipanah, 2016).

Shading and protection of the urban surfaces from the sun radiation is one the most effective way to prevent temperature rise. The vernacular and traditional architecture and urban design in a hot and dry climate provides more thermal comfort. The compact structure of the old districts of the cities could provide more shade for the streets and pathways. The larger ratio of the height to width of the urban corridors reduce the approach of the solar radiation to the street surfaces (Bakarman & Chang, 2015). But in modern urban design with disperse structure, trees and other shading elements should protect urban structure the sun's radiation. The research by Dialesandro et. al. compares the urban forest temperature to the urban area temperature in 10 different dry cities, which in average is 5.6 ˚C. Also, the cooling effect of them in a buffer about one kilometer is in average about 1.7 ˚C (Dialesandro, Wheeler, & Abunnasr, 2019).

Effects of trees and vegetation to mitigate UHI

Planting trees and vegetation is one of the most effective strategies to mitigate UHI. Vegetation in urban areas change the micro-climate by effecting air temperature, relative humidity, wind pattern, and precipitation (Byrne, Bruns, & Kim, 2008). Vegetation prevent the increase of temperature by shading the area, evapotranspiration, and altering the wind pattern. Based on researches leaves and branches of the trees and other kinds of vegetation absorb a high percentage of solar radiation for photosynthesis or reflect it, and the area covered by leaves can receive almost the 10 to 30 percentage of the sun's energy in summer times and remains cool (EPA, 2008). The shading efficiency is related to the tree's orientation, canopy height, leaf size, plant species, and structure of the tree (Oliveira, Andrade, & Vaz, 2011) (Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016).

The process of evapotranspiration by vegetation can also decrease the air temperature of its surrounding area. Evapotranspiration includes the two function: First, evaporation of water from the soil or water remains on the surface of the leaves by the rainfall or irrigation. Second, transpiration of water from the roots and give it from the surface of the leaves back to the atmosphere, like breathing, emitting moisture by evaporation of the water from the leaves (Evapotranspiration and the Water Cycle, n.d.).

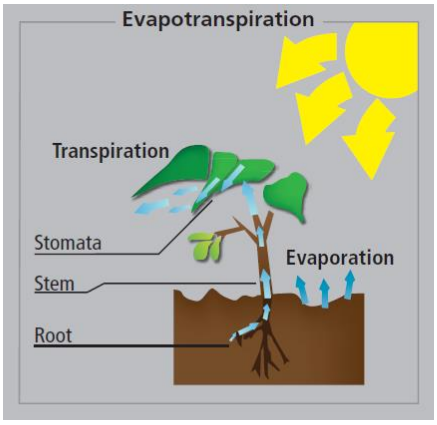


Figure 3. Evapotranspiration
Source: (EPA, 2008), chapter02, page: 3

Based on researches, urban green areas can reduce the air pollution and provide fresh air in the surrounding's areas. Also, the cooling effect of the green areas decreases the energy consumption in summer time, and improve the pleasant area for social activities, which improves the quality of life in urban areas (Oliveira, Andrade, & Vaz, 2011).

The efficiency of green areas depends on such as the shape, size, species of the trees, the intensity of canopies in a green area, size and shape of the green area, location, and altitude of the green area. Feyisa's et al. researches on 21 parks in Addis Ababa (Capital of Ethiopia) shows that high intensity of tree canopy covers in a park has higher cooling effects during the day. In addition, parks with a shape near to circle have higher cooling intensity but lower cooling distance. But irregularly shaped parks have greater cooling effects distance in the surrounding areas (Feyisa, Dons, & Meilby, 2014). Also, based on the experimental study of Shashua-Bar et al., the cooling effect of the shade by trees are higher than other shading elements (Shashua-Bar, Pearlmutter, & Erell, 2009).

The monitored temperature of two green sites in the city center of Manchester shows that the concrete surfaces are 19–23˚C hotter than the air temperature. However, the grass surface temperature is 0–3˚C cooler than the air temperature. The research states that the combination of the trees and grass reduce more the temperature, as the grass shaded by trees is 4-7 ˚C cooler than the air temperature (Armson, Stringer, & Ennos, 2012).

As mentioned, the cooling effect of green areas extends to its surrounding built-up areas. Studies on the extent of parks cooling effect show the size and plant intensity of parks influence the distance of cooling effect, as the greater park area cool down the larger built-up surrounding area (Lin, Yu, Chang, Wu, & Zhang, 2015). In addition, the development of more small-scale green spaces in the district would provide additional environmental and accessibility advantages to the vast majority of urban neighborhoods (Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016).

An experimental study on the cooling impact of two parks in Singapore shows maximal 1.3 ˚C difference in average temperature to the built-up area on the boundary of the urban park. In this study, the ENVI-met simulation displays the reduction of 10 percent of energy consumption by buildings on the boundaries of these two urban parks, due to cooling impact (Yu & Hien, 2006). Upmanis et al. have done a study on the impact of urban parks the nocturnal temperature around in two parks Göteborg, Sweden. The result indicates that the maximum difference of Temperature in summer was about 5.9 ˚C between the park and its surrounding the largest extension of the cooling impact is about 1100 meter from the park boundary. However, the smaller park with an area about

3,6 h has the maximum 30-40 m effect (Upmanis, Eliasson, & Lindqvist, 1998). A more recent research on Beijing's urban parks via remote sensing found that, the cooling effects of urban parks reach 840 m outward from the park but as little as 35 m in another (Lin, Yu, Chang, Wu, & Zhang, 2015).

Also, the cooling effect of green urban parks is dependent to the neighborhoods parameters such as climatic parameters, urban density, height of the buildings, and amount of the anthropogenic heat. For instance, high rise buildings can block the cool breeze from the parks or the wind direction can change the orientation of cool flow (Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016). The ENVI–met simulation for different scenarios of adding green elements to a neighborhood in Tehran shows shading hard surfaces by trees with wide canopies or other building elements such archways can highly reduce the air temperature (Ramyar, Zarghami, & Bryant, 2019).

Furthermore, the quality of cooling effect of the vegetation also depends on the plant species. The height and canopy geometry, leaf and branches characteristics effect the amount of solar radiation that reach beneath the canopy (Santamouris M. , Energy and climate in the urban built environment, 2013). Studies shows that different types of trees with different size and density of leafs and branches filter the solar radiation in different amount (Shahidan, 2010) (Shashua-Bar, Potchter, Bitan, Boltansky, & Yaakov, 2010). The research by Karimi et. al. on the effect of different species such as plane and pine trees, and Buxus shrubs in an urban park in Tehran shows that the trees with wide and high crown provide better thermal comfort in the park. Higher crown as well as shading allows the air flow in the environment (Karimi, Sanaieian, Farhadi, & Norouzian-Maleki, 2020).

Since the objective of this study is the effect of green areas on the urban heat island, therefore, the other UHI mitigation strategies are explained briefly in the Appendix.

1-2. An introduction to the case study, the city of Tehran

Tehran is the most populated province of Iran, which includes the city of Tehran and the other 12 cities. Tehran, the capital of Iran is located on the southern slopes of the Alborz Mountains and the northern border of central desert of Iran. The city of Tehran is located within the longitudes of 51°to 51°40'E and the latitudes of 35°30'to 35°51'N (Bokaie, Zarkesh, Arasteh, & Hosseini, 2016). Figure 4 displays the location of the Tehran city in the world and the Tehran province.

The city altitude is between 900m to 1700m. The upper part of the city between the elevation of 1500 and 1700 m has a colder climate and more considerable water resources (Habibi & Hourcade, 2005). So, green gardens could grow through the history in this elevation; however, most are constructed recently to high-rises for residential and commercial uses. The densest part of the city with residential, commercial, and industrial land-uses locates between the 1100 to 1500 m. In this altitude, the trees are scarce in comparison to the higher elevation, and the water flows through streams in underground. The southern part of Tehran, between the altitude of 900 and 1100 m, has a hot and dry climate during the summer and cold weather during the winter. The water stream flows from the northern mountains also nourished these areas and allowed agricultural activities (Habibi & Hourcade, 2005). However, the city of Tehran is growing toward the south and west. And the agricultural fields are invaded by urban areas.

According to the population census from 2016-17, the province of Tehran has a population of ca. 13 million, and the central city of Tehran is the most populated in Iran, with about 8.7 million people (Statistical center of Iran, 2016). The city of Tehran has 22 districts in an area of about 751 km², and with seven other counties covers 5,918 km². The area of green spaces in Tehran, which consists of green or open spaces, parks, agriculture, and greenbelts, is about 140 km² (Structural and Strategic Plan of Tehran, 2007).

Figure 4. Location of the Tehran city
Source: Author, Data source: (Statistical center of Iran, 2016)

Historic urban development of Tehran

The early steps of Tehran urban development accelerated in the late 1780s, as the capital of Iran, with a population of about 15,000. The early growth of Tehran was slowly within a century when the population increased to about 500,000. The first comprehensive plan of Tehran was provided in 1968. The comprehensive plan contained Tehran's development orientation and its boundary. The vision of this plan was for about 5 million populations in 30 years and expansion to an area of 180 km² (Habibi & Hourcade, 2005). The concentration of the industrial and commercial centers in Tehran attracted a large amount of population around Iran to the capital city. So, not only the city of Tehran, but also all the surrounding rural areas expanded to accommodate the new population, and the rural regions gradually jointed to the central city. Most parts of the expansion were out of the reach of the comprehensive plan. Therefore, high amounts of natural lands were intervened and destroyed by urban development around Tehran.

After the revolution of 1979 in Iran, the city did not follow the comprehensive plan of 1968. Nevertheless, Tehran mostly developed based on the planned expansion orientation in this first plan. Also, in 1993, the Tehran's municipality declined the newly revised comprehensive plan. In the evaluations, the new plan was unreachable, according to management and financial sources. In this plan, Tehran expanded in boundary about 707 km2 with 22 districts. Simultaneously, the city disorderly grew without an approved plan and determined perspective.

Between 1996 to 2001, Tehran's municipality provided the first strategic plan for Tehran. The strategic plan consisted of six main visions: "a clean city, ease of movement in the city, the creation of parks and green spaces, the development of new cultural and sports facilities, reform of the municipal organization, and planning for the improvement of urban space" (Madanipour, 2006). In this plan, the public financial sources supported of the projects, but due to the change of the policies, the municipality of Tehran should manage the plan independently. So, the strategic plan failed according to the lack of a necessary mechanism to attract private investments (Zonooz, 2016) (Habibi & Hourcade, 2005).

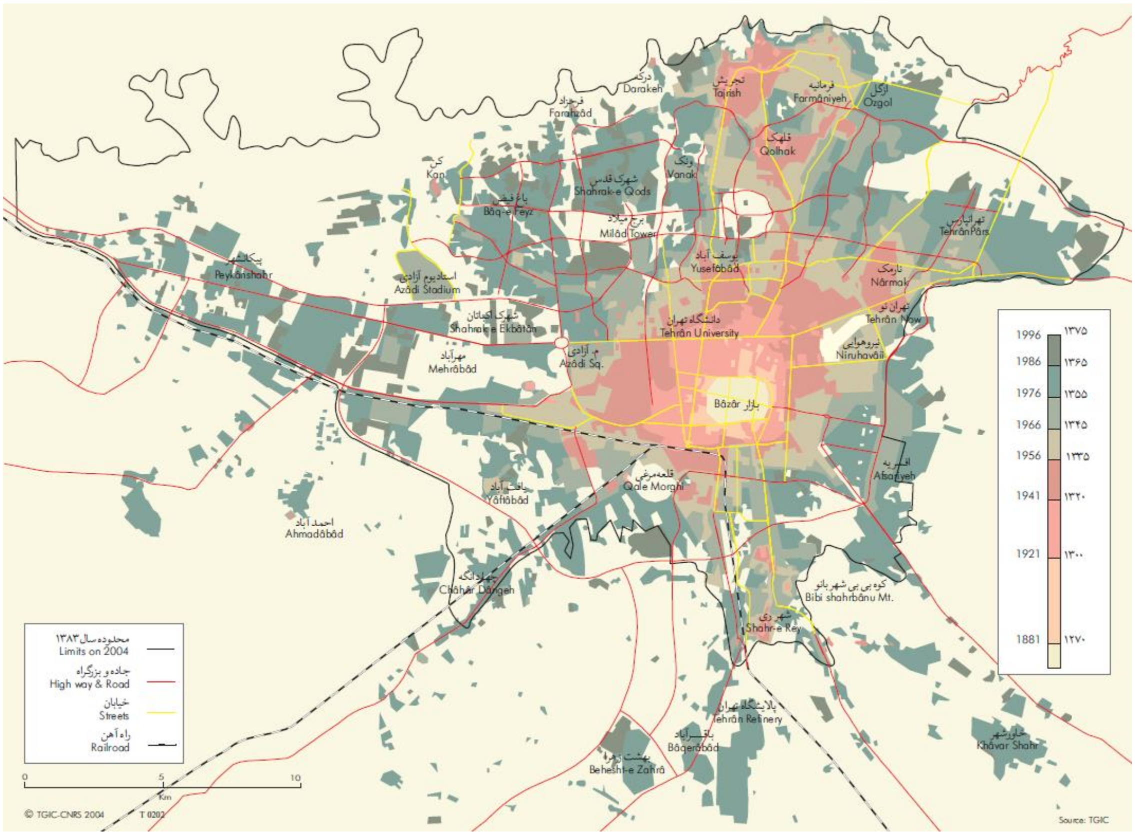


Figure 5. The Evolution of Built up Areas in Tehran
Source: (Habibi & Hourcade, 2005)

Ministry of housing and urban planning and Tehran's municipality have planned the last comprehensive plan for the city of Tehran in 2007. Based on the offered zoning plan, in 2012, new local policies have been provided for every 22 districts of the Tehran, based on their local potentials. However, due to the low quality of the management and supervision of the implementations, the plans are not entirely successful. Also, the municipality of Tehran has the full responsibility to afford the budgets for the new projects and maintain the city, without governmental financial support. Therefore, it forces the municipality to compensate for the expenses from selling the density for higher buildings, and changing the land use instead of receiving high penalties from the private sector. Although, these actions of the municipality are against the rules of the local plan, and they are changing fast the urban form and more deteriorate the urban ecology (Zonooz, 2016).

	1926	**1936**	**1946**	**1956**	**1966**	**1976**	**1986**	**1996**	**2006**	**2011**	**2016**
Tehran City	500	750	1,000	1,560	2,719	4,530	6,042	6,759	7,975	8,293	8,737
Tehran Province	515	770	1,025	1,600	2,806	4,827	6,960	8,873	11,228	12,183	13,276
Iran	10,456	11,964	14,159	18,954	25,788	33,708	49,445	60,055	70,495	75,149	79,926

Table 1. Population of Tehran and Iran 1926-2016 (thousand people)
Source: Author, Data Source: (Statistical center of Iran, 2016)

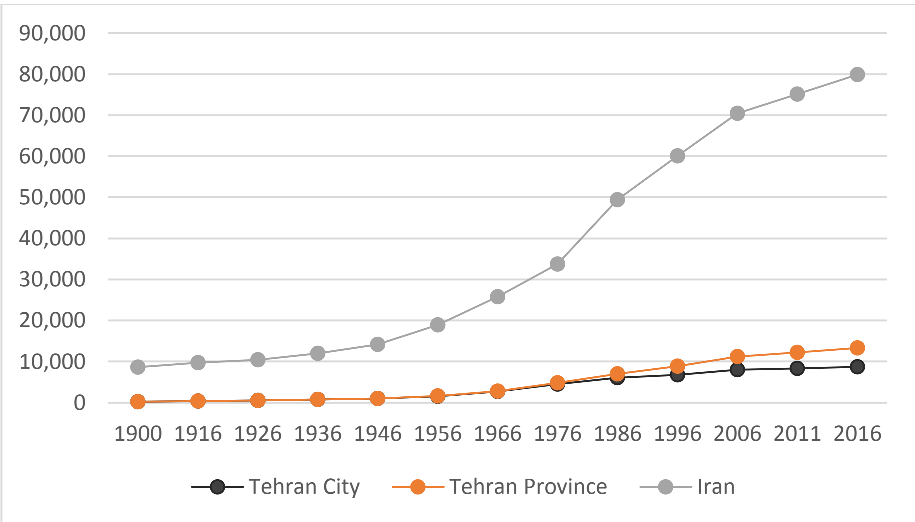


Figure 6. Population of Tehran and Iran 1926-2016 (thousand people)
Source: Author, Data Source: (Statistical center of Iran, 2016)

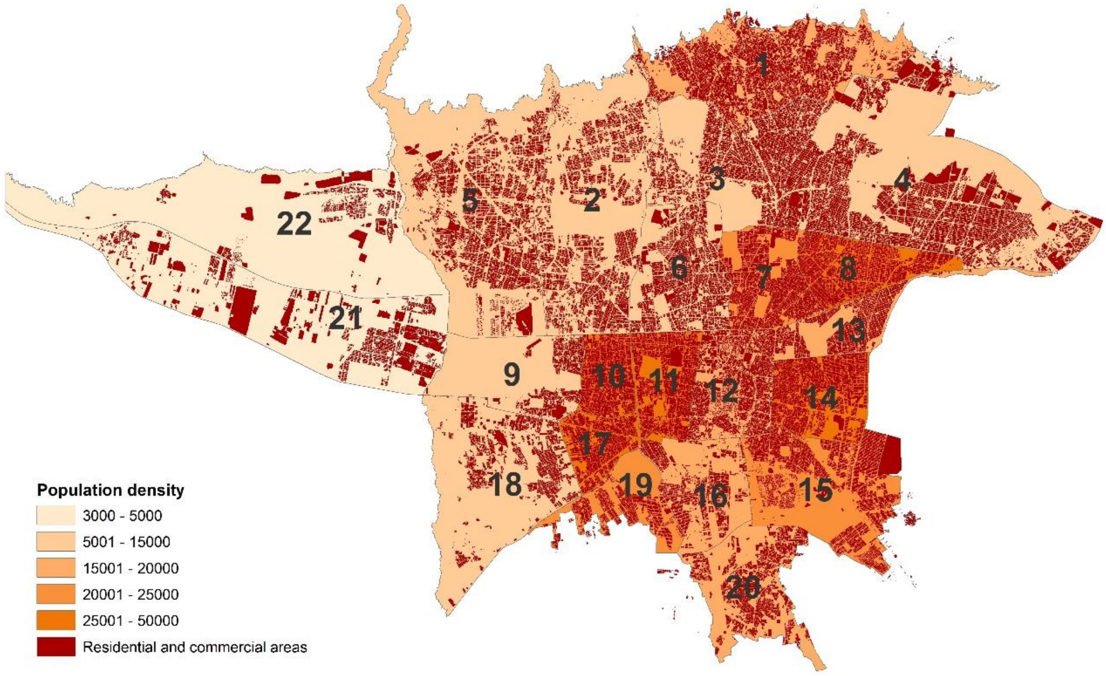


Figure 7. Population density per square kilometer of 22 Tehran's districts in 2018
Source: Author, Data source: (Statistical Yearbook of Tehran 2018, 2018)

Urban climate of Tehran

According to the climate classification Köppen, Tehran has a semi-arid (steppe) desert and cold climate (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006) (Raziei, 2016). But depending on the elevation, the climate of Tehran is different from north to the southern area. The province of Tehran locates on the border of two contrasting climates, humid climates in the north on the higher altitude and dry climate and desert area in the south with lower altitude. But, due to the uncontrolled exploitation of lands and disregard climatic capabilities and limitations, the borders of Tehran in the desert region in the south of the province shows a developing trend (Pre-study for regional planning in Tehran, 2009). So, the central city of Tehran has mostly a dry climate, the mean annual precipitation in the last two decades (2000-2016) in Tehran is about 148 mm (based on GPCC dataset). However, Tehran, in comparison to the central cities of Iran, has less scarcity of water. The high precipitation in Alborz mountains on the north side of Tehran can mostly provide the demanded water for the people of Tehran.

Tehran has the four seasons. The climate can generally be characterized as mild in the summer, hot and dry, pleasant in the fall and cold in winter. Summer days are dry and hot (with midday temperatures ranging from 30 to 40 ° C), while winters are cold (2 ° C in the north, 5 ° C in the south and below freezing temperatures in the night) (Agharabi, 2014).

Station	Duration	Height above sea level	Mean max. temp.	Mean min. temp.	Mean temp.	Max. temp.	Min. temp.
Geophysic	1989-2018	1,419	21.8	13	17.2	50	-11.7
Chitgar	1990-2018	1,305	22.5	12.5	16.2	42	-16.6
Mehrabad	1942-2018	1,191	23.1	12.4	17.1	43	-15

Table 2. Annual temperature
Data Source: (Statistical Yearbook of Tehran 2018, 2018)

Station	Duration	Height above sea level	Maximum	Minimum	Mean
Geophysic	1989-2018	1,419	446.7	132.8	290.1
Chitgar	1990-2018	1,305	406.5	48.2	236.4
Mehrabad	1942-2018	1,191	360.5	109.7	229.1

Table 3. Annual precipitation
Data Source: (Statistical Yearbook of Tehran 2018, 2018)

Month	Temperature (˚C)					Precipitation		RH (%)		Frost days	Sun -shine hours	Max. wind speed (m/s)
	Mean max.	Mean min.	Mean	Max.	Min.	Total (mm/ mon)	Max. (mm /d)	Max.	Min.			
Apr	22.4	12.6	17.5	30.3	2.6	37.2	21.4	47	18	0	215.4	15
May	24.3	14.5	19.4	29.4	7.6	33.9	7.6	62	22	0	225.7	19
June	32.6	20.9	26.7	37.2	16.8	8.9	3.4	47	14	0	317.6	22
July	38.7	26.6	32.6	41	23.4	0	0	28	8	0	382.5	10
Aug	38.1	26.3	32.2	41.4	19.8	0	0	33	11	0	356.6	11
Sep	33.9	22.9	28.4	37.6	19.2	0.2	0.2	33	12	0	332.3	15
Oct	26.2	16.4	21.3	32.6	12.2	7.6	3.4	52	22	0	253.1	11
Nov	16.5	9.3	12.9	26.2	5.8	51.2	17.8	72	38	0	153.7	13
Dec	14	6.2	10.1	17.4	3.4	51.2	16.2	71	39	0	177.6	12
Jan	10	1.8	5.9	14.8	-2.8	37.7	16.8	70	34	7	184.8	17
Feb	11.4	2.9	7.2	15.4	-1.6	32.4	14	66	31	6	196.53	17
Mar	14	4.7	9.3	19.2	-1.1	23.6	12.6	61	22	1	211.2	15

Table 4. Climate Data of Mehrabad Station in 2018-2019, RH= Relative Humidity
Data Source: (Statistical Yearbook of Tehran 2018, 2018)

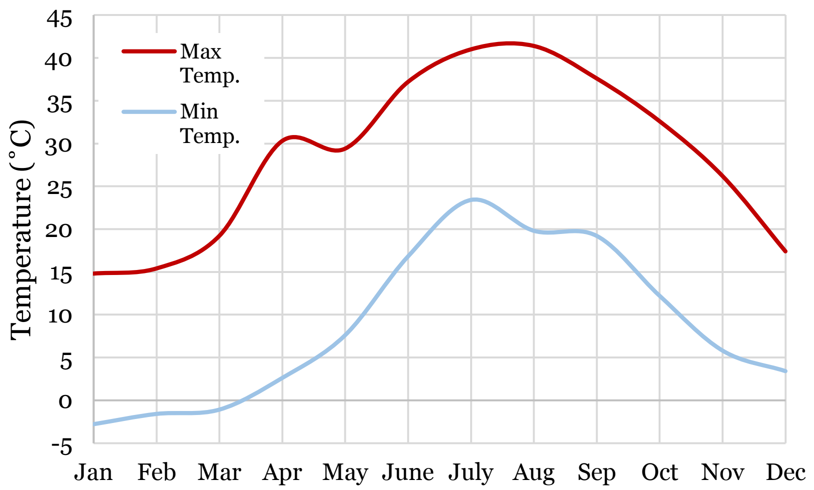


Figure 8. Maximum and minimum temperature in 2018,
Source: Author, Data Source: (Statistical Yearbook of Tehran 2018, 2018)

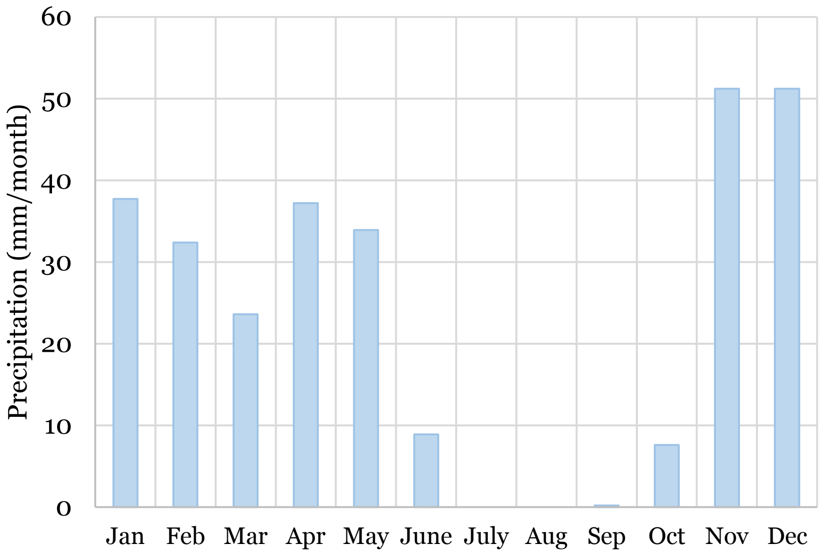


Figure 9. Total monthly precipitation in 2018,
Source: Author, Data Source: (Statistical Yearbook of Tehran 2018, 2018)

Land cover of Tehran

In the last comprehensive plan for Tehran, Figure 11, the zoning plan includes four main zones, residential, activities (commercial, administrative, and industrial), mixed-zone, and protection zone (green and open areas) (Structural and Strategic Plan of Tehran, 2007):

The residential zone is about 266 km^2, which includes the residential lands with other supporting land-uses for residential areas. Residential zones have various densities, and incompatible commercial and industrial land-uses are forbidden in these areas. The local plan of every district defines the local conservation rules, according to the natural and historical values. The activity zones cover about 182 km^2 of land-uses in Tehran. The major commercial, industrial, and administrative activities are running in these land-uses. In order to divide the unadaptable land-uses from the residential urban areas, and provide the further expansion possibility for the activities the residential and activity zones are separated. Mixed zones have both housing and activity potential, or uncontrolled growth of the commercial and industrial activities in the housing areas in the past formed the mixed urban structure. This zone covers 47 km^2 of the land-uses.

The forest parks, public and private gardens, agricultural fields, and open natural lands in the surrounding of Tehran covers about 107 km2 of Tehran lands. Local plans limit the construction and land-use change in the green zone, to improve the life quality and urban ecology in Tehran. Mostly, the recreational activities are allowed in these land-uses.

Green land cover in Tehran

According to three different types of topographies, Alborz mountainous area, foothills area, and desert, the Tehran region has three different main zones of green areas (Figure 10): Alpine meadows and steppe, steppe of foothills, and steppe of the plateau cover the Tehran region (Habibi & Hourcade, 2005).

District	Area of Urban Parks (m^2)								Area of other green spaces (m^2)
	< 5,000		between 5,000 and 10,000		between 10,000 and 100,000		>100,000		
	No.	Area	No.	Area	No.	Area	No.	Area	
1	130	258,126	35	271,934	33	783,603	6	8,843,762	6,346
2	106	282,820	51	351,639	45	811,461	6	1,851,303	11,386
3	59	114,999	18	125,366	14	255,919	6	1,176,091	3,596
4	175	312,629	47	333,940	31	715,996	11	12,872,96	5,778
5	97	255,336	51	369,628	55	1,412,236	4	993,428	9,395
6	46	88,491	11	76,590	7	166,297	2	450,538	2,337
7	53	81,812	5	30,340	6	256,897	-	-	1,040
8	71	117,294	9	66,406	7	174,937	-	-	1,346
9	20	31,672	2	14,375	6	141,289	-	-	2,591
10	35	51,000	7	50,738	9	141,820	-	-	599
11	16	25,870	5	34,581	8	200,500	1	350,000	917
12	49	51,029	4	25,140	6	110,895	2	427,413	761
13	37	85,884	9	56,852	17	363,005	-	-	1,697
14	50	106,491	24	175,176	21	688,699	-	-	3,805
15	61	149,803	25	172,189	38	1,213,452	8	3,589,720	4,710
16	13	41,019	13	86,337	28	971,294	2	685,539	1,292
17	42	92,487	14	89,142	12	327,501	-	-	553
18	20	52,706	20	149,587	51	1,209,98	5	980,960	4,254
19	23	60,058	7	50,871	32	1,000,76	5	2,325,229	3,419
20	98	220,920	36	267,228	41	1,245,45	1	180,000	4,884
21	16	39,023	16	109,774	22	543,071	4	705,660	5,466
22	37	107,153	14	112,352	18	330,597	8	4,841,586	4,954
Sum	1,254	2,626,622	423	3,020,185	507	13,065,6	71	40,274,19	81,136

Table 5. Green spaces areas in 22 districts of Tehran
Source: Author, Data Source: (Statistical Yearbook of Tehran 2018, 2018)

Due to the climatic characteristics, the low average rainfall, and the human intervention, the southern side of the Alborz mountains, where the Tehran province starts, doesn't have dense and enriched green coverage. Therefore, the natural tree cover is thin and incapable of forming a complete crown. In this area, trees usually grow scattered, and between them, bushes grow (Pre-study for regional planning in Tehran, 2009).

Forest parks and city parks in Tehran are mainly hand planted. The area of urban parks in the city of Tehran was about 60 km^2 in 2018. But the ratio of the urban parks to the other land-uses in 22 districts of the Tehran is not equally distributed throughout the city and differs from one to 23 percent. For instance, green space per capita in the district 10 and 22 in order is 0.72 m^2, and 27.10 m^2 (Pre-study for regional planning in Tehran, 2009). Figure 12 shows the distribution and diversity of green areas over the Tehran city in the last comprehensive plan. Table 5 shows the four classes of areas of parks and the area of other types of green spaces in each districts in Tehran.

Even if the total green spaces such as parks, forests, gardens, and agricultural lands cover about 140 km^2 of Tehran (Structural and Strategic Plan of Tehran, 2007), there is a considerable lack of green areas compared to other big and dense cities around the world. Due to international standards, the per capita urban green space varies according to factors such as geographical location, climate, natural green space, etc. and differs between 15 to 50 m^2. Because of the high air pollution and high density of the Tehran population, if we consider 30 m^2 for the urban green space per capita in Tehran, with 8 million people in Tehran the green surface in Tehran should cover 240 km^2, a little less than two times of than current level (Pre-study for regional planning in Tehran, 2009).

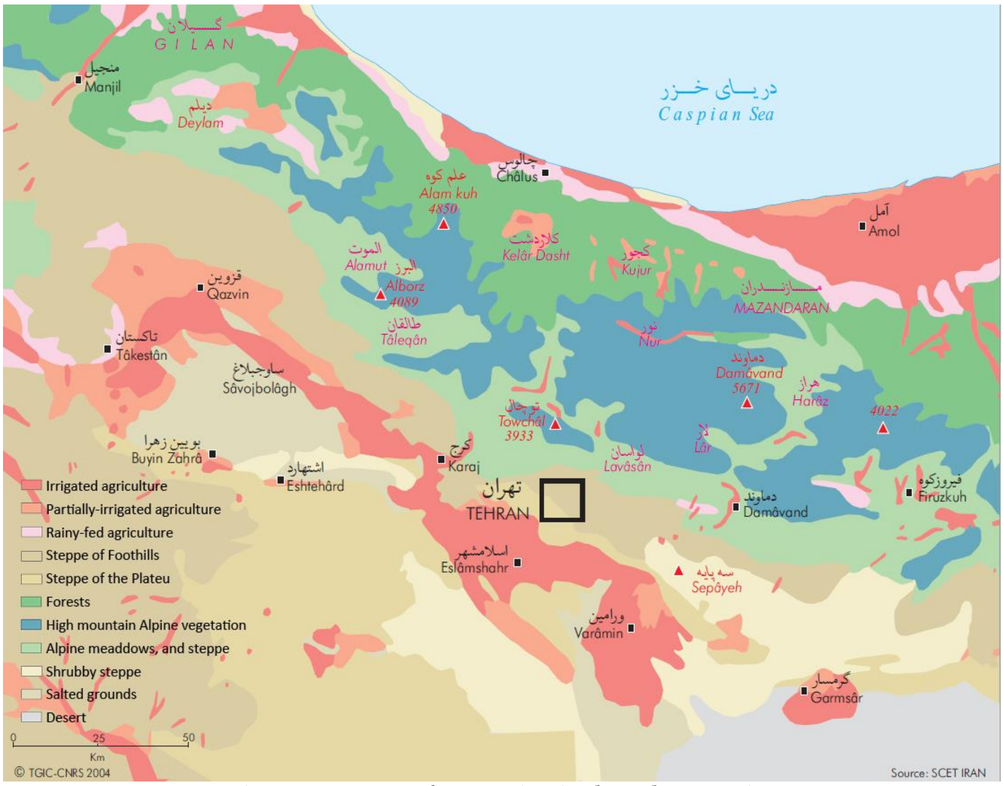


Figure 10. Types of vegetation in the Tehran region
Source: (Habibi & Hourcade, 2005)

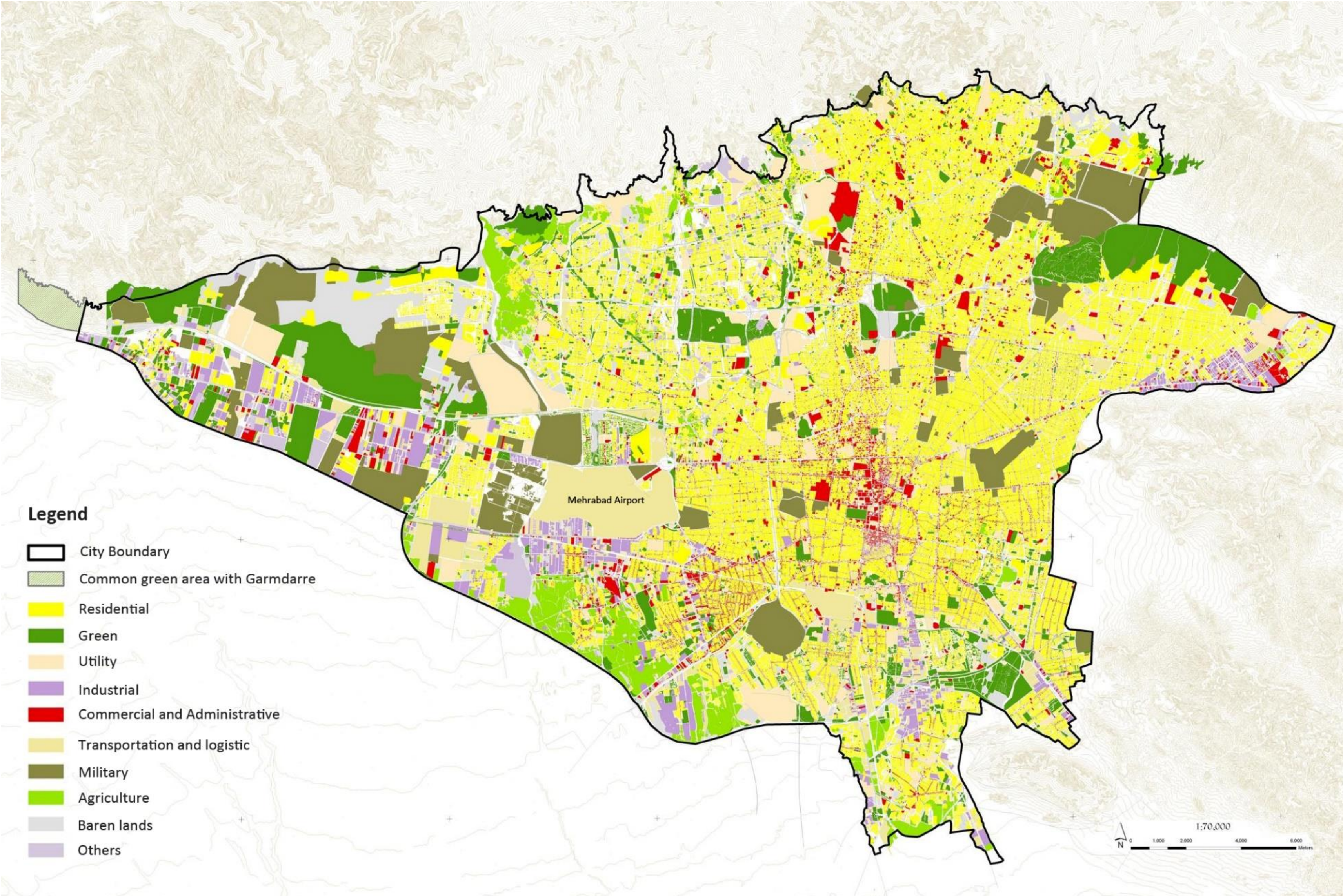


Figure 11. Land-use Plan of Tehran
Source: (Structural and Strategic Plan of Tehran, 2007)

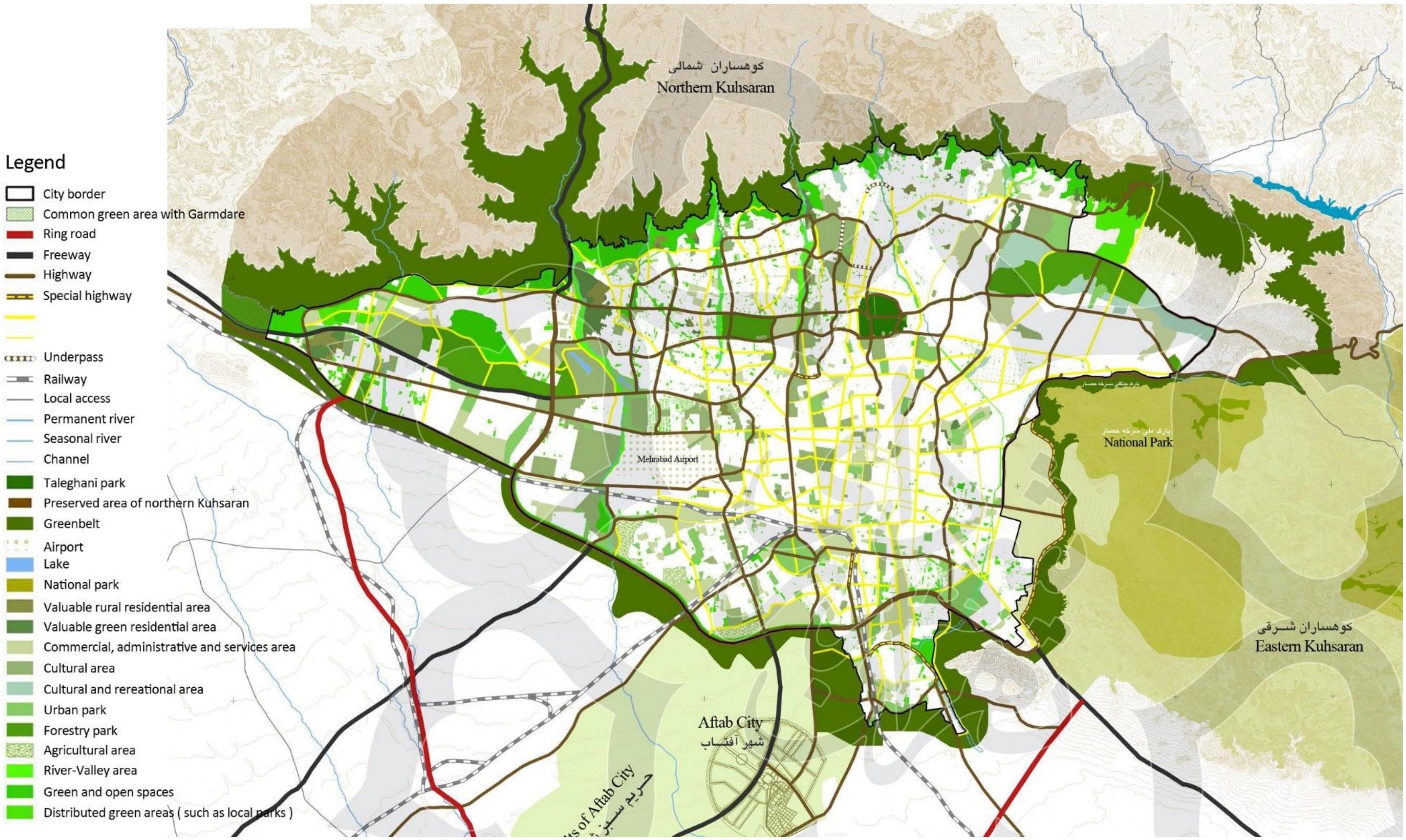


Figure 12. Map of Green areas in Tehran
Source: (Structural and Strategic Plan of Tehran, 2007)

Reasons of urban heat island in Tehran

Formation of the urban heat island in Tehran, mostly during the summer, alter the urban areas to a hot, unpleasant and unlivable spaces for the human activities. High density of buildings and constructed areas in the city of Tehran is one of the main reason of the UHI in Tehran (Shahmohamadi, Cubasch, Sodoudi, & Che-Ani, 2012). Based on the last Tehran master plan, 85 percent of the land cover of Tehran are the constructed areas (Structural and Strategic Plan of Tehran, 2007). Lack of vegetated areas and permeable surfaces decrease the shaded surfaces from the solar radiation and reduce the amount of evapotranspiration. In 8 districts from 22 districts of Tehran, the area of green spaces per capita is under than 10 m^2 (Pre-study for regional planning in Tehran, 2009).

Also, large surfaces of building materials with low albedo and high heat capacity such as concrete and asphalt absorb and retain the heat from the sun and form the UHI in the urban areas of the Tehran city. Complex form of the urban structure in Tehran also traps the heat by reflex of short-wave radiation between the building surfaces, and low sky view factor in urban corridors intensify the UHI by preventing the cooling of surfaces during the night.

High production of anthropogenic heat is also one of the main reason of the UHI in Tehran. Large volume of transports through the city produces more heat in the urban areas in Tehran. Tehran's daily travel demand is about 17.4 million trips for about four million vehicles (Tehran Comprehensive Transportation and Traffic Studies, 2013). Although, the public transportation of Tehran grows in the last years, still most of the suburban areas have poor access to central areas by public transportation such as subway and buses. Therefore, high demand of the private trips should access their workplaces every day (Shahmohamadi, Che-Ania, Etessamb, Mauludc, & Tawila, 2011) Also, Air-conditioning the inside of the buildings during hot days consumes more energy and raises the air temperature in urban areas.

About 70 percent of industrial unites of Iran are producing in the province of Tehran. Based on the last statistics of the Iran Small Industries and Industrial Parks Organization (ISIPO) in 2019, 122 km^2 area of the Tehran province are for industrial activities (ISIPO, 2019).

In addition, Tehran is located in a dry climate and semi-arid region. low air humidity, more clear sky days, low wind speed during the summer aggravate the UHI intensity in Tehran (Sodoudi, Shahmohamadi, Vollack, Cubasch, & I., 2014). The geographical feature of Tehran effects the raise of temperature. The Alborz mountains on the north and east side of the Tehran blocks the air movement as a wall over the Tehran. So, warm air and air pollution stagnate in the urban canopy.

Over a 63-year period from 1951 to 2013, urbanization and global warming have contributed to a rise in Tehran air temperature by 2.3 ° C. Throughout this time, a warming pattern of the order of 0.37 °C/decade was recorded which is more than triple the global temperature rise average (Haashemi, Weng, Darvishi, & Alavipanah, 2016). The research by Nadizadeh Shorabeh et. al. claims that UHI in Tehran will increase 0.32 percent until 2033. Intense land cover changes, increased transportation, and decline of vegetation from 1985 to 2017 represents higher heat classes in the future (Nadizadeh Shorabeh, Hamzeh, Zanganeh Shahraki, Firozjaei, & Jokar Arsanjani, 2020) (Farhadi, Faizi, & Sanaieian, 2019).

1-3. Objective of the study and research questions

The study's key concern is which districts in Tehran are more influenced by UHI. With the presumption that one of the leading causes of the UHI is a shortage of green space in most districts of Tehran. The next question is to identify which districts lack green spaces or have poor-quality green spaces. The prioritization of districts based on these two questions assists in the selection of UHI's most important regions and determines the scale of shortage of green spaces in Tehran as well as the green infrastructure that needs to be improved.

So, the focus of this study is an investigation on the availability, distribution, and the cooling effect of parks in 22 districts of Tehran. Our study helps us to categorize the districts based on the state of the green parks. In a dry climate like Tehran the choice of plant species is also crucial for mitigating the harmful effects of UHI. As a side objective, we would assess the performance of adaptable plant species, suggested in the literature. Due to the lack of ground data and access to conduct practical experiments in the region, it was nearly impossible to include a comprehensive investigation on the native plant species. Therefore, the results from the assessment in this part should not be over interpreted.

2. Methodology

The first step is to evaluate the status of Tehran's green spaces in terms of determining their availability and distribution. Based on the previous studies, no common regulations define the global standards of green spaces per capita or the accessibility of green areas in their neighbourhood. Although the world health organization (WHO) suggests the minimum of $9m^2$ green space per capita for each city. Also, the UK-Natural England recommends the availability of a 2-hectare green space in each neighbourhood, which is accessible in 300m, about five minutes' walk. The US Environmental Protection Agency (US EPA) defines the accessibility of the green space about 500m (WHO, 2016). The department of urban development in Berlin set a target of 6 m^2 per capita and a minimum of 0.5 ha green spaces which is accessible by 500 m distance from every resident. Similar to Dutch "Green City Guidelines" project which suggests the green areas with 500m distant from every home. In addition, the European Environment Agency (EEA) advises that individuals have access to green space within walking distance of 15 minutes, which is around 900-1000 m (Kabisch, Strohbach, Haase, & Kronenberg, 2016). Moreover, the United Nations defines the minimum of 30 m^2 of green spaces per capita and the European Union 26 m^2 (Kumari, Tayyab, Hang, Khan, & Rahman, 2019). Finally, the Comprehensive plan of Tehran 2007 defines the target of the minimum 10 m^2 for the capita for green spaces in Tehran (Tehran Urban Planning and Research Center, 2015).

In this thesis, the minimum of urban park's area per capita is 10 m^2 (based on Comprehensive plan of Tehran), with parks greater than 0.5 ha being considered. Based on statistical data from 2018, the availability of green areas, green areas per capita, and the share of green land uses in each district of Tehran is determined. This step depicts the districts in Tehran that are lacking in green spaces as one of the primary sources for defining the crucial point in the city to alleviate UHI.

The calculation and display of land surface temperature in Tehran is the next step. Land surface temperature (LST) is the temperature of the earth's surface. Due to the elevated surface temperature in Tehran, the LST map can be used to examine high-risk districts. LST data from satellite images (Landsat 8) calculates the surface temperature of Tehran by thermal infrared remote sensing method (TIR) by a resolution of 30 m (Weng, 2009) (Voogt & Oke, 2003). Landsat sensors can detect the range of visible to thermal infrared region of the electromagnetic spectrum, and its free to download from the website of United States Geological Survey (USGS) (Isaya Ndossi & Avdan, 2016). In this thesis, the LST data is from 2013 to 2019 for the summer months (June-September) and are processed in google earth engine.

Based on the measured LST, land-use map of three groups of Tehran's districts are compared. The aim of this comparison is to explain the role of the land cover in the produced temperature, as well as the effects of green areas on temperature reduction. The first category includes the most heavily inhabited areas, with an urban park capita of less than 5 m^2 and total green park's capita less than 10 m^2. In addition, these districts have the fewest urban parks. The second category contrasts two districts of old and new urban parks, each with differing quantities and ages of vegetation. The aim of this comparison is to determine the impact of vegetation richness on park temperature reduction. The third category demonstrates two newly developed districts with primarily industrial land uses, as well as their relative LST. Similarly, this group will illustrate the connection between low green area and high LST.

To display the effects of vegetation on temperature reduction, ten parks with the lowest mean LST and ten parks with the highest mean LST from the overall urban parks are chosen. The normalized difference vegetation index (NDVI) map of each park is compared to the LST. The NDVI map, like the LST, can be extracted from the Landsat 8 satellite images, which are free to download from the USGS website. In this thesis, the estimated NDVI is the last updated of NDVI from the Land sat 8 images during the April to end of July in 2020. The NDVI map is also processed in google earth engine.

As previously stated, vegetation in urban environments will reduce the temperature of green spaces and their surrounding built environment. Any green area has a cooling effect to the outside, showing how much the temperature of the area can be decreased by a green area. So, calculating the cooling extent of the Tehran's urban parks can help measure the green area's impact in the city of Tehran.

The park's cooling extent is largely determined by factors such as the park's shape and scale, the land-use within the park, the park's vegetation density, wind direction, and the urban environment surrounding the park (Cao, Onishi, Chen, & Imura, 2010). The goal of measuring the park's cooling extent in this study is to classify the critical districts that are affected by a shortage of green areas and their cooling impact. As a result, a more thorough study of the cooling extent's relationship to the characteristics of the urban park is avoided.

Previous studies measure the park cooling extent with two methods: Using satellite imagery and thermal infrared remote sensing (TIR) to extract LST from the satellite images. The second method is the experimental method measuring the air temperature in the park's borders in place. This method is not capable to measure the cooling extent for all the parks in one city (Yang, et al., 2017). Although the air temperature can present the exact reflection of cooling effect of the parks in the surrounding area, but remote sensing LST provides uniform sampling of an area related to land cover and land-use (Nichol, Fung, Lam, & Wong, 2009). The importance of linking the LST to air temperature is highly relevant as those datasets are being used outside the science community to guide policy decisions or to interact (Tomlinson, Chapman, Thornes, & Baker, 2011).

Although the relationship between air temperature and LST in heat island measurements is still uncertain at the micro scale, previous studies have verified the cooling effect of the vegetation within the park using remotely sensed LST and the relationship to NDVI (Nichol, Fung, Lam, & Wong, 2009) (Cao, Onishi, Chen, & Imura, 2010). So, in this thesis, based on the first method, the cooling extent of the urban parks is calculated using the retrieved LST from the Landsat 8 satellite images with a resolution of 30 m. The LST data reveals the daily temperature from June to September (summer months) 2013-2019 in Tehran.

Since urban parks have a more comparable landscape structure than other types of green areas, such as farm fields and private gardens, this study focuses solely on the cooling extent of urban parks. The positioning of the urban parks is determined using 2005 land-use data from Tehran. Due to the 30-meter resolution of the satellite images, the urban parks larger than 1000 m² are selected. The cumulative number of parks in the selected park is 804, with sizes ranging from 1001 m² to 32 ha.

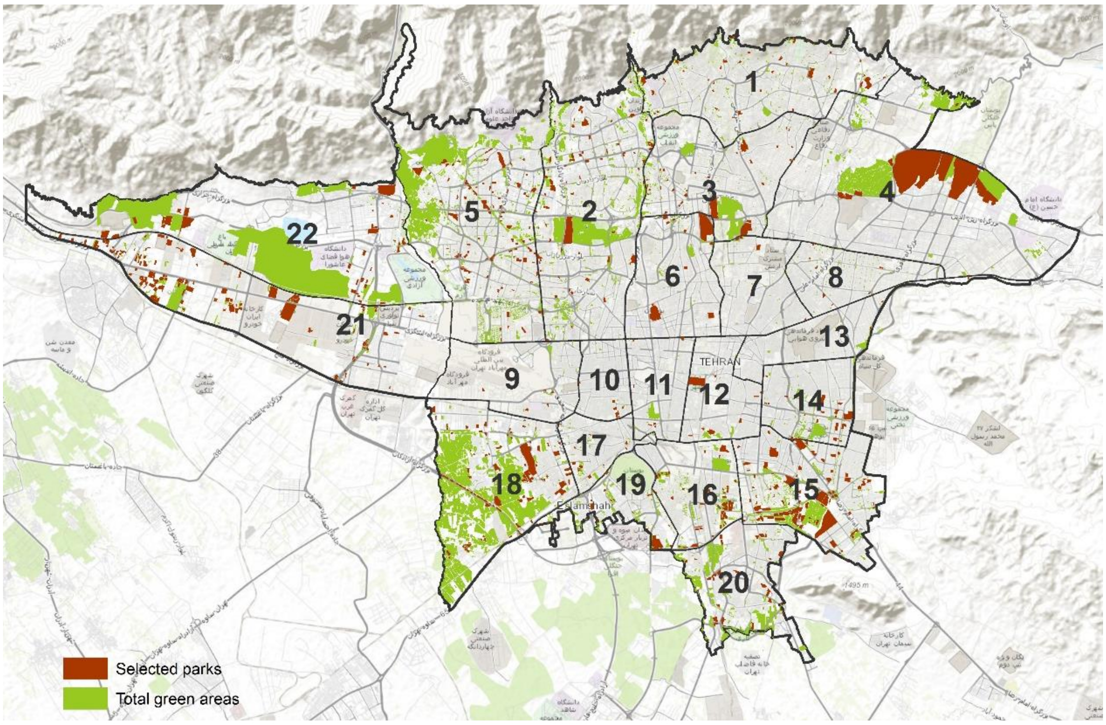


Figure 13. Selected urban parks from the total green areas in Tehran
Source: Author, Data Source: Land-use Data 2005, (Noandishaan, 2015)

The LST of each park is measured next, from the park's boundary to about 900 meters away. The variance of the LST in the surrounding area is seen by the mean LST of every 30 m buffer from the park's boundary to the outside (Figure 14). Figure 15 represents the park's cooling extent, which is the distance from the park's border to the tipping point of the LST, when the LST reaches to a maximum temperature and drops again (Yu, Xu, Zhang, Jørgensen, & Vejre, 2018).

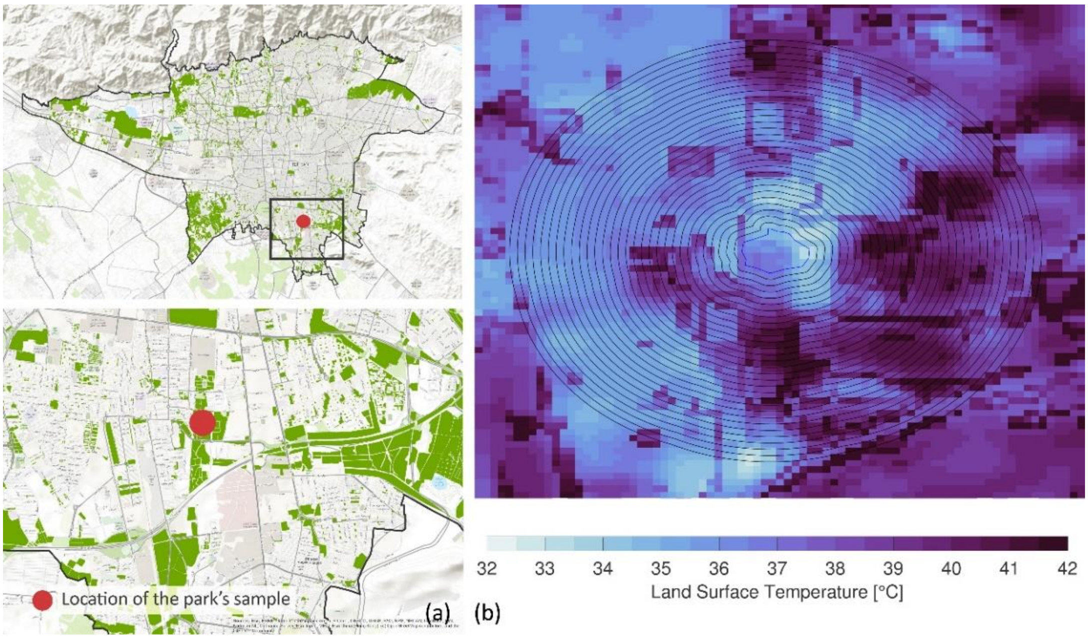


Figure 14. (a). Location of the sample of urban park in Tehran. (b). LST within 900 m buffer from the border of park to calculate cooling extent
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

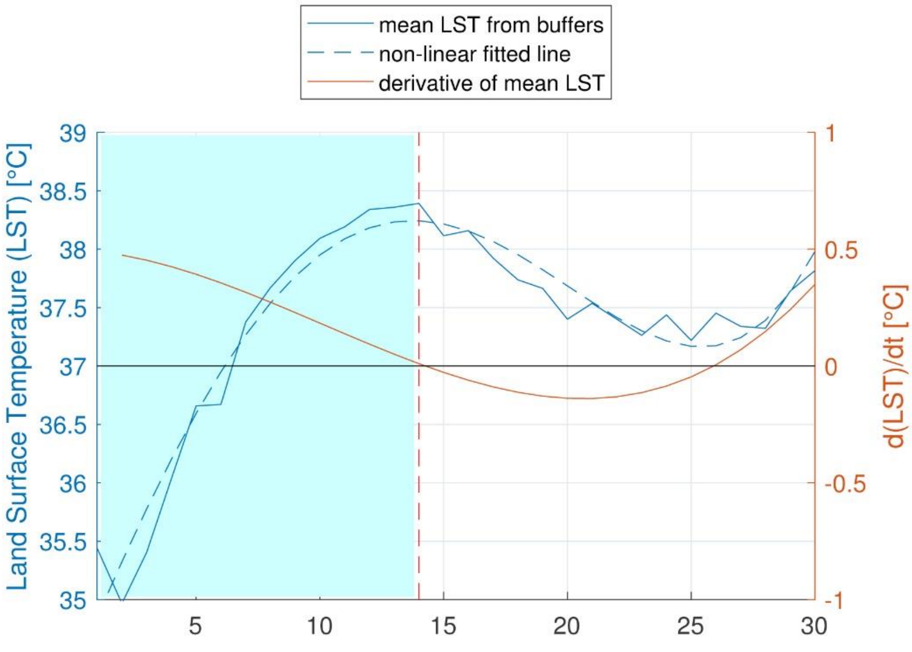


Figure 15. Cooling extent of the sample park from the border of the park to the 1th max. temperature tipping point
Source: Author, Source Data: Landsat 8 USGS and NASA, processed in google earth engine

To calculate the first tipping point of the temperature (1st maximum temperature) from the park's boundary, first, a polynomial curve of order 4 is fitted to the temperature change curve of each park. The newly fitted curve can smooth out minor temperature variations and avoid the miscalculation of the main maximum. The first maximum point of the curve is the first point with first derivation equal to zero and the positive second derivation. The pixel's number multiplied by 30 meters (±15m) defines the cooling extent of each park.

The crucial locations are defined using the last three phases, which include the LST map of Tehran, the current status of green areas in each district of Tehran, and the cooling extent of urban parks. The critical locations suffer from high LST, lack of green areas and green space's cooling effect.

3. Result & Discussion

3-1. Current state of the green space in Tehran

Green spaces make up about 22% of land use in Tehran, and include urban parks, forest parks, green spaces along the highways and streets, gardens, agricultural fields. From the total green spaces in Tehran, 42% is the urban or forest parks as a recreational and public space. The total green space per capita is about 16 m^2 and the capita of the urban parks in Tehran is less than 7 m^2 (Table 6).

District	Total area of urban parks (m^2)	Total area of green spaces (m^2)	District area (ha)	Percentage of green areas in district	Population	Urban parks Area per capita	Green area per capita
1	10,193,514	16,503,712	4,661	35.4	522,526	19.4	31.6
2	3,304,230	14,683,896	4,701	31.2	721,964	4.6	20.3
3	1,681,196	5,268,898	2,922	18.0	337,275	5.0	15.6
4	14,272,915	20,013,693	6,155	32.5	946,728	15.0	21.1
5	3,038,203	12,426,409	5,316	23.4	884,287	3.4	14.1
6	794,524	3,119,503	2,137	14.6	259,868	3.0	12.0
7	381,874	1,409,262	1,534	9.2	312,996	1.2	4.5
8	379,078	1,705,089	1,316	13.0	445,554	0.8	3.8
9	190,958	2,778,630	1,975	14.1	180,818	1.0	15.4
10	254,787	843,299	819	10.3	336,962	0.7	2.5
11	614,056	1,527,996	1,203	12.7	316,492	1.9	4.8
12	632,905	1,375,827	1,601	8.6	241,430	2.5	5.7
13	512,521	2,203,722	1,286	17.1	244,516	2.1	9.0
14	978,556	4,775,736	1,455	32.8	507,783	1.9	9.4
15	5,135,828	9,835,482	2,774	35.5	670,574	7.6	14.7
16	1,784,189	3,076,979	1,652	18.6	260,178	6.9	11.8
17	514,983	1,062,393	825	12.9	289,234	1.8	3.7
18	2,393,237	6,648,183	3,787	17.6	431,276	5.5	15.4
19	3,438,611	6,856,397	2,034	33.7	262,316	13.1	26.1
20	1,939,515	6,798,268	2,358	28.8	378,741	5.1	17.9
21	1,399,425	6,864,068	5,153	13.3	196,998	7.1	34.8
22	5,394,409	10,346,053	5,900	17.5	198,970	27.1	52.0
Sum	59,229,514	140,123,495	61,564	22.8	8,947,486	6.6	15.7

Table 6. Green spaces capita in 22 districts of Tehran
Source: Author, Data Source: (Statistical Yearbook of Tehran 2018, 2018)

The green spaces are not homogenously spread in Tehran's districts. According to the area of each district, seven of 22 districts have more than 25% of green space as land cover, while two districts with about 1500 ha have less than 10 percent of green space. Table 6 and Figure 16 reveal that the overall green space per capita in eight districts is less than 10 m², which is less than the vision of the comprehensive plan of Tehran and other international standards. We may also think of urban parks as a different form of open green space with a dense and consistent green structure. The area of urban parks per capita in Table 6 and Figure 17 indicates that 13 districts in Tehran have less than 5 m², and five districts have between 5 and 10 m². As a result, just four districts have more than 10 m² urban parks per capita.

Figure 17 illustrates the availability of the urban parks larger than 0.5 ha and the urban park's areas per capita in 22 districts of Tehran. Based on the calculations, mostly the central districts, three districts in the east, and the two districts in the north have less than 5 m² urban park's area per capita. The central districts of Tehran are densely covered by commercial, administrative, and residential land uses, and most of the green areas are gradually disappeared without a proper comprehensive plan through the growth of Tehran.

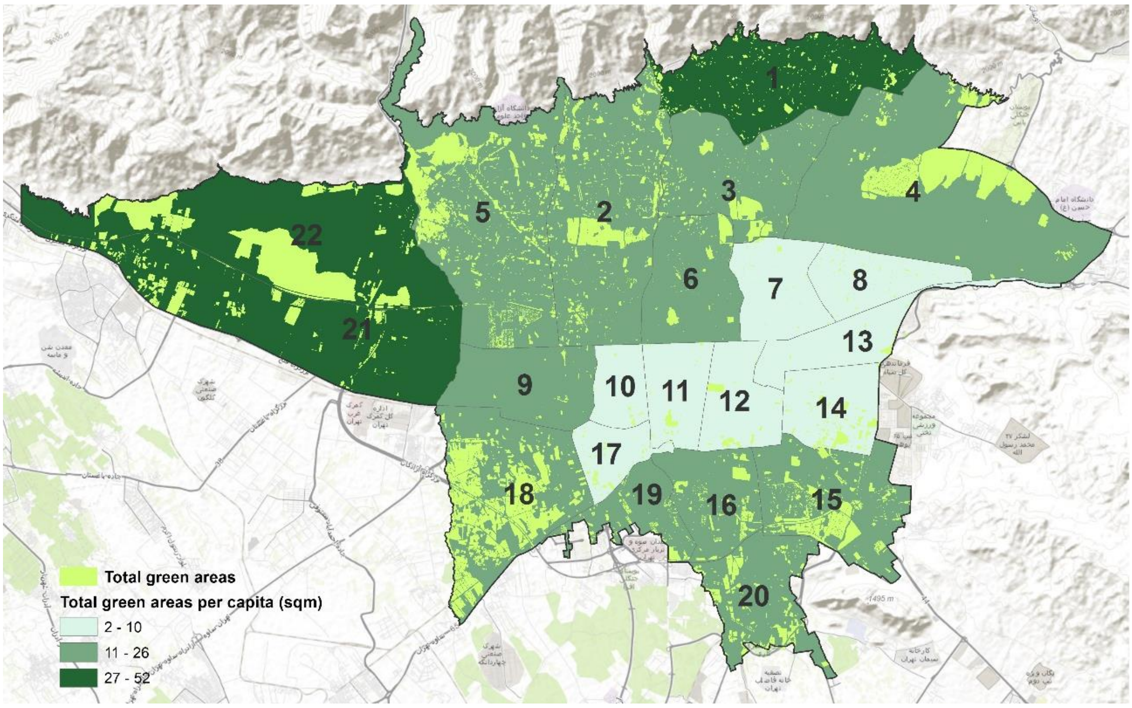


Figure 16. Area of the total green areas per capita in 22 Tehran's districts in 2018
Source: Author, Data source: (Statistical Yearbook of Tehran 2018, 2018)

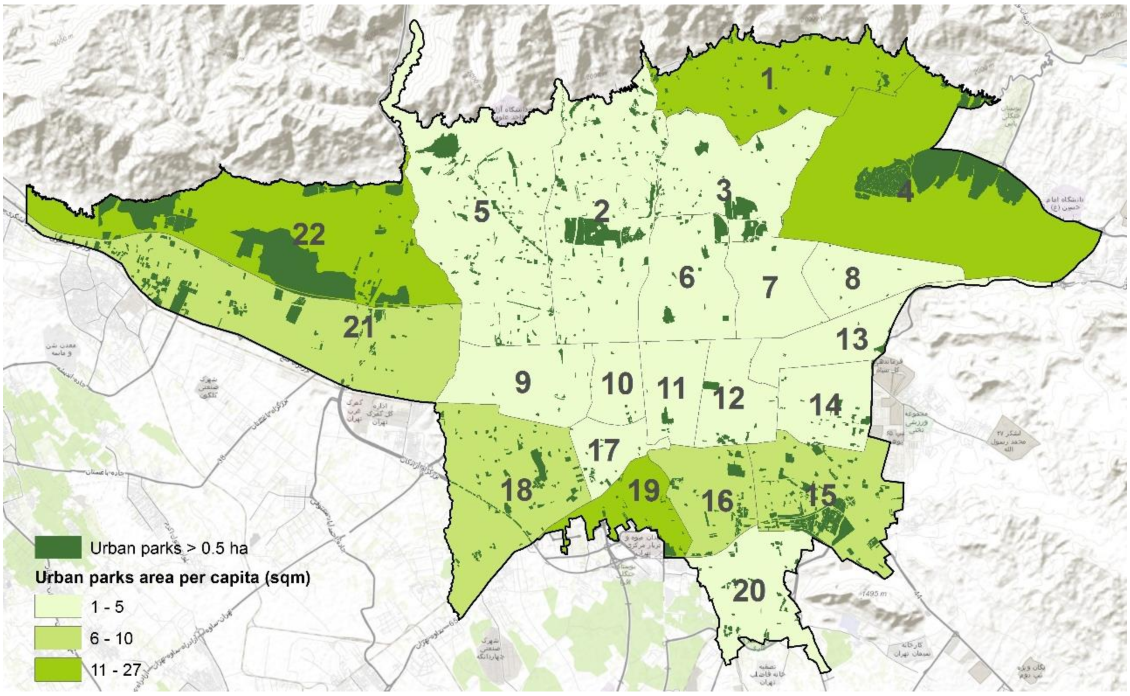


Figure 17. Urban parks larger than 0.5 ha and capita of total urban parks in 22 Tehran's districts, 2018
Source: Author, Data source: (Statistical Yearbook of Tehran 2018, 2018)

3-2. Land surface temperature (LST) in Tehran

The land surface temperature map shows a range of average temperature from 24 to 50˚C during the summer months (June-September) from 2013-2019. the LST varies based on the land cover. Water bodies and green areas are cooler and bare lands, industrial areas, roads, parking lots, and the airport's runway have a higher mean LST. In between, the constructed areas display an average temperature between 32 and 38˚C.

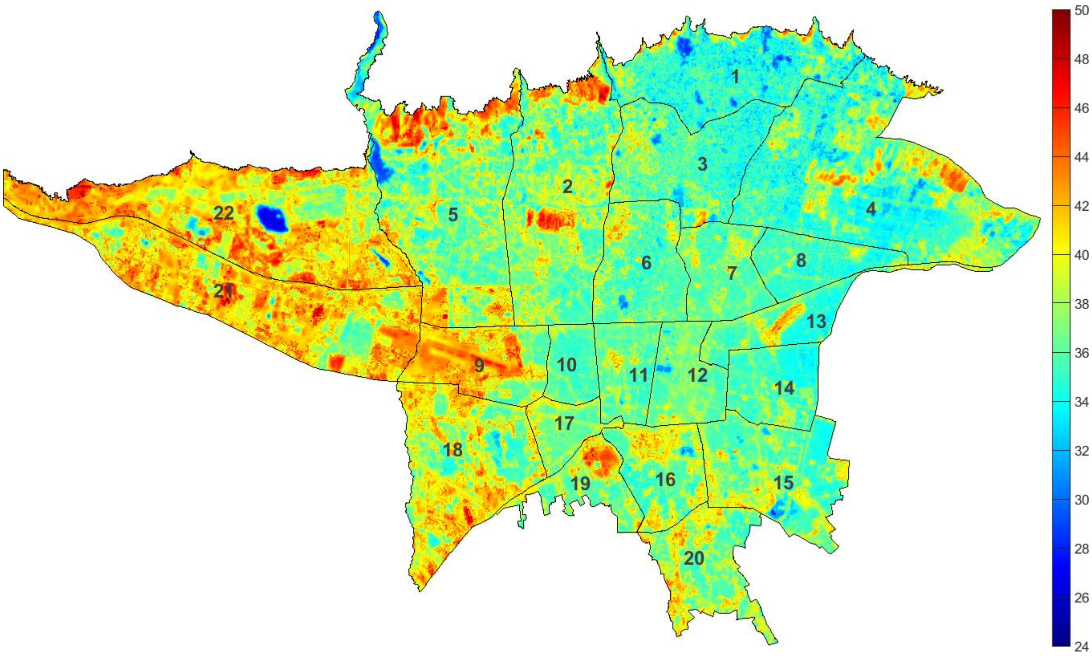


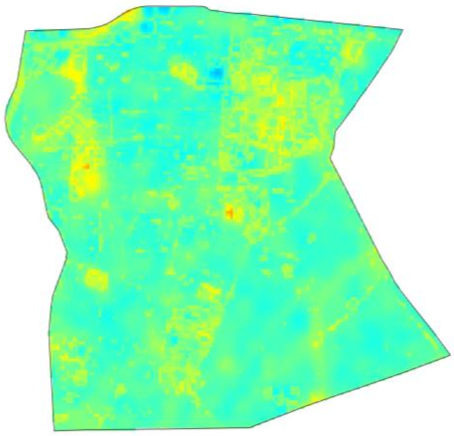
Figure 18. Classified map of mean land surface temperature, June-Sep 2013-19,

Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

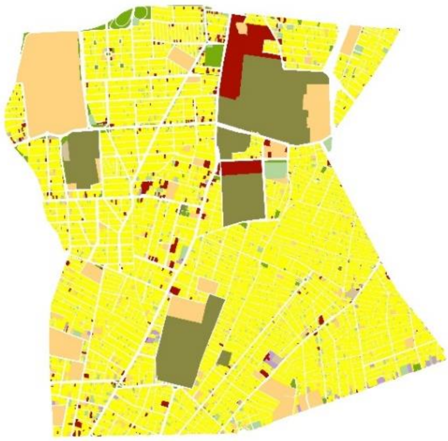
Next step explains the LST of three groups of typical districts in Tehran concerning their land uses. First group contains six districts, 07, 08, 10, 11, 14, and 17. These districts have high population density, capita of urban parks less than 5m², capita of total green areas less than 10 m². All six districts have a similar urban layout. They are located in the center of Tehran, and serve as the core of the commercial and administrative activities in Tehran. So, during the day, high volume of traffic runs in these districts and increasing the temperature by anthropogenic activities. Figure 16 displays three representative of the first group consists of district 07, 10, and 11. The average of LST in these districts is about 34˚C for constructed areas, 39˚C for roads and lands without vegetation, over 42˚C for bare lands, and lands mostly covered by concrete or asphalt. So, the summer's average LST in these central districts in Tehran is higher than about 34˚C. The capita of urban parks in these districts is less than 2 m², and the total green areas cover only about 10% of the whole district.

District	Green areas in district (%)	Population density per ha	Urban parks area per capita	Total green area per capita	Min LST (˚C)	Max LST (˚C)	Mean LST (˚C)	SD LST (˚C)
1	35.4	112	19.4	31.6	27.3	46.6	35.1	2.34
5	23.4	166	3.4	14.1	27.8	49.7	38.1	3.2
7	9.2	204	1.2	4.5	31.5	44.3	36.5	1.54
10	10.3	411	0.7	2.5	33.5	43.3	36.0	1.14
11	12.7	263	1.9	4.8	30.4	44.6	36.6	1.53
21	13.3	38	7.1	34.8	30.8	50.4	41.0	2.33
22	17.5	34	27.1	52.0	26.6	48.9	40.6	3.06

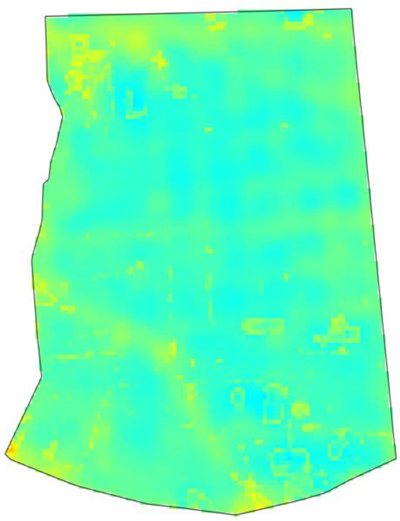
Table 7. Selected districts, Data source: (Statistical Yearbook of Tehran 2018, 2018), mean LST, June-Sep 2013-19
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

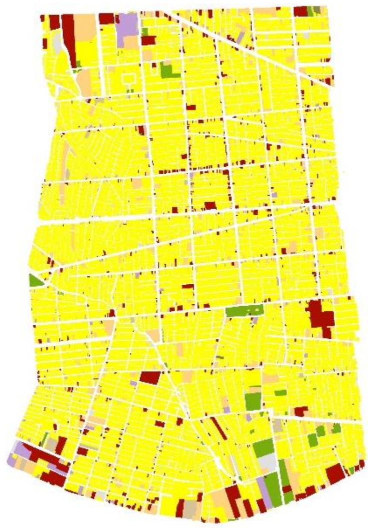


a. *Land surface temperature for District 07*



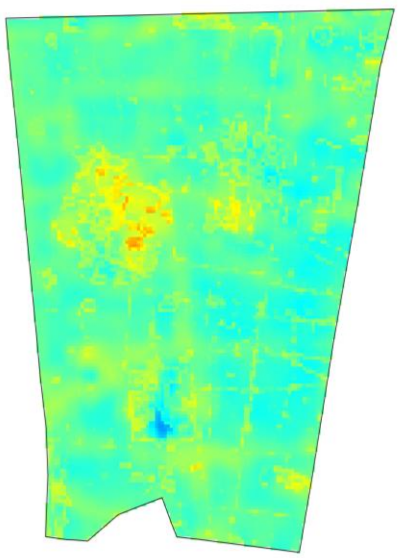
b. *Land-use for District 07*

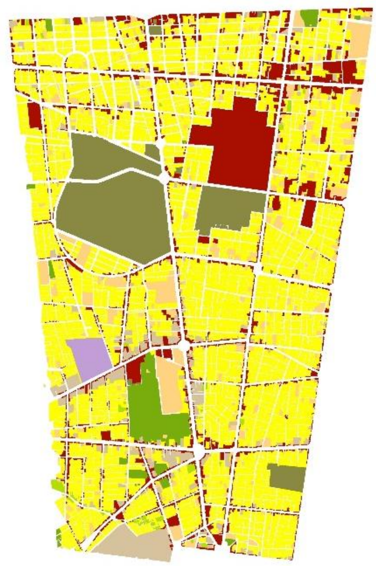




c. Land surface temperature for District 10

d. Land-use for District 10





e. Land surface temperature for District 11

f. Land-use for District 11

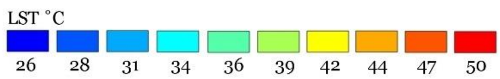
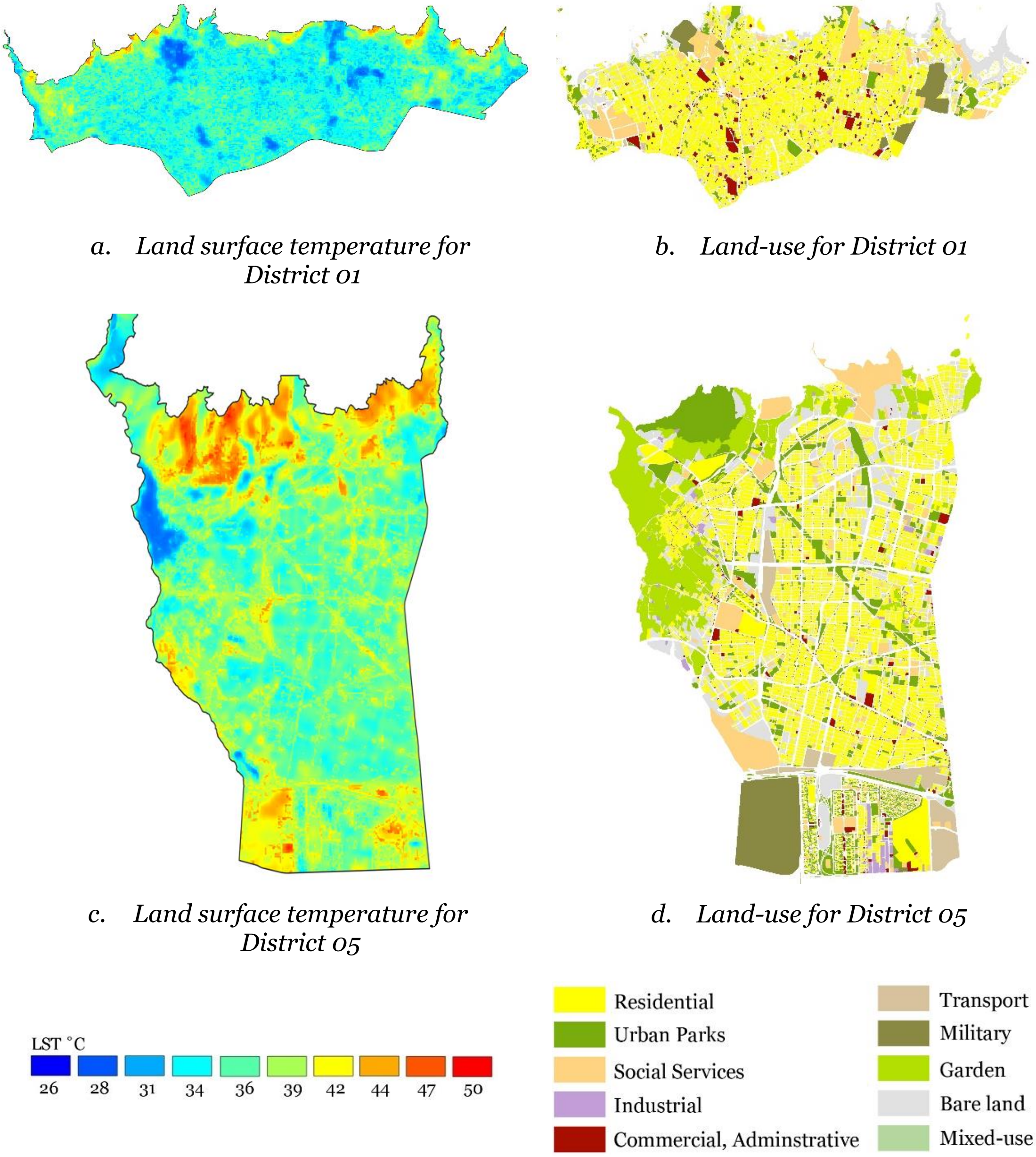


Figure 19. Classified map of mean land surface temperature for districts: 07, 10 & 11, June-Sep 2013-19
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine; Classified map of Tehran's Land use, Data Source: GIS-based Land-use Data 2005, (Noandishaan, 2015)

The second group is a comparison two districts based on their green urban parks. Figure 20 shows that the urban parks act as effective cooling cores in district one, where the LST is lower than 30°C. District one includes old and large green areas, as old gardens with rich vegetation. The urban parks in district five, on the other side, are covered in new vegetation that is incapable of lowering the temperature. Also, Figure 20 shows that in contrast to district 1, which is an old district with dense, old and narrow streets, in district 5, the new wide roads and highways increase the LST to over 39˚C.



a. Land surface temperature for District 01

b. Land-use for District 01

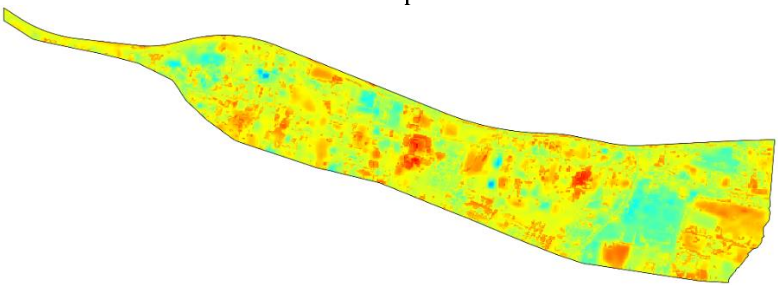
c. Land surface temperature for District 05

d. Land-use for District 05

Figure 20. Classified map of mean land surface temperature for districts: 01 & 05, June-Sep 2013-19 Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine; Classified map of Tehran's Land use, Data Source: GIS-based Land-use Data 2005, (Noandishaan, 2015)

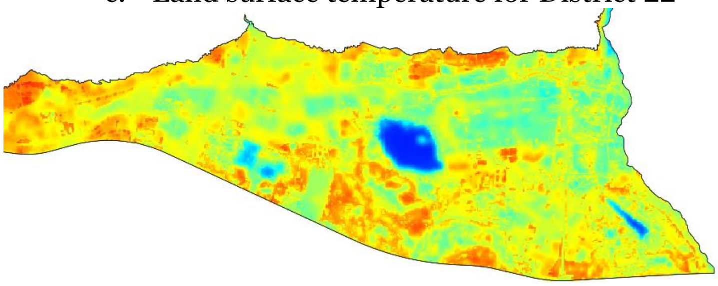
The final group includes districts 21 and 22. Industrial lands and bare lands mostly cover districts 21 and 22. Due to lack of vegetation and shading, the LST of bare lands and undeveloped lands in Tehran's surrounding area, like districts 21 and 22, increases to over 42˚C. Because of the low vegetation cover in these districts, even the green areas have a high LST. The average LST of one of the Tehran's largest urban parks in district 22 is about 47 °C.

a. Land surface temperature for District 21



b. Land-use for District 21

c. Land surface temperature for District 22



d. Land-use for District 22

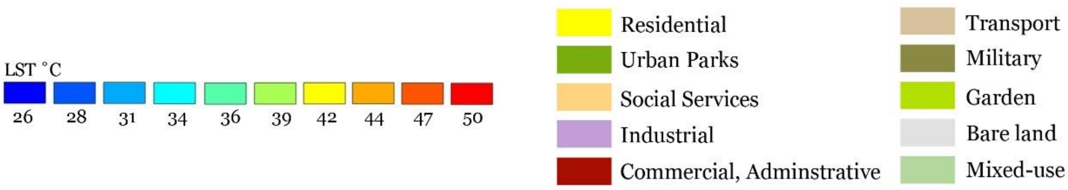


Figure 21. Classified map of mean land surface temperature for districts: 21 & 22, June-Sep 2013-19 Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine; Classified map of Tehran's Land use, Data Source:GIS-based Land-use Data 2005, (Noandishaan, 2015)

Comparison of 10 hot parks to 10 cool parks

The LST of the parks differs due to the vegetation and land cover. Ten parks with the lowest mean LST and ten parks with the highest mean LST from the all of Tehran's urban parks are selected. The mean LST is calculated similar to the previous section, during summer 2013-2019. When the NDVI of these 20 parks is compared, it becomes clear that vegetation is the most effective factor in preventing temperature rise in urban parks. The calculated NDVI is the last updated of NDVI map from the Landsat 8 satellite images during the April to end of July in 2020, as vegetation growth is at its peak during the spring. Based on the USGS definition, the range of NDVI less than 0.1 is barren land, rock, and sand, between 0.2 and 0.5 is the sparse vegetation, shrubs, grassland, and the NDVI of dense vegetation is between 0.6 and 0.9 (USGS, 2018).

In the following, Figure 22 and Figure 23 display the ten parks with low mean LST as cool parks, and the ten selected parks with high mean LST as hot parks. In these figures, the mean LST and mean NDVI of the selected urban parks are comparable. The cool park's mean LST changes from about 30 to 38 °C, and the mean NDVI changes from ca. 0. 25 to 0.45 (Table 8). While in hot parks, the mean LST differs from about 38 to 43 °C and the mean NDVI from 0.18 to 0.3 (Table 9).

Name	ID	Area (ha)	Pixel	Mean NDVI	Min NDVI	Max NDVI	SD NDVI	Mean LST	Min LST	Max LST	SD LST
Golbarg	C01	-	201	0.28	0.26	0.29	0.01	36.6	32.4	39.7	0.18
Ekbatan	C02	-	1027	0.32	0.31	0.34	0.01	37.8	32.3	44.4	0.20
Qaem	C03	51.37	708	0.43	-0.24	0.65	0.13	34.7	31.2	41.7	2.23
Saei	C04	11.89	160	0.35	0.17	0.45	0.05	33.7	31.8	37.6	1.23
Abo Atash	C05	29.07	398	0.45	0.24	0.61	0.06	32.7	30.9	36.8	1.05
Shahr	C06	24.92	342	0.47	0.05	0.59	0.10	32.1	30.1	37.9	1.49
Laleh	C07	26.61	367	0.49	-0.18	0.63	0.10	32.1	29.6	37.6	1.66
Mellat	C08	25.73	350	0.41	-0.20	0.65	0.17	32.6	29.2	39.6	2.37
Niavaran	C09	9.06	125	0.35	0.07	0.54	0.12	31.7	29.6	34.6	1.26
Gheytarie	C10	9.94	134	0.48	0.20	0.5	0.07	30.4	28.6	35.3	1.31

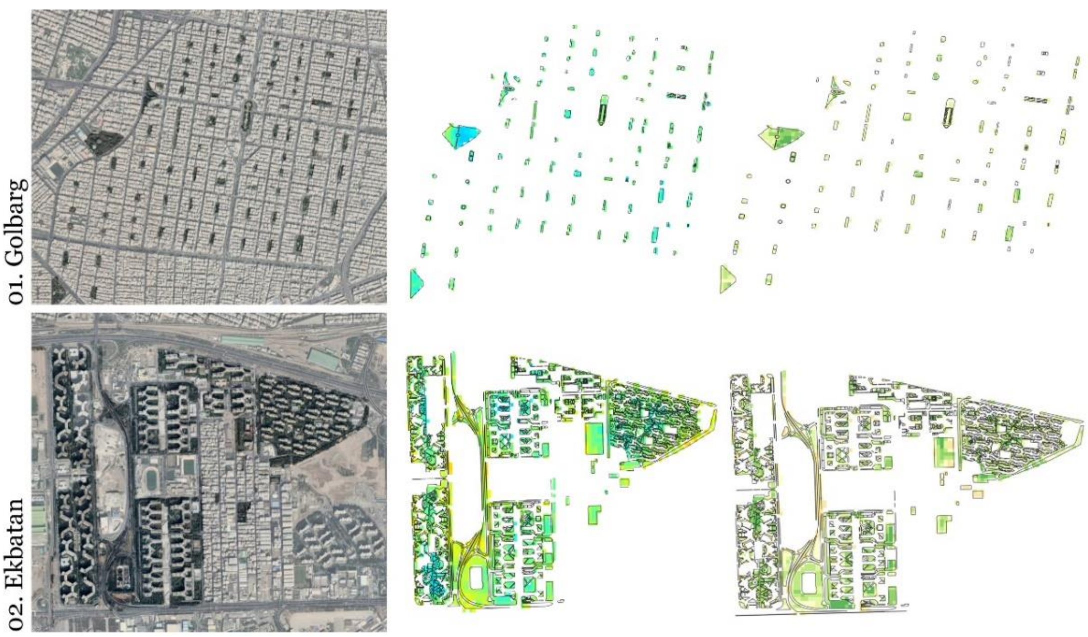
Table 8. mean LST, June-Sep 2013-19, and mean NDVI, Apr-Jul 2020, in 10 selected cool parks
Source: Author, Data source: Landsat 8 USGS and NASA, processed in google earth engine

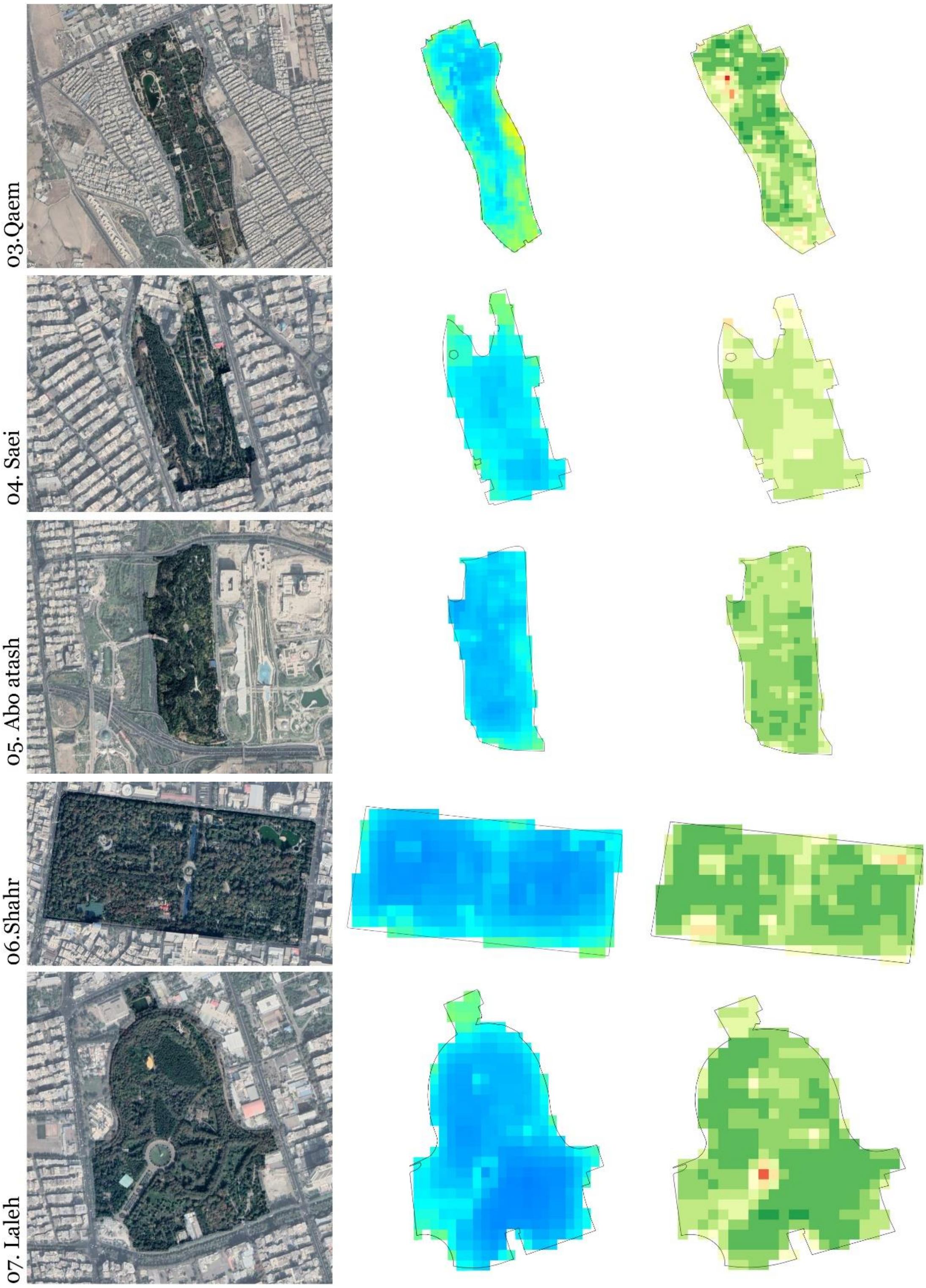
Name	ID	Area (ha)	Pixel	Mean NDVI	Min NDVI	Max NDVI	SD NDVI	Mean LST	Min LST	Max LST	SD LST
Lavizan	H01	360.94	4990	0.30	0.05	0.65	0.09	40.33	33.20	44.51	2.27
Zibadasht	H02	39.93	545	0.18	0.09	0.38	0.03	41.05	36.80	45.28	1.64
Harandi	H03	17.71	243	0.21	0.05	0.38	0.09	39.1	36.5	41.6	0.98
Bahmani nezhad	H04	7.58	104	0.24	0.04	0.57	0.19	38.9	34.6	42.9	2.40
Sabzan	H05	2.46	50	0.22	0.16	0.26	0.03	40.6	38.3	42.4	1.05
Isar	H06	19.74	269	0.23	0.09	0.41	0.06	40.7	36.6	45.8	2.15
Koohsar	H07	118.82	1627	0.22	0.04	0.45	0.05	43.8	36.5	48.6	1.92
Roshd	H08	72.02	992	0.22	0.08	0.53	0.07	43.52	36.75	47.47	2.19
Chitgar	H09	830.47	11405	0.29	0.02	0.61	0.07	42.1	34.6	47.4	2.22
Pardisan	H10	230.54	3169	0.31	0.09	0.56	0.08	41.5	33.3	47.7	3.29

Table 9. mean LST, June-Sep 2013-19, and mean NDVI, Apr-Jul 2020 in 10 selected hot parks
Source: Author, Data source: Landsat 8 USGS and NASA, processed in google earth engine

The cool parks are mostly the old parks in Tehran which are the remains of the old gardens in Tehran, so the vegetation is rich, and the species are mostly native and adapted to the climate. These parks survived intact from urban growth in Tehran's development plans. The two green areas of the Golbarg (C01) and Ekbatan (C02) are the combined green spaces within the residential areas. Even if the green areas are not as large as an urban park, their greenness effectively keeps the surrounding of the residential buildings cool. The mean LST of these green spaces is about 36 and 37 ˚C, which are cooler than other non-green spaces between the buildings covered by impervious materials, without any shading (Table 8, Figure 22, Figure 24, Figure 26).

In contrast, the hot parks are mostly the newly developed parks in the last two decades in Tehran. The new-planted vegetation is unable to cool the parks, as they are not large to provide enough shading like Zibadasht (H02), Bahmaninezhad (H04), Sabzan (H05), Isar (H06), Roshad (H08). Also, in some recent parks, an increase of covered surfaces by impervious materials for other occupations such as play courts, cycling and walking paths reduces the cooling efficiency of parks, including Harandi (H03), Chitgar (H09), Pardisan (H10). Sparse and scattered vegetation are detectable by NDVI maps in Figure 23. The negative NDVI shows the water ponds in the parks and its cooling effect in the LST map. Other parks such as Lavizan (H01), and Koohsar (07) are the forest parks on the hillside of the Alborz mountains in the north of Tehran. Many factors, such as the damages by urban expansions, lack of maintenance, change of the climate, and soil erosion, depleted the variety of the plant species over time and resulting in the loss of native plants. Even these large forest parks due to lack of dense vegetation are unable to decrease the temperature (Table 9, Figure 23, Figure 25, Figure 27).




03.Qaem
04. Saei
05. Abo atash
06.Shahr
07. Laleh

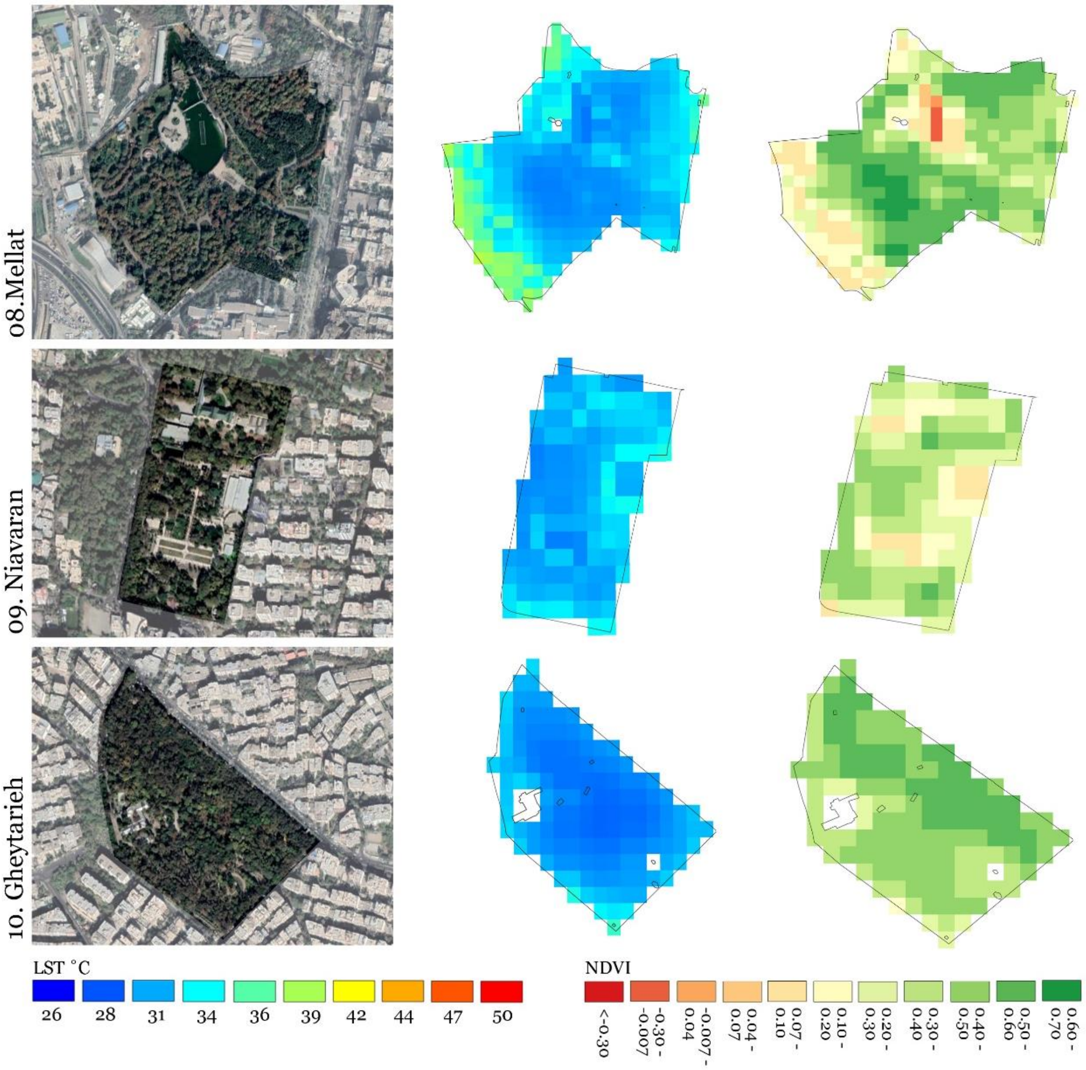
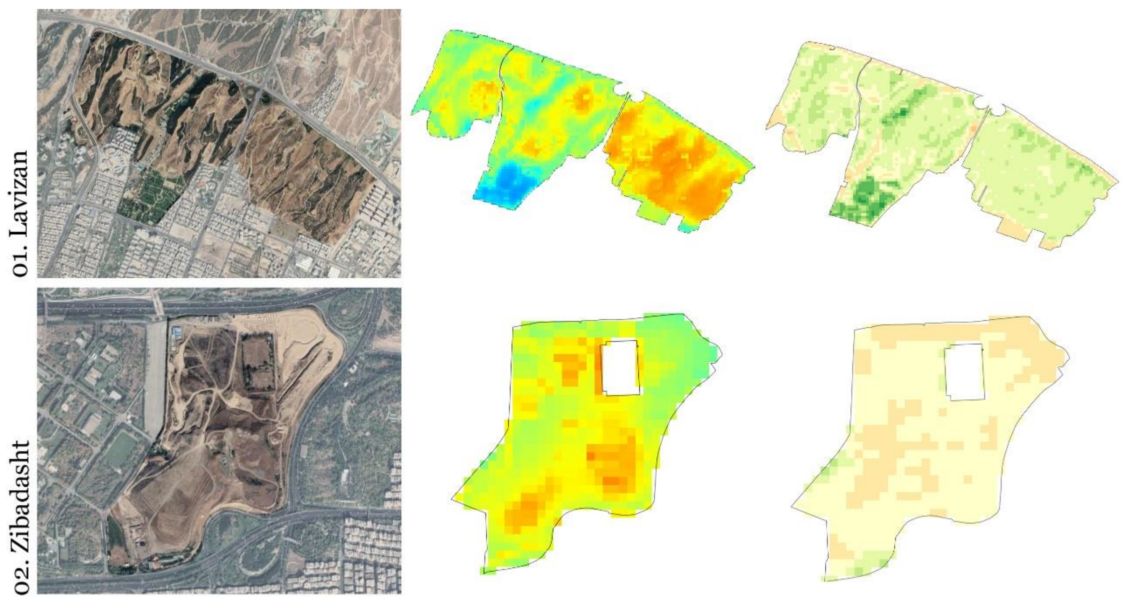
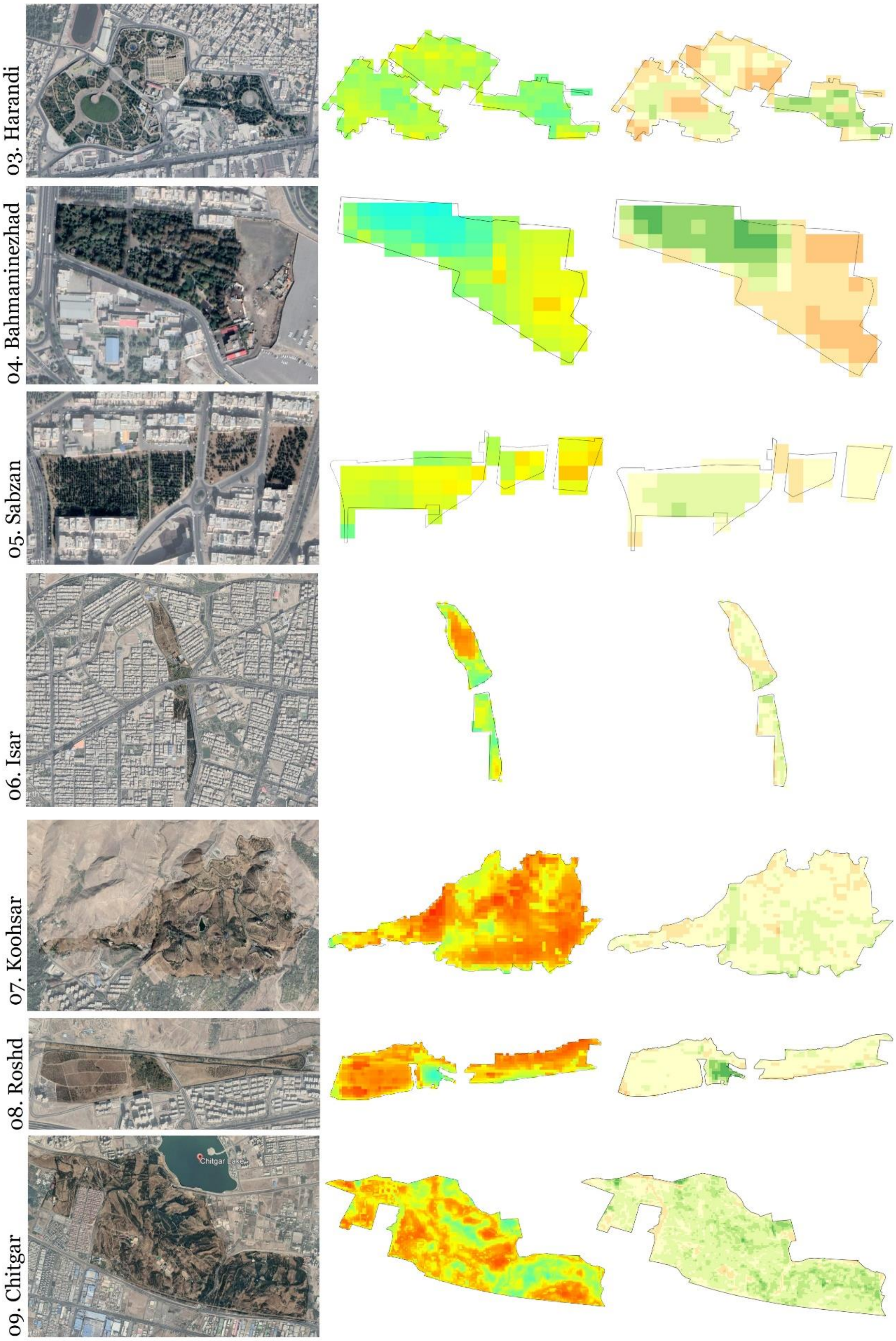


Figure 22. 10 selected cool parks in Tehran, mean LST, June-Sep 2013-19, mean NDVI, Apr-Jul 2020 Source: Author, Data Source: Author; Data source: Landsat 8 USGS and NASA, processed in google earth engine




03. Harandi
04. Bahmaninezhad
05. Sabzan
06. Isar
07. Koohsar
08. Roshd
09. Chitgar

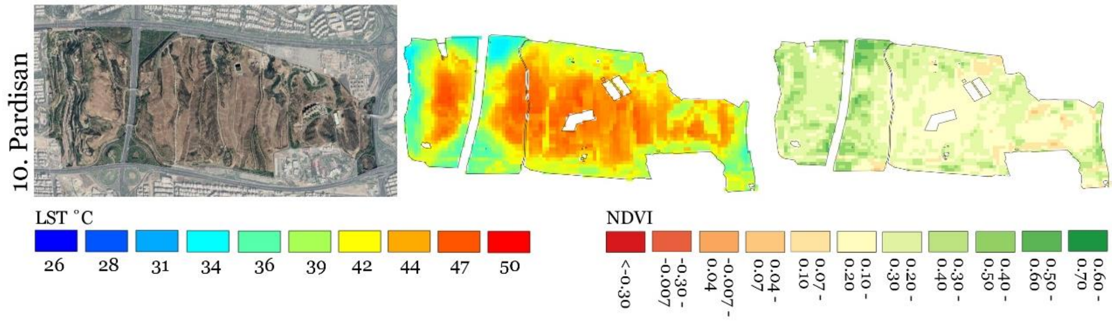


Figure 23. 10 selected hot parks, mean LST, June-Sep 2013-19, and mean NDVI, Apr-Jul 2020, Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

Also, the Figure 24 to Figure 27 show the difference of min, max, and the average of mean LST, June-Sep 2013-19, and NDVI, Apr-Jul 2020 in the 20 selected cool and hot parks. The range of the mean LST in hot parks is higher than cool parks, as their NDVI is lower.

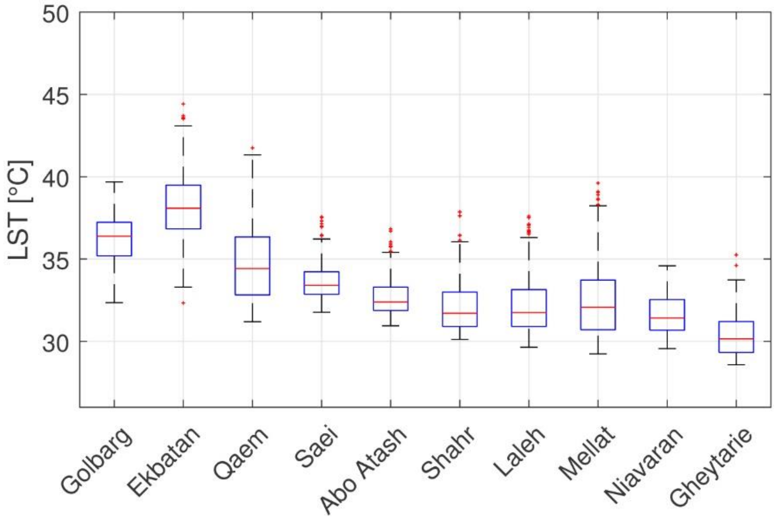


Figure 24. mean LST of the 10 selected cool parks, June-Sep 2013-19
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

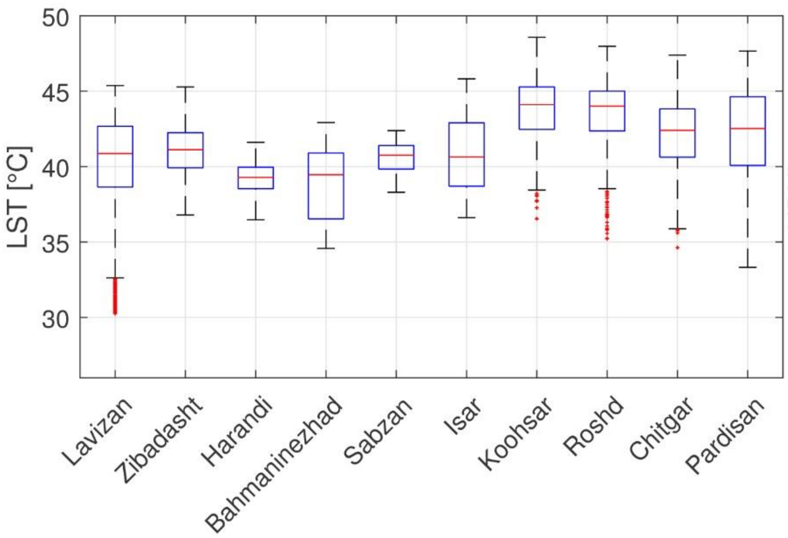


Figure 25. mean LST of the 10 selected hot parks, June-Sep 2013-19
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

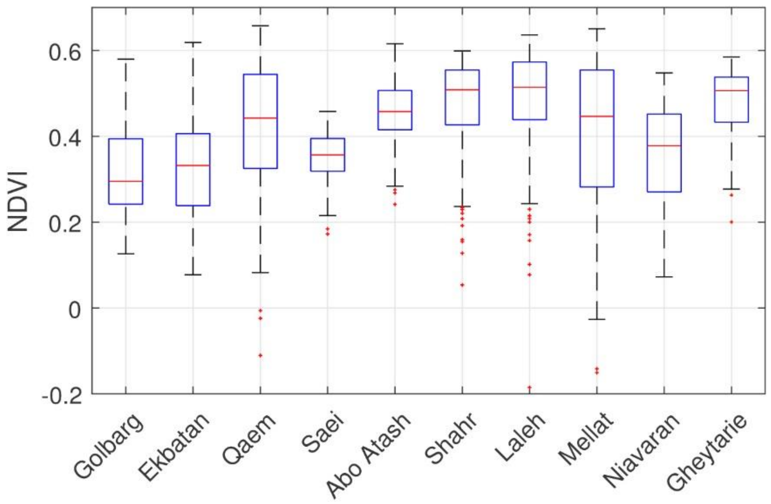


Figure 26. mean NDVI of the 10 selected cool parks, Apr-Jul 2020
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

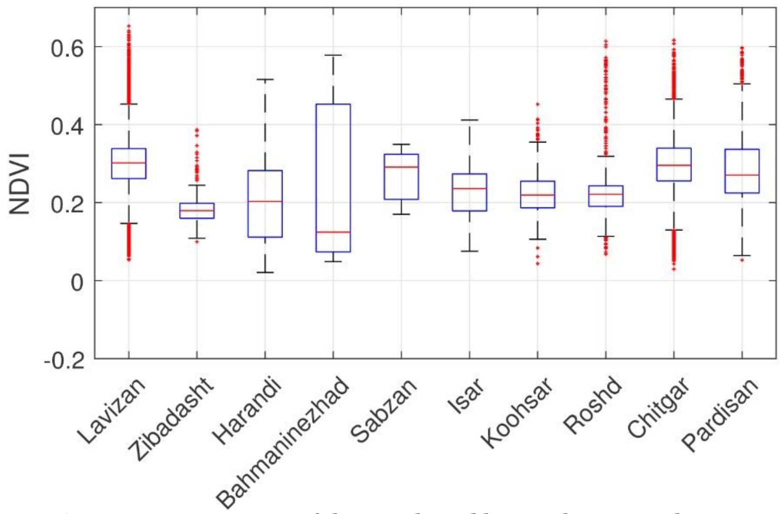


Figure 27. mean NDVI of the 10 selected hot parks, Apr-Jul 2020
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

Cooling extent of the urban parks

Figure 28 shows the calculated cooling extent for the selected urban parks, which are larger than 1000 m^2. As in the methodology mentioned, the selected urban parks larger than 1000 m^2 are the parks which the method of calculation of cooling extent could be assigned to them.

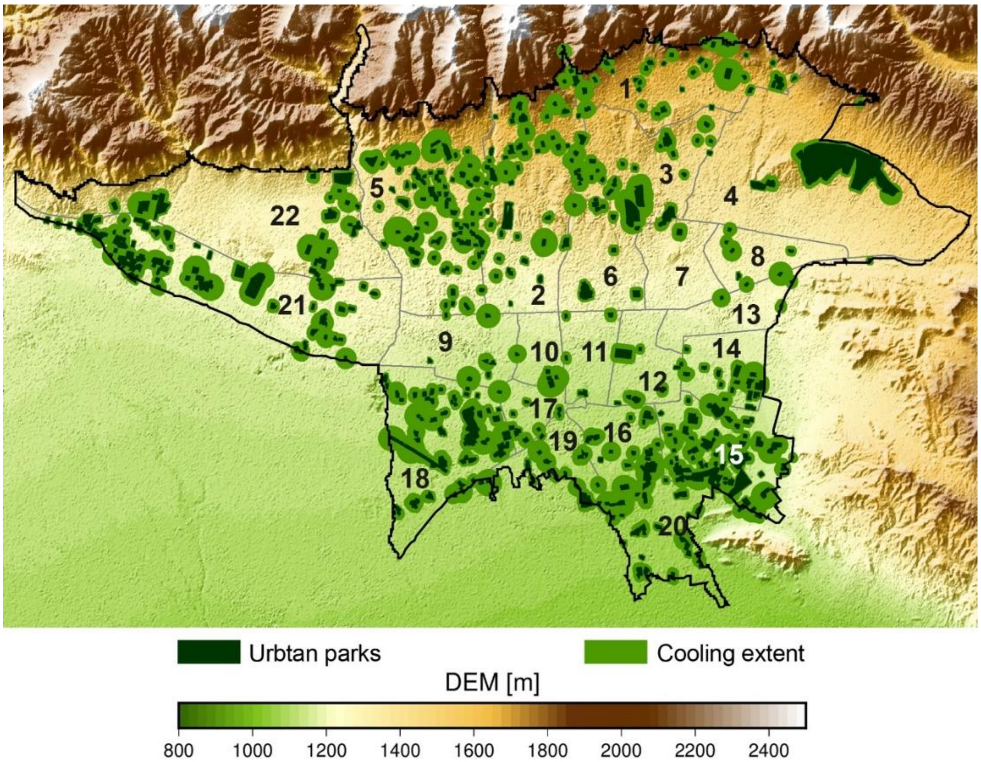
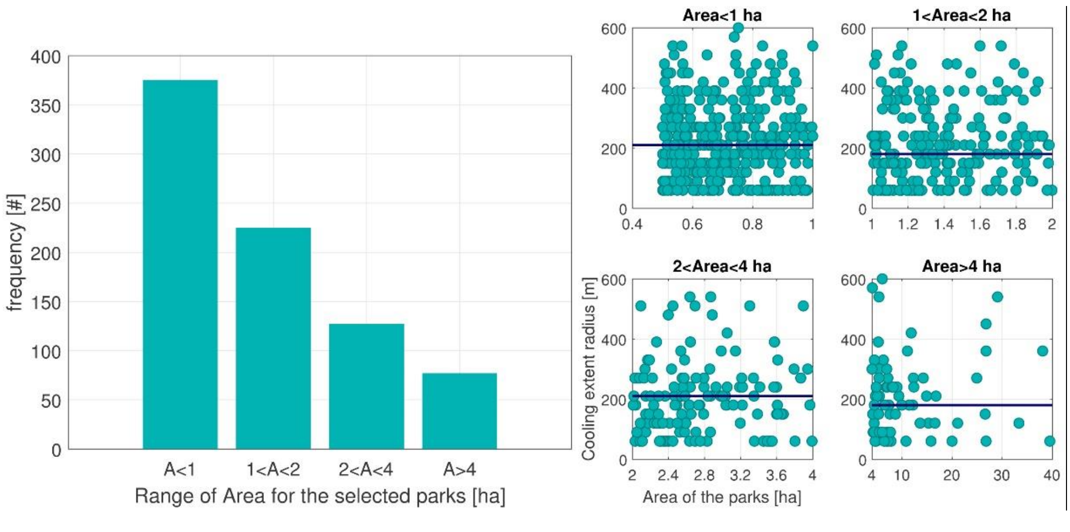


Figure 28. Cooling extent of the selected parks
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

In Figure 29-a, the selected urban parks are divided into four range of area. In each group, the relation of the area of the urban parks to their cooling extent is displayed (Figure 29-b). Although there is no specific relationship between the area and cooling extent of the urban parks the median of the park's cooling extent in all four groups are approximately similar around 200 m. This clarifies that even the limited urban parks (smaller than one hectare) are effective to reduce the temperature. So, for providing cooling cores inside dense neighbourhoods even small park area can effectively work.



(a) (b)

Figure 29. (a) Histogram of selected park's area, (b) Scatter plot of the cooling extent's radius with respect to the corresponding park's area, each sub-figure represents one bar of the histogram
Source: Author

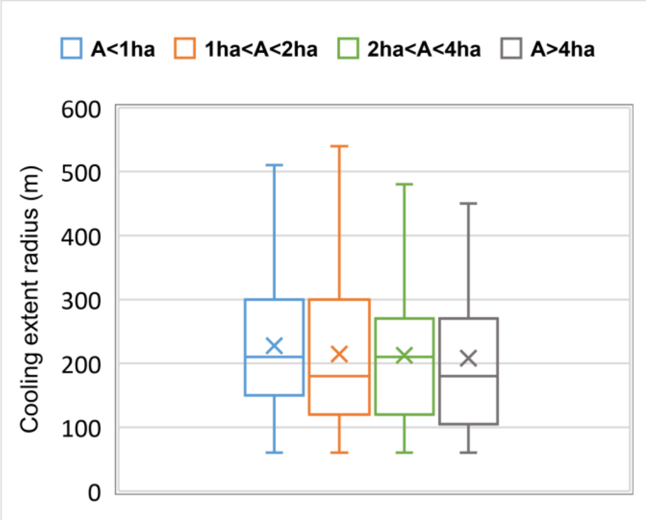


Figure 30. Box plot of the cooling extent's radius in the four corresponding park area's classes
Source: Author

Many urban parks in Tehran are out of rich vegetation and well-designed green surfaces, and they are incapable of providing cooling effect. These parks could not be tracked by the change of the temperature around the boundary in the calculation of the cooling extent. However, if we regard these parks as a possible source of green infrastructure in Tehran. By further improvement in future, they are capable to provide the cooling effect in their surroundings. Based on the last result, we can conclude a cooling extent of 200 m for non-selected parks in the estimation since the median cooling extent in all classes of park areas is around 200 m (Figure 31). So Figure 31 does not represent the current state of the urban parks. The cooling effect will be accomplished because parks with elevated temperatures and less vegetation have a structure that is close to that of most colder and greener parks.

As Figure 31 shows, with consideration of the all urban parks in Tehran with minimum 200 m cooling extent, the central districts such as 6, 7, 9, 10, 11, 12, and 13 in Tehran are suffering from lack of the urban parks and their cooling extent. The highly dense constructed areas in these districts occupied all the spaces and vanished the green areas. Furthermore, in the districts four and 22 in the east and west side of Tehran urban parks do not span the whole district, but are clustered in one location. So, they cannot effectively reduce the temperature over the whole district.

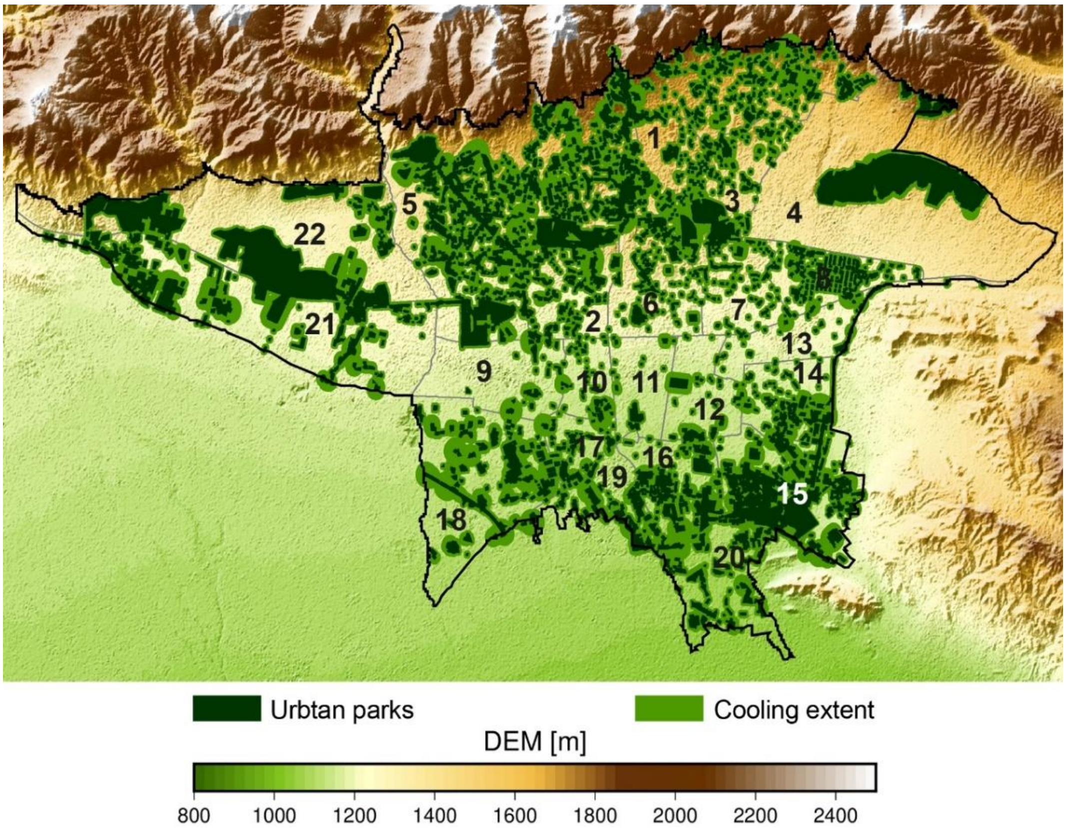


Figure 31. Cooling extent of the total urban parks
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

3-3. Detect the locations for new green areas

This step includes comparing the current state of the urban parks regarding the number of parks, capita of urban parks, mean LST and NDVI, and the measureable cooling extent of the parks in 22 districts of Tehran. So, the result is a classification of districts in Tehran according to the state of the urban parks related to mentioned indicators.

As it is mentioned in section 3-1, the capita of urban parks in most districts of Tehran is less than 10 m^2, however the capita of total green area could be larger. But the role of the other types of green areas in cooling the urban environment such as green spaces along the highways, or agricultural lands, which do not include the high density of vegetation, is lower. Also, districts with low capita of urban parks could have less numbers of parks or parks with smaller areas. The mean LST map shows in some districts not only the capita of urban parks is low, but the mean LST inside the parks is higher, as the parks do not contain sufficient vegetation to reduce the temperature. The LST and NDVI maps in this section are based on the processed map in pervious sections.

As we see in the last section the mean LST and the NDVI has a direct relation. Parks with higher mean LST has lower mean NDVI, suggesting a lower degree of greenness. This relation is also seen Figure 32-c and d. As the districts with parks with higher mean LST have the lower mean NDVI.

Therefore, the most critical districts in Tehran have lower areas of urban parks and high population. Also the existing parks in these districts have lower vegetation intensity and mean NDVI during Apr-Jul 2020 so, the mean LST during the June-Sep 2013-19 in these parks are higher. So, districts 06, 08, 14, and 17 are the most critical districts with urban park's capita lower than 2 m^2 and the higher mean of LST. As a sample, the mean LST of the parks in districts 06 and 08 and measured cooling extent are shown in Figure 32, section a and b.

The next group are the other districts with the capita of urban parks between 2 and 10 m^2. The mean of LST inside the urban parks in these groups are not the highest but still there are urban parks within districts, which has lower mean NDVI and higher mean LST, such as districts 10, 18 and 21. In this group, district 10 is displayed as a sample in Figure 32, section c.

The last group contains the other four districts with capita of parks higher than 10 m^2. District 19 which is one of the districts in the south of Tehran has higher area of urban areas and lower population, but the number of the urban parks is not one of the highest. The mean LST of the most parks in this district is between 36-39 ˚C, which is not a low temperature and shows the necessity of improvement of park's vegetation in district 19. District 4 and 22 have the remains of some preserved forest areas in Tehran. So, the capita of urban parks in these two districts are high. Moreover, district 22 is a new developed district with lower population. Due to lack of dense vegetation in the parks in these two districts, the mean LST of parks is high. Also, the urban parks in these two districts are not equally distributed over the districts. Figure 32, section d and e display the state of the parks in districts 04 and 22.

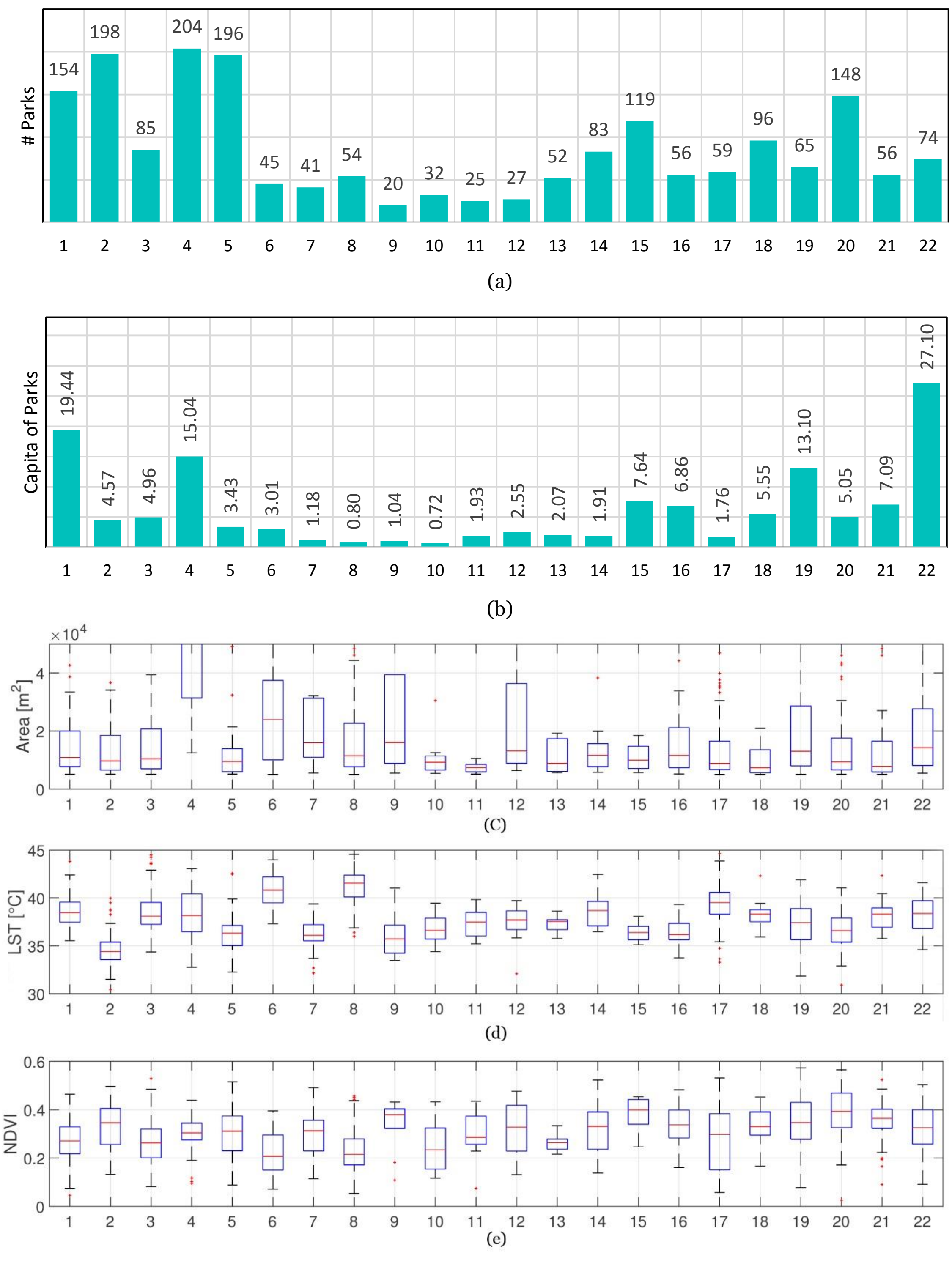


Figure 32. Comparison of the urban park's area larger than 0.5 ha, mean LST, and mean NDVI in 22 districts
a. Capita of urban parks, Source: Author, Data Source: (Statistical Yearbook of Tehran 2018, 2018), b. Number of parks; Source: Author Data Source: (Noandishaan, 2015), c. Area of urban parks; Source: Author Data Source: (Noandishaan, 2015), d. Mean LST of urban parks, June-Sep 2013-19; Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine, e. Mean NDVI, Apr-Jul 2020; Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine

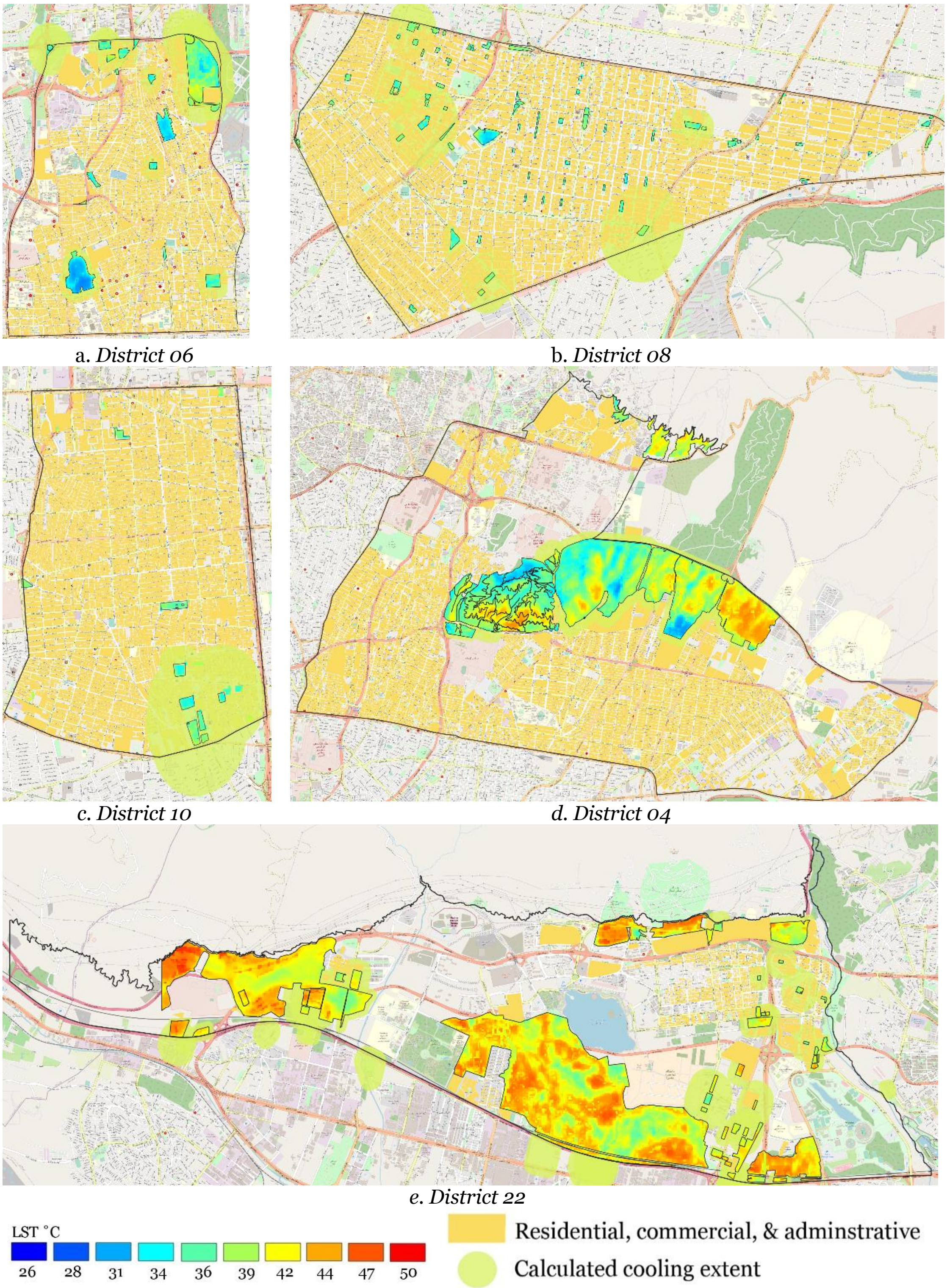


Figure 33. LST of urban parks
Source: Author, Data Source: Landsat 8 USGS and NASA, processed in google earth engine, June-Sep 2013-19, GIS-based Data (Noandishaan, 2015)

As a result of this analysis, we can infer that development of green environment is expected in the majority of districts. Also, many existing parks need improvements to their green elements to have an effective cooling function. Increasing the amount of green areas in Tehran can be applied in various scales. A wide range of private or public green spaces can strengthen the green infrastructure in Tehran to reduce the UHI effect.

In the large scale, the main approach is maintenance of the natural green corridors and valleys, hills, green belts, and forests in the surrounding urban areas with large available open spaces. Unfortunately, urbanization destroys the quality and quantity of green spaces in Tehran. The green areas farther away from the urban areas, at the outskirts of Tehran are safer from urban development. As a result, the regions in higher elevations, which are not achievable for urban expansion, could save the native plants (Pre-study for regional planning in Tehran, 2009). The remains of natural forest parks, in the northern districts 1, 2, 4, 5, and 22, on the hillside of the Alborz mountain and alongside valleys should be protected from the urban expansion and reinforced by native and adaptable vegetation.

The next group is the medium-sized green areas, which involves urban parks, green lines along the main highways, modified land uses within the urban areas like industrial or military land uses, expansion or connection of urban parks (Agharabi, 2014) (WHO, 2017). In most of the districts in Tehran, with urban parks per capita lower than 10 m^2, specially districts 06, 08, 14, and 17 more green areas should be provided. Recovery of brownfields, connecting and expanding the existing urban park, adding green lanes to streets and highways can all be included in urban planning, both short and long term. Agglomeration in the low-density residential areas may also bring additional green surfaces heavily populated districts.

Moreover, in the private scale, like green surfaces in courtyards, green roof and green facade for each building in the form of urban development laws with some guidance on native and adaptable green species can provide more potential of greenness within urban area. In the next section, we will introduce a short list of plants mentioned in the literature that are more resistant to the dry climate in Tehran.

3-4. Locally adapted types of green elements

Although by nature some portions of small to great cities include green spaces, for a sustainable development, human has been providing manmade green elements. In spite of variety, not all green species can grow healthy in different climates. Therefore, it is of a great interest to select more locally adapted types for specific regions, especially in arid to semi-arid regions. Despite of the need, literature lacks comprehensive assessment of the more resilient green species. Moreover, constitutional sectors have not shown required interest in conducting field research or supporting private researches. In what follows, we present a concise summary of previous studies on native and adaptable green species in Tehran. Even though being not conclusive, this summary is potentially informative together with the result of the analysis presented in the previous section.

Mirzadeh et al. recorded 179 species of trees and shrubs in their studies on the cultivated plants in the Tehran City. Based on their studies, 16 tree and shrub species are native in Tehran. The four most dominant tree species in the Tehran city are: *Ulmus L., Fraxinus L. Pinus L. Platanus L.* The variety of the shrubs is wider than trees in this area. The most typical shrubs species are *Pyracantha* Roemer, Cotoneaster Medicus, *Rosa L., Ligustrum, Berberis spp* (Mirzadeh Vaghefi, M., & M., 2008). The diversity of garden species in the province is also relatively high. Almost all cold garden species is cultivated in the area, such as walnuts, cherries, apples, apricots, wild almonds, plums, peaches, grapes, sour cherries, berries, wild olive, populus (cottonwood), and white poplar (Pre-study for regional planning in Tehran, 2009).

The durability of green areas in Tehran totally depends on the adaptation of the plants on the soil situation and semi-arid climate of Tehran. Plants for Tehran should be resistant to low relative humidity weather (drought tolerance) and less water consumption (Asgarzadeh, et al., 2014).

Asgarzadeh et al. have been categorized 60 compatible tree species for Tehran with the Analytic Hierarchy Process (AHP) with suggestion of new species adaptable to Tehran environment. In their analysis, the tree features are prioritized based on the compatible parameters to Tehran climate such as, drought or heat tolerance, soil salinity and alkalinity tolerance, air pollution tolerance, appearance parameters, growth rate, life range, and etc.

Based on these two main studies on the plant species in Tehran, Table 10 shows the categorized dominant and native trees in Tehran (Asgarzadeh, et al., 2014) (Mirzadeh Vaghefi, M., & M., 2008).

***Morus alba* L.**

Growth height: 8-18
Crone width: 6-15

Roots may damage the water pipes and foundations,
Growing very fast

***Morus nigra* L.**

Growth height: 4-12
Crone width: 3-10

Very adaptable,
not suitable for the streets and parking lots

***Ficus carica* L.**

Growth height: 3-10
Crone width: 3-8

Adaptable, endangered by late frost, sensitive to floods and changes in the groundwater level, slightly toxic

***Populus nigra* L.**

Growth height: 12-27
Crone width: 3-8

Aggressive roots,
pioneer colonists,
slope reinforcement,
risk of breakage

***Salix babylonica* L.**

Growth height: 9-13
Crone width: 15-21

Used as an erosion control measure along watercourses,
The roots in the search for moisture are very aggressive

***Salix alba* L.**

Growth height: 15-25
Crone width: 8-15

Tolerance to soil moisture, trees spreads through root runners and could cause damage, risk of breakage

Table 10. Native species trees and shrubs in the Tehran province
Source: (Pre-study for regional planning in Tehran, 2009)

4. Conclusion

During the summer, the absorbed solar energy by the urban structure raises the temperature in urban areas. Mitigation strategies such as green spaces, green or cool roofs, green facades, shading, using high albedo building materials, and management of building energy efficiency can help to reduce the temperature in urban areas. One of the most effective strategies is the green areas and vegetation. The green element can prevent the access of solar energy to the surface by shading the area. Also, they can decrease the temperature by evapotranspiration. Although in the dry climate with low precipitation and water scarcity maintenance of the green spaces is costly.

Over the summer, the city of Tehran with a dry climate is subjected to UHI. The main goal of this thesis is an assessment of the green infrastructure in Tehran based on the current state of the green areas and their future prospect. The first step is an overview of the condition of the 22 districts of Tehran in terms of the existing green areas and urban parks, surface temperature, land cover, and population density. Next, the efficiency of the urban park in the reduction of the temperature inside the parks and in their surrounding built environment is analyzed based on the mean LST and mean NDVI of the parks. The outcome is a classification of the 22 districts of Tehran due to their capita of urban parks, and the efficiency of the parks. One of the most critical steps in developing more green areas in Tehran on multiple scales is to recognize the locally adapted green species, as they are more compatible with the climate of Tehran. So, the native and dominant species in Tehran based on some of the prior researches are introduced.

In what follows is an overview of the main results of the thesis:

- The total green space per capita in eight districts are less than 10 m^2, which is less than the vision of the comprehensive plan of Tehran and other international standards.
- If we can consider the urban parks separately as an accessible green space with dense and homogenous green structure in Tehran, the capita of urban parks of 13 districts in Tehran is less than 5 m^2 and five districts are between 5 and 10 m^2. So, just four districts have more than 10 m^2 urban parks per capita. In two of these four districts, districts 4 and 22 the urban parks are located in one area and they are not distributed across the district.
- Due to the three conditions of high population density, the capita of urban parks lower than 5m^2, the capita of total green areas less than 10 m^2, districts 07, 08, 10, 11, 14, and 17 are in a group of districts with high demand for green areas. The urban structure of these six districts is similar. They are located in the center of Tehran. These districts are the center of the commercial and administrative

activities in Tehran. So, during the day, a high volume of traffic is running in these districts and adding up the temperature by anthropogenic activities.

- As opposed to parks with low vegetation, parks with high vegetation density have lower mean LST. The result of the comparison of 20 parks with the highest and lowest mean LST during the summer months between 2013 and 2019 shows parks with higher mean NDVI from April to July in 2020 have lower LST.

- Calculation of the cooling extent of the parks based on the LST of the built environment in their surrounding is independent of the area of the park. But the dominant cooling extent of the parks no matter the area of the park is about 200m. Although the calculation of the cooling extent by the LST is limited and by measurement of the air temperature in place should be validated. So, in the micro scales, this calculation is not decisive.

- The most critical districts in Tehran are districts 06, 08, 14, and 17 with the capita of urban parks lower than 2 m^2, lower number of parks, higher mean LST and lower NDVI inside the urban parks. Raising the amount of green spaces and upgrading the current green infrastructure in these districts are top priorities.

- In 14 districts of Tehran the capita of urban parks is less than 10 m^2. While the mean LST inside the urban parks in these groups is not the highest but still, there are urban parks within districts, which has lower mean NDVI and higher mean LST, such as districts 10, 18 and 21.

- The six native and dominant green species in Tehran which are adapted to the dry climate of Tehran includes: *Morus alba L., Morus nigra L., Ficus carica L., Populus nigra L. Salix babylonica L., Salix alba L.* (Asgarzadeh, et al., 2014) (Mirzadeh Vaghefi, M., & M., 2008).

The study for this thesis may be strengthened and expanded in several aspects:

- As in dry climate, the difference of the temperature between rural and urban areas can be measured during the night, so assessment of the nocturnal UHI can display the most critical spots.
- One of the main factor to assess the distribution of urban parks is the accessibility of them in their neighborhood. In many regulations and standards in urban development planning, some minimum distance from the residents to the urban parks are defined. This assessment needs a detail calculation of the exact form and structure of the built environment between the household and the park.

- To improve the calculation of the cooling extent of the urban parks, the investigation of the relation between the cooling extent and other properties of urban parks are helpful such as the shape of the park, vegetation index (NDVI), wind direction and ventilation.
- One of the possible natural solutions in Tehran to mitigate the UHI is the restoration of the water streams, which are canalized mostly underground by the urban development. The impact of water streams to reduce the temperature in the scale of microclimates in Tehran will assist to mitigate the UHI.

5. Appendix

Green roof

Green roof works like other green areas in an urban area. Vegetation on the roof of the buildings can shade the surface and cool the air by evapotranspiration. Green roof also works as a thermal mass and insulation. Green roofs minimize the amount of heat transmitted through the roof during warm weather, thus decreasing the energy demands of the building's cooling system (Oberndorfer, et al., 2007). As in the dense cities like Tehran, the extensive texture of the city is covered by building roofs, so, exchanging the conventional roofs with green roofs can effectively reduce heat absorption and urban heat island (EPA, 2008).

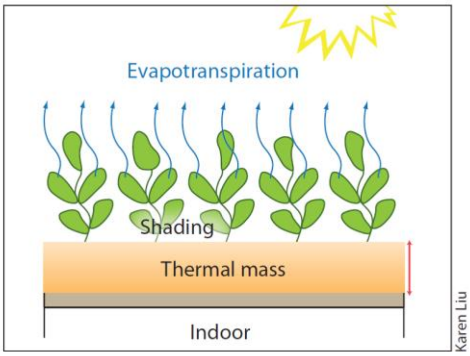


Figure 34. Green roof effects by shading and evapotranspiration
Source: (EPA, 2008)

The choice of green roof type is related to climatic features such as humidity, sunny days, precipitation, and the structure of the building. Two main types of green roofs are (EPA, 2008):

Extensive green roof is light and simple layers of soil and vegetation with low maintenance (Substrate depth=100-250mm, (FLL., 2002)). This kind of green roof may work without permanent irrigation. Vegetation such as Succulents, like sedums can grow better in shallow soil layer of the extensive green roof, which are more drought-resistant plants. Succulents have higher water content and they have better tolerance to sun radiation and lack of precipitation. The research by Razzaghmanesh et al. on different types of green roofs in the dry climate in Adelaide, South Australia shows the *C. rossii* as a succulent's species has 100 percent survival in an extensive green roof with 10 cm depth with rain-based irrigation (Razzaghmanesh, Beecham, & Kazemi, 2014). Studies show that in a dry climate, extensive green roofs require irrigation for survival and development of the succulents (Van Mechelen, Dutoit, & Hermy, 2015).

Intensive green roof works as roof garden and can be planted by different kind of plants and trees (Substrate depth≥350mm, (FLL., 2002)).. In comparison to extensive one, an intensive green roof is costly and a load of the intensive green roof on the structure is higher. The intensive green roof needs long maintenance and a permanent irrigation system.

Building materials with higher albedo

Solar reflectance or albedo defines the percentage of reflectance of the sun's energy from the surface of the material. Materials with lower albedo reflect a smaller amount of the radiated sun and absorb less solar energy as heat (EPA, 2008). Cool materials have two properties: High solar reflectance -the ability of a surface to reflect the solar radiation, and high infrared emittance - the ability of a surface to release the absorbed heat (Santamouris M. S., 2011).

Cool roof

A cool roof is roof-covering materials with high solar reflectance and emittance, mostly with white and bright colors. Cool roofs absorb less heat in comparison too conventional roof. The rooms under cool roof stay cooler and require less energy for cooling. Types of cool roofs are coating, single-ply membrane for low-sloped roofs, and metal roofing, tiles, and shakes for steep roofs (EPA, 2008).

Cool pavement

Cool pavement is permeable pavement with higher albedo and solar emittance. Conventional pavement absorbs more heat during sunny days, which elevates the air temperature and also transfer the heat to the sub layers and reflect it back during the night. Example of cool pavements are permeable or colored asphalt and concrete, pavement combined with grass and low-lying vegetation, natural materials such as dry soil or sand (EPA, 2008).

Water bodies

Water streams inside the cities influence the microclimate of urban areas by the evaporative cooling effect. However, the extent of the effect is related to materials in the river bank and other climate properties such as water temperature, wind speed, solar radiation, relative humidity. Research by Hathway and Sharples on a river in Scheffield, UK shows the cooling effect on average over 1.5 ˚C, which can be less in summer with warmer water in the river (Hathway & Sharples, 2012). Also, the research on Ota River in Japan shows the temperature reduced about 5 ˚C above the river and the cooling effect can stay to the extent of 100 m horizontally and 80 m vertically (Murakawa, Sekine, Narita, & Nishina, 1991). However, due to the high heat capacity of water, the water stays still warm during nights and increase the temperature of the surroundings (Steeneveld, Koopmans, Heusinkveld, & Theeuwes, 2014).

Urban geometry

The orientation of the streets in urban areas and the ratio of the height of the buildings to the width of the streets (H/W) affect the land surface temperature of urban structure. The research by Krüger et al. on cooling energy consumption shows that the high-density buildings with a high ratio of H/W in a north-south orientation have lower cooling demand, due to shading possibility. Also, lower H/W ratio with an east-west orientation reduces the cooling load of the buildings (Krüger, Pearlmutter, & Rasia, 2010).

Based on the researches the geometry of urban canyons influences the energy consumption of the buildings, which affected the overall energy usage of commercial buildings up to 30 percent and residential buildings up to 19 percent humid (Strømann-Andersen & Sattrup, 2011). The deeper urban canyons (H/W= 9.7) have lower temperature in comparison to shallower one (H/W=0.6), due to wind generation and more shaded areas, which is suitable for the summers but unfavorable for winters (Georgakis & Santamouris, 2006) (Johansson, 2006) (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013). In research, Alobaydi et al. compared three urban forms, compact, detached, and attached in the hot and dry climate of Baqdad in Iraq. The results show deeper corridors have lower temperature in comparison to shallower corridors in attached and detached urban blocks (Alobaydi, 2016).

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