Chapter 11

Mitigating Urban Heat Island Effects in Tehran Metropolitan Area

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Additional information is available at the end of the chapter

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1. Introduction

The majority of cities are sources of heat, pollution and the thermal structure of the atmosphere above them is affected by the so-called "heat island" effect. In fact, an UHI is best visualized as a dome of stagnant warm air over the heavily built-up areas of cities [1]. The heat that is absorbed during the day by the buildings, roads and other constructions in an urban area is re-emitted after sunset, creating high temperature differences between urban and rural areas [2]. The exact form and size of this phenomenon varies in time and space as a result of meteorological, location and urban characteristics [3]. Therefore, UHI morphology is strongly controlled by the unique character of each city. Oke [3] stated that a larger city with a cloudless sky and light winds just after sunset, the boundary between the rural and the urban areas exhibits a steep temperature gradient to the UHI, and then the rest of the urban area appears as a "plateau" warm air with a steady but weaker horizontal gradient of increasing temperature towards the city centre. The uniformity of the "plateau" is interrupted by the influence of distinct intra-urban land-uses such as parks, lakes and open areas (cool), and commercial, industrial or dense building areas (warm). In metropolitan areas especially in Tehran, Iran, the urban core shows a final "peak" to the UHI where the urban maximum temperature is found. The difference between this value and the background rural temperature defines the "UHI intensity" (ΔT_{u-r}). The intensity of the UHI is mainly determined by the thermal balance of the urban region and can result in a temperature difference of up to 10 degrees [2]. The UHI intensity varies in a recognizable way through the day under ideal weather conditions. At night, stored heat is released slowly from the urban surface, contrary to the rapid heat escape from rural surfaces. Thus, the UHI intensity peaks several hours after sunset when rural surfaces (and consequently surface air temperatures) have cooled yet urban surfaces remain warm. After sunrise rural areas warm more quickly than urban areas. If the difference in heating rates is great enough, rural air temperatures may equal or exceed urban temperatures. This reduces the UHI intensity to a daytime minimum, and may even generate an urban cool island.

2. Problem statement

These questions might strike the mind that why is UHI crucial problem in urban areas? And why should it be considered? In order to answer these questions, it is imperative to study the negative impacts of UHIs. Their negative impacts affect so many people in so many ways. Wong and Chen [4] summarized major negative impacts of UHI as below:

1. Air quality (environmental factor): UHI effect increases the possibility of the formation of smog created by photochemical reactions of pollutants in the air. The formation of smog that is highly sensitive to temperatures since photochemical reactions are more likely to occur and intensify at higher temperatures. Atmospheric pollution can be aggravated due to the accumulation of smog. In addition, the increased emissions of ozone precursors from vehicles is also associated with the high ambient temperature;
2. Human mortality and disease (social factor): the UHI effect also involves the hazard of heat stress related injuries which can threaten the health of urban dwellers; and
3. Waste of natural resources (economical factor): higher temperatures in cities also increase cooling energy consumption and water demand for landscape irrigation. The peak electric demand will be increased as well. As a result, more electrical energy production is needed and this will trigger the release of more greenhouse gas due to the combustion of fossil fuel. The side effects also include the increased pollution level and energy costs. A feedback loop occurs when greenhouse gases eventually contribute to global warming.

Growing concern for the future of cities and for the well-being of city dwellers, stimulated by trends in world urbanization, the increasing number and size of cities, and the deterioration of many urban environments, has focused attention on the problems of living in the city. Citizens in cities around the world want clean air, clean water, reduced noise, more vegetation and protection of habitat areas, and safety. These are all seen as contributing not only to their health but also to their quality of life. Cities have been blamed for causing environmental catastrophes, diminishing the quality of life. Cities are also at risk from industrial hazards, natural disasters, and the specter of global warming. The likely negative impacts of global warming include increasing storms, flooding, droughts and the probable destruction of some ecosystems. In urban areas, there is an "urban heat island" effect resulting from the production and accumulation of heat in the urban mass. So, how will UHI affect the cities of the future?

The majority of people in the world live in metropolitan areas subject to new and potentially traumatic climatic conditions. A better conceptual approach is needed to understand the role and effects of UHI in cities and to consider in urban design guidelines and implementation measures. As Glantz [5] declared;

> *It must be understood that cities are under real, not imagined, threats from global climate change and must be redesigned to deal with this reality.*

Increasing urbanization and industrialization in Tehran metropolitan area in recent decades caused the urban environment to deteriorate. Tehran suffers from raised temperatures in the city core, generally known as the heat island effect. Raised temperatures, especially in summer, turn Tehran city centers into unwelcome hot areas, with direct effects on energy consumption for cooling buildings and morbidity and mortality risks for the population. These raised temperatures in Tehran city centre derive from the altered thermal balances in urban spaces, mainly due to the materials and activities taking place in cities, by far different to those in rural areas. The increasing numbers of buildings and construction in Tehran caused that vegetation and trees replaced by buildings. Thus, air temperature increases especially in high-density areas. The general lack of vegetation and the low albedo of urban surfaces are strong characteristics of the formation of UHI effect in Tehran metropolitan area. The geometry between a vegetated area and the density-morphology of an urban area are completely different, which has a direct effect on wind and shade distributions. Human activities taking place in Tehran urban areas are responsible for anthropogenic heat release (transport, space and water heating, cooling and the like) and air pollution, the latter affecting clouds cover. The combination of these factors determines the way in which heat is absorbed, stored, released and dispersed in the urban environment, expressed as a temperature increase in the urban area.

Therefore the majority of citizens are suffering from outdoor environment discomfort and this issue has a deeper and problematic dimension in the case of Iran especially in the city of Tehran. This research is an effort to recognize the radical cause of UHI in the city and will suggest some appropriate recommendations to solve this matter.

This research addresses the following objectives:

1. To identify the possible causes of UHI in Tehran metropolitan area;
2. To investigate the severity and impact of UHI on the environmental conditions of Tehran metropolitan area; and
3. To explore, develop and verify the various potential measures/models that could be implemented to mitigate the UHI effects in Tehran.

3. Conceptual framework

According to the Oke [6] model, different climatic events happen in different scales in cities and affect each other. These scales can be divided into two categories:

1. Horizontal scales include: micro-scale, local scale, and meso-scale.
2. Vertical scales (or different types of UHI) include: Air UHI (UCL UHI and UBL UHI), Surface UHI, and Sub-surface UHI.

Since it requires more spaces to explain all the scales, this research concentrates on UCL UHI. Figure 1 shows the conceptual framework of this research. UCL UHI forms via interaction between meteorological and urban structure factors. Since there are many factors which contribute to form UHI, this paper only picks the significant factors, vegetation covers and albedo materials, because other factors such as location, the size of the population and city, density and the like require long term planning. Then, in next stage, it develops a model with the title of "Natural Ventilator of the City" (NVC).

3.1. Interaction between meteorological and urban structure factors

Urban climate is concerned with interactions between the atmosphere and human settlements. As Oke [7] stated urban climate includes the impact of the atmosphere upon the people, infrastructure and activities in villages, towns and cities as well as the effects of those places upon the atmosphere. Therefore, climate has major impact on urbanization. Different climatic parameters affect the design of the city in terms of its general structure, orientation, building forms, materials and the like. Wong and Chen [4] stated that climate has impacts on buildings in terms of their thermal and visual performances, indoor air quality and building integrity. For example, a properly oriented building receives less solar heat gain and result in better thermal performance. In addition climate can influence the pattern of energy consumption.

It is not always one-way influence from climate toward urbanization. Urbanization also has more influence on climate. Buildings in cities influence the climate in five major ways [8]:

1. By replacing grass, soil and trees with asphalt, concrete and glass;
2. By replacing the rounded, soft shapes of trees and bushes with blocky, angular buildings and towers;
3. By releasing artificial heat from buildings, air conditioners, industry and automobiles;
4. By efficiently disposing of precipitation in drains, sewers and gutters, preventing surface infiltration; and
5. By emitting contaminants from a wide range of sources, which with resultant chemical reactions can create an unpleasant urban atmosphere.

Urban areas are the sources of anthropogenic carbon dioxide emissions from the burning of fossil fuels for heating and cooling; from industrial processes; transportation of people and goods, and the like [9, 10, 11]. Increased in pollutant sources both stationary (industrial) and non-stationary (vehicles) result in worsening atmospheric conditions [12]. The urban environment affects many climatological parameters. Global solar radiation is seriously reduced because of increased scattering and absorption [11]. Many cities in the tropics experience weak winds and limited circulation of air

In parallel, the urban environment affects precipitation and cloud cover. The exact effect of urbanization depends on the relative place of a specific city with respect to the general atmospheric circulation [11].

The city affects both physical and chemical processes in the atmospheric boundary layer (the lowest 1000m of the atmosphere) [13, 14] including: 1. Flow obstacles; 2. The area of an irregular elevated aerodynamic surface roughness; 3. Heat islands; and 4. Sources of emissions, such as sulphate aerosols that affect cloud formation and albedo.

One of the well-known phenomena of the urban climate is the UHI The term UHI denotes the increased temperature of a city compared with the temperature of the surrounding rural.

The temperature difference is raised with an increase in population and building density, which it is caused higher temperature than rural areas, as well as lower humidity due to low albedo and non-reflective materials, lower wind speed due to high density, and create various types of UHIs in different layers of urban climate. Hence, according to these data, Figure 2 illustrates the interaction between urban structure and climatic factors. The effect of urban structure factors on climate and vice versa is caused the formation of UHIs in different layers.

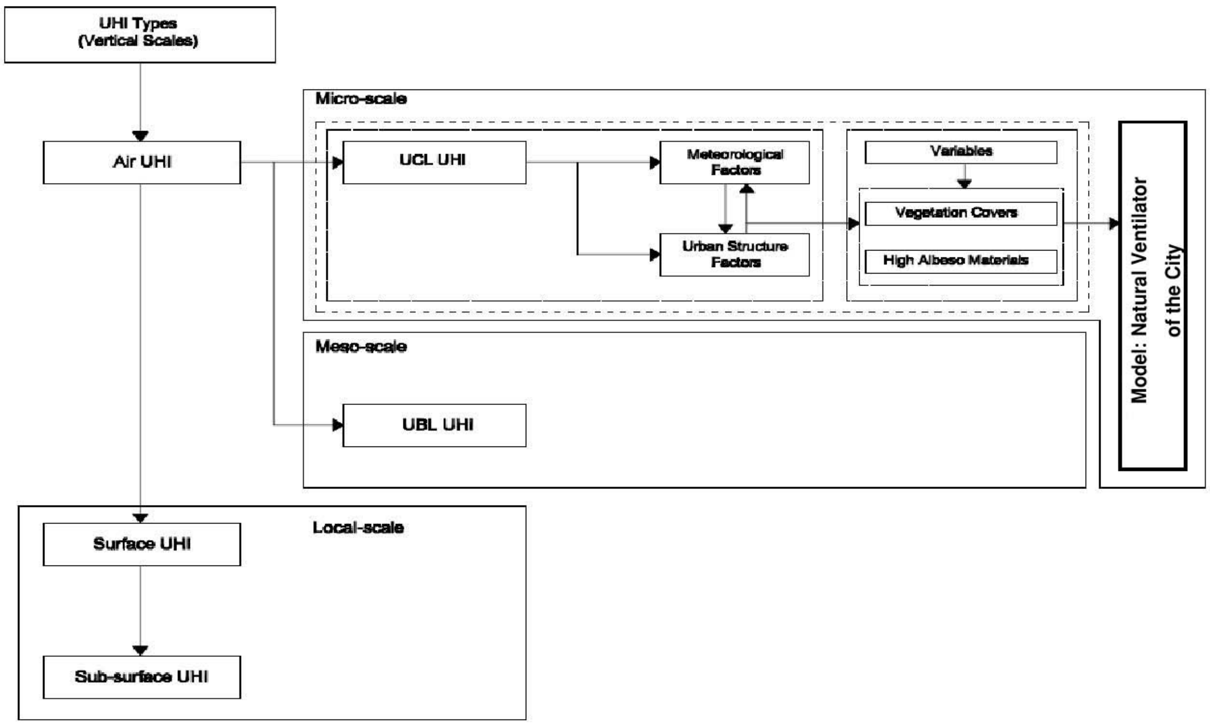


Figure 1. Conceptual frameworkwhich helps the accumulation of pollutants [12]. The wind speed in the canopy layer is seriously decreased compared to the undisturbed wind speed and its direction may be altered. This is mainly due to the specific roughness of a city, to channelling effects through canyons and also to UHI effects [11]. In addition, higher temperatures increase the production of secondary, photochemical pollutants and the high humidity contributes to a hazy atmosphere.

4.2. The effect of vegetation covers and high albedo materials over meteorological Factors

4.2.1. The effect of vegetation covers over meteorological factors: benefits of greenery in built environment

Green spaces contribute significantly to cool our cities and reduce UHI effects. Vegetation covers have extreme impacts on various aspects of life include filter pollutions, reduce air temperature, energy savings, help to mitigate greenhouse effect, provide an appropriate and pleasant environment for people. In fact, vegetation covers with their related benefits, play an important role in preventing the urban ecosystem from facing its ecological downfall. The ability of urban trees to improve the thermal comfort conditions in the surroundings is a function of the seasons, background climate, size of green area, type of surface over which trees are planted, and the amount of leaf cover [1]. Akbari et al. [15] discussed that the effectiveness of vegetation depends on its intensity, shape, dimensions and placement. But in general, any tree, even one bereft of leaves, can have a noticeable impact on energy use. In fact, trees in paved urban areas intercept both the sensible heat and the long wave radiation from high temperature paved materials such as asphalt [16, 17].

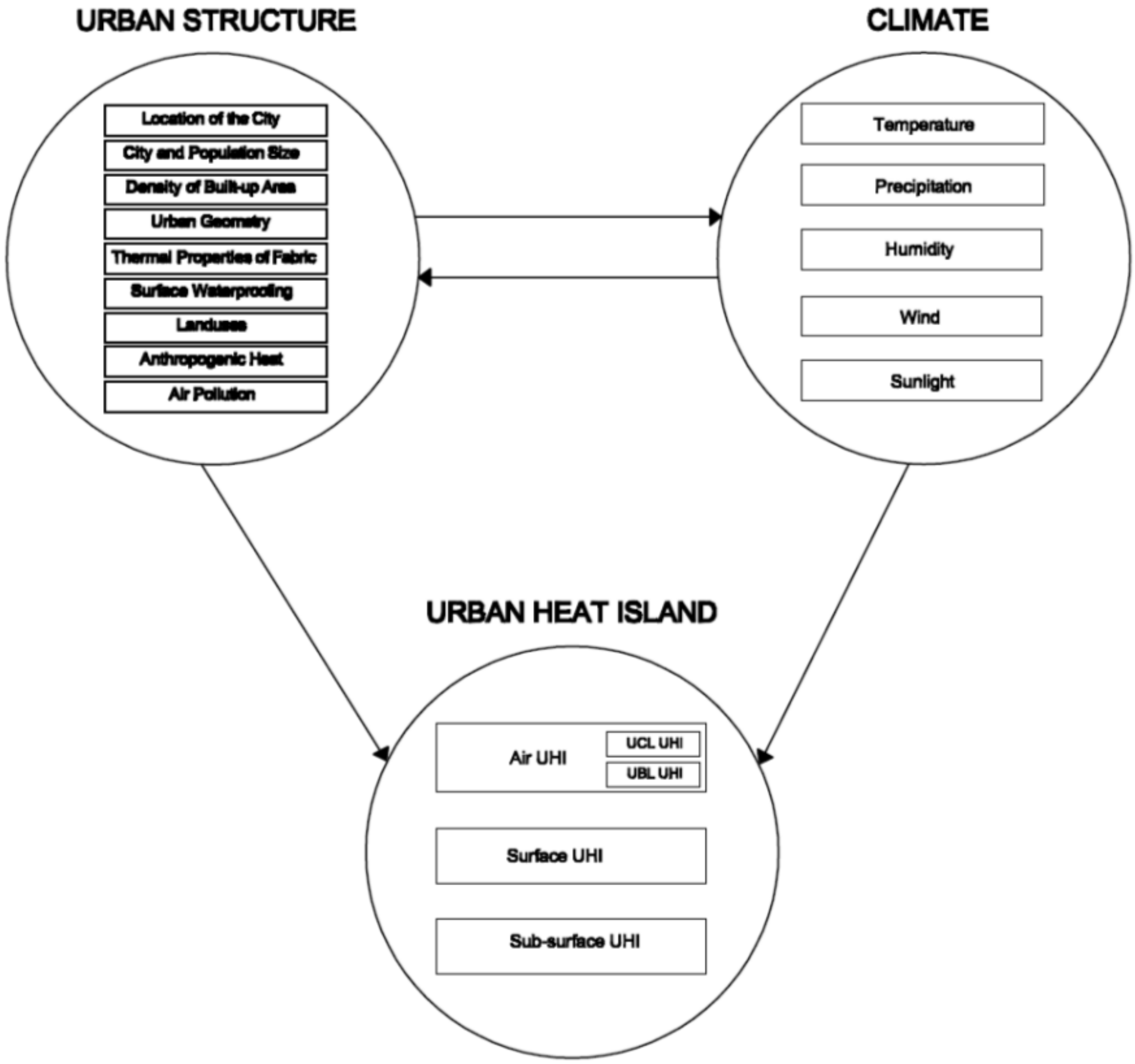


Figure 2. Interaction between urban structure and climate factors

Wong and Chen [4] declared that greenery in a built environment has benefits in all aspects of life such as environment, economic, aesthetic and social.

1. Environmental benefits

Plants can offer cooling benefits in a city through two mechanisms, direct shading and evapotraspiration, which lead to alleviate UHI effects and provide pleasant environment. These benefits are:

- Reduce urban air temperature;
- Reduce air pollution and improve air quality; and
- Provide best ventilation condition.

2. Economic benefits

Economical benefits are associated with the environmental benefits brought by plants in a built environment. These benefits are:

- Energy saving;
- More usable space; and
- Reduce cooling resources through better insulation.

3. Aesthetic benefits

The aesthetic benefits are:

- Improve aesthetic appeal;
- Hide ugly roof tops services; and
- Integrate well with the building aesthetically.

4. Social benefits

The social benefits are:

- Foster community interaction;
- Facilitate recreational and leisure activities; and
- Therapeutic effects and improve health of its users.

4.2.2. The effect of high albedo materials over meteorological factors

The role of building materials, which is mainly determined by two characteristics including technical and optical characteristics [11, 1], is critical in mitigation of UHI effect. The technical characteristics of the materials used determined to high degree of energy consumption and comfort conditions of individual house, as well as open spaces. The optical characteristics of the materials used in the urban fabric largely define its thermal balance [11]. Two significant factors, albedo (reflectivity) which is the ratio of the amount of light reflected from a material to the amount of light shining on the material and emissivity which is the ratio of heat radiated by a substance to the heat radiated by a blackbody at the same temperature, are the most important parameters of optical characteristic [4]. Generally, urban surfaces tend to have lower albedo than surfaces in the rural environment (e.g. vegetation), thus absorb more solar radiation. This causes higher surface temperatures than air temperature; they can become 30-40°C higher than ambient air temperature [18]. Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and thus keeps their surfaces cooler. Emissivity controls the release of long-wave radiation to the surrounding. The albedo and emissivity, aspects related to the durability, cost, appearance and pollution emitted by the materials have to be considered. Using scale models, Simpson and McPherson [19] reported slightly better energy consumption performance under a white roof than a silver-colored roof, indicating the importance of emissivity in addition to albedo. Santamouris [11] reported asphalt temperatures close to 63ºC and white pavements close to 45ºC. Higher surface temperatures contribute to increasing the temperature of the ambient air and the UHI intensity.

Porosity is another characteristic of material that can affect urban temperature and UHI intensity. Porous surfaces absorb water (e.g. soil) account for quite significant latent heat flux in the atmosphere. Lack of porosity materials in urban surface, a high percentage of non-reflective, water-resistant surfaces and a low percentage of vegetated and moisture trapping surface create an evaporation deficit in the city caused UHI intensity. Vegetation, especially in the presence of high moisture levels, plays a key role in the regulation of surface temperatures even more than may non-reflective or low-albedo surfaces [20] and a lack of vegetation reduces heat lost due to evapotranspiration [21].

According to above description these three characteristics of materials are responsible for formation of UHI. Figure 3 shows that low quality of materials such as low albedo and low emissivity and the lack of porosity increase temperature, energy consumption, pollution and finally UHI, while Figure 4 shows that by increasing the quality of materials, UHI intensity can be decreased. The existence of these characteristics of materials properly helps to balance temperature, energy consumption and pollution in so far as reduce UHI effects and achieve ideal condition (UHI=0) (Figure 5). This process can be described in the following way:

$$Al.\downarrow + Em.\downarrow + Por.\downarrow = Temp.\uparrow + En.\uparrow + Pol.\uparrow = UHI\uparrow$$
$$Al.\uparrow + Em.\uparrow + Por.\uparrow = Temp.\downarrow + En.\downarrow + Pol.\downarrow = UHI\downarrow$$

Therefore, the existence of all characteristics of materials and integration between them can extremely contribute to reduce UHI effects rather than existence of one characteristic.

4.2.3. Model: Natural ventilator of the city

The most important part of any models is to pick the significant variables. It is realistic to present a range of key components involved and discuss how much interaction and impacts affect the basic system.

By deducing to researches, vegetation covers and high albedo materials have direct impact on mitigating of urban temperature and UHI effects. In this way, the increasing concern for the UHI impacts and the air quality is believed to be the motivation focusing on these key components and making a conceptual model. According to pervious discussion, many researches declared that greenery and high albedo materials could extremely affect the UHI. In facts, these researches experimented these two variables and observed their impacts on the UHI intensity separately. It is obvious that there are many conceptual models that can control the UHI effects. They all share the same goal that is to reduce UHI effects caused by interaction between two factors including meteorological and urban structure factors. Aside from all this, the study tried to develop the model and observe the impacts of vegetation covers and high albedo materials on UHI in parallel.

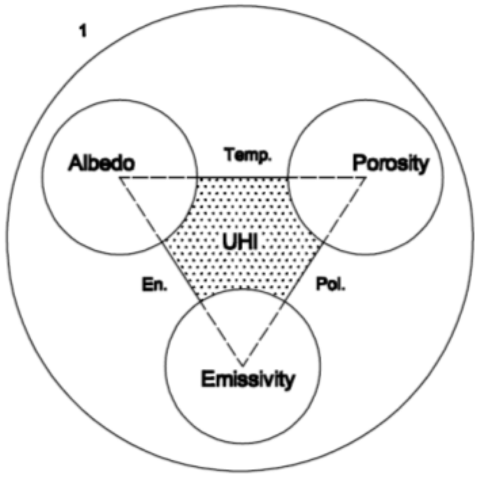


Figure 3. Low quality of material and UHI intensity

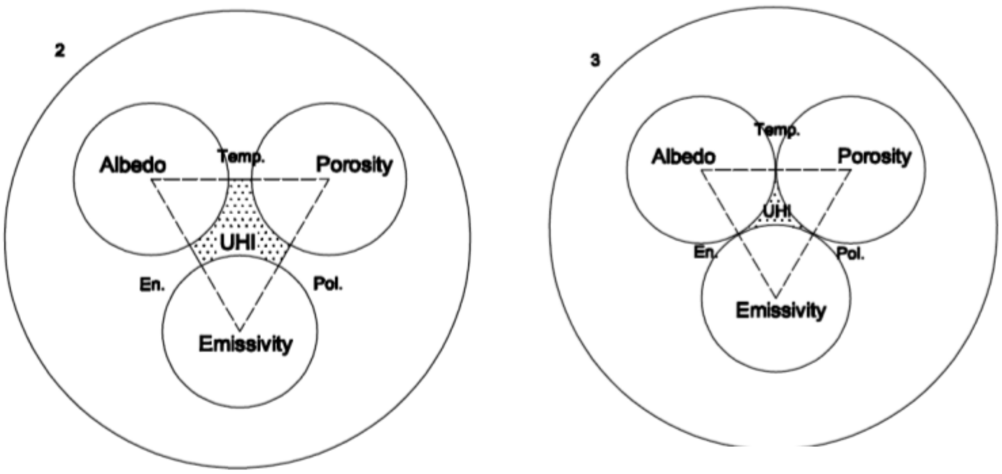


Figure 4. Mitigation of UHI intensity by increasing the quality of the materials

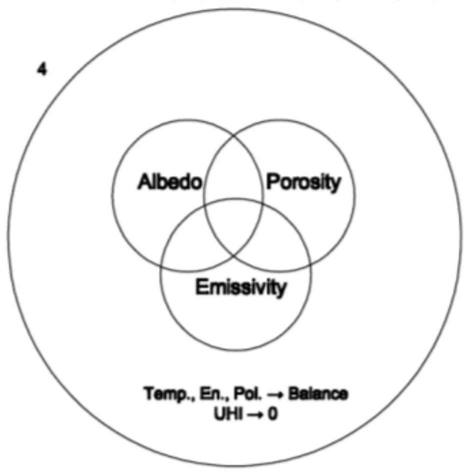


Figure 5. Integration of characteristics of material, creation of balance and reduction of UHI intensity

The key components of the study can be divided into two categories, first meteorological and urban structure factors which with their interactions form UHI over the urban areas; second vegetation covers and high albedo materials which contribute to mitigate the produced UHI. In addition, since focusing on other factors which classified in urban structure factors such as location, population, city size, density of built-up area and the like require long term planning, an optimal and realistic solution is to focus on thermal properties of fabric and surface waterproofing, which can be manipulated and achieved the good results quickly for mitigating UHI effects.

Compiling the four key components into a specific model is meaningful in promoting the passive climate control brought by vegetation covers and high albedo materials in an urban area. The interactions among the four key components and how variables can contribute to mitigate the UHI effects are presented in the model shown in Figure 6. The constituent parts of the model are the impacts of vegetation covers and high albedo materials over meteorological factors. Components with the solid circles indicate relatively stable conditions, while the dashed circles imply their potential variation in an urban area which by changing the amount of them can adjust the urban temperature and mitigate UHI effects. VU is the amount of vegetation covers introduced into an urban area. This can be enforced when more greenery is introduced into the urban area, such as vertical and horizontal green spaces, roof gardens and the like. VM is the ability of greenery to control meteorological factors. HAU is the amount of reflectively, emissivity and porosity of materials introduced into an urban area. This can be enforced when more high albedo materials is introduced into the urban area. HAM is the ability of high albedo materials to control meteorological factors.

In Figure 7, the shaded area represents the UHI intensity which created by interaction between meteorological and urban structure factors. A greater interaction leads to higher UHI intensity that encounters an urban area with imbalance condition.

For achieving balance condition and mitigating the UHI intensity, two variables, vegetation covers and high albedo materials contribute to approach the lower UHI intensity (Figure 8) and achieve ideal condition (UHI=0) (Figure 9).

Based on the model, three hypotheses can be generated:

$$VU = \frac{1}{8}U$$

$$HAU = \frac{1}{8}U$$

$$VU + HAU = \frac{1}{4}U \Rightarrow UHI \downarrow$$

Hypothesis1: if the amount of vegetation cover and high albedo material all together cover approximately a fourth of urban area, the effect of UHI can be reduced (Figure 7):

Hypothesis 2: if the amount of vegetation cover and high albedo material all together cover approximately a third of urban area, the effect of UHI can be extremely reduced (Figure 8):

$$VU \simeq \frac{1}{6}U$$

$$HAU \simeq \frac{1}{6}U$$

$$VU + HAU = \frac{1}{3}U \Rightarrow UHI \simeq Min$$

Hypothesis 3: if the amount of vegetation cover and high albedo material increase and cover half of urban area, the effect of UHI can be achieved zero which is the ideal condition (Figure 9):

$$VU \simeq \frac{1}{4}U$$

$$HAU \simeq \frac{1}{4}U$$

$$VU + HAU = \frac{1}{2}U \Rightarrow UHI = 0$$

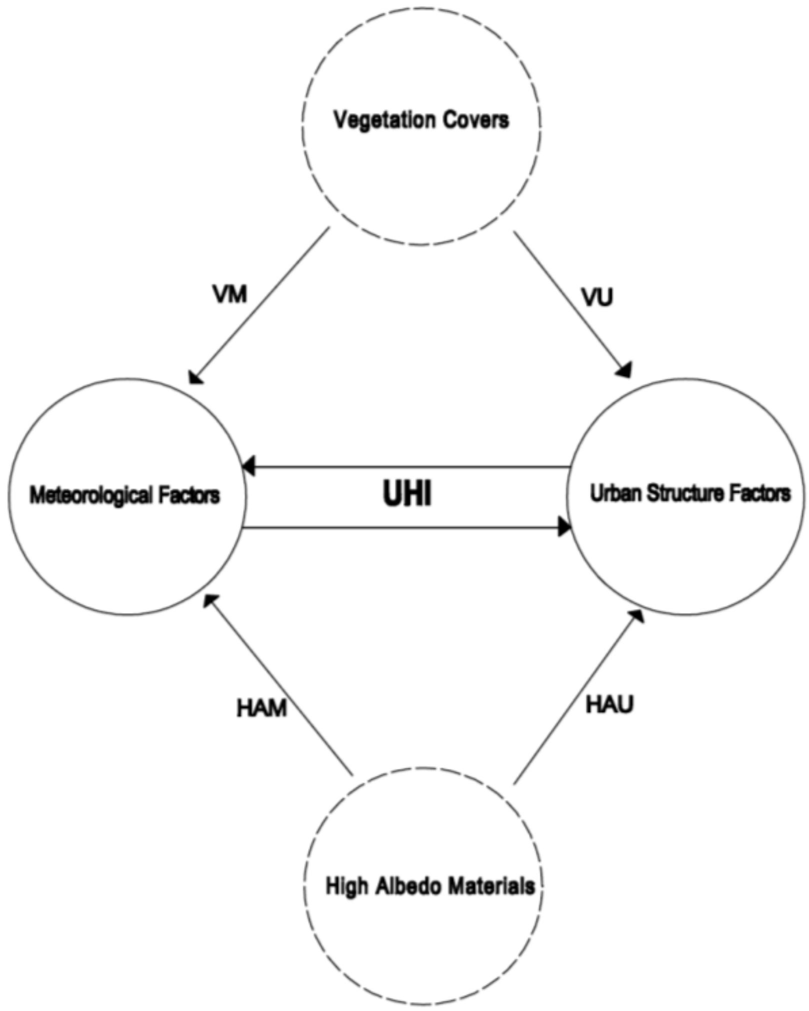
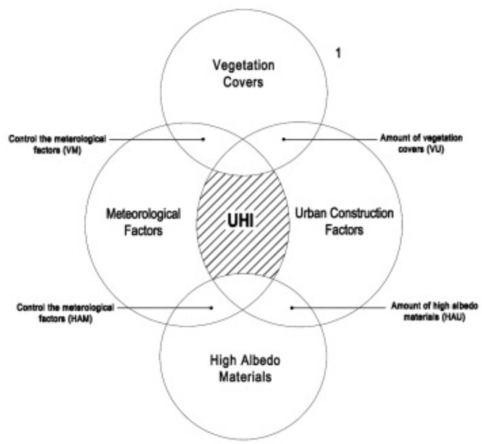


Figure 6. Conceptual model, vegetation covers and high albedo materials are considered to be the major components of UHI mitigation

$$VU\downarrow + HAU\downarrow = VM\downarrow + HAM\downarrow = UHI\uparrow$$



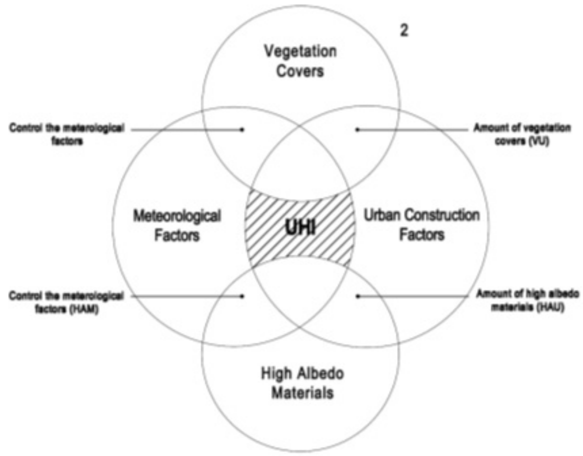


Figure 7. Increasing the amount of greenery and high albedo materials mitigate the UHI effects

$$VU\uparrow + HAU\uparrow = VM\uparrow + HAM\uparrow = UHI$$

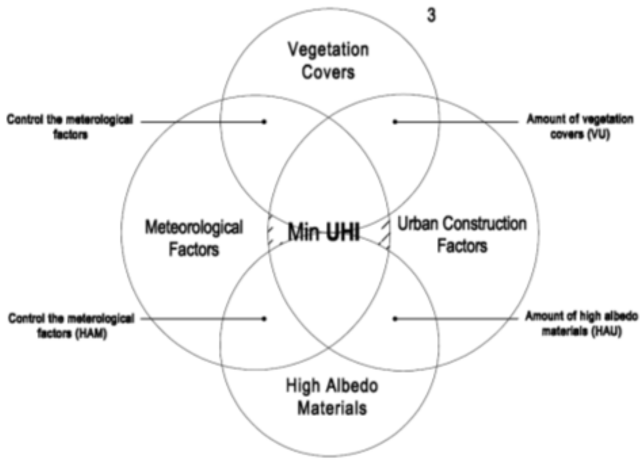


Figure 8. Approach to lower UHI intensity with increasing greenery and albedo of materials

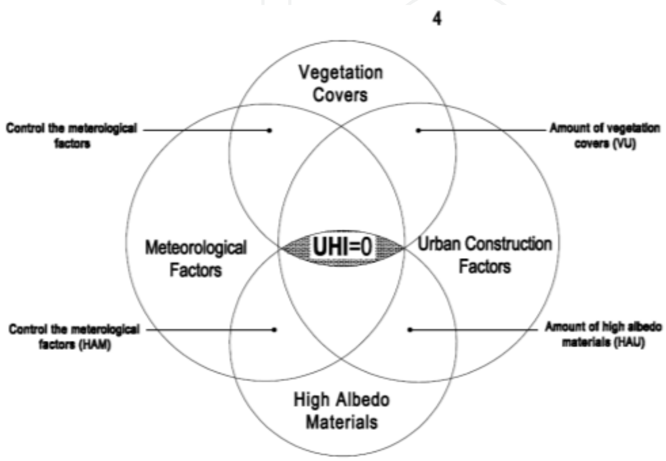


Figure 9. Achieve ideal condition by covering urban areas with approximately 50% greenery and high albedo materials

5. Methodology

In order to test the model, UHI measuring, modeling and simulation have been carried out which described in following way:

5.1. Methodologies used for Urban Heat Island measurements

The methodologies employed for measuring UHI are:

1. Satellite images: broad and visible instantaneous observed;
5. Historical weather data: long-term observation; and
6. Mobile survey: observation of given area within a designated period.

5.1.1. Urban Heat Island measurement through satellite image

A Landsat ETM7+ satellite image obtained on 18 July 2000 was selected (Figure 10). Satellite image with a thermal band was processed to obtain an instantaneous impression of the UHI. In order to map out the UHI, mapping of land surface temperature (LST) and normalized difference vegetation index (NDVI) were necessary. It aimed to overlay two images (NDVI and LST images) and extract maximum temperature value for both urban and rural area as well as identify the possible hot spots in the metropolitan area. Figure 11 shows the process of UHI mapping.

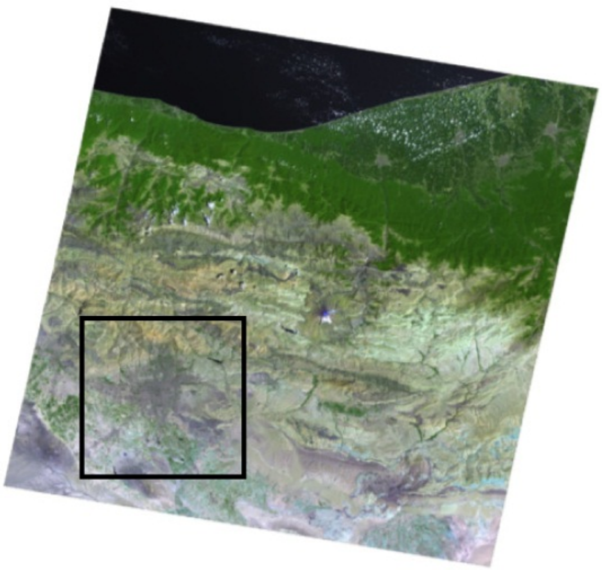


Figure 10. Landsat-7 ETM+ image of Tehran acquired on 18 July 2000 (band combination RGB 7 5 3)

5.1.2. Urban Heat Island measurement through historical weather data

In order to measure UHI intensity during a 25 years period, this study has chosen two stations (Mehrabad station in urban area and Karaj station in rural area). The stations selected to be used from weather station network sources, which under the governmental organization named as Iran Meteorological Organization.

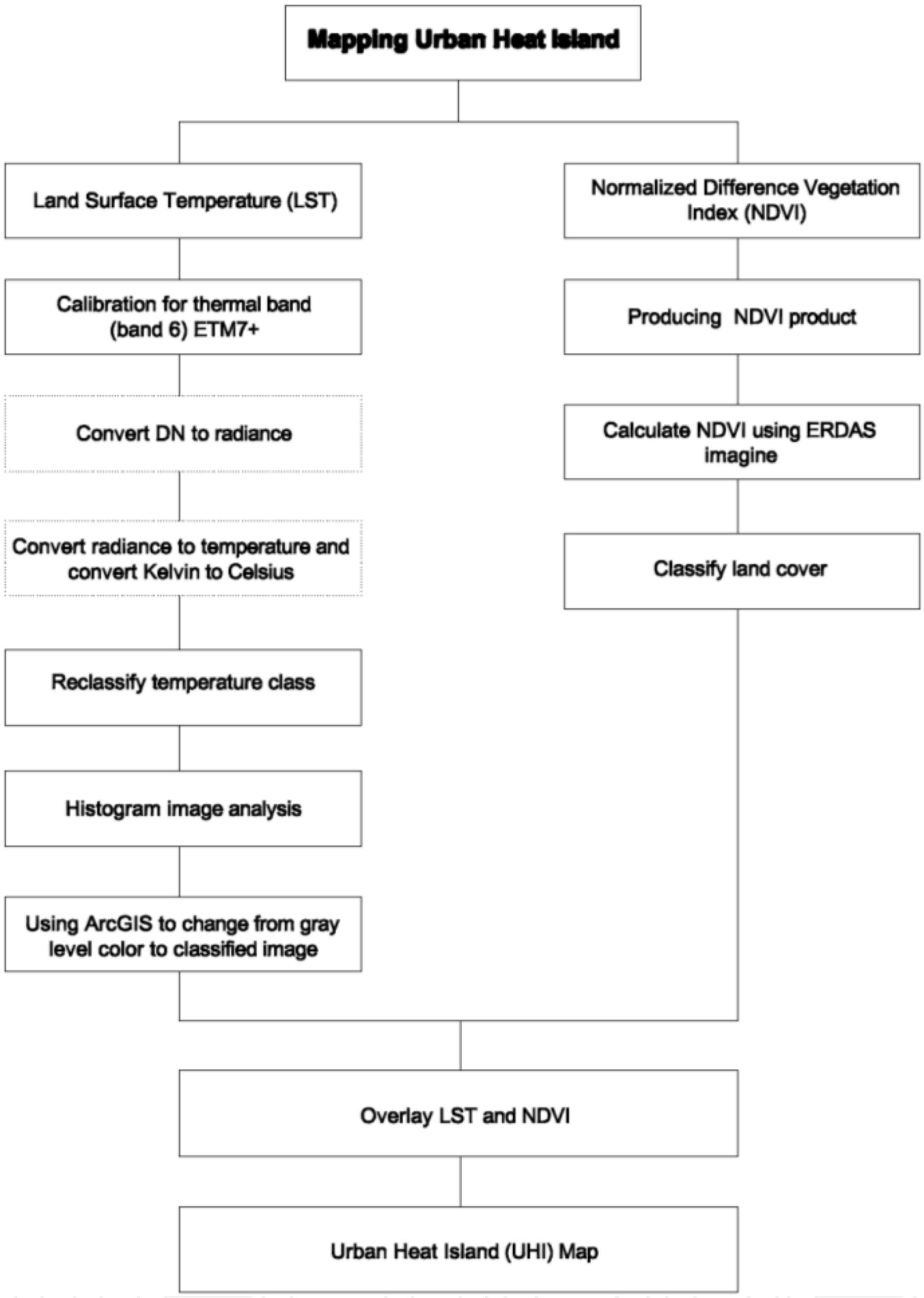


Figure 11. The process of UHI mapping

5.1.3. Urban Heat Island measurement through mobile survey

This survey entailed travelling on a predetermined path throughout a district, stopping at representative locations to take reading using just a single set of weather instrumentation. Using professional measuring instrument: Anemometer, Hygrometer, Thermometer and Light meter called Lutron LM-8000 (4 IN 1).

Method of transport taken in this measurement is to cycle between measurement locations. Since the measurement must be taken in specified period, using car or public transportation was not logical because of traffic jam.

5.2. Methodology used for modeling

This research used modeling based on GIS analysis, which is divided into two analyses (Figure 12); 1. 3D analysis; and 2. Spatial analysis in order to have the classification and the area of vegetation cover, albedo material and both together in current situation of 6 urban district of Tehran.

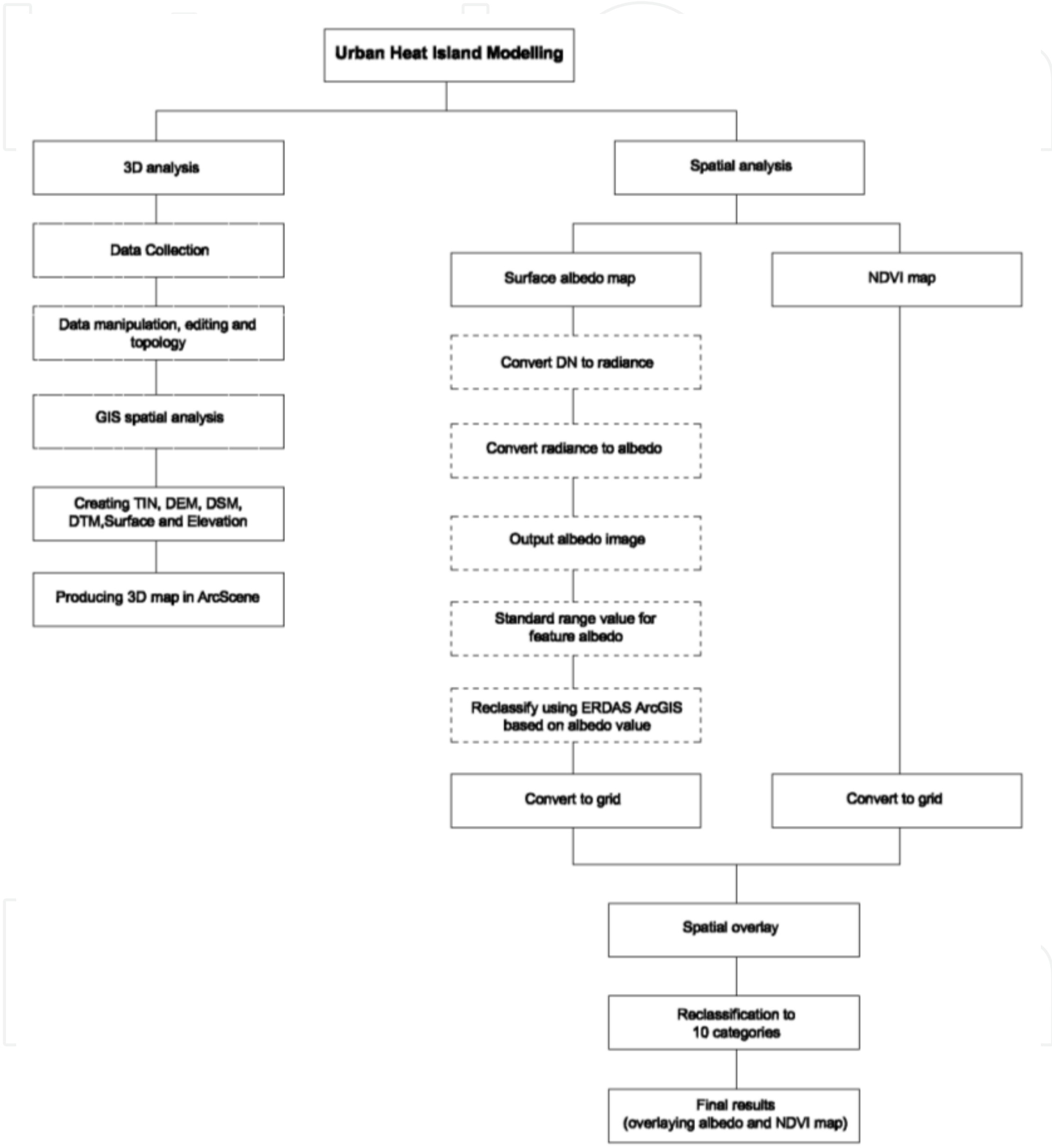


Figure 12. The process of UHI modeling based on GIS

5.3. Methodology used for simulation

This chapter used ENVI-met, three dimensional non-hydrostatic microclimate model, for simulating 'natural ventilator of the city' model with three scenarios. The Figure 13 shows the process of simulation with ENVI-met.

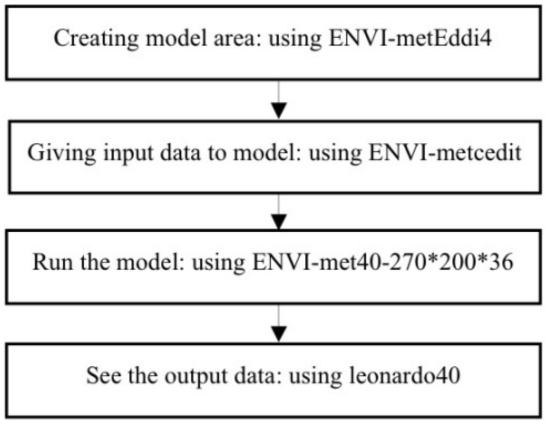


Figure 13. The process of simulation with ENVI-met

6. Model area: 6 urban district of Tehran

This paper put the model and its hypotheses in the context of 6 urban district of Tehran (Figure 14) for following reason:

- with high density of built-up area and low albedo and non-reflective materials, higher production of anthropogenic heat due to the transportation, cooling and heating system and cooking plays an important role on formation of UHI;
- Located near the centre of gravity of Tehran;
- Located on main axes of the city (Enghelab and Vali-e-Asr streets) (Figure 15);
- Surrounded the district by main urban axes (highways)(Figure 15);
- Concentration of superior activities and urban central functions; and
- Concentration of pollutions over central part of Tehran brought by west prevailing wind and increase inversion in Tehran.

Figure 14. The location of 6 urban district of Tehran (in the central part of Tehran)

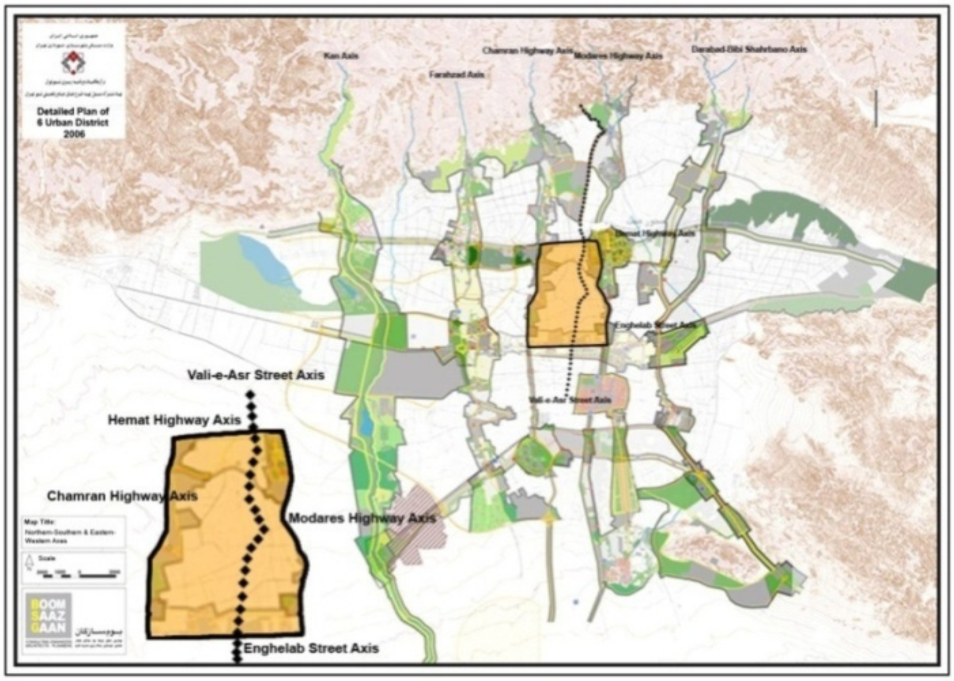


Figure 15. Main northern-southern and eastern-western axes surrounded 6 urban district

The area of the simulation has been shown in Figure 16 where has the higher intensity of UHI. The model area has a size of 230*234 m, resulting in 94*92*25 cells with a resolution of 2*2*2 meters. Within the area only residential buildings with average height of 16 m are located. The geographic coordinates of the model area were set to 35.73° latitude and 51.50° longitude.

Figure 16. The certain area of simulation in 6 urban district of Tehran with higher intensity of UHI

7. Discussion of results

7.1. Urban heat island measurement

7.1.1. Satellite image

The clear observation is the surface temperature of Tehran in 18 July 2000 (Figure 17). The warm region where is represented by red and yellow colour, is mostly located in the central, western and southern part of Tehran where CBD, industrial area and airport are located respectively. On the other hand, northern part of Tehran is relatively cool with green colour. This is due to the concentration of greenery and water bodies as well as less impact from the densely placed urban developments. The contrast between urban and rural areas hints at the prevalence of the UHI effect in Tehran, although the satellite image only provides the instantaneous observation during the daytime.

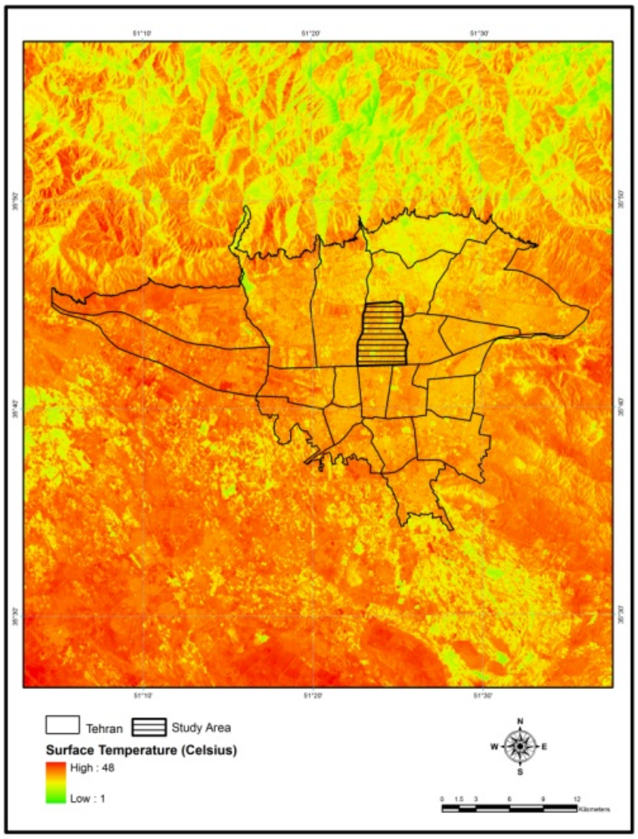


Figure 17. Figure 17. Tehran surface temperature map

The UHI intensity of Tehran is:

Urban max = 39 °C
Rural max = 27°C
UHI = (39-27) °C = 12°C

Therefore, daytime Tehran surface UHI shows 12°C of differences between urban and rural areas.

The UHI intensity of 6 urban district is:

Urban max = 40 °C
Rural max = 27°C
UHI = (40-27) °C = 13°C

Daytime UHI shows a 13°C of difference between urban and rural area. In fact, UHI intensity of 6 urban district is 1°C higher than Tehran.

Study area (6 urban district) image reveals some spots with either high or low surface temperature. As shown in Figure 18, Region 1 represents some of governmental organization, such as energy organization and some commercial and residential land uses. They experienced the highest temperature during daytime especially in the north and west parts of the region mainly because of lack of extensive landscape and being close to the two main highways (Hemat in north and Chamran in west) as well. Similarly, higher temperature was observed in eastern north and east parts of the Region 2. This is also reasonable since the exposed runway absorbs a lot of incident solar radiation during the daytime and incurs high surface temperature. It is due to the bus terminal station located in the Abassabad lands as well. Region 3 represents the most crowded area with higher traffic congestion, which the majority of commercial land uses are located in this region. Region 5 and 6 are close to the CBD of Tehran and neighbour with the Enghelab street, the most crowded street, but the existing of one of the biggest parks of Tehran, Laleh park, in Region 5 was able to reduce the higher temperature partly. Region 4 also represents some of the commercial and residential land uses. Furthermore, as shown in Figure 18, the areas around the main axis of the district which separates the regions of 1, 3 and 5 from regions of 2, 4 and 6, have lower urban temperature which it can be mainly due to the trees axis in the Vali-e-Asr street. This axis is not the worst scenarios, however, some red spots can be seen in this area. Therefore, the worst scenarios have been occurred in eastern north, western north and also some areas in west of the district. These all can be due to the lack of vegetation covers and low albedo materials and higher density of population and production of anthropogenic heat.

7.1.2. Historical weather data

The investigation of a 25 years period of urban (Mehrabad station) and rural (Karaj station) temperature in Tehran makes clear the temperature difference between these two areas. The selection of these two stations is because of the long records and validity. Mehrabad station is located within the west region of Tehran which airport situated there. In Karaj station, the major land use is agriculture. At Mehrabad and Karaj stations, the annual maximum, mean and minimum dry-bulb temperatures indicate a slow upward trend towards warming or cooling during the period 1985-2009 (Figure 19 and 20).

An exploration of the mean temperature trends of Mehrabad (urban) and Karaj (rural) as well as temperature differences between the two locations was made. The results show that (Figure 21) for the first five years temperature difference increased from 1.9°C to 3.6°C. This was an increase of 1.7°C for the period. It dropped by 1.7°C in 1991. Over the next 12 years there were fluctuations. It started increasing from 1.7°C in 2003 to 3.2°C in 2004 and it reached to peak on 2005 before the temperature difference decreased by about 3.6°C to around 2.6°C in 2009. The highest temperature differences is 3.6°C occurred in 1989, 1990 and 2005, while the lowest one with 1.5°C occurred in 1993, 1995 and 1999. It means that from 2003 forward there is higher intensity of UHI.

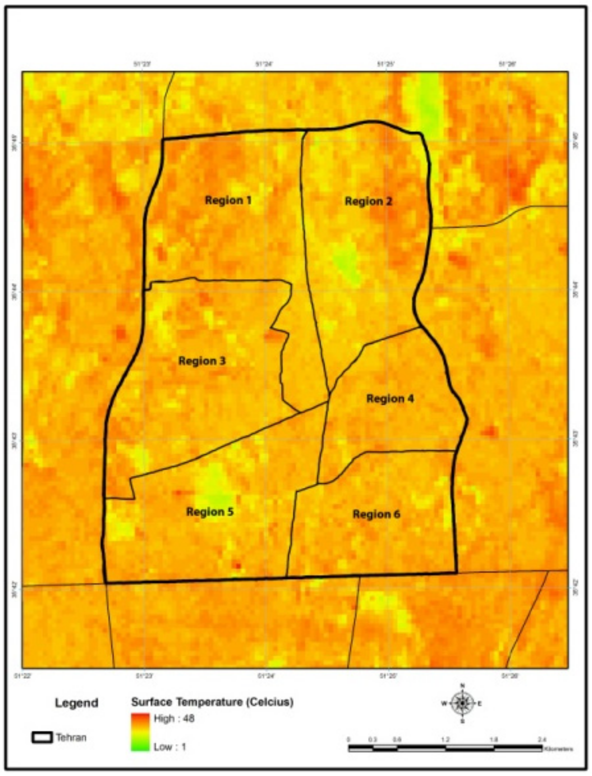


Figure 18. 6 urban district's surface temperature map

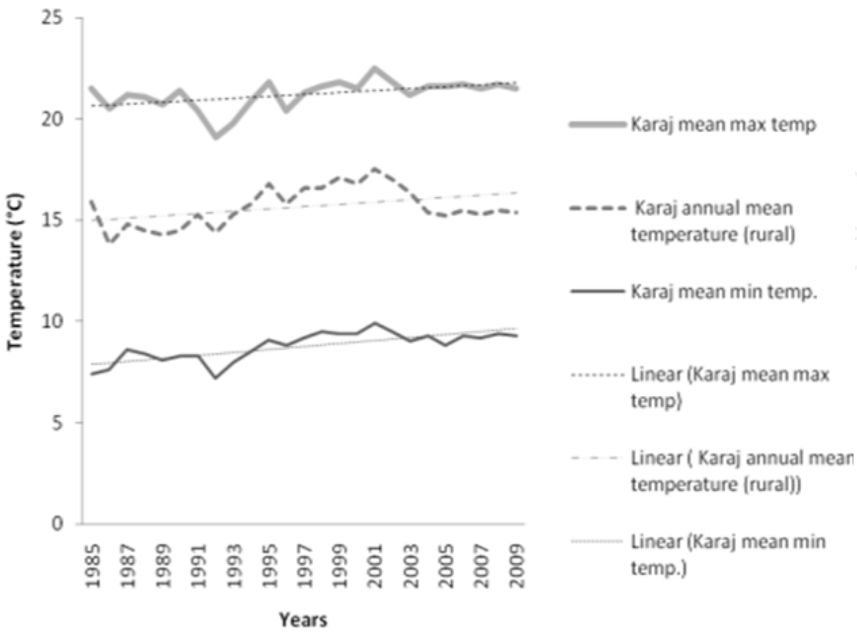


Figure 19. Analysis of the past 25 years' weather data at Mehrabad station

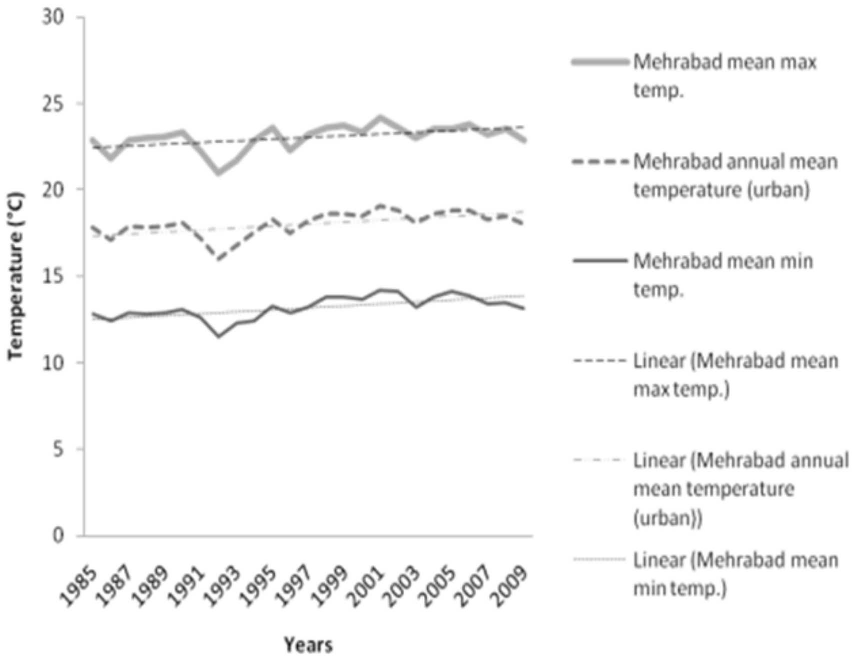


Figure 20. Analysis of the past 25 years' weather data at Karaj station

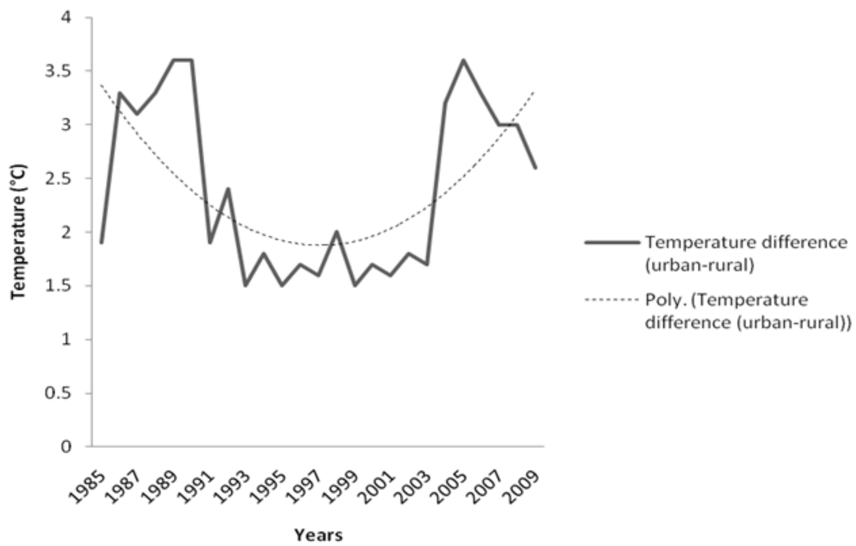


Figure 21. Mehrabad-Karaj mean temperature differences

7.1.3. Mobile survey

Field measurements are used for measuring the air temperature of current situation of the area. In this way, it was chosen 31 points in three parts of the district. In fact, three ways were traversed, two narrow strips around (from point number 1 to 11 and 12 to 21) and the central part of the district (from point number 22 to 31), to cover whole areas of the district (Figure 22). Since there were only two hours with higher radiation intensity to measure points, this study has selected three consecutive days to measure them exactly in these two hours. It investigated the correlation between temperatures and different land uses in current condition of 6 urban district.

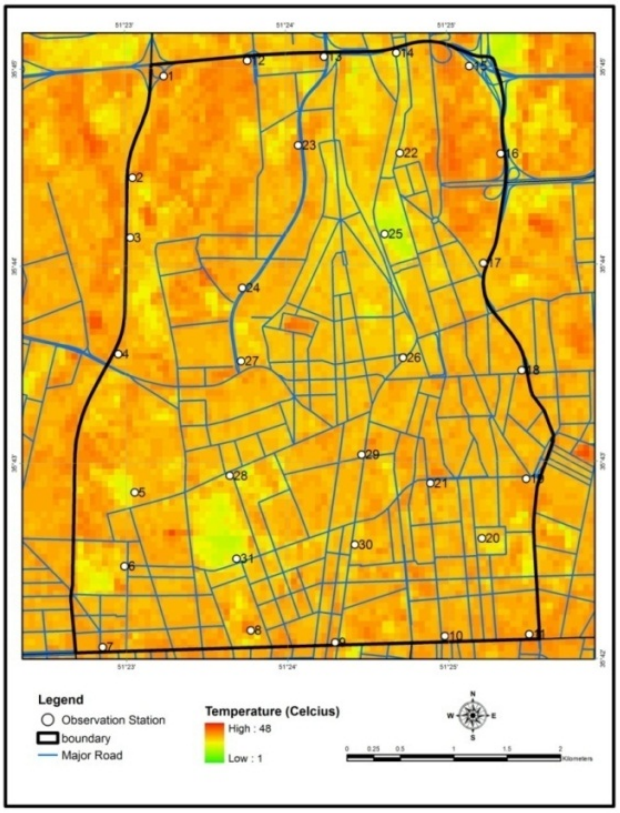


Figure 22. Selection of 31 points in 6 urban district with 1 Km distance for mobile survey

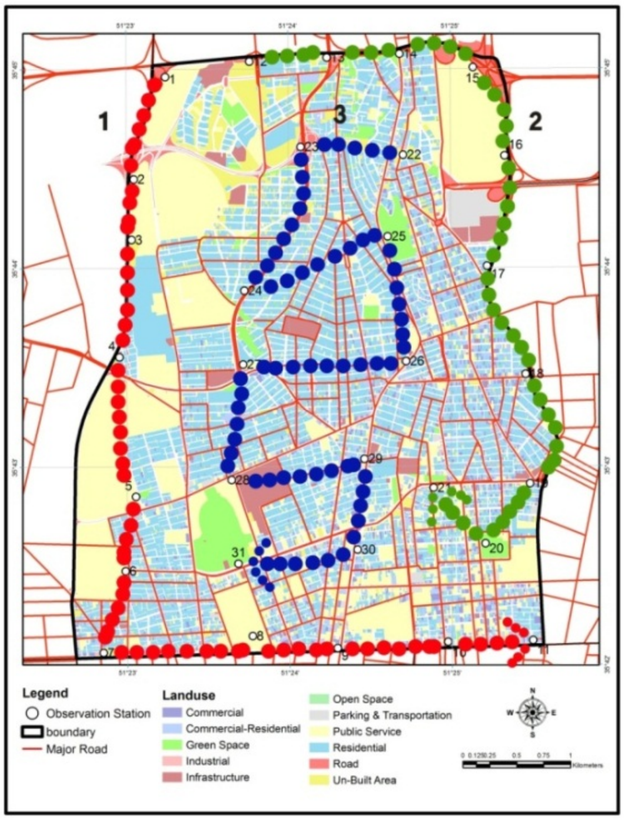


Figure 23. Three routes selected for measuring air temperature in 6 urban district

First route running from north to south and then to east (1 to 11), second route from west to east and then to south (12 to 21) and third route which cover central part of the district (22 to 31) running like zigzag movement to cover whole area of the central part passed through quite a number of different land uses (Figure 23). In order to save time and measure the defined points in defined time, bicycle was selected. According to high traffic jam in Tehran reaching to all points in the exact time by car was impossible. Therefore using vehicle equipped with observation tube which can automatically record ambient temperature was difficult.

The maximum air temperature, 42 °C, was observed in the route number 1 in industrial, commercial and public services. The lowest temperature, 38.5 °C, was observed in residential area (Figure 24). In route number 2, the maximum temperature was also 42°C in industrial and public services and the lowest one was 34°C in park (Figure 25). In route number 3, the highest temperature was 40.5 °C in industrial area and the lowest one was 30 °C in park (Figure 26).

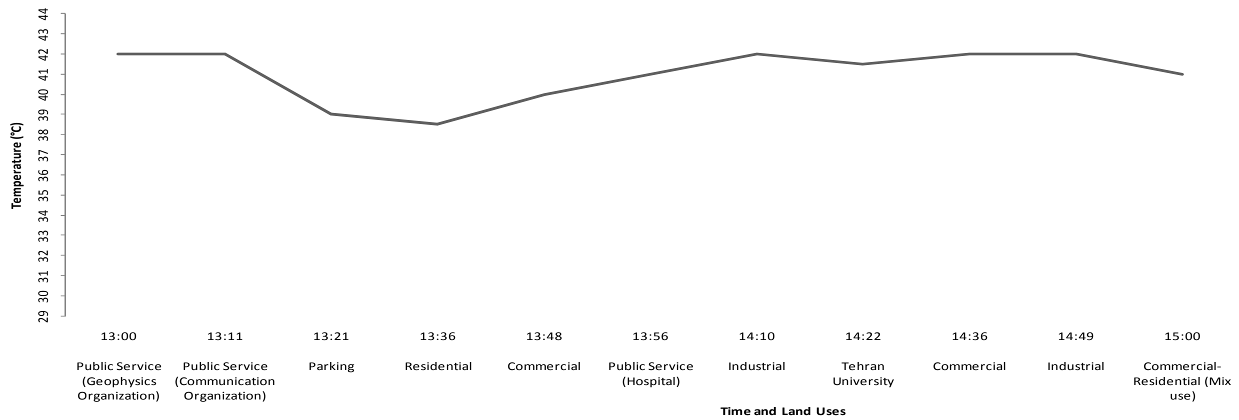


Figure 24. Maximum air temperature in different land uses in route number 1

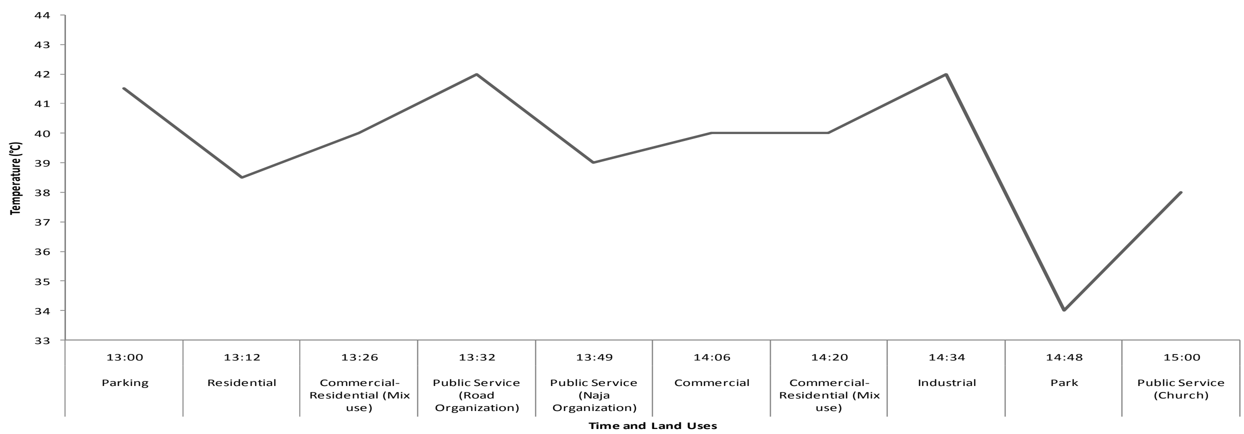


Figure 25. Maximum air temperature in different land uses in route number 2

As seen routes number 1 and 2 have the same highest temperature in industrial area and public services but the route number 3 has 1.5 °C less than the other routes. It is due to the location of routes number 1 and 2 and they are located next to the main highways (Hemat, Chamran, Modares and Enghelab highways) which have the highest traffic jam, air pollution, production of anthropogenic heat and last but not least the lack of vegetation covers which can ventilate air and using low albedo and non-reflective materials. The industrial areas generally have low-rise buildings and the high temperature recorded in these areas is related to the extensive usage of metal roofing in the buildings. The high temperature of commercial and public services buildings is related to use concrete and dark stones (Figure 27) that absorb a huge part of the solar radiation incident on it and later release it to the atmosphere. In addition, calculation of averaging the temperature in every route shows the highest mean temperature in route number 1 with 41 °C, route number 2 with 39.6 °C and route number 3 with 38.25°C respectively (Table 1). From the results it is observed that the daytime temperature seemed to be dominated more by the solar radiation component rather than by the reradiated temperature, which is the main cause of daytime UHI. The average of observations obtained during daytime in three days in 2009 shows that the temperature is 2.2 °C higher than the average of temperature derived from satellite image in 2000. It means that there were more constructions in these 9 years and made the condition much more worse.

Routes	Mean max temperature (°C)	Mean min temperature (°C)
1	41	30.06
2	39.60	29.05
3	38.25	28.90

Table 1. Mean min and max temperatures in three different routes

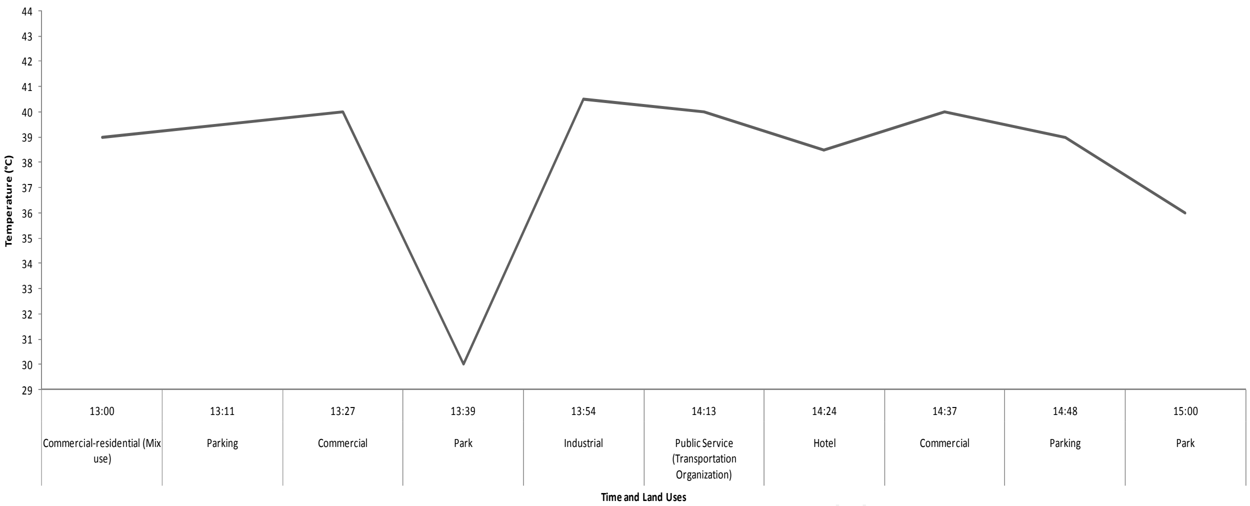


Figure 26. Maximum air temperature in different land uses in route number 3

In urban areas, the night time temperatures varied between 25°C and 35.5°C and it was found that the CBD area was around 7 °C hotter than the locations with greenery (Figure 28, 29 and 30). This also indicates the center of the night time UHI effect which has shifted from the industrial areas during the daytime to the CBD area. The average temperature in every route in night time also shows the highest mean temperature in route number 1 with 30.06 °C, while route number 2 has 29.05°C and route number 3 with 28.90 °C (Table 1). It means that at night time also route number 1 has the highest temperature. Comparing these results with satellite image results shows that west, north-west and east parts of the district in satellite image (2000) have higher intensity of UHI, while mobile survey (2009) shows the condition much worse.

Figure 31 shows the correlation between GIS and mobile survey. P-value, which shows 0.05, is significant difference between GIS and mobile survey. The Pearson correlation which is 0.67 shows that the difference is reliable. This means the reading between these two sources is complement each other.

Figure 27. Using dark stone, concrete and metal materials

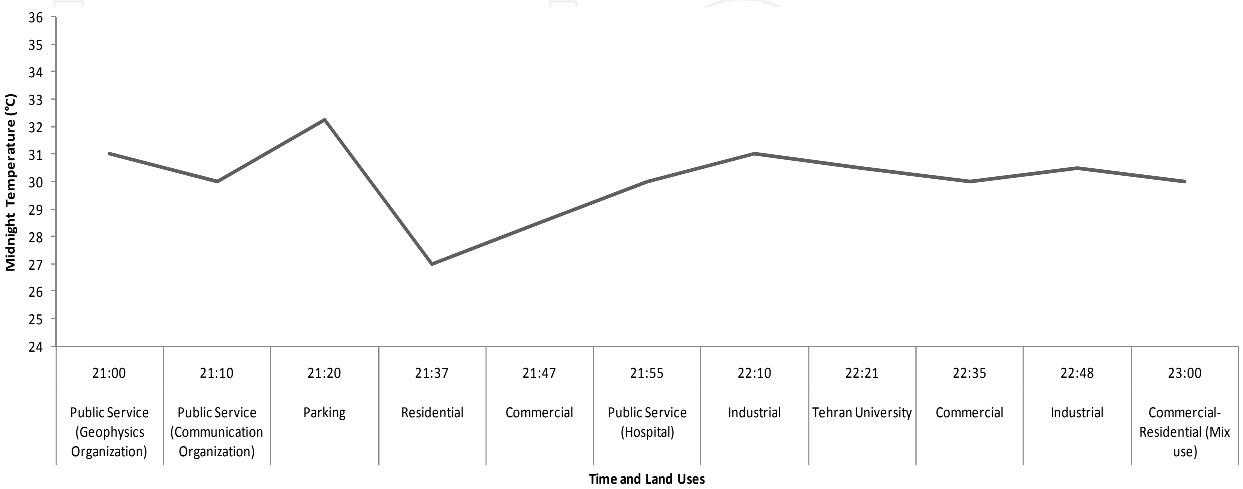


Figure 28. Minimum air temperature in different land uses in route number 1

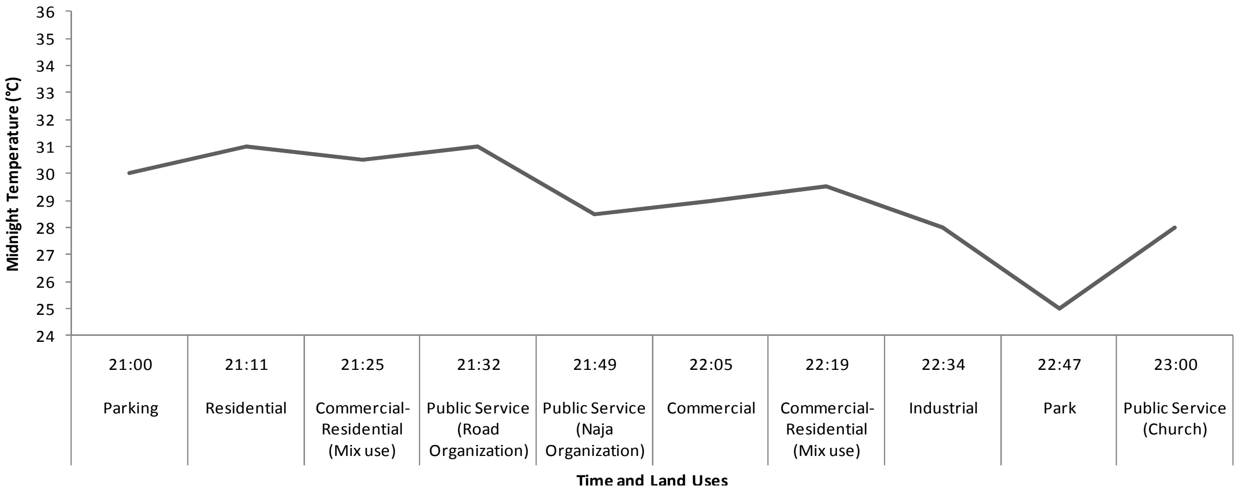


Figure 29. Minimum air temperature in different land uses in route number 2

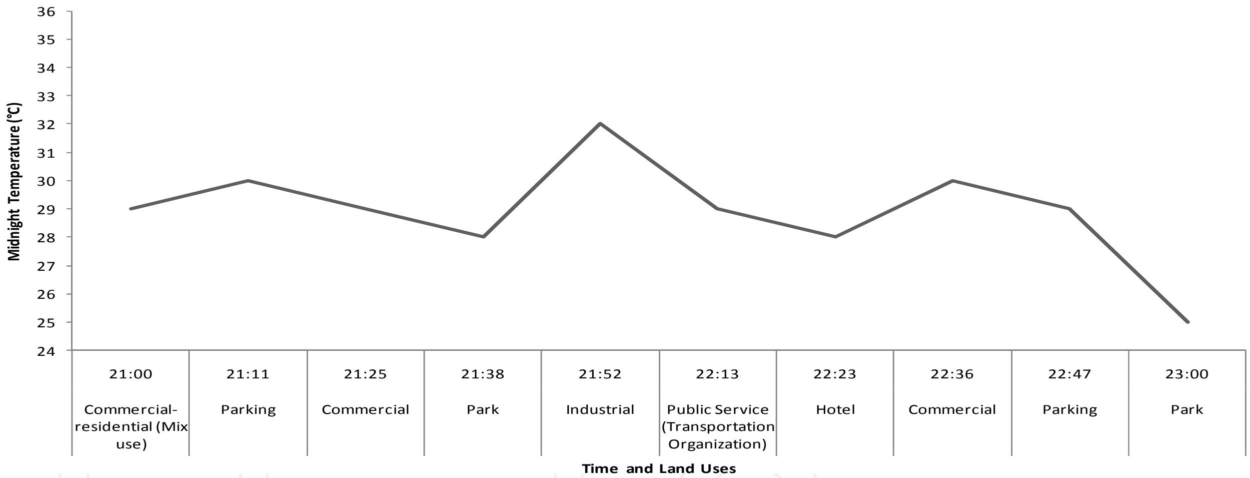


Figure 30. Minimum air temperature in different land uses in route number 3

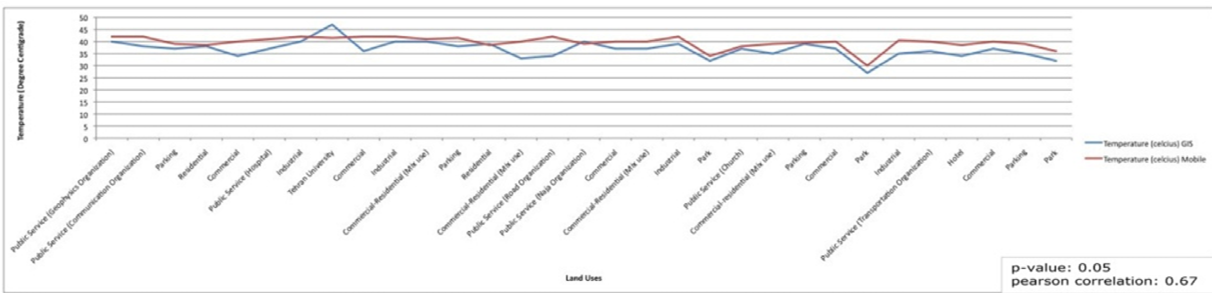


Figure 31. Figure 31. Correlation between GIS and mobile survey

7.2. Modelling based on GIS analysis

The results obtained from modelling based on GIS, 3D and spatial analysis, are described in following way:

7.2.1. 3D analysis

This analysis gives visual views of the district that can help to better understand of the site. The 3D of district (Figure 32) shows that the northern part of the district has some ups and downs that contribute to cause an unequal distribution of pollution and provide warm air canopy over this area. As shown in Figure 18, the northern part of the district has the hottest surface temperature that is due to the concentration of the pollutions and cause to form the UHI.

7.2.2. Spatial analysis

To prove the hypotheses spatial analysis based on ArcGIS has been done in order to estimate the area of albedo (lower, medium and higher), vegetation covers and then overlay them. Results obtained from creating albedo (Figure 33) and NDVI grid maps (Figure 34) in vector format.

1. Albedo Grid Map

As shown in Table 2, albedo has been classified into three groups including (Figure 33):

1. Higher albedo with value of 0.170-0.310 occupied 37% of whole area of 6 urban district. According to the Table 3, this range of albedo belongs to concrete (0.10-0.35);
7. Medium albedo with value of 0.140-0.160 occupied 50% of whole area of 6 urban district. According to Table 3, this range of value belongs to asphalt (0.05-0.2) or corrugated iron (0.10-0.16); and
8. Lower albedo with value of 0.064-0.130 occupied 13% of whole area of 6 urban district. According to Table 3, this range of value belongs to gravel (0.08-0.18), smooth-surface asphalt (0.07) or black coloured materials.

2. NDVI Grid Map

As shown in Table 4, the land cover types have been divided into 4 categories including (Figure 34):

1. Vegetation with value of 0.0-0.7 from very poor to very high density. This type covers 51.57 hectare, 2.4% of whole area of 6 urban district;
2. Non-vegetation with value of -0.0- -0.4 including urban area, desert, mountain area and cloud. This type covers 2087.52 hectare, 97.37% of whole area of 6 urban district;
3. Water with value of -0.4- -0.7 constituted 1.7 hectare, 0.08% of whole area; and
4. There are also some land covers that their types were not recognizable which cover 3.21 hectare, 0.15% of whole area of 6 urban district.

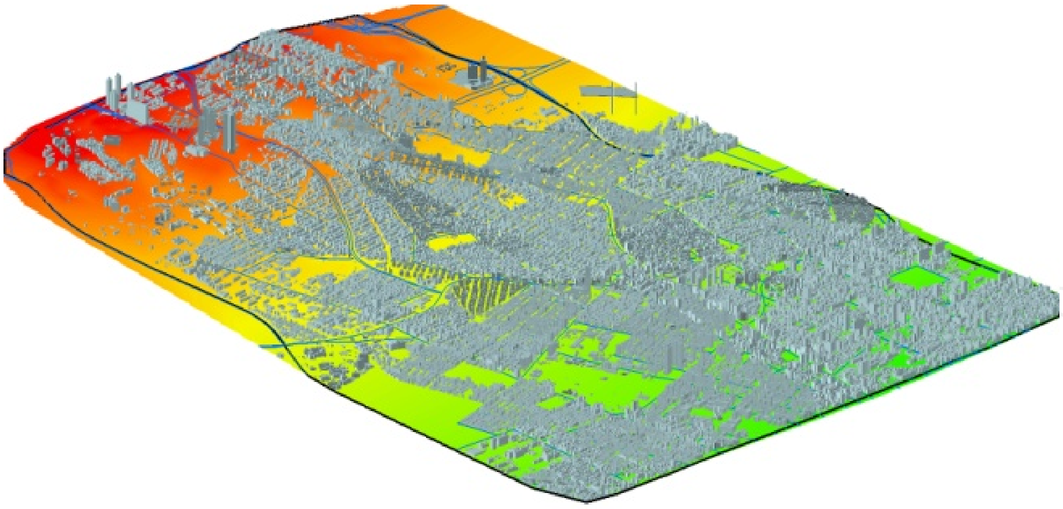


Figure 32. 3D of 6 urban district

Albedo Classification	Albedo Value	Area (Hectare)	Percent of 6 Urban District Area
Higher albedo	0.170-0.310	792	37%
Medium albedo	0.140-0.160	1071	50%
Lower albedo	0.064-0.130	280	13%
		2144	100%

Table 2. Albedo classification with related values and area in 6 urban district

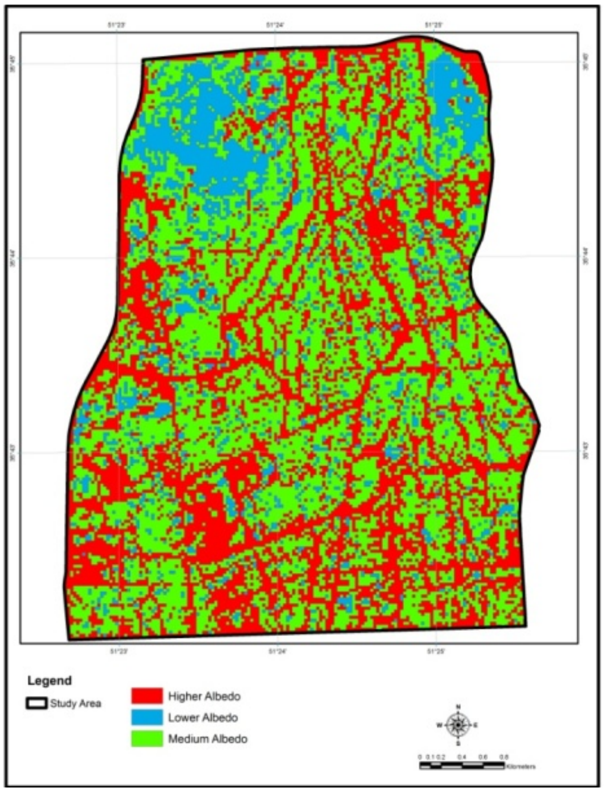


Figure 33. Albedo grid map of 6 urban district

Surface	Albedo
Streets	
Asphalt (fresh 0.05, aged 0.2)	0.05-0.2
Walls	
Concrete	0.10-0.35
Brick/Stone	0.20-0.40
Whitewashed stone	0.80
White marble chips	0.55
Light-coloured brick	0.30-0.50
Red brick	0.20-0.30
Dark brick and slate	0.20
Limestone	0.30-0.45
Roofs	
Smooth-surface asphalt (weathered)	0.07
Asphalt	0.10-0.15
Tar and gravel	0.08-0.18
Tile	0.10-0.35
Slate	0.10
Thatch	0.15-0.20
Corrugated iron	0.10-0.16
Highly reflective roof after weathering	0.6-0.7
Paints	
White, whitewash	0.50-0.90
Red, brown, green	0.20-0.35
Black	0.20-0.15
Urban areas	
Range	0.10-0.27
Average	0.15
Other	
Light-coloured sand	0.40-0.60
Dry grass	0.30
Average soil	0.30
Dry sand	0.20-0.30
Deciduous plants	0.20-0.30
Deciduous forests	0.15-0.20
Cultivated soil	0.20
Wet sand	0.10-0.20
Coniferous forests	0.10-0.15
Wood (oak)	0.10
Dark cultivated soils	0.07-0.10
Artificial turf	0.50-0.10
Grass and leaf mulch	0.05

Table 3. Albedo of typical urban materials and areas [22,3]

NDVI value	Vegetation density	Land cover type	Area (Hectare)	Percent of 6 Urban District Area
0	Unknown	Unknown	3.21	0.15%
-0.4 - -0.7	Non-Vegetation	Water	1.7	0.08%
-0.0 - -0.4	Non-Vegetation	Urban area, desert, mountain area and cloud	2087.52	97.37%
0.0 - 0.1	Very Poor	Vegetation	51.57	2.4%
0.0 - 0.2	Poor			
0.2 - 0.3	Moderate			
0.3 - 0.5	High			
0.5 - 0.7	Very High			
			2144	100%

Table 4. Land cover types with related value and areas in 6 urban district

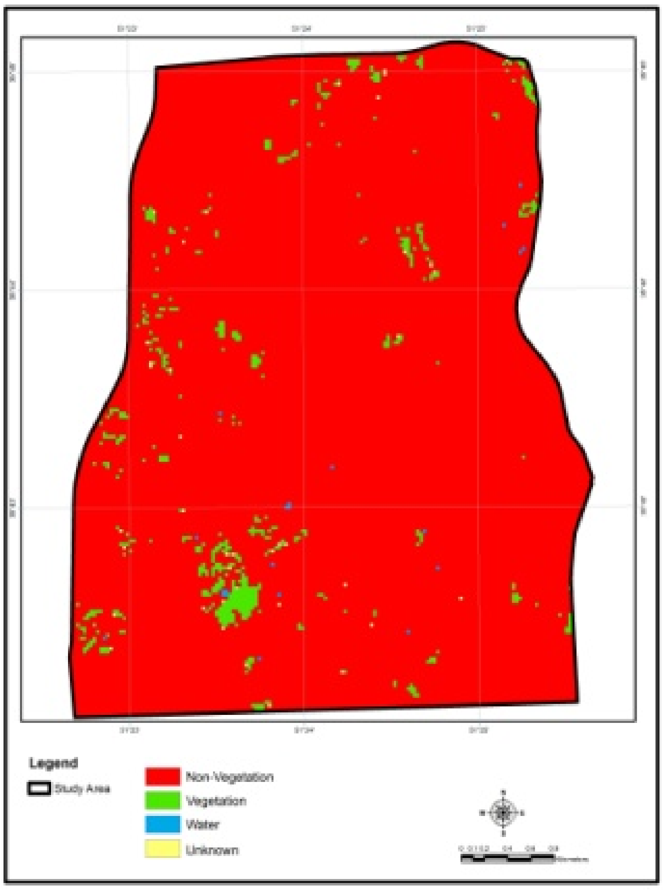


Figure 34. NDVI grid map of 6 urban district

3. Overlaying the albedo and NDVI grid maps

Results obtained from overlaying the albedo and NDVI grid maps have been shown in Figure 35 and Table 5.

No.	Albedo Classification	Land Cover Type	Area (Hectare)
1	Higher Albedo	Unknown	3.05
2	Higher Albedo	Non-Vegetation	739.16
3	Higher Albedo	Vegetation	48.80
4	Higher Albedo	Water	1.06
5	Medium Albedo	Unknown	0.16
6	Medium Albedo	Non-Vegetation	1068.08
7	Medium Albedo	Vegetation	2.76
8	Medium Albedo	Water	0.48
9	Lower Albedo	Non-Vegetation	280.28
10	Lower Albedo	Water	0.16
			2144

Table 5. Results of overlaying albedo and NDVI grid map of 6 urban district

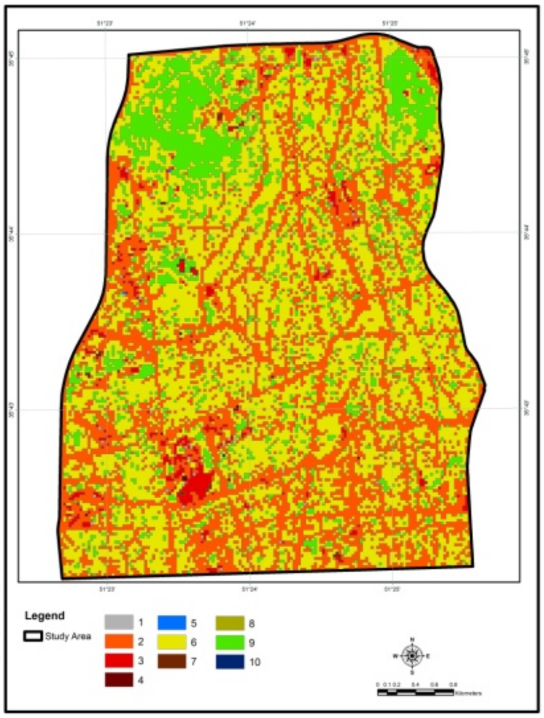


Figure 35. Overlaying albedo and NDVI map of 6 urban district

Each number shows the combination of albedo and land cover types. It can be divided into following groups:

1. Higher albedo with non-vegetation and vegetation covers;
2. Medium albedo with non-vegetation and vegetation covers; and
3. Lower albedo with non-vegetation cover (as seen in Table 5 the combination of lower albedo and vegetation cover does not exist).

Number 2 (Orange colour) shows the combination of higher albedo and non-vegetation with 739.16 hectare area, number 6 (yellow colour) shows the combination of medium albedo and non-vegetation with 1068.08 hectare area, number 9 (green colour) shows the combination of lower albedo and non-vegetation with 280.28 hectare area, which occupied 34.5%, 50% and 13% of 6 urban district respectively. Number 3 (red colour) shows the combination of higher albedo and vegetation with 48.80 hectare area, number 7 (brown colour) shows the combination of medium albedo and vegetation with 2.76 hectare area which occupied 2.27% and 0.12% of 6 urban district respectively. Other numbers are negligible which are not observed in Figure 35. Although number 3 includes high albedo and vegetation cover, it encompass the very low percentage of area which not only it has not impact on mitigation of UHI, but also this value of albedo (with value of 0.17-0.310) with lower reflectivity can increase the UHI intensity. The area of vegetation cover is negligible in comparison with whole area of the district. Number 6 with 50% of whole area of 6 urban district including non-vegetation cover and medium albedo materials (with value of 0.14-0.160) has been widely distributed in the district and provided worse condition for this district. After number 6, number 2 is in the worse condition with 34.5% of whole area of 6 urban district including non-vegetation cover and high albedo materials (with value of 0.17-0.310). Then number 9 with 13% of whole area of 6 urban district and the combination of lower albedo and non-vegetation cover stands in the next rank. It has been widely distributed in region 1 and 2 that the topography of these regions also provided higher UHI intensity. It is also observed in Figure 16 that these regions have higher UHI impacts.

7.3. Analyze the model of natural ventilator of the city

The area of 6 urban district is 2144.33 hectare with population of 232583. According to Table 4, vegetation covers constitute 51.57 hectare of 6 urban district area. Therefore, per capita of vegetation cover in this district is 2.21m^2.

Population of 6 urban district = 232583
Vegetation cover area = 51.57 hectare = 515700 m^2
Therefore, per capita of vegetation cover = 2.21 m^2

It means that only 2.4% of whole area of 6 urban district is composed of vegetation cover with 2.21 m^2 per capita.

Based on studies and investigations of United Nation (UN) Environment, acceptable per capita of green spaces in cities is of between 20 and 25 m^2 for each person [23].

In fact, 6 urban district with 2.21 m^2 per capita of vegetation cover is around 18 m^2 less than indicator of UN that makes the situation worse and increases UHI intensity in given area.

According to hypotheses, if a fourth area of 6 urban district is covered with vegetation covers and high albedo materials, therefore:

Area of 6 urban district = 21443300 m^2

21443300 ÷ 4 = 5360825 m^2

$$5360825 \div 2 = 2680412.5 \text{ m}^2 \longrightarrow \text{Vegetation covers}$$
$$2680412.5 \text{ m}^2 \longrightarrow \text{Higher albedo materials}$$

Therefore, per capita of vegetation cover is:

$2680412.5 \div 232583 = 11.5 \text{ m}^2$

In comparison with the UN indicator (20-25 m^2), it is 8.5 m^2 less.

Therefore, this hypothesis is not applicable

If a third area of 6 urban district is covered with vegetation covers and high albedo materials, therefore:

Area of 6 urban district = 21443300 m^2

$21443300 \div 3 = 7147766.67 \text{ m}^2$

$$7147766.67 \div 2 = 3573883.33 \text{ m}^2 \longrightarrow \text{Vegetation covers}$$
$$3573883.33\text{m}^2 \longrightarrow \text{Higher albedo materials}$$

Therefore, per capita of vegetation cover is:

$3573883.33 \div 232583 = 15.3 \text{ m}^2$

In comparison with the UN indicator (20-25 m^2), it is still 5 m^2 less.

Therefore, this hypothesis also is not applicable.

If the amount of vegetation cover and high albedo material increase and cover half of urban area, the effect of UHI can be achieved zero which is the ideal condition, therefore:

Area of 6 urban district = 21443300 m^2

$21443300 \div 2 = 10721650 \text{ m}^2$

$$10721650 \div 2 = 5360825\text{m}^2 \longrightarrow \text{Vegetation covers}$$
$$5360825 \text{ m}^2 \longrightarrow \text{Higher albedo materials}$$

Therefore, per capita of vegetation cover is:

$5360825 \div 232583 = 23 \text{ m}^2$

In comparison with the UN indicator (20-25 m^2), it is acceptable.

Therefore, this hypothesis is applicable.

In addition, as Reagan and Acklam [24] calculated, when the reflectivity of the rest of area (5360825 m^2) with poorly insulated building is increased from 0.25 to 0.65, the heat gains through the roof are reduced by half. It means that the albedo values mentioned in Table 2 is higher albedo in current classification of 6 urban district and it does not have higher reflectivity.

Figure 36 shows the areas with higher intensity of UHI chosen to implement natural ventilator model as shown in Figure 18. These areas cover approximately half area of 6 urban district with vegetation cover along with high albedo material and they act as ventilation holes and mitigate UHI effects.

Figure 36. Covering the half area of 6 urban district with vegetation cover along with high albedo material

7.4. Simulation through ENVI-met

ENVI-met was employed to simulate "natural ventilator of the city" (NVC) model. This simulation compares the current situation of 6 urban district of Tehran with three scenarios according to the variable of the NVC model. These three scenarios were created as follows:

- Scenario 1: change current low albedo material to high albedo materials;
- Scenario 2: cover the model area with vegetation cover; and
- Scenario 3: cover the model area with vegetation cover along with high albedo material.

The boundary condition was set according to the current situation of model area based on weather data obtained from the mobile survey. One typical time scenario, 1200 hr, was selected for analysis.

Figure 37 illustrates the current situation of the model area and three scenarios in ENVI-met. The material used for buildings, in current situation of 6 urban district, is concrete with albedo of 0.30, for roofs and roads is asphalt with albedo of 0.14-0.16 and some parts of the area have covered by loamy soil with albedo of 0.17-0.23. There is the lack of vegetation cover in this area. In scenario 1, low albedo materials were changed to high albedo one, asphalt to bright asphalt with albedo of 0.55, concrete was covered with white coating with albedo of 0.85, and loamy soil to light colored soil with albedo of 0.6. In scenario 2, horizontal and vertical surfaces were covered by vegetation cover. In fact, these two scenarios show that how vegetation and high albedo material can contribute to UHI mitigation separately. In scenario 3, the model area was covered with high albedo material along with vegetation cover in order to see that how these two variables can contribute together to mitigate the effect of UHI.

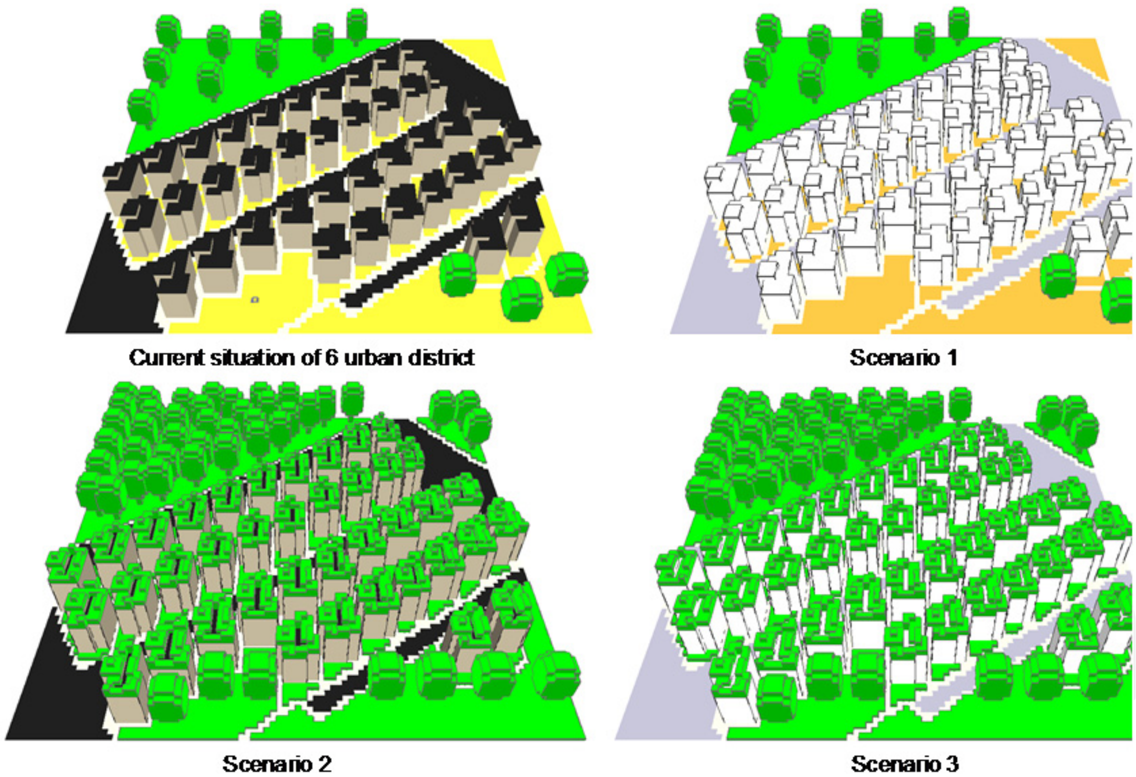


Figure 37. Current situation of the model area and three scenarios in ENVI-met

Figure 38 shows the daytime (at 1200 hr) simulation of the current situation of 6 urban district and three scenarios. As seen in this Figure, in current situation of 6 urban district, higher temperature (above 295.80 K) occurs in roads and roof of buildings with low albedo material such as asphalt and the areas with less vegetation cover. The simulation results show that when the points are closer to the green area (east north), lower temperatures (294.60 K) were observed.

In scenario 1, the cooling effect of high albedo materials can be seen in the simulation (Figure 37). In the east north part, it is not seen higher temperature while in current situation there is higher temperature and it decreased to around between 294.20 and 295.20 K and in building area to around less than 294K. It means that high albedo materials have extreme effects on decreasing the ambient temperature.

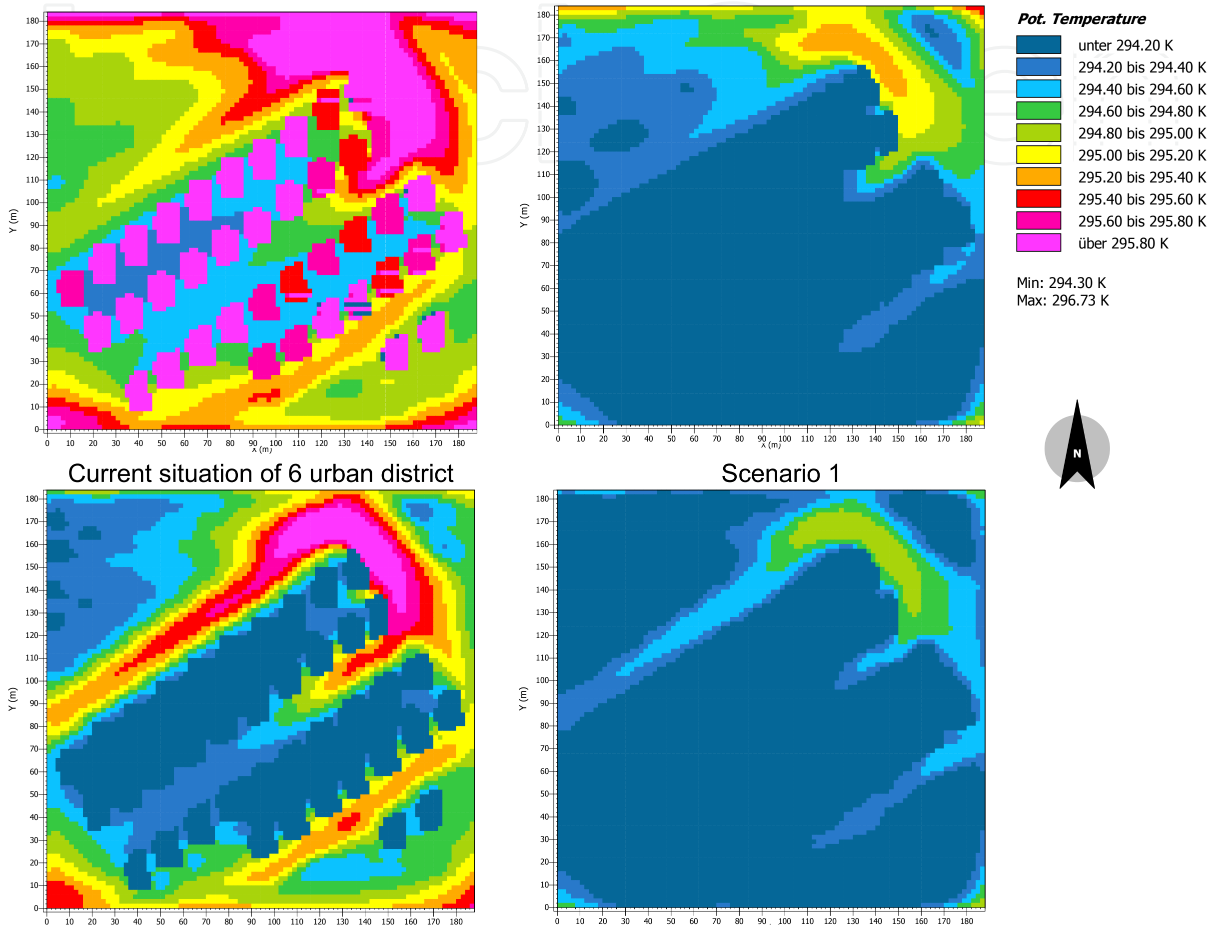


Figure 38. Daytime simulation of 6 urban district and three scenarios in ENVI-met

When the vegetation is added in scenario 2, the temperature in the areas with trees and roof gardens has been reduced from around 295 K to 294.20 K. In fact, the moisture levels in the soil dose not cause the temperature to be similar to those on the hard pavement areas. Although the vegetation cover decreased temperature, there is still higher temperature in roads. Green roofs contributed to decreased the temperature in housing area. While the vegetation is replaced with hard pavement (current situation), it can be seen that the whole area now has a higher temperature at about above 295.80 K. The qualitative analysis of the temperature data showed that the coolest areas were in the Saee and Laleh parks located in route number 3. It means that field measurement has also shown the same results that greenery can decrease temperature. The reduction of the air temperature in the areas with more vegetation cover can reach 0.8 °C. In the comparison of the scenarios' 1 and 2 and current situation for temperature, scenario 1 has more effect on the surrounding built-up area than vegetation cover.

In scenario 3, the combination of vegetation and high albedo material has been examined in order to test that how these two variables can affect the surrounding built-up area in parallel. As seen in Figure 38, in scenario 3, it is obvious that the combination of these two variables can affect to reduce the temperature around 2.43°C. Scenarios' 1 and 2 also contribute to reduce the temperature singly, while in scenario 3 which is the combination of scenario 1 and 2 has extreme contribution to mitigate the air temperature.

Therefore, in the cross-comparison of the three scenarios for temperature, the best cooling effect on the surrounding built-up area is observed in the third scenario and cooling effect of greenery along with high albedo material can be confirmed by the simulation.

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