Mapping Urban Garden Destruction in Tehran Using Landsat Imagery and Machine Learning

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ABSTRACT:

In recent decades, Tehran has experienced widespread migration and rapid development due to the concentration of commercial, financial, cultural, and educational activities, leading to changes in land use and disruptions. These issues are particularly significant in relation to private green spaces (gardens), which play a vital role in environmental services and urban quality of life. Urban management, through legal tools and effective policies, can play a key role in either preserving or demolishing these spaces. Examining the relationship between urban management laws and the status of these spaces can contribute to sustainable development and urban livability. In this study, the overall destruction of green spaces in Tehran was first examined. To this end, laws related to private urban green spaces were identified, and the most important ones were specified. Then, Landsat 2, 5, 7, and 8 satellite images for the years 1976 to 2016, with ten-year intervals and based on selected legal variables, were extracted for the summer season of Tehran. In the next step, supervised machine learning methods (Support Vector Machine, Random Forest, and Decision Tree) and unsupervised methods (K-Means) were employed to classify the images, and changes in land use were calculated by comparing these classified images. The results of the study show that from 1976 to 1986, 11.11%, from 1986 to 1996, 19.60%, from 1996 to 2006, 15.62% and from 2006 to 2016, 26.73% of Tehran green spaces were destroyed. These results indicate that the destruction of green spaces in Tehran has followed a continuous and increasing trend, particularly in Municipal Districts 1, 2, 3, and 5. After identifying the general destruction of green spaces, a case study was conducted in Tehran to examine the main objective of this paper, which is to analyze the destruction of gardens. In this context, the Kan gardens in District 5 were selected as a representative example of urban gardens, and the impact of urban management laws on the destruction of these gardens was examined using satellite images and ground-truth data. The results of the study show the significant impact of urban management laws and policies on the destruction of gardens.

1. INTRODUCTION

Analysis of the Tehran, Capital of Iran, urban expansion, shows that the city had a vast vegetation cover in the past (Ata et al., 2023), which contributed toward improving the quality of life and generated different environmental, social, and economic benefits (Hassanpour et al., 2020). Today, Tehran has become one of the fastest-growing cities in the Middle East and developing countries (Rabiei-Dastjerdi et al., 2016). This continuous growth and development have led to the disruption of its urban system, as the city has attracted a large population (Rabiei-Dastjerdi et al., 2015). Several factors have influenced the population growth in Tehran over the past years. One of these factors is various political events such as the Islamic Revolution of 1978-79, the eight-year war with Iraq and international sanctions, all of which have had significant impacts on this trend. Furthermore, political crises in neighboring countries, have led to widespread migration to Tehran, particularly from Afghanistan. All these events have led Tehran to become one of the largest and most important cities in Iran, with the population growth and urban development in the city accelerating (Rabiei-Dastjerdi, 2023). Population growth has led to increased demand for energy, food, housing, water, transportation, and healthcare, resulting in further exploitation of natural resources and significant changes in land use (Amini et al., 2022).

This process has put significant pressure on the available land and resources (Mohammady et al., 2016) and has considerably increased the demand for urban land (Khezai et al., 2023; Mohammadi et al., 2019). Urbanization, as one of the most significant forms of irreversible land use changes (Mohammady et al., 2016), has led to the replacement of green spaces with built-up areas and road networks (Abbaspour et al., 2023). This process results in unfavorable living conditions (Ahmadi et al., 2019), particularly due to the intensification of urban heat islands, increased energy consumption and harm to citizens' health (Ganjirad et al., 2025), as well as environmental pollution (Delavar et al., 2019).

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Land use change and its modeling is a complex process influenced by numerous natural, social, economic, and managerial aspects, including regulations and laws (Shafizadeh-Moghadam et al., 2017). One of the major challenges in this field is the lack of access to accurate spatial data and the dynamic nature of this process (Nadi et al., 2003). However, remote sensing (RS) and geospatial information systems (GIS) provide effective spatial modeling capabilities for monitoring urban changes, allowing for precise measurement of land use changes (Tayyebi et al., 2008). In recent years, various remote sensing platforms have been launched, among which the spatial resolution of Landsat data enables a more detailed study of land use changes (Amini et al., 2022). Moreover, Landsat is the only platform that has provided data for over four decades and remains active. The Landsat satellite data, captured by the Multi-Spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) sensors, allow for the analysis of land use changes (Defries et al., 2000). Machine learning (ML) algorithms, combined with multi-temporal satellite imagery, have been widely applied for assessing land use and vegetation changes in Tehran. In image classification, techniques including Support Vector Machine (SVM) and Random Forest (RF) are highly employed. In addition, the use of various indices, like the Normalized Difference Vegetation Index (NDVI), enables precise determination and monitoring of vegetation and garden condition (Arabi Aliabad et al., 2023).

For instance, Amini et al. (2022) used RF algorithm in land use/land cover (LULC) mapping. Their research demonstrates the application of ML techniques and satellite data for LULC change analysis and improving classification accuracy. Ferdous et al. (2020) propose supervised ML techniques, such as decision trees, as an effective method for addressing classification issues. Their findings suggest that the application of ML in image classification can significantly improve feature extraction and classification accuracy. Singh (1989) introduced various methods for change detection from satellite data, which primarily use classified images. These classified images are employed in the change detection process, which identifies differences in the state of an object or phenomenon by observing it at different times. They can effectively distinguish changed areas from unchanged areas and enhance the accuracy of the results .Alimohammadi et al. (2004) pointed out that radiometric and geometric errors in multi-temporal data, along with errors introduced during processing stages, particularly in classification and change detection operations, can significantly affect the accuracy and reliability of land use change. Therefore, it is essential to correct satellite images before their implementation.

Several studies have shown a decline in vegetation coverage in Tehran. For example, Heydarian et al. (2014) identified land use changes in Tehran using Landsat satellite imagery, and their results show a decrease in vegetation coverage. Rafipour et al. (2017) argue that the cause of this phenomenon lies in the insufficient impact of urban planning regulations and policies on the protection of green spaces. Despite the historical-cultural background for the preservation of green spaces and existing deterrent laws, the process of damage and degradation of these areas continues. The speed and intensity of construction, facilitated by regulations that permit development in these areas, particularly in the context of a profitable real estate market over recent decades, have accelerated the destruction of gardens and their conversion into high-rise buildings. Another reason for this can be found in Rabiei-Dastjerdi et al. (2016) study, where they argue that the rapid population growth of Tehran is influenced by various factors such as rural-to-urban migration (urbanization), post-war migration (reconstruction), and the influx of foreign migrants (globalization).

Hence, this study aims to examine the impact of laws and regulations on land use changes and the degradation of gardens in Tehran. To achieve this, Landsat images from the past five decades have been utilized, along with ML techniques and change detection methods. Change detection over time series is a crucial step in land use dynamics analysis, and it must be accompanied by the identification of factors affecting such changes and an assessment of their impact on environmental changes resulting from land use.

2. METHODOLOGY

To examine the effect of laws on green spaces and garden destruction in Tehran, a systematic framework of methodology was developed. It consists of remote sensing data, ML methods, and legal documents analysis and covers all the major steps of the research from data collection to model evaluation. Figure 1 demonstrates the conceptual model of the research.

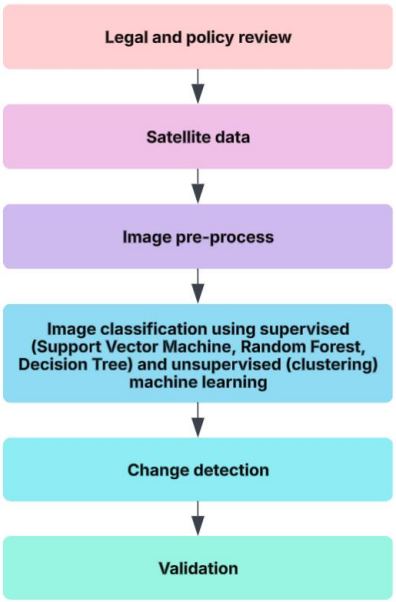

Figure 1. Conceptual model

The first stage of this research was dedicated to reviewing and analyzing the laws and regulations that affect the preservation or destruction of green spaces in Tehran and Iran. In this regard, the relevant institutions responsible for protecting and developing green spaces were first identified.

These included Tehran Municipality, the Islamic City Council, the Supreme Council of Provinces, the Ministry of Agriculture, the Department of Environment, the Ministry of Roads and Urban Development, the Ministry of Interior, and Deeds and Property Registration Organization.

Urban green spaces in Iran gained serious attention after the urban system was administered based on the law, with the approval of the Green Space Preservation and Expansion Act by the Revolutionary Council in 1980. In the same year, a directive allowing the construction of residential buildings in gardens, subject to specific regulations, was approved. In 1981, a directive was issued to refrain from issuing building permits for gardens to preserve trees and green spaces. In 1983, regulations for the division and partitioning of gardens were established. In 1985, it was mandated that approval from the Article 7 Commission was required for tree cutting on properties exceeding 500 square meters, as well as in streets or front of parking entrances. In addition, in 1989, directives were issued to control tree cutting and prevent unauthorized land use changes in gardens. In 1995, the Agricultural Land and Garden Usage Law was passed by the Islamic Consultative Assembly, prohibiting the conversion of agricultural land and gardens outside the legal boundaries of cities and towns unless necessary. Then, Article 686 of the Islamic Penal Code (approved in 1996) provided penalties, including imprisonment or fines, for the intentional destruction of trees under the Green Space Preservation and Expansion Act, in addition to compensation for damages. In 1997, a directive was issued for the partitioning of wooded lands and gardens. In 2003, the construction of high-rise buildings in gardens was regulated under the High-rise-Garden Resolution. Furthermore, the Executive Guidelines of Article 14 of the Urban Land Law (approved in 2008) are of particular importance in preserving green spaces.

To evaluate the impact of these regulations, and taking into account the time lag between their enactment, implementation, and actual influence, as well as expert consultations in the field of urban management, the study focused on analyzing land use changes and the degradation of green spaces in Tehran over the period from 1976 to 2016 using satellite imagery. The aim of this phase was to identify and clarify the relationship between urban planning laws and policies and the reduction of green spaces in Tehran, in order to accurately assess how these regulations have influenced land use changes and the decline of urban green areas.

3. Case Study

The satellite data used in this study pertains to five key years including 1976, 1986, 1996, 2006 and 2016 (Figure 2), which coincide with legal changes and urban growth in Tehran. These years were selected to track the temporal evolution of green space loss. The satellite images from 1976 were obtained from the USGS Landsat 2 archive, and from 1986, 1996, 2006, and 2016, they were acquired using Landsat 5, 7, and 8 from the Google Earth Engine platform. All of these images were taken during the Summer to ensure consistent vegetation conditions for analysis, providing a comprehensive view of land cover changes in Tehran and insights into the impacts of urban expansion on green spaces.

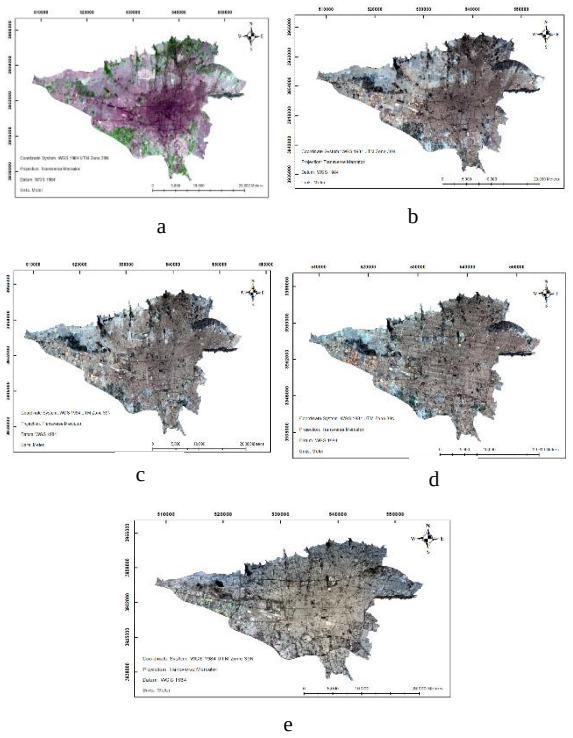

Figure 2. Landsat satellite images of Tehran from 1976 to 2016, (a) 1976, (b) 1986, (c) 1996, (d) 2006, (e) 2016. Scale ≈ 1:100000.

All satellite images were first geometrically and radiometrically corrected and then transformed to the WGS84 UTM Zone 39N coordinate system to ensure alignment with one another. Since the Landsat 2 images had a 60-meter spatial resolution and the other employed images had a 30-meter spatial resolution, all images were resampled to a 60-meter spatial resolution for consistency. Next, NDVI was calculated for each image to enhance vegetation coverage and classification accuracy, and this index was then stacked with the original images.

After the images were preprocessed, these data were run through ML algorithms for land cover type identification and classification. Initially, the optimum number of clusters for the images was determined using unsupervised ML by the K-means algorithm and the Elbow method. The aim of this method is to determine the number of clusters that best separate the data. The K-means algorithm was first run for different numbers of clusters, and for each number of clusters, WCSS (Within-Cluster Sum of Squares) was calculated. WCSS specifies the amount of scatter of the data within each cluster, i.e., the lower the value of WCSS, the closer the points within the clusters are to the cluster center, and the denser and more consistent the clusters are.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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Then, a plot was drawn (Figure 3) where the horizontal axis was the number of clusters and the vertical axis was the WCSS value. The WCSS value falls with the increase in the number of clusters because, as new clusters are introduced, the points get closer to the cluster centers. However, after a point, the fall becomes extremely gradual. This is referred to as the elbow point, and it represents the optimum number of clusters. In Figure 7, 4 clusters were identified as the elbow point, which represents the optimum split for the data.

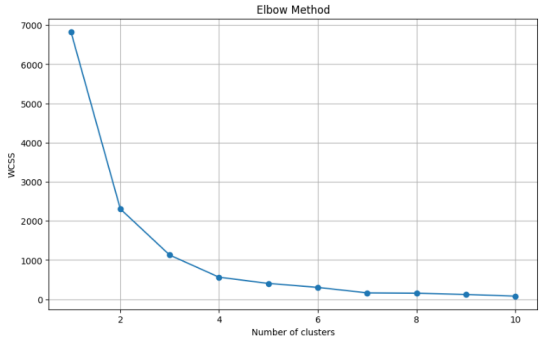

Figure 3. Elbow method plot for determining the optimum number of clusters in the K-means algorithm.

Then, in the supervised ML stage, these classes were divided into two main categories including green spaces and non-green spaces areas. For more accurate classification, three ML algorithms including RF, DT, and SVM were used. These algorithms were trained using sample data from vegetation and non-vegetation areas. By calculating the overall accuracy and Kappa coefficient, it was found that the SVM algorithm provided the most accurate results in distinguishing green spaces from non-green spaces (Figure 4).

In general, change detection methods can be categorized into two main approaches: pixel-based and object-based (Dahle et al., 2021). In this study, the pixel-based method was used, and pixels in the images were compared with each other using the Post Classification Comparison method to identify changes and degradation of vegetation over ten-year intervals (1976-1986, 1986-1996, 1996-2006, 2006-2016). For each time period, the area and percentage of degradation of green spaces were calculated to determine the extent and scale of green space reduction in Tehran. Although change detection was performed for the entire city of Tehran, special attention was given to areas with significant vegetation loss, such as the Kan region in the western part of Tehran, which has historically been recognized as an area with large gardens. The degradation of green spaces in this area was examined by comparing satellite images with high-resolution images from Google Earth over the years.

In this study, to ensure more accurate validation, archived data from Google Earth spanning multiple years were utilized to confirm the presence of green spaces and the extent of vegetation loss in the selected areas. Some pixels were randomly selected and used as reference data for evaluating classification accuracy. Using these data and calculating the confusion matrix, the change detection accuracy was determined.

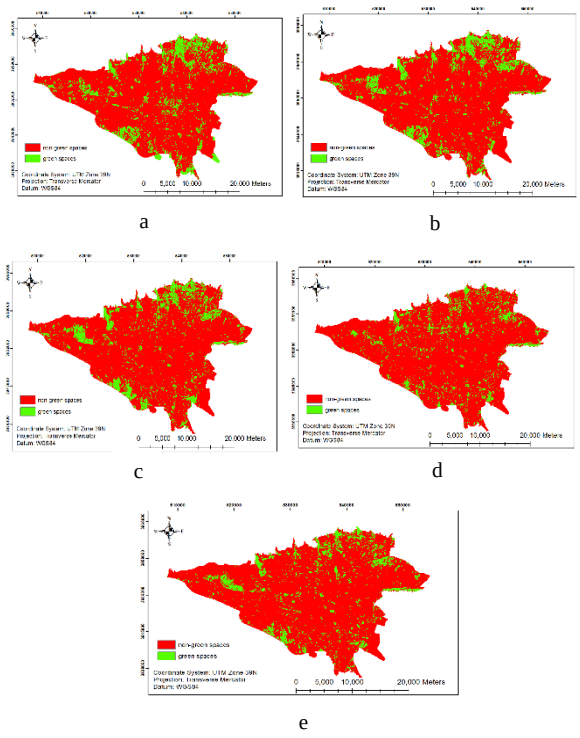

Figure 4. Green spaces classification in Tehran (1976-2016) using the SVM method, separating green spaces (green) from non-green spaces (red) areas, (a) 1976, (b) 1986, (c) 1996, (d) 2006 and (e) 2016.

The performance of the three ML algorithms, including SVM, RF, and DT, was evaluated using overall accuracy (Figure 5) and the Kappa coefficient (Figure 6).

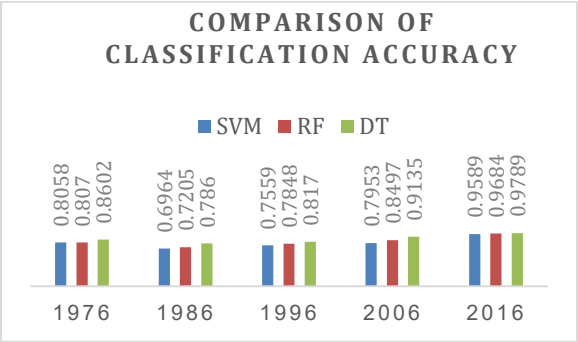

Figure 5. Comparison of overall classification accuracy for three ML methods (SVM, RF, and DT) across different years (1976, 1986, 1996, 2006, and 2016).

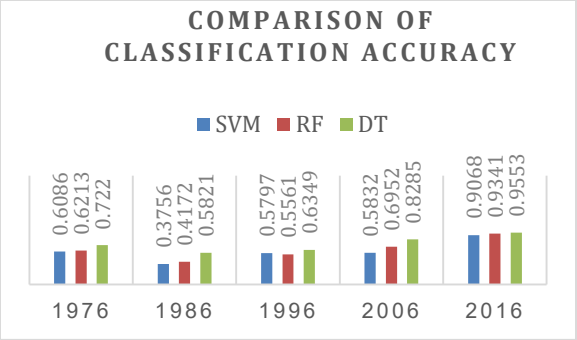

Figure 6. Comparison of the Kappa coefficient for classification accuracy using three ML methods (SVM, RF, and DT) across different years (1976, 1986, 1996, 2006, and 2016).

The results demonstrated that the SVM algorithm outperformed the other methods in accurately classifying vegetation and non-vegetation areas in Tehran. Accordingly, the classified images produced by the SVM method were selected as the basis for the land use change analysis, and the extent and percentage of vegetation loss were calculated for each ten-year interval.

The results of the land cover classification comparison revealed the identification and analysis of vegetation changes and degradation during the time intervals of 1976-1986, 1986-1996, 1996-2006, and 2006-2016 (Table 1).

Time	Destroyed area (m^2)	Destroyed Percentage
1976-1986	10,800	11.11
1986-1996	21,128,400	19.60
1996-2006	14,234,400	15.62
2006-2016	24,242,400	26.73

Table 1. Vegetation destruction area and percentage in Tehran over different time periods

These findings indicate a significant reduction of vegetation cover across large areas of Tehran during the mentioned periods (Figures 7). The red areas indicate regions where vegetation loss has occurred. To assess the accuracy of the detected changes, ground reference data were used, based on which the average overall accuracy of the output was estimated at approximately 73%.

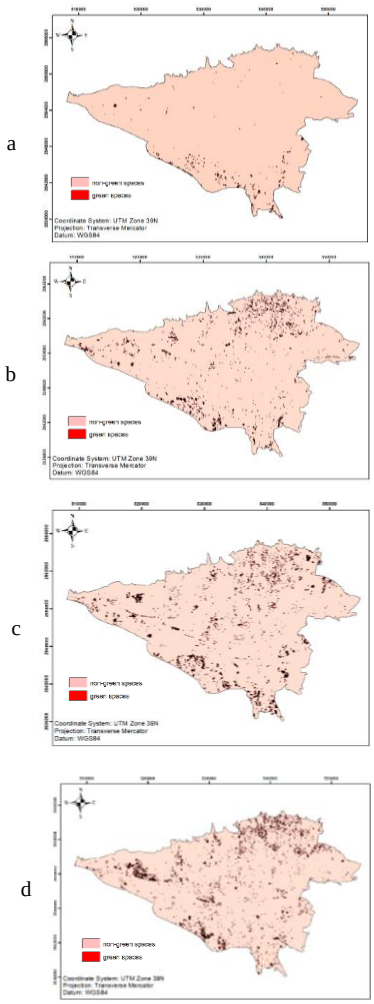

Figure 7. Green spaces degradation maps of Tehran, (1996-2006), a) 1976-1986, b) 1986-1996, c) 1996-2006, d) 2006-2016.

Furthermore, as one of the key outputs of this study, the persistent green spaces degradation map was generated (Figure 8). This map illustrates the spatial patterns of areas that experienced continuous reduction in green space, represented by the black color, throughout all the analyzed periods. According to this map, Tehran Municipality Districts 1, 2, 3, and 5 were identified as the main hotspots of persistent green space destruction in Tehran.

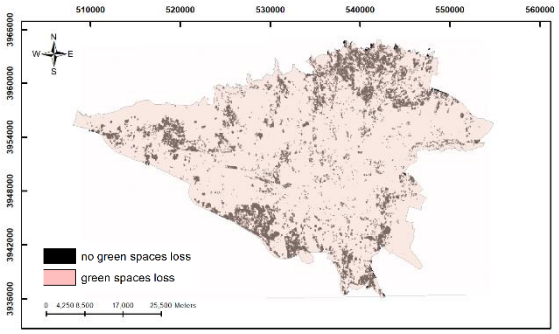

Figure 8. Persistent green space loss map of Tehran. The map is presented for the time interval of 1976-2016.

Up to this point, the overall degradation of green spaces in Tehran, encompassing public green spaces (such as parks), semi-public spaces (open areas of offices and cultural centers), and private spaces (including productive and non-productive gardens), has been examined. As mentioned, the greatest degradation of green spaces is clearly observed in Districts 1, 2, 3, and 5. Since private green spaces are essentially gardens, the primary objective of this paper is to assess the extent of degradation in these spaces. To achieve this, we focused on a case study of the Kan gardens in Municipality District 5 (Figure 9) in western Tehran. This area was chosen due to its long-standing history of gardens.

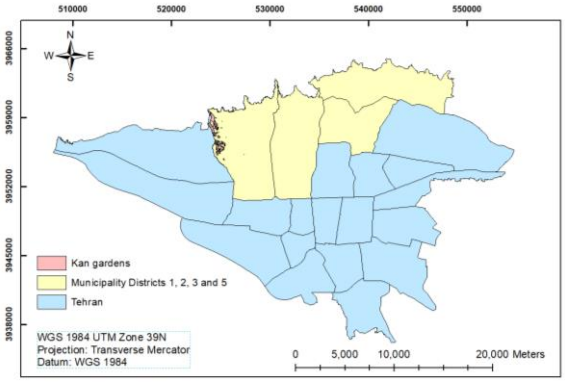

Figure 9. Municipality Districts 1, 2, 3 and 5 of Tehran, including the Kan gardens

Google Earth images revealed that many of the gardens, which in 1976 formed a significant portion of the landscape in this area, were completely replaced by dense urban developments by 2016 (Figure 10). The light blue area in the images highlights the Kan region. That is why these spaces play a crucial role in improving the ecological and environmental capacity of the city, with no cost of maintenance to the urban management.

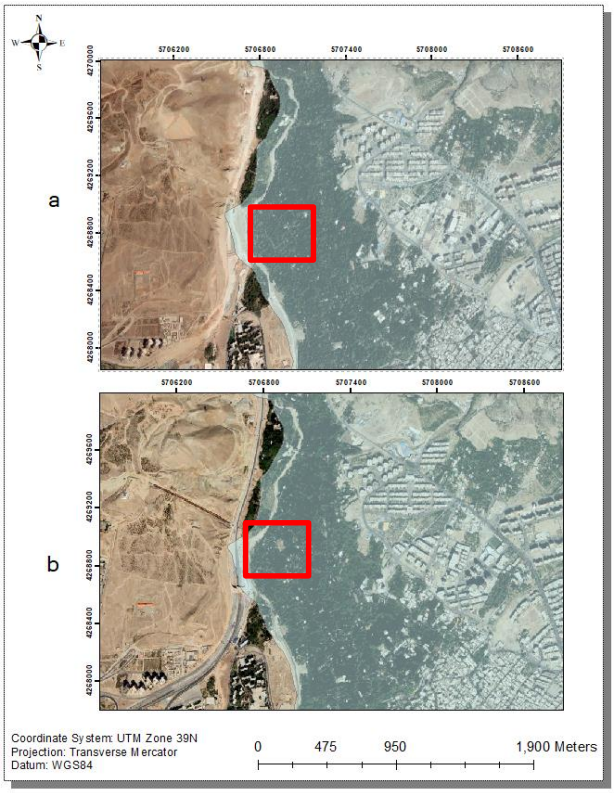

Figure 10. An example of green space destruction in Municipality District 5 of Tehran over the time period from 2006 to 2016: (a) Satellite image from 2006, (b) Satellite image from 2016, Source: Google Earth, Scale ≈ 1:2000.

Analysis of the decline in urban vegetation cover in relation to key legal and policy milestones reveals distinct patterns of accelerated land use change during specific periods in Tehran. The findings of this study indicate that the highest rate of green space degradation occurred between 1996 and 2016. However, the legal foundations of this trend were laid in earlier years through a series of regulations and policy decisions.

The first major turning point was the enactment of the Urban Land Law in 1987, which aimed to regulate urban land management and granted the government authority to acquire or change the use of urban land. A critical development followed in 1995 with the implementation of Article 14 of this law, which significantly contributed to widespread land use conversion of gardens into construction projects. The second key milestone was the "Tower-Garden" resolution passed in 2003. This regulation, originally intended to manage population density and prevent uncontrolled horizontal urban expansion, allowed owners of gardens larger than 1,000 square meters to obtain permits for constructing high-rise residential or commercial buildings, provided that a minimum amount of greenery was preserved. Despite the existence of certain green space preservation requirements, in practice, these were either ignored or interpreted in a flexible and permissive manner. As a result,

the resolution effectively became a legal tool for the gradual destruction of private urban gardens.

Overall, the analysis demonstrates that although many laws and policies were introduced with the stated goals of sustainable urban management and environmental protection, the lack of strong oversight, environmental impact assessments, and integrated implementation mechanisms turned these frameworks into catalysts for the rapid degradation of urban green spaces. This experience underscores the need to reassess urban policymaking through a comprehensive, coordinated, and environmentally centered approach.

4. CONCLUSION

This study was conducted to analyze the spatio-temporal patterns of green space degradation in Tehran from 1976 to 2016, utilizing Landsat satellite imagery and ML algorithms. The findings indicate that a significant land-use change occurred during this period, with many green spaces and gardens being converted into urban areas.

Spatial analyses revealed that in the northern parts of Tehran, where urban expansion is constrained by natural barriers such as the Alborz Mountain range, gardens have been severely degraded and replaced by high-rise buildings. Similarly, the western expansion of the city has led to a substantial decline in green spaces and orchards in that region.

In terms of classification accuracy assessment, the results showed that the SVM algorithm outperformed other ML methods, including DT and RF, in distinguishing between vegetated and non-vegetated surfaces. However, the overall accuracy of detected changes was reported to be around 73%, indicating moderate model performance. This outcome highlights the necessity of employing higher spatial resolution data and refining modeling approaches. Although a spatial resolution of 60 meters was selected due to temporal and data availability constraints, utilizing higher-resolution imagery could improve both the accuracy and reliability of the results. It should be noted that the performance of ML models is highly dependent on the quality of input data and the availability of accurate ground-truth information.

Beyond spatial analyses, an investigation into the relationship between vegetation decline and changes in urban management policies revealed that certain existing regulations despite their ostensibly protective intentions, have inadvertently facilitated the process of green space degradation. Factors contributing to this issue include weak enforcement of laws, legal ambiguities, an economy-driven approach toward garden lands, inconsistent and varying definitions of “garden”, high maintenance costs of gardens, greater profitability of construction compared to agriculture and environmental preservation, and the lack of legal responsibility of municipal authorities regarding the preservation of private gardens.

These findings clearly emphasize the urgent need for a comprehensive review of urban planning law and underscore the importance of strengthening executive and supervisory mechanisms to protect urban green spaces. It is also recommended that future research utilize satellite data of higher spatial, spectral, radiometric, and temporal resolutions, as well as more accurate ground truth data and more advanced socio-economic data—such as land use policies, development plans in terms of detailed plans, large-scale migration to Tehran, and high demand for urban construction. Moreover, incorporating recent advanced deep learning methods can enhance the accuracy of change detection and enable a more comprehensive analysis of the drivers of urban land-use changes. Furthermore, more recent validation criteria, such as Receiver Operating Characteristic (ROC), Total Operating Characteristic (TOC), Figure of Merit, Recall, and Precision, can be applied in subsequent research.

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