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Introduction to a quantitative method for assessment of visual impacts of Tehran Towers

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Landscape arrangement significantly influences observer's visual experience of the environment. Since measuring this qualitative experience is more based on personal judgments than mathematical techniques, representing "quantifying methods" in this field demands a significant amount of caution and accuracy. This research is an attempt to quantify visual impacts of seven-story- and higher-buildings on observers' view of Tehran's district 3 from 1993 to 2006. For this purpose observers' visibility of the surrounding landscape was calculated for 17 random points of the region, at 1.5 and 10 m, before and after construction of towers in that period by use of Geographical Information System (GIS, Arcmap V.9.2). The result of this research indicates that visibility of citizens of Tehran has decreased from 13% in 1993, after construction of 12 towers, to 45% in 2006 after construction of 255 towers. The objective of this research was to assess the visual impacts of structures on landscape and to attempt to clarify the necessity and importance of applying Visual Impact Assessment (VIA), among other environmental assessments in new urban developments.

Key words: Landscape, geographic information system (GIS), viewshed, visibility, building, regional planning, visual impact assessment.

INTRODUCTION

Visual impact assessment (VIA)

The arrangement of landscape significantly influences the visual experience of the environment. The sales price of a home or the aesthetic impact of a scenic lookout is greatly influenced by the view that it offers, which is usually determined by the landscape features that are directly visible from observer locations. While view quality is partially dependent on the relatively unchanging landscape elements like mountains or valleys, views are also affected by more readily altered landscape features, particularly built structures such as buildings (Miller, 2001; Medineckiene et al., 2010). The arrangement of these elements can significantly impact how humans experience their environment, as even slight changes in these elements may drastically alter human perception of

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the visualscape. Changes in land use associated with urbanization often impact human perception of the landscape, frequently with negative economic and social consequences (Sander and Manson, 2007).

The first step in understanding these negative impacts is to quantify them, a process which is usually known as Visual Impact Assessment (VIA). Tidey and Pullar (2001) have defined VIA as “the formal process used to evaluate the visual metrics of a proposed development with respect to passive human interaction”.

Unlike many other Environmental Impact Assessment methods, VIA is based more on experience and judgment (Environmental Assessment and Landscape Institute, 1995; Paliokas et al., 2007; Ramos and Panagopoulos, 2004). Therefore, quantification of these impacts is the important factor that distinguishes different methods of visual impact measurement from one another.

Classification of research in the field of VIA

Many research projects, with different approaches, have been carried out in the field of VIA. Below is a general classification of most of these methods. However, there remain some exceptions which were not included in this classification.

(i) Some researchers have surveyed the impacts of color, texture, lines, shapes and combinations of new urban developments on the observers’ view. For analyzing visual impacts of new developments on the landscape, these researchers have surveyed the harmony of these developments with their background environment and finally presented some solutions for new developments that are in accordance with the landscape (Shang and Bishop, 2000; Liu and Bai, 2001; Garcia et al., 2006; Hernandez et al., 2004).

(ii) Other researches into development impact assessment have used virtual environments for analyzing the impacts of one suggested development. They use computer simulations to create virtual environments which are very similar to the actual environments. Then, by applying different suggested development scenarios in these virtual environments, they simulate and usually quantify the visual impacts of development, and finally suggest the best scenario (Tyrväinen et al., 2006; Pullar and Tidey, 2001; Schofield and Christopher, 2005).

(iii) Some approaches in this field are based on public inquiries. Usually in this type of research some photos are first taken of the study area. Then, by the use of computer techniques, suggested developments are added to them. The photos are then handed to people to comment about the proposed development. Finally, by using statistical methods, the researchers find the best location for suggested developments (Tahvanainen et al., 2002; Scenic Spectrums Pty Ltd, 2004; Rogge et al., 2007; Theocharis et al., 2009).

(iv) Another group of research projects in the field of VIA is based on using satellite or photographical images. These researches survey and compare satellite or photographical images from two or more years and find changes in environmental aspects such as vegetation, topography, water resources and man-made constructions. Then the percentage of change in each of the above-mentioned aspects is calculated to assess changes in visual aspects (Mouflis et al., 2008; Ayad, 2005; Millington et al., 2009).

(v) Another approach in VIA research is the analysis of development impacts by using GIS tools (Zhang et al., 2004). These researches add new suggested landscape developments as new features to present layers, then measure changes in view line before and after these developments. They finally suggest a percentage of changes in the landscape or view line as the visual impact of development (Rogge et al., 2008; Moller, 2006).

Objectives of the research

Considering the above-mentioned researches in the field of VIA and the models and experiences they represent, this study has taken a new step towards the completion of previous research by using Geographical Information System (GIS) and viewshed measurements to assess the visual impacts of newly constructed buildings in Tehran. Tehran is the largest city of Iran and the nineteenth largest city in the world (United Nations, 2008). Nowadays, new developments in the city centre and suburbs have destroyed its original and native appearance. The dense vegetation and several stream channels in the city’s mountainous landscape have been replaced by apartment buildings and towers. The existence of so many towers within a short distance not only has negative aesthetic results but also restricts eyesight to short distances, which is one of the main causes of myopia (nearsightedness) especially among children (American Optometric Association, 2009).

With this approach, in this study the amount of decrease in view due to construction of new towers in the 3rd district of Tehran during the fourteen years from 1993 to 2006 was calculated and the amount of landscape change by 2024 was predicted. Compared to most of the previous studies in the field of visual impact assessment, the main difference of this research is its scale. In this method, the scale is closer to the regional planning scale of 1:25,000, while most of the other research in this field has focused on scales such as 1:5000 and 1:2000. The general hypothesis of this research is as below.

The increase in the number of towers in the 3rd district of Tehran has caused changes in the visibility to citizens of their surrounding landscape in this city district. The results provide valuable data for regional planners to help them identify and locate places suitable for new urban developments by considering visual pollution and suggested mitigation plans for reducing visual pollutants

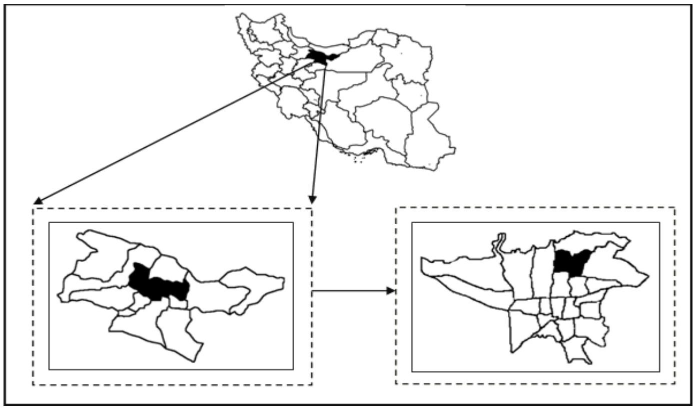


Figure 1. Study area.

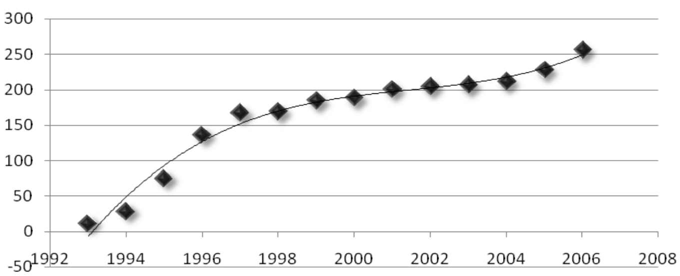


Figure 2. Number of towers constructed in District 3 of Tehran during 1992-2006.

in densely populated urban regions.

MATERIALS AND METHODS

Given the increasing rate of tower construction in Tehran between 1993 and 2006 and the continuation of this process to the present, this essay has studied the visual impacts of tower construction during these fourteen years. The measured parameter in our method is visibility at the observer points. To increase the accuracy of the results, the GIS (Arcmap V.9.2) was employed, to provide accurate and spatial measurements of the desired parameter.

Study site

Due to the higher average rate of tower construction in this region during the study period compared to other regions (Municipality of Tehran, 2006), District 3 of Tehran was selected as the study site in this research (Figure 1). This region is located in the northern part of Tehran at 1344-1506 m above sea level (National Cartographic Center of Iran, 2006). The landscape of the study site consists of the Alborz Mountains to the north and the Tehran plain to the south, which creates a beautiful landscape on a clear day for the citizens. However, as mentioned, due to the increasing rate of tower construction, most of the landscape is obstructed by buildings and towers. Figure 2 illustrates the increasing rate of tower construction in this region from 1992 to 2006 (Municipality of Tehran, 2006). A schematic view of the study site with the location and dimension of towers is shown in Figure 3. To better illustrate the relief in the region, topography was somewhat exaggerated.

Viewshed analysis by means of GIS

Viewshed analysis has been widely accepted in VIA analysis (Manwell et al., 2002). Viewshed is determined by drawing the “lines of sight” between the objective point and observer point in a grid-type landscape model. Big topographic obstacles in the view line such as pits, trees and buildings limit the view (Burrough and McDonnell, 1998). By the use of such simple data, big progress can be made in understanding the observed landscape and in making a visual impact assessment.

Viewshed analysis is binary in the sense that an object is either visible or not (Moller, 2005). Viewshed is also referred to as the “visibility basin”, which is the spatial illustration of visual capability. The visibility basin shows which points are and which points are not visible from an observer’s point of view. Therefore, by calculating the visibility basin for many observer points, Viewshed could be created, and the result is a raster layer in which each cell contains the number of visible points from that cell.

Locating towers and Viewshed settings

New and modern tools in GIS have ideally made viewshed mechanized. The viewshed algorithm in Arcmap calculates visibility in the centre of each cell by comparing the right angle in the centre of that cell with the right angle of the local horizon in the raster network. Here, the local horizon defines land features that obstruct the view line. A point would be visible if it is located above the local horizon (ESRI, 2001). For calculating viewshed in this research we used Triangular Irregular Network (TIN) which has been mentioned by Stillwell and Clarke (2004) and the updated 1:25,000 topographic maps printed by the Iran Mapping Organization in 2006. These data were available in 250 m resolution, which enabled highly accurate calculations in this research. Although these maps included exact geographical locations of buildings, to acquire information about the heights of the towers we had to use the data published in 2006 by the Municipality Statistics Centre. These data, which were provided in table format, included the heights and areas of the towers in the 3rd district but unfortunately the exact locations of towers were not determined. So we combined the two available datasets, to locate the buildings approximately on our maps. Fortunately the high accuracy of the existing maps did not allow any significant possible error at this data-combination stage. Since the statistical data of tower heights prior to 1993 were not easily accessible, to make a comparison with the present situation we assumed that no high towers existed in this city district before 1993. Considering the 1993 statistics, which report only 12 constructed towers in that year, this could not be a wrong assumption.

On the basis of these assumptions, we first produced the TIN of the study area by using the existing topographic map. In the second step the “layer” of seven-storey and taller towers constructed in each year which obstruct the view line was added to the TIN. This created a network of different elevations for each year corresponding to the height of the towers. Therefore an individual TIN was produced for each year, which included the topography of the area and the tower heights. In order to prevent possible errors resulting from the addition of small features higher than neighbouring points, a buffer was selected for each tower with a height equal to the altitude where the tower was located. As a result, for each tower two values were added to the TIN. One value was the accurate height of the tower in the specified place and the other was the buffer around each tower according to the elevation of the place where the tower was located. The TINs produced good

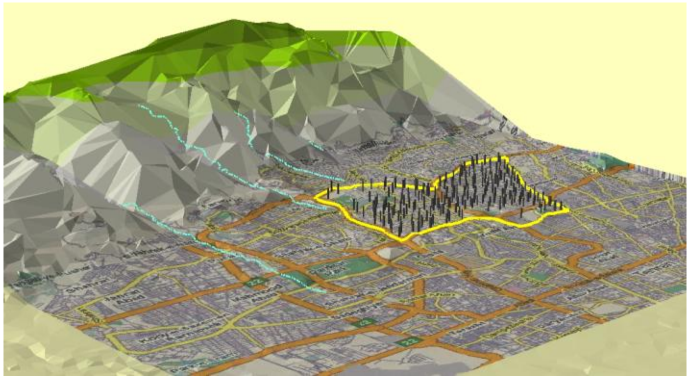


Figure 3. Schematic view of the position of District 3 in the Tehran plain (outlined in yellow) and the location and dimension of towers.

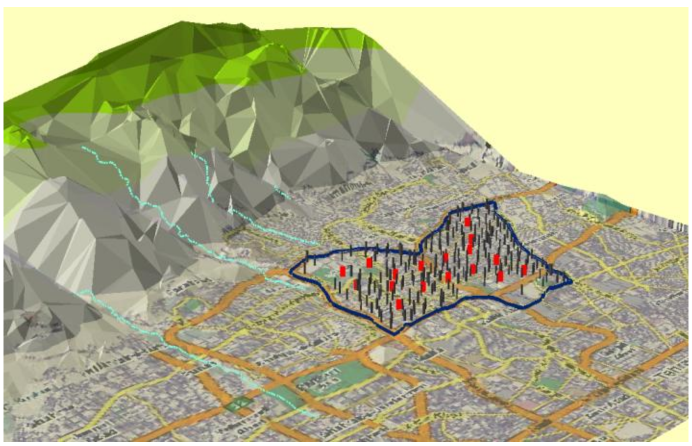


Figure 4. Position of Observer Points (red squares) in the study area.

references for measuring the Viewshed or Visibility Basin for each year.

Creating viewsheds from 1993 to 2006

The next step was to create viewsheds on each TIN that (as mentioned before) was representative of topography and the number and height of the towers in each year. For positioning observer points, the "Fishnet" tool in Arcmap was used, determining the observer points regularly and with specified distances. To prevent "edge effects", no observer points were determined within 500 m of the region's boundaries. So the boundaries of the region were dragged into a -500 m buffer with respect to the observer points. Figure 4 shows the observer points in the study area.

As shown in Figure 4, since these points have been chosen with regular distances, it could be said that the observing situation in the whole region is the mean of observing situations in all the observer points. After the observer points were located, their heights were identified. For this purpose, we used two different heights for making viewsheds: first, an observer height of 1.5 m, which is close to the average height of adults in Iran (1.66 m) (Haghdoost et al., 2008); and second, the observer height in the third floor of buildings, which is 10 m. Considering the fact that most of the residential buildings in Tehran have five stories (Annual Statistics of Tehran City, 2007), the height of the average storey (third floor), 10 m, was taken as the observer height. Finally, by combining seventeen points in different parts of District 3 during the fourteen years from 1993 to 2006, and by considering the two observer heights, 1.5 and 10 m, a total of 476 viewsheds were created on the TINs (2*14*17=476). This was the most time-consuming part of the process, and its outcome, the 476 viewsheds, were summarized and analyzed.

Cell statistics and evaluation

In this step all the results and maps created in previous steps were analysed. Seventeen viewsheds in each year at two different heights were analysed by using the "Cell Statistic" tool. This tool performs statistical analysis on the values that belong to each cell in different layers. The analysed layers were 17 viewshed layers for each consecutive year. Zero was the value allocated to each cell for no visibility and 1 was the value allocated in case of visibility.

In particular the visibility for each year was calculated using the cell statistic function and then it was compared with the visibility of all the past years. So, the result shows the cumulative difference in visibility between the destination and all the past years. As an example, if a cell has a value of 0.5, it means that it would be visible during seven of the fourteen years and would be invisible in the other seven years. Therefore one final layer was made for each year and height showing the average data for that year. By using this simple algorithm, the different amount of visibility during each of the studied years was calculated for all cells. The outcome was maps that illustrated differences in lines of sight in different years spatially. These maps were again classified by using the "Reclassify" tool in Arcmap to show these changes more clearly.

RESULTS AND DISCUSSION

Viewshed analysis at 1.5 m

Figure 5 shows significant changes in visibility at 1.5 m in Tehran's District 3 during the fourteen studied years. This figure is the result of average viewshed value differences between each of the fourteen years and the 1992 viewshed values, at 17 observer points. As this figure illustrates, visibility has declined by increasing number of towers in continuous years. The rate of this decrease is shown as a linear equation in Figure 6. This figure shows that visibility in the 3rd district has decreased almost linearly with a slope equal to -0.85, as the number of towers has increased. Assuming 1992 as the reference year, visibility has decreased by 18% in 1993 compared to the previous year and by 23% in 1994. At an almost linear rate it drops to 40% in 2006. This is an indicator of the high impact of newly constructed buildings on the visual capability of Tehran residents.

According to this figure, and by considering the current construction rate in Tehran, an increase in the number of towers in future years to 478 and 713 will decrease visibility by 60 and 80% respectively. This means that citizens of Tehran in the 3rd district will experience a 60% decrease in their surrounding landscape in 2019 and an 80% decrease in 2034. In view of this exponential decrease in the visual capability of citizens, especially

Figure 5. Percentage of decrease in visibility at 1.5 m, after construction of Towers between 1993 and 2006.

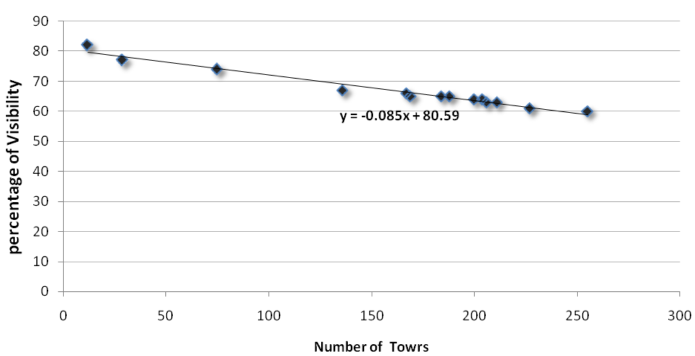


Figure 6. Decrease in visibility at 1.5 m in Tehran's 3rd district with the increase in the number of towers, 1993-2006.

children, urban planners should pay more attention to the granting of construction licences. To illustrate better the decline of visual capability, the visibility difference in 1993 and 2006 is shown in Figure 7.

Another remarkable point in the visibility graphs is relationship between the changes in these graphs and the changes in policies of Tehran municipality, which is clearly shown in Figure 8. This figure shows changes in visibility in the 3rd district at 1.5 m during 1993 to 2006. This figure shows that the visibility rate decreased considerably during 1993 to 1996. However, this rate was almost unchanged between 1996 and 2000 and showed a small decrease by 2004. After 2004, again, a fast decreasing trend is seen in visibility. Between 1996 and 2004, the policies in issuing construction licences were

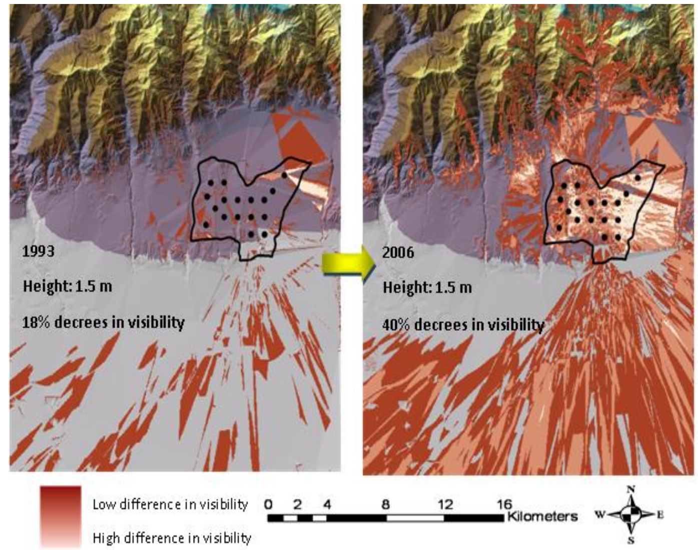


Figure 7. Significant difference in visual capability of observers at 1.5 m in Tehran's 3rd district after tower construction in 1993 and 2006.

changed by Tehran's municipality, and the impacts of this change are clearly seen in this graph (Abdi and Khodayian, 2004).

Viewshed analysis at 10 m

Here the results of visibility decrease at 10 m due to tower construction are presented. Figure 9 shows the differences in percentage of visibility between each of the fourteen years studied and the reference year (1992) as pie charts. As the graphs show, the trend of visibility changes at this height is approximately similar to those at 1.5 m, but visibility decrease at this height is almost 2% less than at 1.5 m. Average visibility decrease during these fourteen consecutive years is about 33% at 1.5 m and about 31% at 10 m. The cause of this difference might be the elimination of the impact of smaller towers on the view at a greater height. This means that the visual capability of observers in the higher storeys is not affected by the smaller towers.

The decreasing trend of visibility at a height of 10 m is shown as a linear curve in Figure 10. The remarkable point is the -0.148 slope in the visibility trend, which is steeper than that at 1.5 m (-0.085). This could be attributed to the higher rate of construction of taller towers in the region. If we assume 1992 as the reference year again, the visibility decrease at 10m will vary in a linear trend from 12% in 1993 to 47% in 2006. Given the rate of visibility decrease at this height, and assuming that the current construction rate in Tehran continues, this leads to 60 and 80% visibility decreases in 2011 and 2018 respectively.

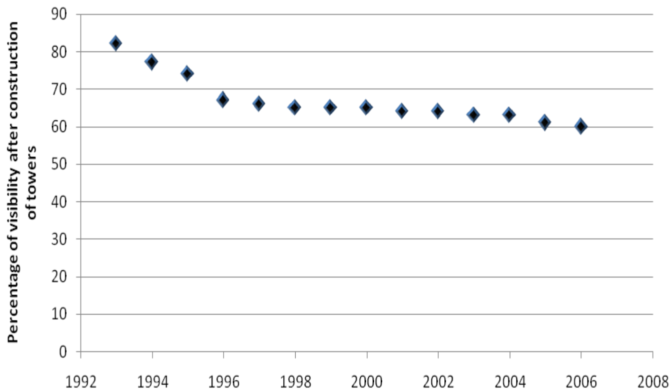
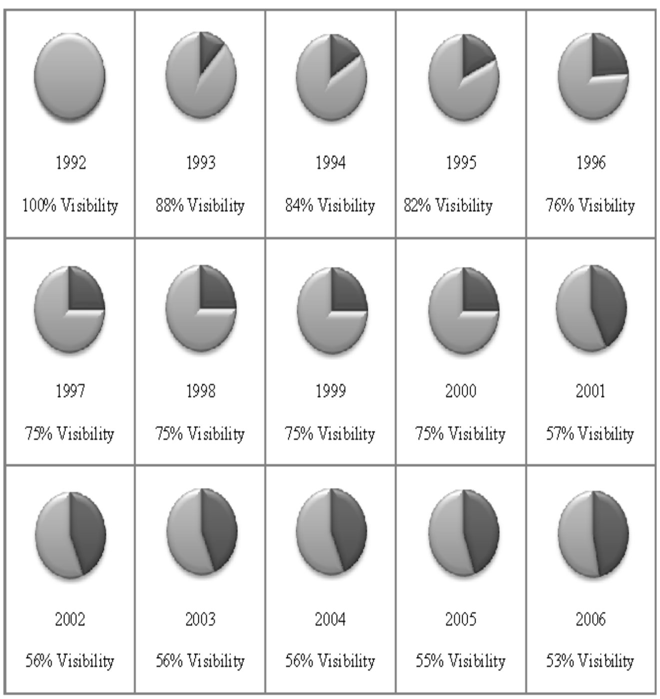


Figure 8. Decrease in visibility at 1.5 m in Tehran's 3rd district, 1993-2006.



CONCLUSION AND RECOMMENDATIONS

Since visual quality might have positive or negative impacts on the observer's experience of a region, researchers and planners are interested in studying the visual influences of new developments on the landscape. Predicting the impact of one structure on the landscape allows new developments to be made in a way that maintains the visual quality, or at least has minimal negative impact. In this regard, this research has quantitatively measured the visual impacts of building construction on the observer's view in the 3rd district of Tehran from 1993 to 2006.

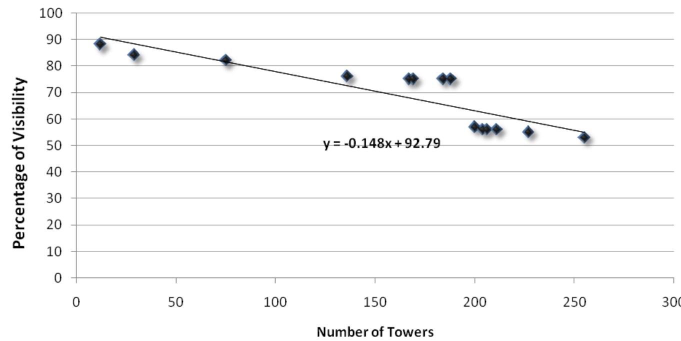


Figure 10. Visibility decrease at 10m after construction of towers, 1993-2006.

The results indicate that the increase in the number of towers in the 3rd district of Tehran has reduced the visibility of the surrounding landscape in this region. Visibility has an inverse relationship with the number of towers, so with the construction of twelve towers in 1993 visibility at a height of 1.5 m in this region dropped to 82%. This linear decreasing trend continued at an almost constant rate and a slope of -0.085, and finally, in 2006, after the construction of 255 towers in this region, visibility decreased to almost 60%. Extrapolating this linear graph to 2019 and 2034 shows 40 and 20% decrease in the initial view, respectively. Slightly different results were obtained for observers at 10 m: visual capability of observers at this height will be reduced to 40 and 20% of the initial value in 2011 and 2017, respectively. These worrying results indicate the severe impacts of tower construction on the visual capability of citizens. One of the negative aspects of this decline in visibility is the restriction of the view to short distances and therefore an increase in myopia, especially among children. Such an impact and many other unknown ones should force officials and planners to control the rates of tower construction in metropolitan areas, despite the two major challenges in these areas:

(1) Housing the increasing population;
(2) The lack of space for supplying houses for this population.

However, there are some solutions in this regard, such as:

(i) Designating open areas around each tower which can be dedicated to green spaces. This open space can create a proper distance between the observer and the building to decrease its visual impact (Ashihara, 1983).
(ii) Preventing the construction of towers as individual free-standing buildings in areas of single housing units. Oh (1998) mentions that visual impacts of towers are not only dependent on their heights but also dependent on their arrangement in city visage. For example, two tall

towers built close to each other may have smaller visual impacts than a shorter but isolated tower (Oh, 1998).
(iii) Building towers in staircase forms and at a proper distance from each other to prevent decreases in visibility.

Nevertheless, proposing solutions for decreasing the visual impacts of building construction needs special attention to be paid to all related factors which are beyond the scope of this study and should be addressed elsewhere. Another result of this study is the presentation of VIA as a method for quantifying the visual impact of buildings, which is hard to quantify, like other environmental assessments. Despite the high importance of landscape in people's lives (Wherret, 2002; Lothian, 1999), a lack of accurate quantitative techniques for its assessment has created a lot of subjectivity in this field of science. This research addresses this issue and represents a new and accurate technique for quantifying visual impacts of tower construction on landscape. For this purpose the parameter of visibility, and its changes before and after new developments, were easily measured by employing GIS (Arcmap V.9.2). Visibility is one of the parameters that enable quantification of visual impacts with minimum subjectivity. Also, our method has a fundamental difference from previous methods in which the VIAs that measured the visibility parameter focused on the number of constructed buildings that were visible from the observer points: in this research, manmade buildings as topographic features were added to the existing topographic map and individuals' visual capability was calculated according to the new topography. Application of this method produces interesting data that could be used by researchers for calculating the average change of landscape for observers. There are of course uncertainties in this method - for instance, whether this decrease in urban landscape could be recognized as a visual impact or not (Stamp, 1997). Many researchers might believe that towers and buildings are inseparable components of a city and it is not reasonable to recognize them as having a visual impact. Moreover, this paper has only mentioned the percentage of visibility decreases and has not calculated any visual impact thresholds (Oh, 1998). We did not specify how much visibility decrease counts as a visual impact threshold.

Nevertheless, this method has opened a new window to research in the field of landscape assessment by recognizing VIA as another tool for environmental assessment in urban planning, and by analysing one of the most important issues of modern urban life, which is the visual impact of manmade features.

Future researchers in this field can evaluate the economic costs of visual impacts for residents. Considering the facts that nowadays almost 50% of the world's population lives in cities (United Nations, 2005) and the majority of metropolitan areas are experiencing a large variety of developments, evaluating the economic costs of these development-related visual impacts is essential for the cities. These economic costs may include medical, social, psychological and other costs (Ibrahim, 2000).

In addition this research study focused on the building higher than seven stories, however it seems that even a unique small building could obstacle the view of a tower from some locations which should not be ignored, especially in the landscape of small towns or countryside. So, further researches in this field can be concentrated on the calculating the impacts of any manmade obstacle on the observers view and propose the suitable solutions for reducing these kinds of impacts. Also, standards for calculating thresholds of visual impacts will be useful and applicable, and there is a scientific gap in this field. Proposing scientific and practical approaches to decreasing these visual impacts is another important aspect in this modern science which is steadily gaining an important role in scientific associations and executive plans.

Conflict of Interest

The authors have not declared any conflict of interest.

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