GI_Forum 2019, Issue 2
Page: 98 - 112
Full Paper
Corresponding Author:
metemu@itu.edu.tr
DOI: 10.1553/giscience2019_02_s98

Creation of Nominal Asset Value-Based Maps using GIS: A Case Study of Istanbul Beyoglu and Gaziosmanpasa Districts

Muhammed Oguzhan Mete and Tahsin Yomralioglu
İstanbul Technical University, Turkey

Abstract

Estimating the value of real estate has applications in fields as diverse as taxation, buying and renting properties, expropriation and urban regeneration. Determining the most objective, accurate and acceptable value for real estate by considering spatial criteria is therefore important. One stochastic method used to determine real estate values is 'nominal valuation'. In this approach, criteria that may affect land value are subjected to various spatial analyses, and pixel-based value maps can be produced using GIS. Land value maps are in raster data format and need to be compared with the actual market values. Pixel-resolution analyses are required that depend on the selected grid dimensions. First of all, nominal value maps were produced using a nominal valuation model, using criteria for proximity, visibility and terrain. These were weighted in order to produce a nominal asset value-based map according to the 'Best Worst Method'. Changes in the unit land values were examined for maps at various resolutions; a resolution of 10 metres emerged as the ideal pixel size for valuation maps.

Keywords:

GIS, real estate valuation, land valuation, nominal valuation

1 Introduction

Owning a property is important to humans in terms of financial security because real estate has a value. In order to calculate property values, parametric land values of the real estate are determined by using nominal valuation. This method provides mass valuation of real estate according to the properties' spatial characteristics. The sub-unit can be cadastral parcels or the cells (pixels, grids) used to divide the study area to determine the value. It is possible to produce a pixel-based land value map using GIS techniques (Yomralioglu, 1993; Nisanci, 2005). Pagourtzi, Assimakopoulos, Hatzichristos and French (2003) reviewed real estate valuation methods, including spatial analysis ones. Yomralioglu and Nisanci (2004) suggested a nominal valuation method based on spatial factors of real estate which can be analysed using GIS software. Pagourtzi, Nikolopoulos and Assimakopoulos (2006) proposed GIS-based real estate valuation using fuzzy theory and spatial analysis. Yomralioglu, Nisanci and Yildirim (2007) applied a nominal valuation method in land readjustment applications for planning purposes. Liu, Zhe and Wang (2011) proposed a real estate appraisal system based on GIS and a back propagation neural network. Bostancı, Demir, and Karaağaç (2015) created a nominal value map using the Fuzzy Analytic Hierarchy Process (AHP) and Multi-Criteria Decision Making (MCDM) to calculate weight factors. Demetriou (2016) suggested a land valuation framework for land consolidation processes using Multiple Regression Analysis (MRA) and Geographically Weighted Regression (GWR) within GIS. Bencure, Tripathi, Miyazaki, Ninsawat and Kim (2019) developed a land valuation model for mass appraisal applications using AHP in GIS.

Determining the criteria that may affect real estate value is the most important step in the valuation process. The effects of the factors can vary in terms of influence level. In order to reflect the varying influence of each criterion on the value, weight coefficients were determined using the 'Best Worst Method', a Multi-Criteria Decision-Making (MCDM) method.

The aims of this study were to create a dynamic real estate valuation model and to produce nominal value maps using GIS. The resolution of raster-based value maps should be defined in the model as a parameter, and overlay analysis should be used to calculate the land value of the parcels. Before calculating the parcel values, the Modifiable Areal Unit Problem (MAUP) needs to be dealt with in order to estimate appropriate scales of aggregation. In this context, maps with different pixel sizes are produced and the effect of the resolution on the values is examined to decide the ideal pixel size.

Subjectivity is a major problem in valuing real estate (Demetriou, 2016). Since the valuation process is based on the experience and judgement of appraisers, inflated values may arise in the market (Pagourtzi et al., 2003): human beings do not concentrate on scientific parameters that affect the value of a property. However, scientific and mathematical approaches are gaining importance, with the use of information systems and statistics in real estate valuation processes. In this GIS-based study, nominal values are generated as a result of proximity, terrain and visibility analyses for the creation of a land value map. Property-owners or buyers will know or want to know, for example, whether the property has an appealing view (Visibility criterion) or is on flat terrain (Terrain criterion), and how far amenities such as public transport or shopping centres are from the property (Proximity criterion).

2 Nominal Valuation

There are various methods for real estate valuation appropriate for different objectives and needs. Most are based on the market value. Classical methods include sales and market comparisons, the income capitalization method, and the replacement cost method. In addition to these there are stochastic methods based on statistical approaches. One such method is nominal valuation, which provides calculated parametric scores of weighted criteria which affect real estate values (Yomralioglu et al., 2007). This method does not require the market value and provides a distribution of land values as parametric quantities by using scientific approaches (Mete, 2019). Furthermore, using this method (as presented in Yomralioglu, 1993), it is possible easily to convert nominal coefficients into market price. In the present study, the method is used to create pixel-based nominal land value maps in order to achieve standardization in the real estate market, avoiding overpricing due to subjective judgements, inadequate knowledge and lack of data. However, criteria that affect property values vary and change constantly, based on location. In the method presented here, coefficients are calculated by determining the minimum and maximum values for the criteria in order to express the values of properties relative to each other.

3 The Nominal Asset value-based approach

3.1 Methodology

In order to calculate land values, all the criteria that affect the land value, and their relative weights, should be determined. With the help of GIS, it is possible to identify each criterion's effects on real estate values, and the total nominal land value can be expressed using the following formula:

$$V_i = S_i * \sum_{j=1}^{k} (f_{ji} * w_j) \tag{1}$$

where,

***V**: Total nominal value,*
***S**: Parcel or pixel area,*
***f**: Criterion value,*
***w:** Criterion weight,*
***k**: Total number of factors.*

In the context of this study, pixel-based land value maps with resolutions of 1, 10, 50 and 100 metres were produced. As raster data format provides some advantages over vector format for storing and presenting huge datasets, nominal land value maps were created in raster format. Pixel values that indicate nominal values can be added as an attribute in vector-based parcel data using basic GIS operations

3.2 Determination of criteria and weights

In order to produce a nominal value map, we identified 23 criteria affecting land values. These criteria were categorized into three main groups: proximity, visibility and terrain aspects. In order to determine the weight coefficients of each criterion, the Best Worst Method was used: by comparing, pair-wise, each criterion with all the others, the decision-maker's preferences lead to the identification of both the best criterion and the worst in comparison to the others, and weights can be determined (Rezaei, 2016).

A Likert scale of 1 to 9 is used in the comparisons between the criteria to determine the levels of preference. The decision-making process according to this method can be summarized as follows.

1. A set of decision-making criteria is determined. In the case of a house purchase, for example, the criteria may be classed as physical, spatial, legal or economic.

2. The best and the worst of these criteria are identified.

3. The degree to which the best criterion is preferred over the other criteria is determined. Using a scale of 1 to 9, 1 point is given to a criterion with equal importance to the best criterion, and 9 points are given if the best criterion is more important than the other criterion.

4. The pair-wise comparisons are completed by determining the degree of preference of the worst criterion according to other criteria. (In this, we followed a survey by Nisanci (2005) regarding criteria and weights.)

3.3 Choice of best and worst criteria

The metro is the most comfortable form of rail transport within İstanbul, and 16% of all public transport journeys in the city are by metro (İETT, 2018). Consequently, for this study proximity to a metro station was chosen as the best criterion. Proximity to a police station was chosen as the worst, and the two criteria were compared to other criteria to calculate the weights. The weights and consistency ratio (ξ^L) are calculated using the following equation (Rezai, 2016):

$$\begin{aligned}
&\min \xi^L \text{ such that} \\
&\left| w_B - a_{Bj} w_j \right| \le \xi^L, \text{ for all j} \\
&\left| w_j - a_{jW} w_W \right| \le \xi^L, \text{ for all j} \\
&\sum_j w_j = 1 \\
&w_j \ge 0, \text{ for all j}
\end{aligned} \tag{2}$$

where,

a_{Bj} : *preference for the best criterion over criterion j*

a_{jW} : *preference for criterion j over the worst criterion.*

The consistency ratio in decision making can be between 0 (complete consistency) and 1 (very inconsistent). For high consistency, the value is expected to be ≤ 0.25 (Rezai, 2016). The consistency ratio for the 23 criteria was calculated as 0.024, and was thus very high.

The criteria determined for the nominal real estate valuation model and their weights are shown in Table 1.

Table 1: Criteria Affecting Real Estate Values and Weight Coefficients

Criterion	Weights	Criterion	Weights
Proximity to Main Road	0.04440	Proximity to Educational Institutions	0.02664
Proximity to Highway Junctions	0.03330	Proximity to Universities	0.03330
Accessibility to Street	0.06660	Proximity to Health Institutions	0.02664
Proximity to Railways	0.10942	Proximity to Hospitals	0.03330
Proximity to rapid-transit bus (BRT) Stations	0.10942	Proximity to Fire Station	0.00951
Proximity to Bus Stations	0.04440	Proximity to Police Station	0.00951
Proximity to Quays	0.02664	Proximity to Parking Lots	0.03330
Proximity to Shopping Centres	0.03330	Proximity to Historical Places	0.03330
Proximity to Green Spaces	0.02664	Proximity to Hazardous Areas	0.02664
Proximity to City Centre	0.04440	Sea View	0.06660
Bosphorus View	0.10942	Slope	0.02664
Aspect	0.02664		

3.4 Modelling and analysing using GIS

To produce nominal land value maps from the proximity, visibility and terrain analyses that are included in the model, the weighted sum tool is used. The process of creating a nominal asset value-based map from raster data is shown in Figure 1.

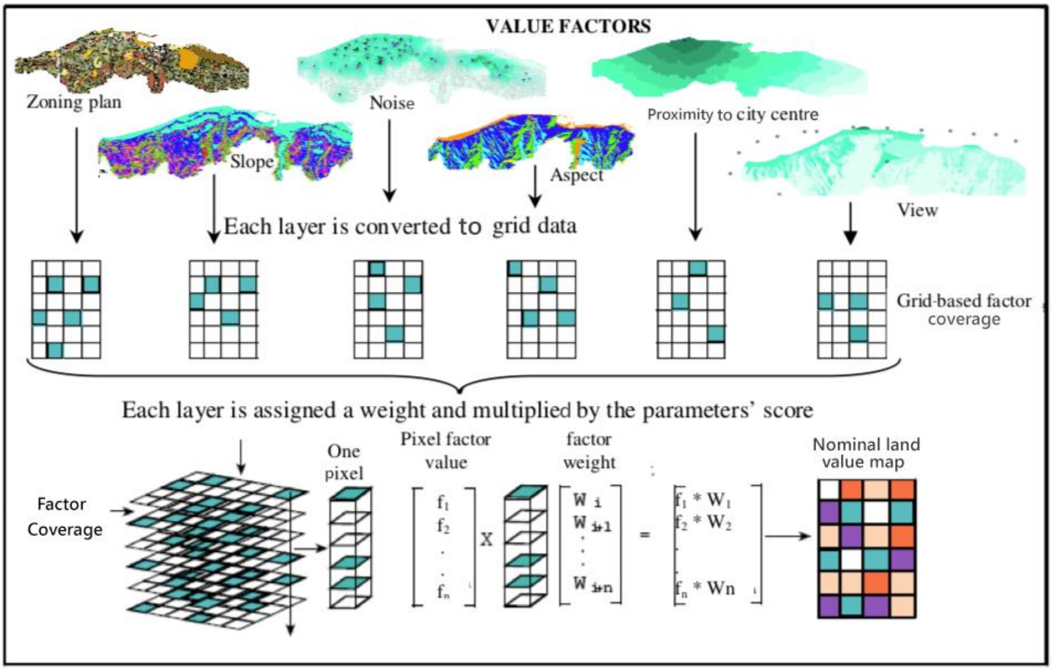


Figure 1: Process of creating nominal asset value-based map (Yomralioglu et al., 2007)

The Euclidean Distance tool is used in the proximity analysis sub-model. The values of the raster maps are generated from the proximity analyses, rated from 0 to 100 using the 'reclassify' tool according to the walking or driving distances. For example, railway stations which can be reached by walking 0–100 metres are given the value 100; distances between 100 and 250 metres are rated 90.

On the other hand, main roads which can be accessed by driving 0 to 1 kilometre are given the value 100; distances between 1 and 2 kilometres are rated 80. The maximum distance that can affect the land value is 5 kilometres for proximity to the main roads, since distances of more than 5 kilometres are not considered reasonable access in the real estate valuation process (Mete, 2019).

It is mandatory for zoning parcels to have access to roads. However, there may in practice be some cadastral parcels that do not satisfy this requirement. To evaluate this, access from the parcel to the road network is analysed using GIS software which checks whether any segment of the parcel's boundaries coincides with a road. If the condition is satisfied, relevant parcels are rated 100; otherwise, they score 0.

Slope and aspect analyses are conducted in the terrain sub-model. For height data, ALOS World 3D Digital Surface Model (DSM) produced by the Japan Aerospace Research Agency (JAXA) was used. ALOS has 30-metre spatial resolution. In the slope analysis, the effect of 0 to 1% slope on the value is classified as 100; a slope of more than 12% results in a classification of 0. In the aspect analysis, south-facing slopes are given a value of 100. For this purpose, the values between 135° and 225° (i.e. facing southeast, east or southwest) are classified as 100 and the remaining values as 0. The visibility sub-model identifies places which have a view of an island, the Bosphorus or the sea. Vector data of the sea, the Bosphorus and islands are created and visibility analysis is performed. Areas which have a clear view are given a value of 100; places that have no view score 0. Figure 2 shows the nominal land valuation model.

Figure 2: Nominal Land Valuation Model

Some criteria have a negative effect on the land value, like steep slope or proximity to hazardous areas. To ensure that such negative effects are reflected accurately in the land's value, the pixel values of those criteria are inversed in a reclassification phase. For instance, places which are next to hazardous areas are given a value of 100 in this analysis. After reclassification in the output raster, values of 100 are inversed – as having a nominal land value, in the relevant analysis, of 0.

4 Case Study

4.1 Description of study areas: Beyoğlu and Gaziosmanpaşa Districts, Istanbul

Istanbul is the most densely populated city in Turkey. The city's Beyoğlu and Gaziosmanpaşa districts were selected as study areas for the creation of a nominal asset-based land value map, as shown in Figure 3. According to the 'Address Based Census Registration System' (Turkish

Statistical Institute (TUIK)), in 2019 the populations of Beyoğlu and Gaziosmanpaşa were 230,526 and 487,046 respectively. Beyoğlu covers 8.96 km² and Gaziosmanpaşa 11.67 km². Both districts are densely populated and located close to the city centre. These districts have recently become desirable places to live due to urban regeneration projects, and real estate transactions here have increased significantly. Consequently, land values in the areas have also changed. For these reasons, we aimed to create nominal asset-based land value maps for the two districts in order to compare the nominal values of various locations that have different characteristics.

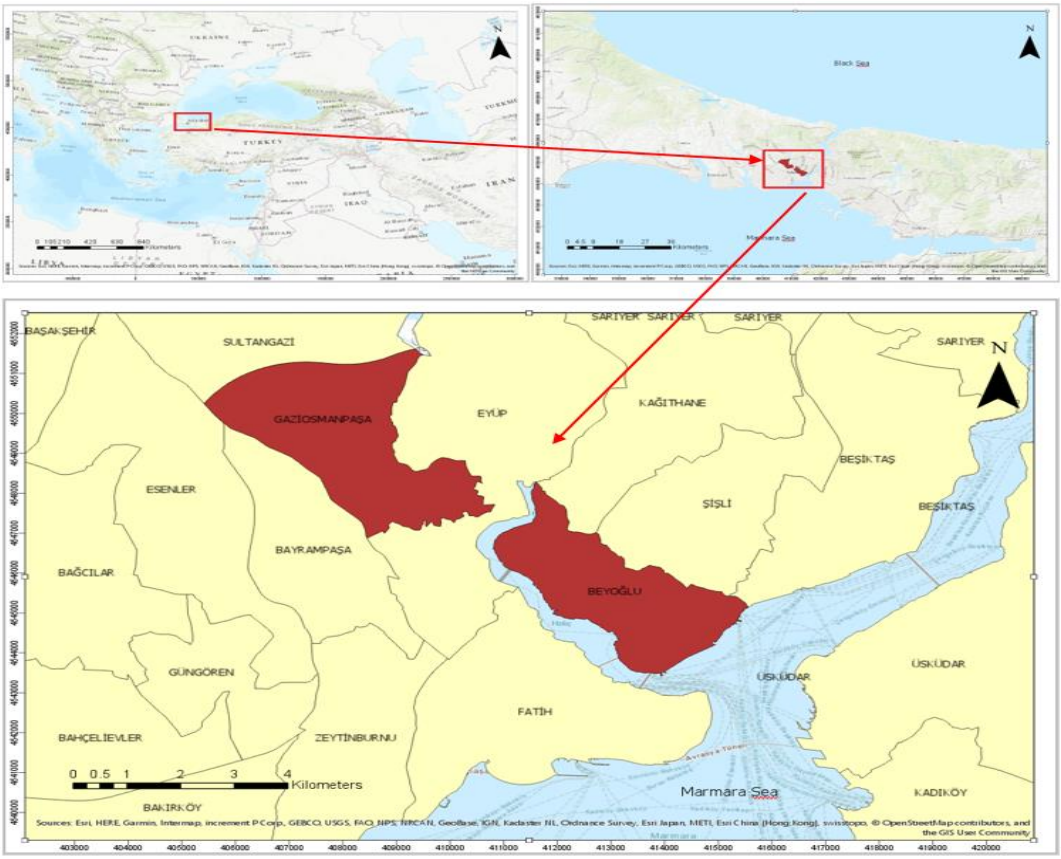
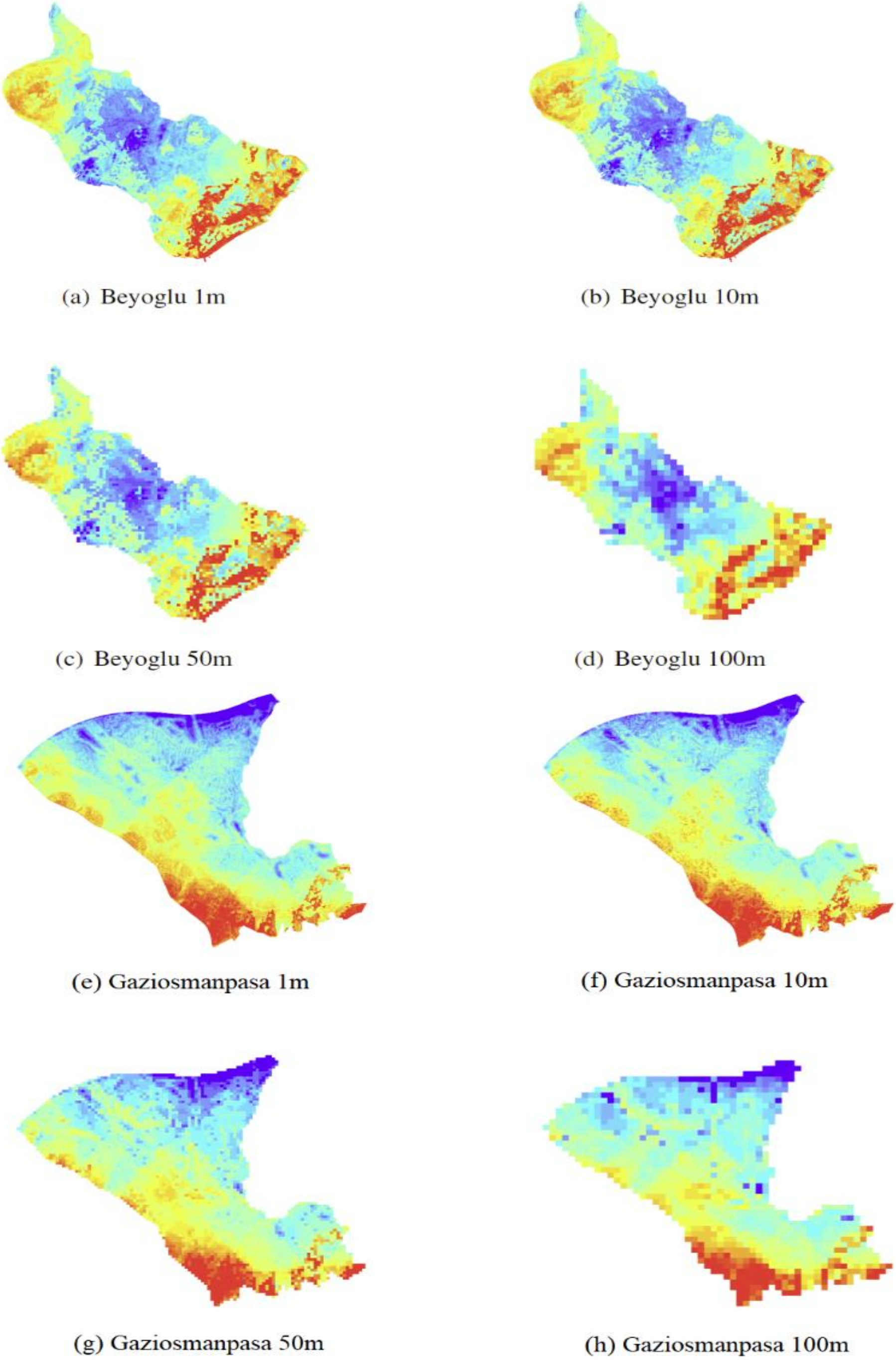


Figure 3: Study Areas: Beyoğlu and Gaziosmanpaşa Districts of Istanbul, Turkey

4.2 Production of nominal land value maps

To produce a land value map using the nominal valuation model, the pixel size must be defined as a model parameter. The nominal land value maps of Beyoğlu and Gaziosmanpaşa districts were produced separately, at 1-, 10-, 50- and 100-metre resolutions. Examining the effect of the resolution on the land values determined the best pixel size to be used (Figure 4).



(a) Beyoglu 1m

(b) Beyoglu 10m

(c) Beyoglu 50m

(d) Beyoglu 100m

(e) Gaziosmanpasa 1m

(f) Gaziosmanpasa 10m

(g) Gaziosmanpasa 50m

(h) Gaziosmanpasa 100m

Figure 4: Land Value Maps of Two Districts using Different Pixel Sizes. Values range from dark blue (lowest) to red (highest).

In Beyoğlu, the highest land values are seen in the eastern strip of İstiklal Street, one of the city's most famous streets, and the Marmara Sea in the south. Places with high nominal value are distributed along the shoreline of the Golden Horn and the Sea of Marmara (Figure 5).

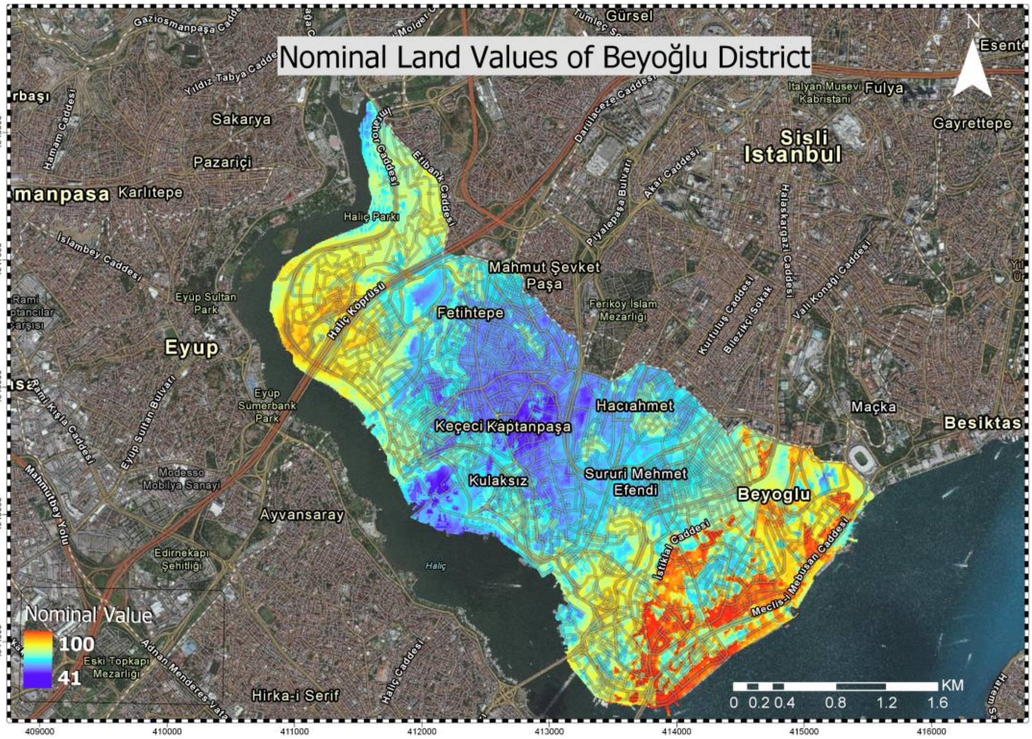


Figure 5: Nominal Land Value Map of Istanbul Beyoğlu District

Regions with higher nominal values in Gaziosmanpaşa centre on the Merkez Neighbourhood, and on the borders with Bayrampaşa and Eyüpsultan districts to the south. There are many public buildings in Merkez, such as the District Office, Asya Hospital and Duygu Hospital, and public gardens; the neighbourhood has good access to highways (1.5 to 2 kilometres away) (Figure 6).

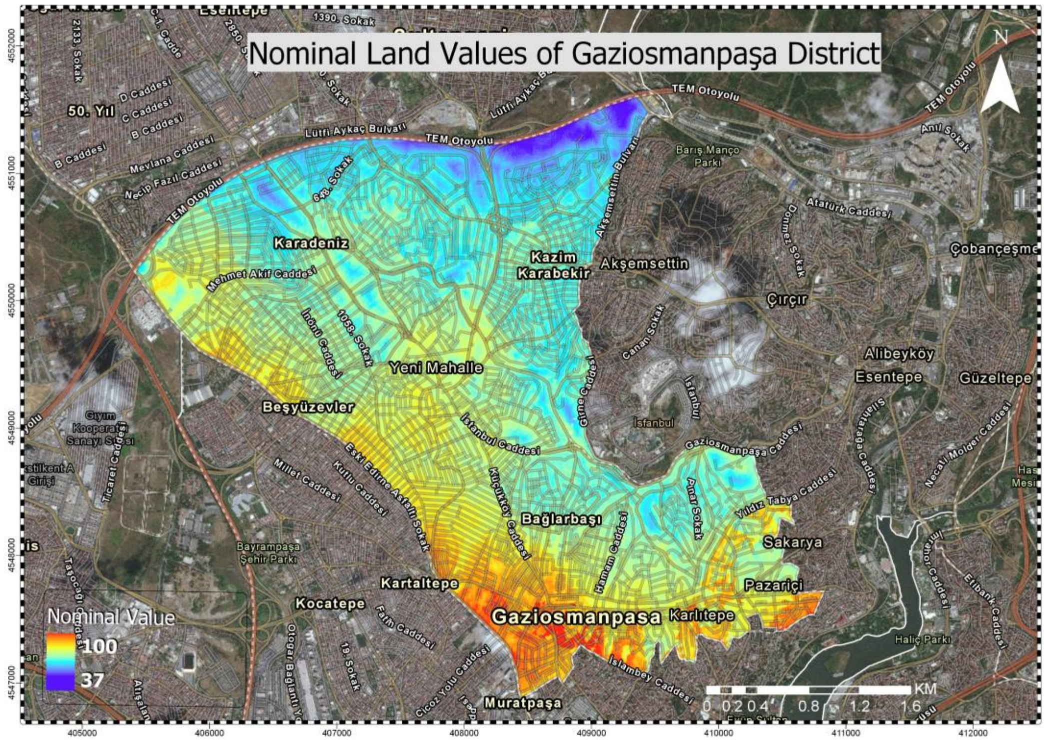


Figure 6: Nominal Land Value Map of Istanbul's Gaziosmanpaşa District

4.3 Examination of the effects of resolution differences on the nominal values

After creating nominal land value maps of Beyoğlu and Gaziosmanpaşa at resolutions of 1, 10, 50 and 100 metres, parcel values were added as an attribute in the parcel layers to examine the effect of the resolution changes. The pixel-based nominal land value maps were then converted to vector format, and vector pixel grids containing the nominal values were created. The generated vector-based nominal value layer is intersected with the parcel layer by using overlay analysis. The total nominal value of each parcel is obtained by multiplying the values of the respective pixels and the areas of the intersections.

Finally, all the nominal values within the parcels were added as an attribute in the parcel layer by performing a spatial join between the intersection vector and the parcel layer, so that all polygons which intersect with the nominal value pixels are included in the calculation.

A vectorized pixel that intersects with a parcel affects the nominal value in proportion to the area of the intersection. For example, if only half of a pixel falls inside a parcel boundary, the nominal value of the parcel will be affected by half of this pixel area.

After the same operation has been carried out for maps with different resolutions, the average relative errors for all the nominal land values of parcels are calculated with reference to 1-

metre resolution map values (Table 2). Thus, the effect of the resolution change on the nominal value can be expressed as a percentage. The average relative error for 22,481 parcels in Beyoğlu district is 2.40% at 10-metre resolution, 5.50% for 50-metre resolution, and 8.35% at 100-metre resolution. Because of the large number of parcels, standard deviations provide useful information regarding error distribution for the values. The standard deviation for 10-metre resolution values is 5.36%, for 50-metre resolution it is 8.39%, and for 100-metre resolution it is 13.44%. The average parcel size in Beyoğlu is 284.36 m².

The average relative error for the 23,776 parcels in Gaziosmanpaşa is 7.64% at 10 metres, 11.00% at 50 metres, and 13.11% at 100 metres. The standard deviation of the 10-metre resolution values is 2.40%; for 50-metre resolution it is 4.51%, and for 100-metre resolution it is 8.40%. The average parcel size in Gaziosmanpaşa is 346.37 m².

Table 2: Average Relative Errors of Parcels for Different Resolutions

RESOLUTION (m)	BEYOĞLU (22,481 parcels)		GAZİOSMANPAŞA (23,776 parcels)	
	RELATIVE ERROR (%)	STANDARD DEVIATION (%)	RELATIVE ERROR (%)	STANDARD DEVIATION (%)
10	2.40	5.36	7.64	2.40
50	5.50	8.39	11.00	4.51
100	8.35	13.44	13.11	8.40

Various streets in Beyoğlu and Gaziosmanpaşa were chosen for the investigation of nominal land value changes according to resolution: Müeyyetzade Neighbourhood and Yüksek Kaldırım Street in Beyoğlu; Barbaros Hayrettin Paşa Neighbourhood and 1103rd Street in Gaziosmanpaşa. Figure 7 shows a graph of the change of the unit m² values of the parcels according to the resolution.

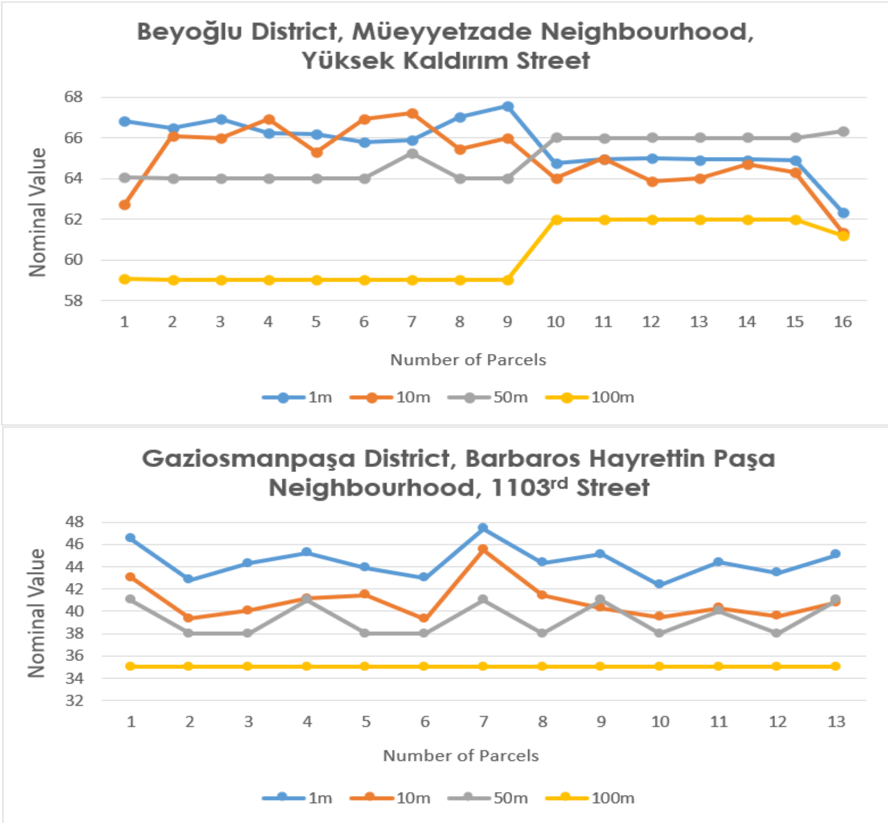


Figure 7: Variation of Nominal Values as Unit m2 for the Different Resolutions

To investigate the effects of pixel size on nominal land values in the parcel layers, average unit values of the parcels within the chosen streets were calculated for different resolutions. The market values of reference parcels on Yüksek Kaldırım Street and 1103rd Street were collected from a real estate valuation company in order to allow indexing 1-metre pixel nominal values to the market values. After calculation of the market values of the parcels within the streets, average unit values were calculated for resolutions of 10, 50 and 100 metres taking into consideration the average relative error values as shown in Table 2. The effect of 10-metre resolution on unit values is calculated as 142 Turkish Lira (TL)/m² in Beyoğlu Yüksek Kaldırım Street; for 50-metre resolution it is 325 TL/m²; and for 100-metre resolution it is 494 TL/m². On the other hand, for 1103rd Street in Gaziosmanpaşa the effect of the 10-metres resolution on unit values was 257 TL/m²; for the 50-metre resolution it was 370 TL/m²; for 100-metre resolution it was 441 TL/m². The effect of resolution change on average unit values is always downwards as can be seen in Figure 7.

Additionally, to verify the selection of the appropriate grid resolution, a statistical concept was used for representing the smallest and the narrowest objects in a raster, the formula for which was:

$$p \leq \begin{cases} \dfrac{\sqrt{\alpha_{MLD}}}{4} & \text{if S} < 3 \\ \dfrac{\sqrt{\omega_{MLD}}}{2} & \text{if S} > 3 \end{cases} \tag{3}$$

where,

p is pixel size, α_{MLD} is the area of the smallest object, ω_{MLD} is the width of the narrowest object, and S is the shape complexity index derived as the perimeter to boundary ratio:

$$S = \frac{P}{2 \cdot r \cdot \pi}\ , \quad r = \sqrt{\frac{\alpha}{\pi}} \tag{4}$$

where,

P is the perimeter of a polygon, α is the area of the polygon, and r is the radius of the circle with the same surface area (Hengl, 2006).

The smallest polygon is 49 m^2, and the largest is 40,125 m^2; the average size of the polygons is 284.36 m^2, with a standard deviation of 324.78 m^2. Using formula **(3)**, pixel size should be between 1.75 m (S=1.29) and 50.08 m (S=1.31). We recommend that the output raster map of the study area should be produced with a pixel size of between 2 and 50 metres.

5 Results and Discussion

In traditional valuation methods for real estate based on comparisons, the acceptable difference between the mean value and the comparable values is 15%. In our study, in order to examine the effect of resolution differences on value, relative error and standard deviation values were calculated for all parcels in two districts. According to our results, resolutions of 10 and 50 metres gave values that are within the acceptable range of values.

In addition, using this method the production of nominal land value maps with GIS at larger levels, such as region and country, could be fast and efficient for spatial resolutions up to 50 metres. On the other hand, it is not possible to produce a land value map at 100-metre resolution with the desired accuracy, since the average absolute relative error and standard deviation are high in comparison with the 1-metre resolution map (Table 2). The square-metre unit values for resolutions of 1 and 10 metres result in very similar graphs for the selected streets in both districts (Figure 7). Therefore, rather than 1-metre resolution, 10-metre resolution can be used for value maps of large areas.

In the form of the value map produced within this study, a model has been created that is based on uninflated, scientific findings from which buyers and sellers of properties can benefit in their transactions. With further development of the model, users will be able to see the values of real estate based on property information in the land registry by using Web GIS and Cloud GIS. Thus, this model could contribute to the national economy by helping to realize state-level valuation studies through a pioneering use of GIS.

Acknowledgements

This work was supported by the Scientific Research Projects Coordination Unit of İstanbul Technical University. Project Number: MYL-2018-41706.

References

ALOS Global Digital Surface Model. Available online: ttps://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm (accessed on 31 January 2019).

Bencure, J. C., Tripathi, N. K., Miyazaki, H., Ninsawat, S., & Kim, S. M. (2019). Development of an Innovative Land Valuation Model (iLVM) for Mass Appraisal Application in Sub-Urban Areas Using AHP: An Integration of Theoretical and Practical Approaches. *Sustainability, 11*(13), 3731.

Bostancı, B., Demir, H., & Karaağaç, A. (2015). Determination of Nominal Value by Fuzzy Analytic Hierarchic Process Weights, *Proceedings of World Cadastre Summit 2015*, pp. 876-884.

Demetriou, D. (2016). The assessment of land valuation in land consolidation schemes: The need for a new land valuation framework. *Land Use Policy, 54*, 487-498.

Hengl, T. (2006). Finding the right pixel size. *Computers & geosciences*, 32(9), 1283-1298.

İstanbul Electric, Tram and Tunnel (İETT), (2018), İstanbul'da Toplu Taşıma [Public transportation in İstanbul], Available online: https://www.iett.istanbul/tr/main/pages/istanbulda-toplu-ulasim/95 (accessed on 31 January 2019).

Liu, X. S., Zhe, D. E. N. G., & Wang, T. L. (2011). Real estate appraisal system based on GIS and BP neural network. *Transactions of Nonferrous Metals Society of China, 21*, s626-s630.

Mete, M. O. (2019). Coğrafi bilgi sistemleri ile İstanbul ili nominal taşınmaz değer haritasının oluşturulması [Creation of nominal asset value-based map using Geographic Information Systems in İstanbul city] (Master's dissertation, İstanbul Technical University Institute of Science and Technology). Retrieved from https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=Mir2lXQK1dkmQ9Ige3PZbu1Yx9Cc VR0iMMy8sXZw9pkxXd-x3C3BRPToxuQ54z52

Nisanci, R., 2005, Coğrafi Bilgi Sistemleri ile Nominal Değerleme Yöntemine Dayalı Piksel Tabanlı Kentsel Taşınmaz Değer Haritalarının Üretilmesi [The Production of Pixel Based Urban Land Value Maps with Nominal Valuation Method Using GIS] (Doctoral thesis, Karadeniz Technical University Institute of Science and Technology, Trabzon).

Pagourtzi, E., Assimakopoulos, V., Hatzichristos, T., & French, N. (2003). Real estate appraisal: a review of valuation methods. *Journal of Property Investment & Finance, 21*(4), 383-401.

Pagourtzi, E., Nikolopoulos, K. and Assimakopoulos, V. (2006). Architecture for a real estate analysis information system using GIS techniques integrated with fuzzy theory, *Journal of Property Investment & Finance*, 24(1), pp. 68-78. https://doi.org/10.1108/14635780610642971

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model, *Omega*, 64, pp. 126-130.

Turkish Statistical Institute (TUIK). Available online: ttps://biruni.tuik.gov.tr/medas/?kn=95&locale=tr (accessed on 31 January 2019).

Yomralioglu, T. (1993). A Nominal Asset Value-based Approach for Land Readjustment and Its Implementation Using Geographical Information Systems (Doctoral thesis, University of Newcastle upon Tyne).

Yomralioglu, T., & Nisanci, R. (2004). Nominal asset land valuation technique by GIS, *Proceedings of FIG Working Week, Athens, Greece, May 22-27, 2004*.

Yomralioglu, T., Nisanci, R. & Yildirim, V. (2007). An Implementation of Nominal Asset Based Land Readjustment, *Proceedings of FIG Working Week, Hong Kong SAR, China, 13-17 May 2007*.