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Research Article

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Integrating GIS Modelling and Least Squares Regression for Spatial Land Valuation in Palestine

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Abstract

The desire for land ownership in Palestine has significantly intensified. The scarcity of available land for sale, which is spread over a broad geographical area, leads to disputes regarding the establishment of appropriate and equitable prices and value assessments. Nevertheless, determining the value for land appraisals proves challenging due to the diverse factors influencing the evaluation process. These factors can be categorized according to market conditions, regional economic activities, political influences (such as land classifications established by the Oslo agreements between Palestinians and Israel), legal considerations (type of ownership), and parcel-specific factors (including location, size, shape, topography, and usability, among others). The data obtained from various sources in GIS formats has facilitated the resolution of the complexities associated with land appraisal by employing the most prevalent values in GIS modeling techniques. A specific study area, identified as a cadastral block, was chosen for this purpose. Historical data regarding land transactions from both official and private sectors were gathered. Subsequently, spatial information was compiled, encompassing various land classifications, land uses, and parcel data. The different factors were utilized as weights for input. The historical data were then applied to address the least squares problem to optimize a parameter associated with each factor. Following this, the weights and parameters were incorporated into a GIS model to estimate the value for each block parcel. Ultimately, the results were validated, achieving a tolerance of less than 2% compared to actual transactions.

Keywords: Geographic Information Systems (GIS); Land Valuation Modeling; Spatial Multi-Criteria Analysis; Least Squares Solutions; Cadastral Parcel Appraisal

I. INTRODUCTION

Land appraisal principles refer to the basic guidelines and considerations used by appraisers to determine the value of land. These principles are essential to providing accurate and reliable estimates of real estate values(Ling and Archer, 2018). Specific approaches and methods will vary depending on the purpose of the valuation and the location of the property. Appraisers value property based on its prime and best use. Here, the most economically advantageous use of property is legally permitted, physically possible, and economically feasible(Kok and Monkkonen, 2019). The land is valued based on potential uses such as residential, commercial, agricultural, and recreational. Besides, the supply and demand principle plays an important role in real estate valuation. Appraisers consider factors such as the availability of similar properties in the market, the demand for a particular type of property, and market trends that affect property values. Therefore, appraisers often use a sales comparison approach to estimate property values. This approach involves analyzing recent sales data for similar properties within the area to determine fair market value(Wen, Xiao and Zhang, 2019).

Adjustments are made to account for differences in size, location, zoning, and other relevant factors. The location of a property has a great impact on its value. Factors such as proximity to facilities (schools, shopping malls, parks), transportation infrastructure, natural features (natural views, access to water), and neighborhood attractions all contribute to a property's value. As well, Appraisers consider the physical characteristics of the land such as size, shape, topography, soil quality, drainage, and environmental factors that may affect its use (Isaac and O'Leary, 2017). These factors can affect a property's value and suitability for various purposes. Furthermore, an appraiser evaluates the legal aspects of a property, such as zoning regulations, easements, restrictions, and legal restrictions that may affect value and use. Compliance with local regulations and availability of permits for the desired land use are important considerations. Also, economic conditions such as interest rates, inflation, employment rates, and general

market stability can affect property values. Appraisers evaluate these economic factors to determine their impact on the current and future value of real estate(McCluskey *et al.*, 2018).

In the case of income properties, the appraiser considers the income or income the property may generate. This approach involves estimating future cash flows and expenses and applying an appropriate capitalization rate or earnings multiple to determine value. Appraisers carry out an in-depth analysis of the local real estate market to understand current trends, current sales, and market conditions. This analysis helps provide context and support for land valuation. It is important to note that land valuation principles may vary depending on the specific requirements and regulations of various jurisdictions and valuation agencies (Ellerman, 2025).

Various forms of land ownership are recognized and used in Palestine. However, it is important to note that the issue of Palestinian land ownership is complicated by the Israeli-Palestinian conflict and historical context (Yiftachel, 2006). Below are some of the common ways of land tenure in Palestine. In Palestine, private ownership of land is recognized if an individual or organization has legal ownership of the land. Private property can be established in several ways, including inheritance, purchase, and other legal means. Private landowners have certain rights and responsibilities regarding using, transferring, and managing their land. Collective ownership is land owned and managed collectively by a community or group of individuals. In some areas of Palestine, such as certain farming villages, agricultural land may be owned and shared by local communities (Hadawi, 1957). Collective ownership is often based on customary or traditional practices and may involve communal decision-making processes. However, the State ownership of land refers to land owned and controlled by the Palestinian Authority or any other government agency. State land can be allocated for various uses such as public infrastructure, development projects, and public facilities. The Palestinian Authority has the authority to manage and regulate state lands under relevant laws and regulations. The last one is the Waqf land which refers to land dedicated to religious or charitable purposes according to Islamic law. These lands are often owned and managed by religious or charitable organizations such as mosques, or religious or charitable foundations. Waqf land is intended to be used for the benefit of the community and is subject to specific Islamic rules and regulations (Palestinian Land Authority, 2008; World Bank, 2008).

The Oslo Accords, signed between Israel and the Palestinian Liberation Organization (PLO) in the 1990s, established the framework for a transitional government in parts of the West Bank and Gaza Strip. This agreement divided the country into various classifications. It is important to note that the implementation of the Oslo Accords has faced challenges and the specific categories and their implications have evolved. Common land classifications under the Oslo Accords are areas A, B, and C (Yiftachel, 2006; Selby, 2010),see figure 1. Area A classification refers to land under civil and security control in Palestine as defined in the Oslo Accords. In Area A, which includes major Palestinian cities and their surrounding areas, the Palestinian Authority manages and controls both the urban areas and the land. Area B classification refers to land under civil Palestinian administration but under joint Israeli-Palestinian security administration as defined in the Oslo Accords. The Palestinian Authority administers the urban areas in Area B, but Israeli security forces have the right to operate in these areas. Worst, Area C classification refers to land under full Israeli civilian and security control as defined in the Oslo Accords. Area C covers most of the West Bank, including Israeli settlements, military installations, nature reserves, and open spaces. The Israeli Civil Administration administers the administrative affairs and planning and zoning of Area C. The Palestinian Authority has limited control over Palestinians living in Area C(World Bank, 2024).

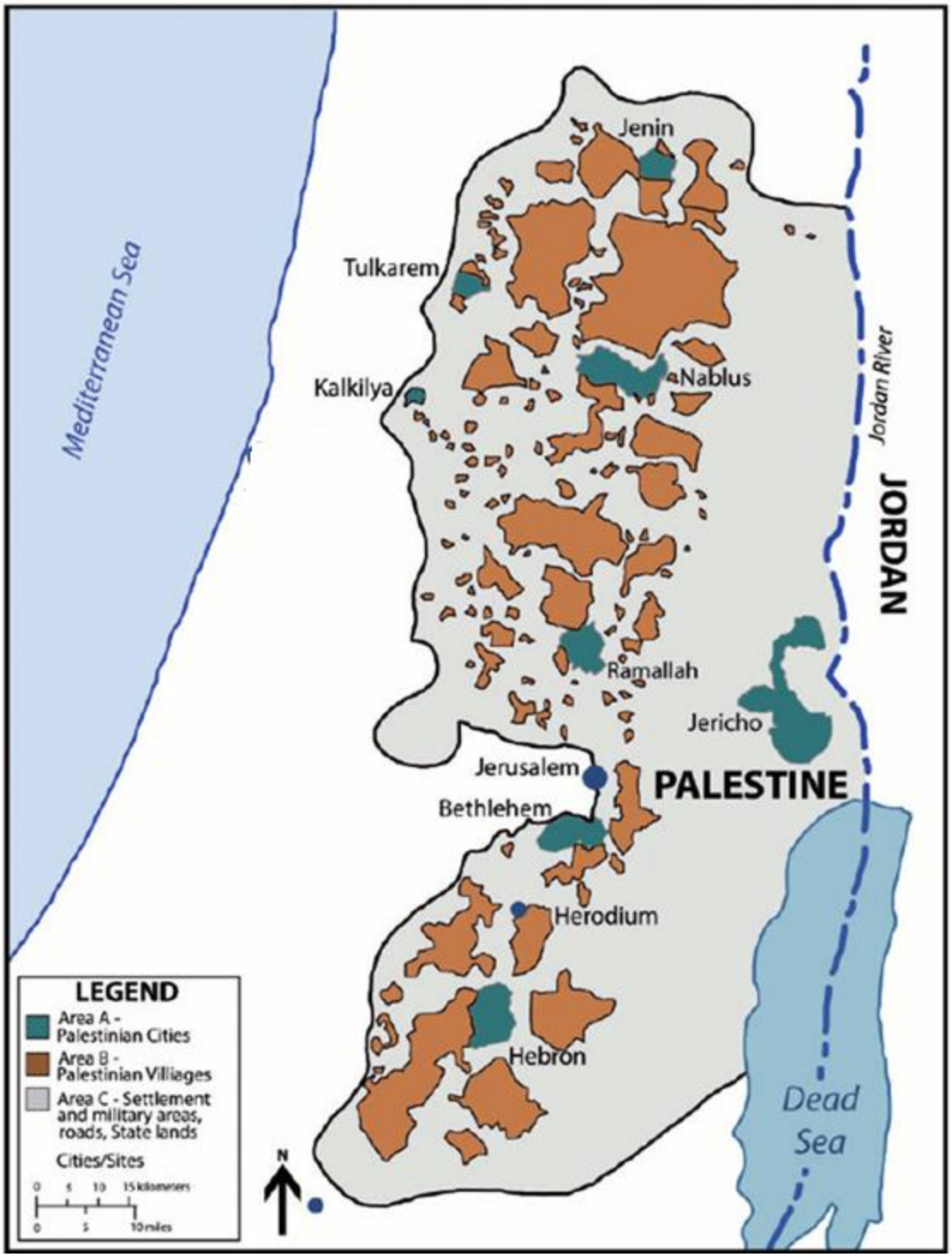


Figure 1 Oslo classification A, B, and C .(UN-Habitat, 2015)

It is worth noting that the Oslo Accords were intended as an interim agreement leading to a final Status of Forces Agreement between Israel and the Palestinians. However, final status negotiations are underway, the country's classification and scope of control remain the subject of disputes, and political debate continues. Classification under the Oslo Accords has affected issues such as land use, planning and development, infrastructure, and access to resources, leading to conflicts and challenges among the parties concerned (Fischbach, 2003). It is important to note that Palestinian land tenure issues are highly complex, and intertwined with political, legal, and historical factors.

Land title disputes, land confiscations, and inconsistent legal frameworks can complicate land title determination and recognition, especially in areas under Israeli control. Different legal systems apply in different regions, and land ownership issues often raise legal issues and require various administrative and legal procedures (Norwegian Refugee Council, 2012).

In Palestine, there are different types of land registry documents used to establish property rights and record real estate transactions. Although specific documents and terminology may vary, common types of land registry documents are listed below. The Taboo (Land) Certificate is the most important land registry document in Palestine. It is issued by the Palestinian Land Authority (Taboo) and contains details of the property such as Its Location, Boundary, and Ownership Information. Similarly, the Deed document serves as proof of ownership and contains information about the property owner, their rights, and any restrictions or obligations concerning the property (Kamel, 2014). While, a Sales contract is a contract between the buyer and seller of real estate that sets out the terms and conditions of the sale, including the agreed price, terms of payment, and other relevant details. Differently, a title deed is a legal document that establishes ownership of real estate. This includes information about legal descriptions of real estate, boundaries, mortgages, and liens on real estate. A Mortgage Deed is created when real estate is used as collateral for a loan. It sets out the terms of the mortgage, including the loan amount, interest rate, repayment terms, and the rights and obligations of the borrower and lender. Also Lease agreement is used when the owner of a property grants another party the right to use the property for a specified period in exchange for rent. Define the terms of the lease, including the term, rent amount, and all other terms. The other way of getting ownership is the power of attorney, which gives someone legal authority to act on behalf of the property owner in matters related to the property. For example, it can be used when the owner cannot handle real estate transactions personally. Also, the lease agreement is commonly used for bare state land developments that end with ownership (Tamim, 1995).

In addition to the classical factors affecting land appraisal value, the complexity of land appraisal in Palestine is heightened due to an unstable market. This instability stems from the fact that lands may fall under multiple authorities and regulations according to the Oslo Agreements. The boundaries between specific classes are irregular and difficult to delineate. Furthermore, varying political and military factors affect land availability, buyer demand, and prices. These factors can vary even within small areas (e.g., a single block) (Kohlbry, 2026).

Despite the complexity of the data and influencing factors, a considerable amount of data is readily available to researchers, including both private and public sources such as statistics, purchase records, selling offers on web platforms and social media, as well as general and detailed maps (topographic, cadastral, political, etc.) (World Bank, 2023). In this situation, GIS can be a useful tool for creating a methodical model for the land appraisal procedure (Grunewald, Richter and Meinel, 2024b, 2024a). The model can apply least squares solutions to estimate the weights of various factors by combining statistical and spatial data from prior transactions (Strang, 2019).

II. Methodology

Land use (urban/master plans maps) Political classification (Oslo), cadastral maps block, topographic maps, market values, and sales.During the land appraisal process in Palestine, different data sources are used. The data were transformed into numerical variables representing factors that affect the price/value estimations. The value estimates are calculated using a linear model in equation (1). some variables have direct values like; shape index, and area. On the other hand, the qualitative variables were given weights for each class (Dimopoulos and Moulas, 2016; Grunewald, Richter and Meinel, 2024a). The weights were validated during the iteratively repeated the least squares solution of the unknown parameters by tying to minimize the residuals.

$$Value = a_0.T + a_1.A + a_2.S + a_3.O + a_4.D + a_5.R + a_6.C + a_7.W + a_8.L + a_9.S + a_{10}.E + a_{11}.V + a_{12}.B \qquad (1)$$

The model incorporates a set of weighted variables representing the main physical, legal, and planning characteristics of each land parcel. These include slope (a0), political classification under the Oslo agreements (a1), land use based on urban plans (a2), service road class (a3), road condition (a4), parcel area (a5), and road width (a6). Additional factors include distance to the nearest main road (a7), shape index (a8), time factor (a9), on-site enhancements (a10), general view (a11), and the overall possibility to build or invest (a12).

The main source is the land property. Here, the cadastral map is one of the most important factors in which the parcel area, shape, ownership, and sales info. The Palestine Land Authority registration departments provide tabular and maps about the parcels. Here, the sales data are normalized to prices per square meter. The shape and regularity of a parcel are represented by the standard shape index (SI) as a function of area (a) and the parameter (P) in equation (2) (Alturk, 2024). The SI value 1.020-1.291 is translated to a regularly shaped parcel with the highest weight of 1.10. And SI value 1.292- 1.541 indicates that the shape is semi-regular and weighted to value 1.0. Finally, if SI is larger than 1.542, then the shape of the parcel is assumed to be irregular with a weight of (0.9),

$$SI = \frac{P}{2\sqrt{\pi a}} \qquad (2)$$

Another source is political classification maps according to Oslo agreements (A, B, and C). areas (A) are classified as more secure by governing Palestinian civil and military laws .in this case, lands are more wanted and prices are always higher than similar parcels but with other classifications. Therefore, a weighting factor of 1.1 was assigned to the land parcel in this class. A similar class is (B) because it is ruled by Palestinian civil laws, so such parcels a slightly cheaper than similar parcels in class (A). so that a weight value of 1.0 was given to this class. The third class is area (C), where Israeli military laws are applied even for civil uses of land parcels. Due to the difficulties in using or investing in these parcels, a smaller number of buyers normally search for or desire to buy in these areas, which are commonly called unsafe areas. As a result, a lower weight factor of 0.6 is implemented (Norwegian Refugee Council, 2012).

Also, urban maps are an important source that reference land use and the possibility of investment in a parcel. In addition, these maps provide classifications of roads and service areas, which can affect the price estimates. Another factor that can affect the prices and their estimates is the nature of the topography, which varies in Palestine from flat to extreme slopes (Grunewald, Richter and Meinel, 2024b). These data were transformed into variables that can used in the appraisal Model as explained in Table (1).

Table 1 Classification and Weighting for Influencing Factors

Category	Classification	Value
Slope	Flat	1.1
	Near flat	1.05
	Middle slope	0.95
	High slope	0.90
	Extreme slope	0.85
Land Use	Nature Preserve	0.7
	Residential C	0.96
	Residential D	0.93
	Archaeological	0.7
	Industrial	1.2
	Residential A	1.08
	Residential B	1.0
	Residential Agricultural	0.9
	Commercial	1.14
	General Facilities	0.88
Road Type	Primary	1.0
	Secondary	0.92
Road Condition	Paved	1.09
	Unpaved	0.92
	Unopened	0.85
	Base Course	0.87
Road Width	Wide (>10m)	1.05
	Medium (5m-10m)	1.0
	Narrow (<5m)	0.92
Distance to Major Road	0–50 m	1.0
	50–150 m	0.95

	150–300 m	0.9
	300–450 m	0.85
	450–600 m	0.8
	600–750 m	0.75
	750–900 m	0.7
	>900 m	0.68
Enhancements	Low	1.0
	Middle	1.05
	High	1.1
Build/Invest Possibility	Low	0.9
	Middle	1.05
	High-Middle	1.1
	High	1.15
General View	Bad View	0.9
	Houses View	1.05
	Commercial View	1.1
	Nature View	1.2

The concluding phase of the methodology entailed the construction of a comprehensive land valuation model utilizing the ModelBuilder environment within ArcGIS Pro (Balogun, 2019). All categorized attributes, such as land use, road condition, slope, shape index, enhancements, general view, and Oslo classification, were integrated with the foundational cadastral parcel layer through a sequence of spatial operations and field calculations. Each parcel received the relevant classification weights based on the standardized scoring table. By employing the Field Calculator, these weights were multiplied by the respective coefficients obtained from the least squares analysis to determine an overall adjustment factor for each parcel (Palestinian Land Authority, 2008).

The final model workflow involved Spatial joins to link parcel-level attributes, Raster and vector-based classification layers, Calculation of weighted scores using Field Calculator, Multiplication of weighted factors and coefficients, Estimation of the final land value using a base unit price. A systematic set of procedures within ArcGIS ModelBuilder was used to implement the GIS-based valuation model, guaranteeing scalability, consistency, and reproducibility across different geographic regions. The process starts with the reclassification of slope (Figure 3.a), as illustrated in Figure 2, and then planning-related attributes like land use, road class, Oslo classification, and general view are integrated (Figure 3.b). Euclidean near tool was used to calculate the distance to the closest main road (Figure 3.c), and the shape index was used to evaluate the parcel geometry (Figure 3.d). Other factors were included, such as investment potential (Figure 3.f) and physical improvements (e.g., building presence, number of floors, parking, internal stores) (Figure 3.e). After giving each component a weight (a0–a12), the Net Adjustment Factor (NAF) was calculated as shown in the equation (3), and the estimated cost of the land was determined by equation (4) (Grunewald, Richter and Meinel, 2024a).

$$NAF = a0 \times a1 \times \ldots \times a12 \quad (3)$$

$$Estimated\ Land\ Price = (Net\ Adjustment\ Factor) \times standardvalue \times Parcel\ Area \quad (4)$$

A new attribute field with the estimated land price per square meter was the end result of automating this entire process within ModelBuilder

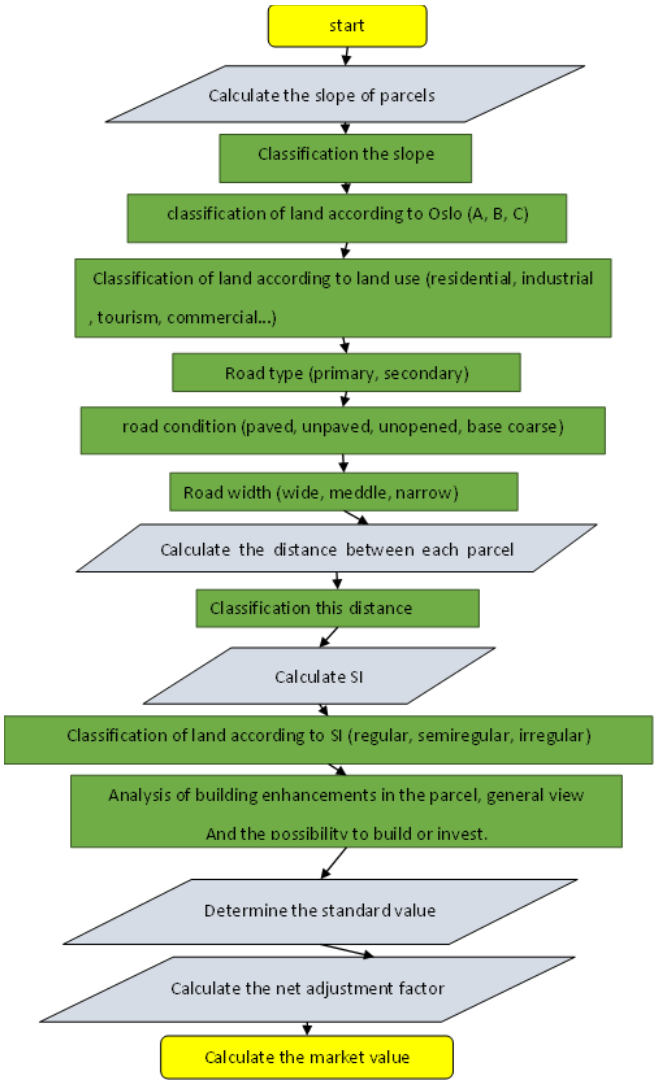
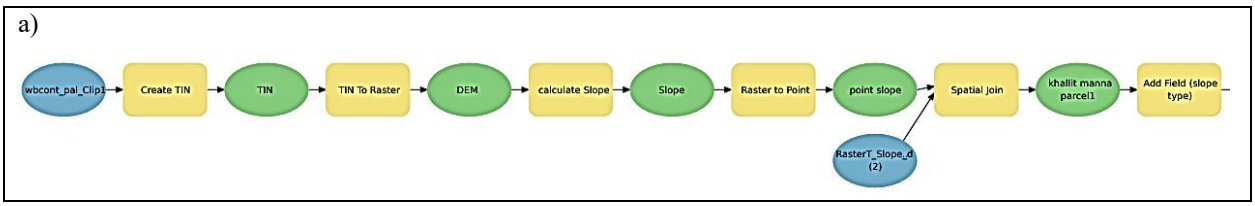


Figure 2 flowchart of the GIS -based land valuation workflow

To account for changes in market conditions over time, a temporal growth factor was applied to the estimated land value. Based on observed trends in the local real estate market, an annual increase rate of 12% was used to simulate price a appreciation. The final land price was adjusted using equation 5 using is the number of years since the baseline year (n) (Blackledge, 2017).

$$Final\ Adjusted\ Price = Base\ Price \times (1 + 0.12)^{n} \qquad (5)$$

This made the results more realistic and helpful for long-term planning by enabling the model to capture not only the physical and spatial characteristics of each parcel but also its time-sensitive value growth.



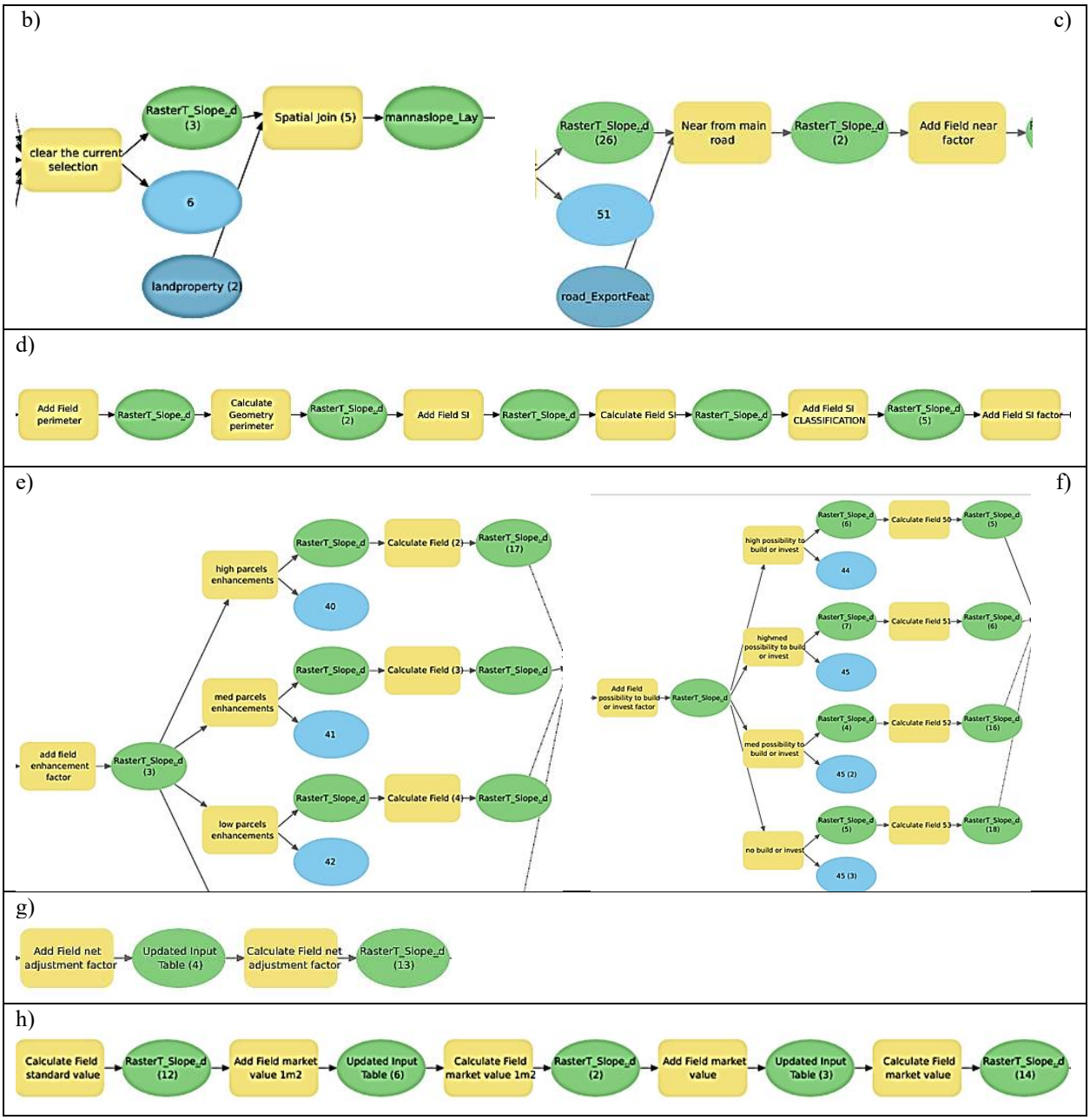


Figure 3 ArcGIS ModelBuilder Workflow for Land Valuation

III. Results and Analysis

The study area, Khallit Manna, in the Hebron Governorate's city of Dura (figure 4), was chosen because it had a variety of land use types, political classifications (Areas A, B, and C), and planning data. Additionally, it represents the cadastral reality of Palestine.

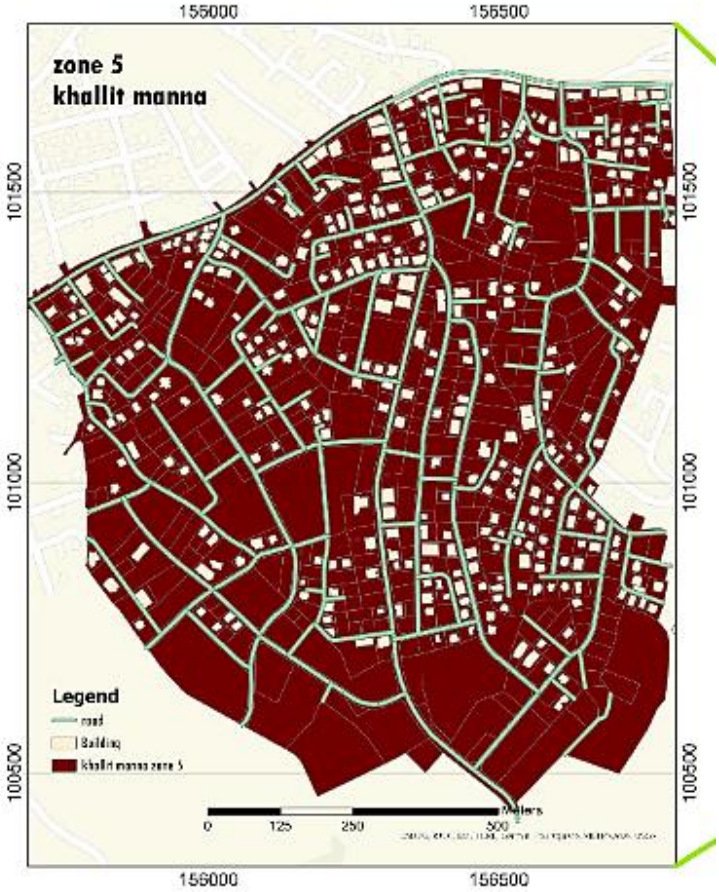


Figure 4 study area

In order to develop a model for estimating land value, a selection of land parcels with established market values, obtained from a certified appraiser, was utilized. The influence of various spatial factors on land value was assessed through the application of the least squares method. These factors encompass general view, Oslo classification, slope, type of land use, and proximity to major roads, among others. The data was structured in a matrix format, where each column signifies a spatial factor and each row corresponds to a land parcel. The observed land values constitute the observation vector L, while the matrix of spatial variables is referred to as matrix A (Ghilani, 2018). The unknown coefficients that indicate the contribution of each spatial factor to the overall land value are determined through the least squares method as outlined in equation (6)(Strang, 2019).

$$X = (A^t A)^{-1} A^t L \quad (6)$$

Where A^t is the transpose of matrix A ,$(A^tA)^{-1}$ is the inverse of the normal equation matrix $N=A^tA$ matrix , X is the resulting vector of coefficients (one for each factor), while L is the vector of actual land prices (observations matrix) (Younis, 2015). here, thirteen land parcels were employed. The significant factors included road type, condition, width, slope category, shape index, land use type, Oslo area classification, improvements, construction or investment potential, and overall perspective, see figure 5. Initially, each of these variables was assigned a weight according to established classification tables. The model was implemented using Excel to perform matrix multiplication and obtain the least squares solution.

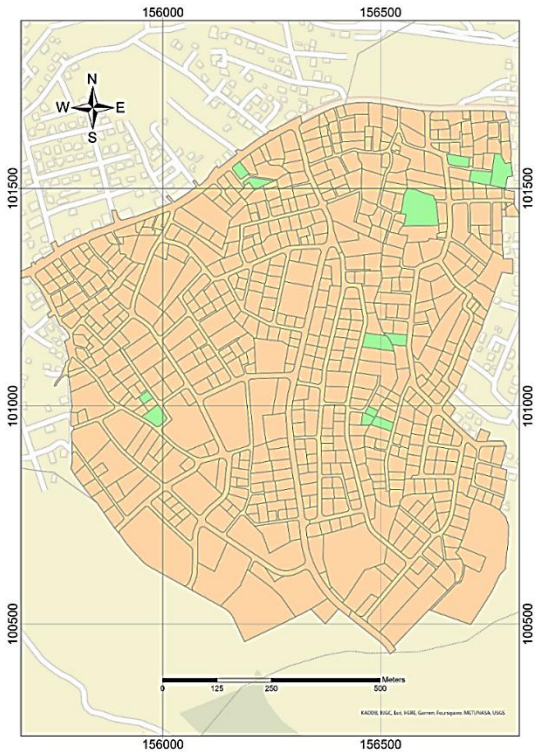


Figure 5 distribution of the 13 Sample Parcels Used for Model Calibration

The resulting coefficient vector X encapsulated the estimated influence of each factor on land value. Matrix A represents the values of the contributing elements for each land parcel. Each column denotes a specific element, while each row corresponds to one of the 13 selected parcels. These values were derived from spatial classification and field research. Concurrently, the L matrix indicates the actual known market sale prices for the selected parcels, and the vector L comprises the known land values expressed in dollars. As a result of the calculations, Matrix X embodies the computed factor coefficients. The weights for each factor, determined through least squares, are included in the output vector X. The value of each parcel within the study area was subsequently evaluated using these coefficients, which reflect the relative contributions of each factor to land value. The validation of the model is conducted using the Residual Vector (v). The model is verified by calculating the residual vector v, which illustrates the difference between the values obtained from the model ($\hat{L}$) and the actual land values (L), following the resolution of the least squares system in equation (7) (Maling, 2019).

$$v = A \cdot X - L \quad (7)$$

The forecasted prices closely matched the actual market values, as evidenced by the remarkably low v values of the 13 parcels. This significant level of concordance suggests that the model successfully incorporates the key factors influencing land price. The Root Mean Square Error (RMSE) , which represents the average estimation error, was determined using Equation (8). In the context of spatial valuation models, the RMSE was found to be below 2%, reflecting an exceptionally high degree of precision (Smith, 2016).

$$RMSE = \sqrt{\frac{\sum_{I=1}^{N}(Vi-\bar{V}l)2}{N}} \quad (8)$$

Table 2 the minimum, maximum, and average residuals, and the Root Mean Square Error (RMSE)

MAX	185.43
MIN	-87.16
AVG	0.1
RMSE	74.86

The projected land values for each parcel within the study area were established after the GIS-based valuation model was finalized. The application of regression coefficients derived from the least squares model to the classified attributes of each parcel produced the outcomes. To generate a thematic valuation map for the entire cadastral block, the final value per square meter was computed by multiplying all weighted factors by the base land price. The valuation map clearly illustrates that the highest estimated values were associated with parcels that had regular shapes, significant development potential, and were situated near major roads within commercial or residential A zones. Conversely, parcels characterized by inadequate road access, steep inclines, or politically restricted zones (Area C) were assigned considerably lower values, see figure 6. The anticipated land values for 13 selected parcels were compared with the existing market prices to assess the reliability of the model. The discrepancies between the predicted and actual values in the residual vector, $v = AX - L$, were minimal (Ghilani, 2018). The Root Mean Square Error (RMSE), calculated to be below 2%, validated the model's precision and the effectiveness of the selected variables and regression coefficients.

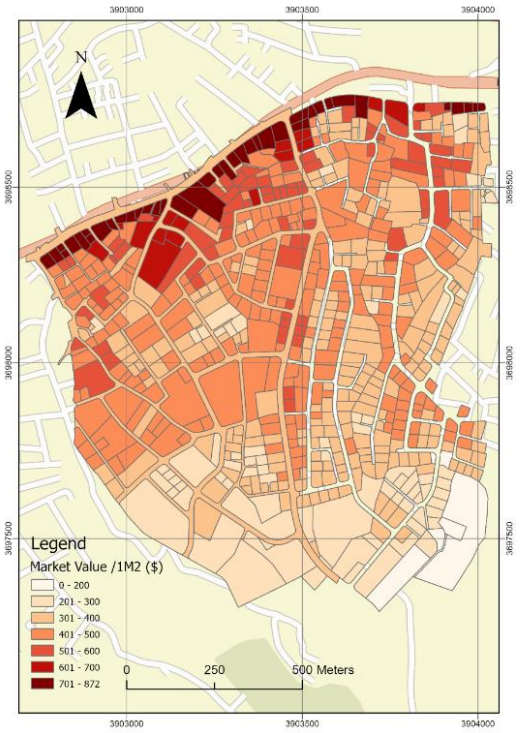


Figure 6 Map of estimated land prices ($/m2)

To show the spatial distribution of the important elements incorporated into the land valuation model, a series of thematic maps was created. Each subfigure is labeled alphabetically, and these maps are shown together under Figure 7. The zoning categories assigned to parcels are shown in the land use classification (Figure 7.a), with the commercial and residential A zones receiving the highest weights because of their potential for development. The impact of accessibility quality is reflected in the road type and condition map (Figure 7.b & Figure 7.c), which differentiates between primary and secondary roads as well as paved and unpaved surfaces[.When road width (Figure 7.d) was examined separately, parcels next to wider roads scored higher. Derived from DEM analysis, the slope classification (Figure 7.e) favors flatter land for development feasibility by classifying parcels according to the steepness of the terrain. Regular-shaped parcels are deemed more desirable, according to the shape index (Figure 7.f), which assesses the geometric regularity of parcels. Euclidean analysis was used to determine the distance to major roads (Figure 7.j), with higher accessibility weights going to closer parcels. The Oslo area classification (Figure 7.h) was used to address legal and regulatory constraints, with Area A parcels having the highest potential for investment and planning. Each parcel's visual surroundings are depicted on the general view map (Figure 7.i), where parcels that overlook commercial or natural features receive higher scores. The number of floors, internal stores, and parking availability are all

integrated structural features in the building enhancements map (Figure 7.k). In order to depict each parcel's overall preparedness and appeal for investment, the investment possibility map (Figure 7.j) integrates a number of indicators.

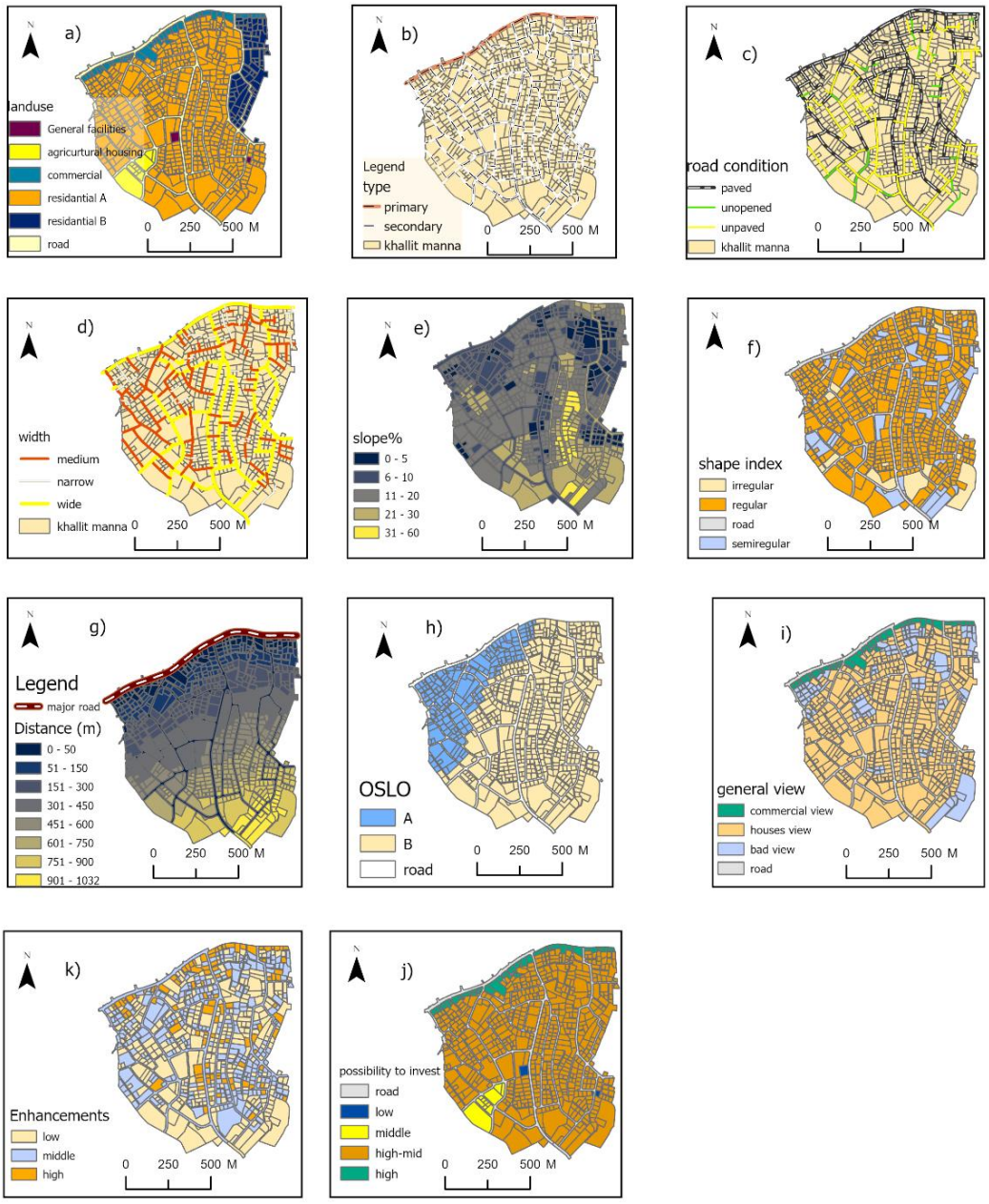


Figure 7 Maps of Influencing Factors Used in the Valuation Model

Conclusions

This research introduced a GIS-based framework for assessing land value, integrating least squares regression with spatial data analysis to establish a systematic and scalable approach to property valuation. The model produced precise

price estimates for each parcel within the study area by incorporating various physical, infrastructural, visual, and political elements, such as land use, road accessibility, slope, and Oslo classification. The valuation methodology was enhanced in terms of consistency and transparency through the application of ArcGIS Pro and ModelBuilder, which rendered the workflow entirely automated and reproducible. With residual values approaching zero and a root mean square error (RMSE) below 2%, the validation outcomes indicated a significant level of accuracy, confirming that the selected and computed factors closely mirrored actual market dynamics. The spatial patterns observed in the output maps, which illustrated lower values in restricted or underserved regions and elevated values in accessible and commercially attractive areas, further validated the model's rationale. These findings illustrate how GIS can support data-driven decision-making in urban planning and underscore the importance of spatial context in land valuation. Moreover, the model's generalizability allows for its application to other cadastral blocks in Palestine and the West Bank. It offers flexibility for municipalities, real estate professionals, and policymakers seeking an impartial approach to land value assessment, as it utilizes widely accepted GIS tools and standard planning layers. Future enhancements may include the development of a web-based interface to render the valuation process more interactive and accessible, the integration of economic variables, or the modeling of land price trends through time-series analysis.

The precision of spatial data has a significant impact on the dependability of GIS-based land valuation in addition to the model's accuracy. Spatial misalignments can result from variations in coordinate systems and datum transformations, which can impact boundary accuracy, parcel positioning, and distance computations. To preserve the integrity of valuation results, it is crucial to make sure that spatial referencing is consistent, especially in areas where several geodetic systems are in use.

Data Availability Statement

Data archiving is not mandated for this study. The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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