land MDPI

Article

A Computational Geospatial Approach to Assessing Land-Use Compatibility in Urban Planning

Omid Mansourihanis [1], Mohammad Javad Maghsoodi Tilaki [2,*], Samira Yousefian [3] and Ayda Zaroujtaghi [1]

[1] Department of Geosciences, Texas Tech University, Lubbock, TX 79409, USA; omansour@ttu.edu (O.M.); azaroujt@ttu.edu (A.Z.)
[2] Department of Geography, School of Humanities, Universiti Sains Malaysia, Gelugor 11800, Malaysia
[3] Urban Planning Department, Tarbiat Modares University, Tehran 14117, Iran; s.yousefian@modares.ac.ir
* Correspondence: maghsoodi.tilaki@gmail.com; Tel.: +60-4-653-3371

Abstract: Amidst rapid urbanization, sustainable development requires moving beyond subjective land-use planning techniques toward innovative computational geospatial models. This paper introduces a GIS-based quantitative framework to enable objective, rigorous land-use compatibility analysis. Uniquely, the model evaluates radial impacts and expert-defined criteria across multiple scales, overcoming the limitations of qualitative approaches. Cell-by-cell computation identifies emerging spatial conflicts with enhanced realism. A case study in Qaemshahr, Iran, demonstrated the model's proficiency in revealing incompatibilities and hotspots, surpassing conventional methodologies. Quantitative analysis provided accurate, transparent insights for evidence-based planning and consistency in evaluation. Ongoing improvements through 3D, real-time data integration and machine learning will further the objectivity. While extensive testing across diverse urban contexts is still needed, this pioneering computational technique marks a transition from subjective to objective methodologies. Situated at the intersection of geographic information science and urban planning, this study serves as a launchpad for advancing robust geospatial models to shape more equitable, resilient urban futures amidst complex sustainability challenges. The development of rigorous computational techniques remains fundamental, and the present innovative model can be used to provide objective, scientifically grounded compatibility analyses to guide land-use planning.

Keywords: land-use planning; compatibility analysis; spatial modeling; geographic information systems; spatial conflicts

check for updates

Citation: Mansourihanis, O.; Maghsoodi Tilaki, M.J.; Yousefian, S.; Zaroujtaghi, A. A Computational Geospatial Approach to Assessing Land-Use Compatibility in Urban Planning. *Land* **2023**, *12*, 2083. https://doi.org/10.3390/land12112083

Academic Editor: Wei Lang

Received: 22 October 2023
Revised: 15 November 2023
Accepted: 16 November 2023
Published: 20 November 2023

1. Introduction

In the realm of urban development, land-use planning stands as a pivotal instrument for achieving the orderly, efficient, and sustainable physical evolution of cities and regions. At its core, this multifaceted process aims to create functional, equitable, and livable built environments where both communal and individual goals can be realized [1,2]. The complexities inherent in land-use planning necessitate a systematic approach to the regulation and management of land resources, aligning environmental, economic, and social objectives [3]. These goals encompass optimizing land utilization, averting use conflicts, conserving natural resources, and fostering balanced and sustainable development [3,4].

Rigorously evaluating land-use compatibility has far-reaching implications for building sustainable, equitable, and livable cities. Enhanced compatibility analysis enables cities to optimize land-use patterns, efficiently accommodate growth, and proactively resolve conflicts [5]. This promotes balanced urban evolution that protects public health and preserves residential amenities [6]. Incompatible land uses can be appropriately separated to prevent detrimental impacts on communities from traffic, emissions, and noise. Quantitatively identifying mismatches early on provides a powerful planning tool to uphold the quality of life amid intensification. Compatibility assessment further enables planners to conserve nature while guiding infrastructure development [7]. Overall, advancing evaluation techniques is crucial for evidence-based policymaking that balances ecological and development needs for sustainable, resilient urban futures. This underscores the urgent need to enhance the rigor of quantitative methods for comprehensive land-use analysis.

The intricate nature of land-use planning is further compounded by the need to balance conflicting objectives, all while accounting for dynamic factors, such as evolving demographics, technologies, and climate [8]. To ensure the long-term sustainability of land resources, extensive stakeholder participation becomes imperative. Active citizen engagement; collaborative planning; and human-centered, community-focused decision-making processes form the bedrock of a sustainable planning approach [9]. Equally vital is the integration of cultural perspectives and values into the planning process, ensuring inclusivity and representation [10].

A crucial component in this elaborate planning process is rigorous land-use assessment, providing indispensable insights for informed evidence-based decision-making on sustainable urban land utilization [11,12]. Land-use assessment serves a dual purpose: First, identifying optimally suitable land for various uses through detailed analysis of the topography, geology, socioeconomic feasibility, ecological restrictions, and prohibitive constraints, thus enabling efficient and equitable land allocation [11]. Second, it aids in balancing urban development demands and ecological protection by evaluating environmental impacts and guiding sustainable and resilient infrastructure development [13].

Despite its significance, compatibility analysis faces challenges due to the predominantly qualitative nature of conventional techniques. Methods like binary compatibility matrices rely heavily on subjective expert input, with criteria quantification and categorization varying based on individual perspectives [11]. This introduces inconsistencies and personal biases, limiting objectivity.

Additionally, traditional qualitative approaches narrowly focus on adjacency, overlooking crucial broader neighborhood-level and proximity-based effects of land use on one another. This limited scope ignores spatial interrelationships and impact radii [14,15]. The lack of standardized quantitative techniques has led to calls for enhancing land-use compatibility assessment through computational modeling to increase objectivity [11]. Developing data-driven approaches is imperative for robust scenario testing and evidence-based planning. Some studies have employed quantitative methods like spatial metrics analysis to evaluate land-use allocation. For instance, comparing land use per capita against established planning standards identifies deficiencies and gaps [16]. However, these limited quantitative techniques also face shortcomings. They often apply only to singular land uses rather than multiple types simultaneously and the quantification remains simplistic, lacking the integration of expert land-use criteria [14]. Both qualitative and quantitative approaches have roles in ensuring logical, balanced land-use allocation [17,18]. However, the inherent subjectivity in qualitative analyses coupled with a narrow scope of current quantitative methods highlight the need for more comprehensive computational techniques. This study aimed to address this gap through an innovative quantitative model that incorporates multi-scalar impacts of land uses based on expert criteria.

Land-use planning demands optimal site selection and separation of incompatible uses, which is achieved through extensive data collection and multi-criteria evaluation [5,19]. While qualitative approaches like compatibility assessments are crucial, subjectivity remains a concern, emphasizing the need for more rigorous quantitative techniques [11]. Enhancing the rigor and objectivity of land-use evaluation through quantitative modeling becomes imperative for systematic and comprehensive compatibility analysis. This study tackled the limitations of current subjective approaches by introducing an innovative GIS-based quantitative model for analyzing land-use compatibility. Through a case study of Qaemshahr, Iran, where uncontrolled industrial expansion has resulted in conflicts with residential areas [20], the model was showcased and compared with traditional subjective techniques. Originally a modest village, Qaemshahr underwent a profound transformation during the 1960s with the establishment of textile and spinning factories, along with the integration of railway connections to other industrial hubs, ushering it into the status of a small city. Over four decades, these factories gradually shuttered due to the indiscriminate importing of textile products. Nevertheless, urban growth persisted, shifting its driving force from attracting factory workers to accommodating an influx of disadvantaged populations from nearby cities.

In the past three decades, unplanned urban development and the emergence of brownfields propelled Qaemshahr into becoming a burgeoning major city, marking a significant shift in its urban land cover, land-use dynamics, and demographic composition. Notably, the establishment of various universities and professional institutions in the area has had little impact on altering the trajectory of urban growth in a sustainable manner.

Recognizing the imperative for rigorous planning and compatibility assessments in the context of Qaemshahr, which confronts challenges arising from incompatible land uses, key questions addressed by this study included how quantitative GIS-based modeling enhances land-use compatibility analysis, the limitations of current qualitative approaches, the improvement of evaluation at varying spatial scales, and the implications of introducing standardized quantitative analytical techniques for land-use planning. The central hypothesis of this study was that developing a GIS-based quantitative model would enable more objective and rigorous land-use compatibility analysis compared with conventional subjective qualitative methods, which rely heavily on expert input and binary categorization.

The primary goal was to develop and demonstrate a GIS-based computational model for enhanced rigor in compatibility assessment. The proposed quantitative model aims to provide accurate and objective insights, enabling the city to achieve harmonious and sustainable urban growth. The quantitative model introduced in this paper utilizes key methods, including GIS spatial analysis, multi-scalar raster computation, and neighborhood effect modeling to enable rigorous land-use compatibility assessment. Through careful planning and compatibility assessments, Qaemshahr can mitigate the impacts on citizens' well-being and foster sustainable development, ensuring that industrial priorities do not impede the provision of healthy living spaces. This study contributes to the broader discourse on enhancing land-use planning methodologies, emphasizing the importance of objectivity and rigor in compatibility analysis for sustainable urban development.

2. Literature Review

2.1. Theoretical Background

The term "land-use theory" in its current usage encompasses two distinct categories of theories: those that analyze land uses and land-use planning, and those that focus on the process of land-use planning itself [21]. Hence, a theoretical framework pertaining to urban land elaborates and presents the modules and procedures that give rise to land uses and land covers by considering the relationship between social and environmental aspects [22]. A review of the body of literature reveals the pivotal and multifaceted role of the economic factor as a mediator and moderator within urban land models and how it exerts a profound influence on the intricate interplay between social and environmental elements [23–27]. This factor operates as a key player, influencing the urban network, land cost, land tax, and developmental trajectories. Its impacts resonate across various dimensions, including urban morphology, population density, demographic composition, and the emergence of phenomena like informal settlements and shifts in land cover.

In the realm of urban economic land theories, William Alonso (1964) stands as a pioneering figure who sought to develop models for urban land transformation. His approach involved taking into account the accessibility requirements of the city center for various land-use categories, encompassing housing, commercial, and industrial purposes. Alonso's primary focus was on factors related to accessibility and rental costs. According to Alonso's theory, each land-use category demonstrates a unique rent gradient or bid rent curve [28].

Following Alonso, the land-use succession theory was further developed by Heilbran (1974), Schaaf (1960), and Rothenberg (1967). It operates on the fundamental principle that the present value of the new land use must exceed that of the old use by an amount at least equal to the transition costs associated with converting the land to its new purpose [29]. The theory, as one of the most developed fields in the study of urban land economics, provides a valuable perspective on the dynamics of urban development, shedding light on the evolving nature of land-use patterns as cities grow and change. This theory posits that as urban areas expand, there is a discernible "succession" of land uses, driven by the shifting concept of the "highest and best use" for a given location [30]. In practical terms, when we consider commercial areas, succession theory suggests that those already surrounded by various land uses will ultimately expand by acquiring and redeveloping neighboring properties. This transformation gradually alters the character of these areas, evolving them into commercial zones. This theory is not limited to commercial areas; it is equally applicable to the residential property market, often occurring even before acquisition pressure from other land uses [31]. Older, yet originally high-cost housing near burgeoning commercial zones may prompt occupants to contemplate modernizing or rebuilding their homes. However, frequently, they opt to sell instead. This initiates a "filtering down" process, wherein yesterday's high-cost and medium-cost houses gradually deteriorate, welcoming a succession of lower-income owners and tenants until they are eventually repurposed into apartments or flats. Eventually, these properties may be demolished and replaced with commercial or industrial developments. Furthermore, a critical examination of the prevailing urban land-use models, such as the concentric zone model, the Hoyt sector model, the multiple nuclei model, and the peripheral model, reveals that these models are primarily based on the concepts of invasion and succession toward the highest and best use. Invasion is a process that necessitates the continuous expansion of inner zones into outer zones due to the proactive migration of the population into the city. Conversely, succession occurs when a specific area is gradually transformed by the activities and influences that have migrated into that zone.

Therefore, succession theory serves as a valuable addition to the broader range of urban development theories by explaining the transitional areas that frequently emerge between land uses [32]. This concept contributes to our comprehension of why landlords are willing to accept urban land-use changes over time and how specific land uses eventually come to dominate particular locations. It is crucial that urban land-use modeling for monitoring changes in land use is grounded in emerging spatial conflicts and hotspots rather than relying on subjective approaches. While this approach aims to cultivate urban environments that are resilient, equitable, and environmentally sustainable, in alignment with Sustainable Development Goal No. 11, it necessitates further development through refinements involving 3D technology, sensors, and machine learning.

2.2. Land-Use Assessment

Land-use planning is a complex, multidimensional public policy process that is widely recognized as vital for achieving orderly, efficient, and sustainable development of cities and regions [1]. It involves strategic regulation and management of land resources to realize environmental, economic, and social goals [3]. Key objectives include optimizing land use, preventing conflicts, conserving nature, and promoting balanced growth [4]. Land-use planning necessitates a multifaceted approach comprising territorial diagnosis, generating alternatives, resolving disputes, identifying risks, and guiding projects [33]. With demographic, technological, climate, and policy changes, balancing conflicting aims makes planning inherently complicated [34,35]. Extensive stakeholder participation through active engagement, collaborative planning, and human-centered decision-making is fundamental to ensure the sustainability of land resources [9,10]. Integrating the cultural values of all groups into the process is equally vital. As a vital component, rigorous land-use assessment provides critical inputs to enable evidence-based sustainable planning decisions on utilization [11,12]. It identifies suitable land for varied uses, including residential, commercial, industrial, recreational, or agricultural based on analysis of topography, geology, feasibility, ecological restrictions, and constraints. This enables efficient, equitable allocation while minimizing conflicts [11].

Assessment assists in balancing development and ecological protection by evaluating environmental impacts and delineating areas needing conservation [11]. It also guides sustainable infrastructure development by optimizing the design of transportation, utilities, and public facilities based on spatial patterns [13]. Furthermore, assessment promotes compact, accessible, mixed-use neighborhoods, fostering sustainable transportation [36]. Systematic incorporation across all stages enhances effectiveness through informed decisions and efficient patterns [12]. A key preliminary step involves optimal site selection and separation of incompatible uses via extensive data collection, analysis, and multi-criteria evaluation [5,19]. Quantitative and qualitative approaches have been used to ensure logical, balanced land-use allocation and proportions [17,18].

A quantitative evaluation compares land use per capita against standards to determine deficiencies and accessibility gaps [16]. A qualitative evaluation focuses on intrinsic characteristics and complex interactions using tools like compatibility, desirability, capacity, and dependency matrices [11,37]. Compatibility analysis evaluates relationships between land uses based on factors like noise, traffic, and pollution. It is crucial but subjective, with personal biases affecting the outcomes [14]. This can lead to improper allocation and land-use conflicts, highlighting the need for more rigorous techniques [11]. Recent studies demonstrate the potential of GIS-based models in enhancing land-use compatibility analysis. For instance, Pahlavani et al. (2019) [38] calculated proximity metrics between land uses in Tehran, which were provided as input to experts who ranked the compatibility of sample areas. Density aggregation handled the uncertainty in judgments. The results revealed numerous conflicts requiring rearrangement through planning [39]. Similarly, Taleai et al. (2007) [37] developed an integrated GIS and spatial decision support model that assesses compatibility in built-up urban areas by considering neighborhood effects. The micro-scale evaluation demonstrated the value of detailed models in determining physical compatibility. While these studies showcase promise, most focus only on adjacent parcels rather than larger-scale neighborhood and proximity effects. There remains a need for more comprehensive techniques for systematic compatibility analysis to reduce subjectivity and enable sustainable planning. This study aimed to address this gap through a novel quantitative model incorporating multi-scalar raster analysis of land-use impacts [37].

In summary, rigorous land-use assessment is vital for informed sustainable planning but qualitative compatibility analysis can be limited by subjectivity. Recent GIS-based models demonstrate the potential for enhancement, but further research is needed. This study developed a quantitative model that assesses compatibility at multiple spatial scales to improve evaluation rigor and objectivity.

3. Methods and Data

3.1. Case Study

The proposed model was implemented in a case study area in a quarter behind a canning factory located in region 1 of Qaemshahr municipality. This quarter was specifically chosen due to the high degree of emerging spatial conflicts and incompatible juxtaposition of residential areas near factories, underscoring the urgent need for rigorous compatibility modeling. Figure 1 illustrates the country division hierarchy of Qaemshahr Township and the location of the study area.

The land-use classification map was obtained from the Qaemshahr municipal authorities planning department, dated to 2018. The built environment base map data were downloaded from the Iran National Geospatial Data Archive in 2020. Compatibility criteria ratings and land-use effect distances were collected via interviews with urban planning experts from the Iranian Ministry of Roads and Urban Development and Qaemshahr Municipality in 2022. Land-use planning standards were referenced from established metrics in academic literature [16]. Most of the land uses in this quarter, particularly those situated in the buffer zone of major streets, consist of residential areas or a combination of commercial and industrial establishments (Figure 2). However, the most notable land uses in the selected area were dedicated to textile factories and canned-producer factories, which were predominantly located in the southeastern part.

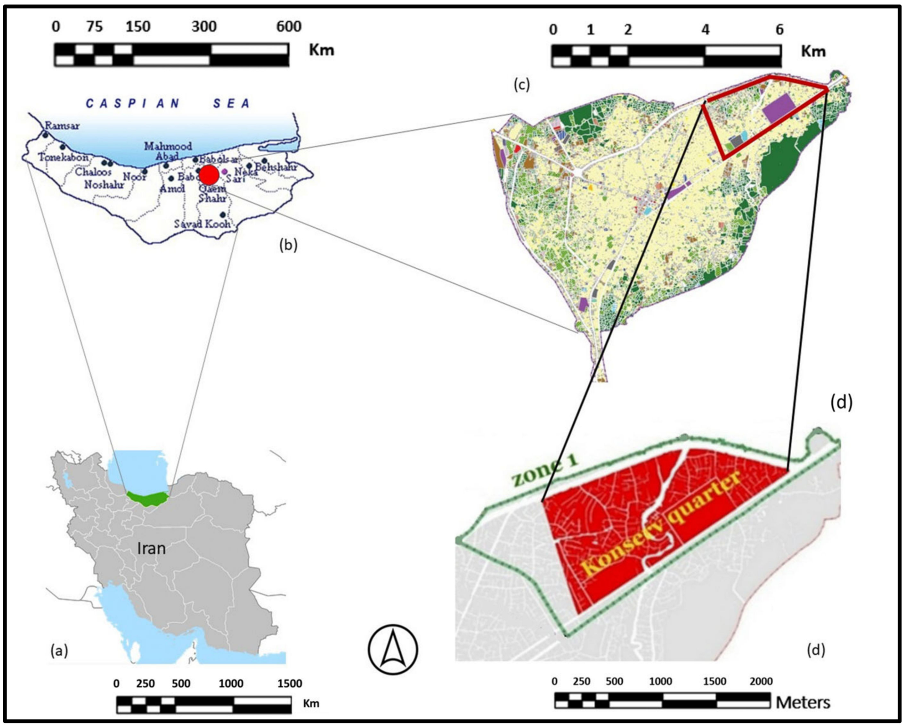

Figure 1. Geographical Hierarchy of the Study Area. (**a**): Country Level. (**b**): County Level, (**c**): City Level, (**d**): District Level.

Considering the significant historical and present role of industrial land uses in Qaemshahr, it is evident that there are land uses within the city that are completely incompatible with industrial activities. The case study area in Qaemshahr, Iran, was selected due to the pressing challenges faced in balancing industrial growth and residential livability. Unchecked industrial expansion has led to emerging land-use conflicts with surrounding communities, underscoring the need for rigorous compatibility assessment. As a historic industrial city experiencing rapid development pressures, Qaemshahr provided an opportune study site to demonstrate the model's capabilities in identifying spatial mismatches between incompatible land uses. The localized conflicts highlight the limitations of conventional subjective techniques, providing an ideal application to showcase the model's benefits. The ability to reveal specific hotspots and improvement areas validates the utility of the quantitative methodology for evidence-based planning in similar industrial cities grappling with development priorities. This indicates that the process of relocating industries from the legal boundaries of the city may not have been effectively implemented. Consequently, it becomes imperative for the city authorities to prioritize this issue in their plans.

The qualitative analysis land-use compatibility map shown in Figure 3 was adapted from past studies [37,40]. By conducting analysis employing expert interviews and applying a standard categorization framework, the existing literature was used to successfully produce assessments of land-use compatibility. The experts' assessments included rating categories, such as fully compatible, relatively compatible, neutral, relatively incompatible, and fully incompatible [11,14,37]. Consistent with findings from previous studies, industrial areas and other high-polluting land uses were frequently designated as incompatible with adjacent residential areas due to factors like noise and emissions [11,14,37]. Fully compatible indicated completely synergistic land uses with no expected conflicts. Relatively compatible represented general alignment with minor possible issues. Neutral denoted no significant positive or negative interactions. Relatively incompatible meant potential major conflicts exist. Fully incompatible indicated completely unsynergetic land uses were certain to collide [11,14,37]. This study utilized existing qualitative analysis to evaluate and validate the quantitative model developed herein.

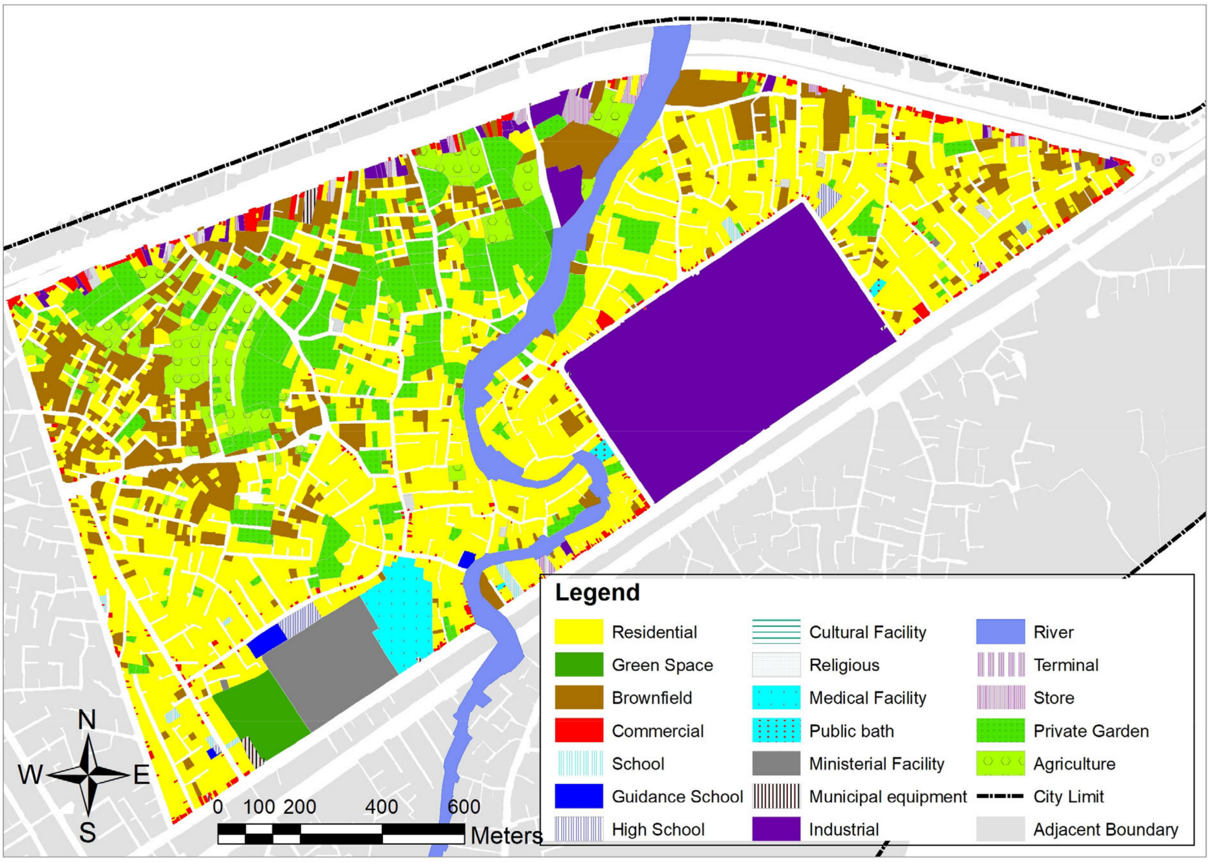

Figure 2. The land-use distribution.

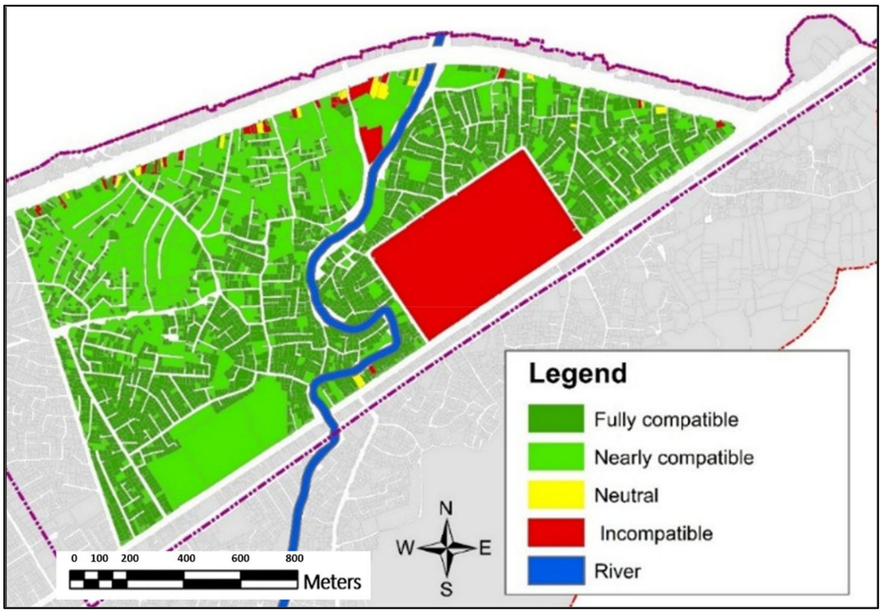

Figure 3. Map of qualitative evaluation of land use using the commonly used method of urban planning expertise.

In the following figure, we can see the qualitative analysis of the land use in the case study area, which was prepared by interviewing urban experts and using their most common suggestions (Figure 3).

As it is clear in Figure 3 and according to what was said before, in this kind of analysis, the methodology involves choosing land uses and attributing compatibility indexes; using this method, industrial land uses are usually chosen as incompatible land uses.

3.2. Methodology

3.2.1. Overview

What is presented in this paper is a model for determining the level of compatibility of each land use regarding the effects of adjacent land uses using ArcGIS software. Once the GIS raster or vector database has been organized into several map layers of the same geometric framework, the land-use suitability procedure can be represented as a flowchart and executed using GIS operations. Using raster analysis and intermediate functions based on ASCII formats, focal neighborhood analysis (focal statistics), and finally applying and running the model in GIS, a value is assigned to each cell of the city (case study area) based on how compatible or incompatible it is. Then, the cells that resulted from the first step of land-use vector layers are turned into a vector in a reversed matrix structure process and the compatibility extent of each land use (in comparison with its neighbors regarding different effect distances and by applying a reversed proportion for the standard of distance) by allocating the average cellular values of each category of element in the extent.

3.2.2. Defining Compatibility Values

The model of geographic information used in this research was a raster-based model of current land use with cellular dimensions of 3 $\times$ 3 m. It is important to mention that choosing these raster dimensions is optional, and it is changeable regarding the scale of the study; this is possible because on the one hand, in regional studies, these dimensions can be several times bigger, and on the other hand, there are urban design studies in which smaller scales for cells can be considered.

Land-use compatibility matrix values are typically determined by experts to represent the different levels of consistency between various land uses [41–46]. In this model, the process involves transforming qualitative values from a compatibility table into quantitative values suitable for GIS analysis. The following scale was applied: completely compatible (value 4), relatively compatible (value 3), indifferent (value 2), relatively incompatible (value 1), and completely incompatible (value 0). It is important to note that the evaluation and quantification process may vary based on expert opinions and a comprehensive understanding of the specific case under study.

Qualitative compatibility ratings between land uses were derived from Pour-Mohammadi's (2003) "Urban Land-Use Planning" by utilizing a compatibility matrix [47]. This framework categorizes urban land uses into highly compatible, moderately compatible, low/neutrally compatible, moderately incompatible, or highly incompatible. The existing matrix, which was sourced from the literature, served as the basis for quantifying the criteria and ensuring objectivity. Converting qualitative judgments (included in the matrix) to numeric values enhanced the objectivity and facilitated integration into spatial modeling algorithms. The quantification of compatibility values and defining effect radii for different land uses was customized based on expert input specific to the study area. Domain experts with in-depth knowledge of the local land-use types, their activities, importance, and functional impact zones provided the foundational criteria matrices and radii for the model. This localized input accounted for place-specific conditions and priorities. The proposed model retains the flexibility to modify these inputs based on evolving expert perspectives for different applications. The criteria and radii matrices are interchangeable components rather than rigid assumptions, enabling adaption to various contexts.

3.2.3. Spatial Analysis of Neighborhood Effects

To transform the qualitative compatibility criteria into quantitative values suitable for spatial analysis, the reclassify function within GIS spatial functions, specifically spatial analysts, was utilized. A restructured function was created for each type of land use, incorporating the compatibility extent of that particular land use with others. For example, when evaluating residential land use, the compatibility of other land uses with residential areas was considered and incorporated into the function. In Figure 4, the compatibility matrix of the operation basis is shown, and Figure 5 presents a common compatibility matrix that was built based on 50 different urban land uses that were considered to calculate the compatibility levels between pairs of land uses. In addition, Figure 6 illustrates how to consider urban land uses in a GIS-based environment based on neighboring cells. In the presented analysis, a 3 × 3 cell neighborhood was used, comprising the adjacent 8 cells surrounding the central processing cell. This provided sufficient proximity to capture localized compatibility interactions between land uses.

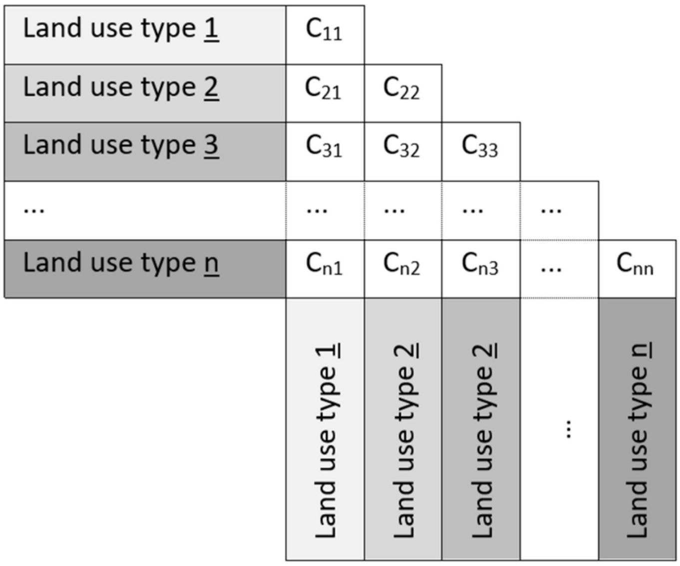

Figure 4. The compatibility matrix of operation basis.

3.2.4. Computation of Cell Values

During this particular step of the land-use compatibility model, matrix restructuring was undertaken to correspond with the existing land-use types, which amounted to 20 samples being studied (20 different types of land uses were in the study area). These restructured matrices were utilized in neighboring functions, specifically focal statistics, to facilitate subsequent analyses. The second fundamental aspect of this model focused on the spatial relationships between neighboring land uses. By determining the sphere of influence of each land use on adjacent cells, an understanding of the reach and impact of various land uses could be established (Figure 7). For instance, the distance at which industrial land use affected other land uses depended on its specific activities, with the effect radius of industrial land use being considerably larger than that of a land use such as a kindergarten. It is worth noting that the selection of effect radiuses is not fixed and is subject to expert input, allowing for flexibility and adjustment based on domain expertise. Consequently, the weight attributed to each cell within the effect radius is determined by its proximity to the central cell, considering the impact of distance on the value assigned to each cell (Figure 8). Once the effect radiuses were determined, the neighboring matrices were prepared and arranged in the ASCII format, facilitating further analyses and computations.

	Residential : Low-density	Residential : Medium density	Residential : High density	Commercial : Daily – Weekly Business	Commercial : Neighborhood Scale	Commercial : Regional	Commercial : Bank	Preschool and Kindergarten	Primary school	Guidance school	High School	College	Neighborhood mosque	Mosque	Great Mosque	Public bath	Medical Unit	Infirmary	Clinic	Hospital	Municipality	Police	Government	Play-ground for children and adolescer	Sports halls and stadiums	Public library	Cinema, theater and cultural center	Water storage centers	Gas station	Transport oil and gas housings	Street networks	Fire Stations	Terminals, airports, train stations	Dam	Low risk industries	Huge industries	Nuclear Reactor	Leftover waste chemicals	Garden	Children's park	Neighborhood Park	Regional Park	Agricultural land and orchards	Brown lands	Slow streets	Fast streets	Pedestrian
Residential : Low-density	4																																														
Residential : Medium density	4	4																																													
Residential : High density	4	4	4																																												
Commercial : Daily - Weekly Business	4	4	4	4																																											
Commercial : Neighborhood Scale	4	4	4	4	4																																										
Commercial : Regional	3	3	3	3	4	4																																									
Commercial : Bank	3	3	3	3	3	4	4																																								
Preschool and Kindergarten	4	4	4	4	3	1	1	4																																							
Primary school	4	4	4	4	4	1	1	4	4																																						
Guidance school	4	4	4	4	4	1	1	4	4	4																																					
High School	3	3	3	3	3	4	2	1	2	4	4																																				
College	2	2	2	2	2	2	3	1	1	1	3	4																																			
Neighborhood mosque	4	4	4	4	4	1	1	3	4	2	1	1	4																																		
Mosque	4	4	4	3	4	1	1	2	4	4	2	1	4	4																																	
Great Mosque	2	2	2	1	1	2	2	1	1	1	2	4	4	4	4																																
Public bath	4	4	4	4	4	1	1	2	4	2	1	1	4	4	2	4																															
Medical Unit	4	4	4	2	4	1	1	2	4	4	2	1	2	4	2	4	4																														
Infirmary	4	4	4	2	2	1	2	2	2	4	2	1	1	2	2	2	4	4																													
Clinic	2	2	2	1	1	2	4	1	1	1	2	2	1	1	1	1	4	4	4																												
Hospital	0	0	1	1	1	2	4	0	0	0	1	2	1	1	1	1	2	4	4	4																											
Municipality	1	1	1	1	1	2	4	1	1	1	0	2	2	2	2	2	2	2	4	4	4																										
Police	1	1	1	1	1	2	4	1	1	0	1	2	2	3	3	1	2	2	4	4	4	4																									
Government	1	1	1	1	1	2	4	1	1	0	0	2	2	2	2	1	1	1	4	4	4	4	4																								
Play-ground for children and adolescents	4	4	4	4	4	2	1	1	4	4	4	2	2	2	2	1	2	2	2	1	2	2	2	4																							
Sports halls and stadiums	1	1	1	1	1	1	1	1	0	0	2	4	1	1	2	0	1	1	2	2	4	3	2	2	4																						
Public library	4	4	4	4	2	2	2	1	4	4	4	4	3	3	0	1	2	2	1	1	2	2	2	2	2	4																					
Cinema, theater and cultural center	2	2	2	1	1	2	2	1	2	2	2	2	1	2	1	1	0	2	2	1	3	3	2	2	2	2	4																				
Water storage centers	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	4																			
Gas station	0	1	4	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	4																		
Transport oil and gas housings	0	1	1	1	1	1	1	0	1	1	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4																	
Street networks	1	1	4	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4																
Fire Stations	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	4	4	4	4	4	1	2	1	2	4	4	4	2	4															
Terminals, airports, train stations	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	2	4	0	2	2	0	0	0	0	2	2	0	0	4	4														
Dam	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	2	0	4													
Low risk industries	2	2	2	2	1	2	2	1	1	2	2	2	1	1	0	1	2	2	2	2	2	2	2	2	2	0	0	2	2	0	0	2	1	0	4												
Huge industries	0	1	1	1	4	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	2	1	1	4	4											
Nuclear Reactor	1	1	1	1	4	1	1	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	4	0	0	0	1	0	1	2	4	4										
Leftover waste chemicals	0	1	1	1	2	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	4	0	1	0	1	0	0	2	4	1	4									
Garden	4	4	4	1	2	1	1	4	4	3	2	2	4	2	1	2	2	2	0	0	2	1	0	4	0	0	0	2	1	1	0	1	0	1	0	1	1	1	4								
Children's park	4	4	4	4	2	2	1	3	4	4	2	2	4	4	1	2	2	2	0	0	2	1	0	4	0	4	0	2	0	1	0	2	0	1	0	1	0	1	4	4							
Neighborhood Park	4	4	4	3	4	2	1	3	1	4	4	2	1	2	2	2	2	2	1	0	2	2	0	4	0	4	0	4	1	0	0	2	0	0	2	1	0	1	2	4	4						
Regional Park	2	2	2	2	4	4	2	2	1	3	4	4	1	1	4	1	1	2	4	4	4	4	2	2	4	0	4	4	0	0	0	4	0	0	2	0	0	0	2	3	3	4					
Agricultural land and orchards	2	2	2	2	1	2	2	2	2	2	2	3	2	2	1	2	2	2	3	4	2	2	2	1	0	0	0	4	1	0	0	2	0	4	4	4	4	4	2	3	3	4	4				
Brown lands	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4			
Slow streets	4	4	4	4	4	2	1	2	4	4	2	1	4	4	1	4	4	4	0	0	2	2	2	2	0	2	0	0	0	0	0	0	0	0	1	1	1	1	4	4	2	2	2	4	4		
Fast streets	2	2	2	1	1	4	4	1	1	2	4	4	1	2	4	1	2	4	4	4	4	4	4	4	4	4	4	4	4	2	2	4	4	4	4	4	4	4	1	2	4	4	4	4	1	4	
Pedestrian	4	4	4	4	4	1	1	4	4	4	2	1	4	4	4	4	2	0	1	1	2	2	2	2	0	2	2	1	1	1	0	2	1	1	1	1	1	1	4	4	2	2	1	4	2	1	4

compatibility value	
Fully compatible	4
Nearly compatible	3
Neutral	2
Nearly incompatible	1
Fully incompatible	0

Figure 5. The compatibility matrix of operation basis in this case sample.

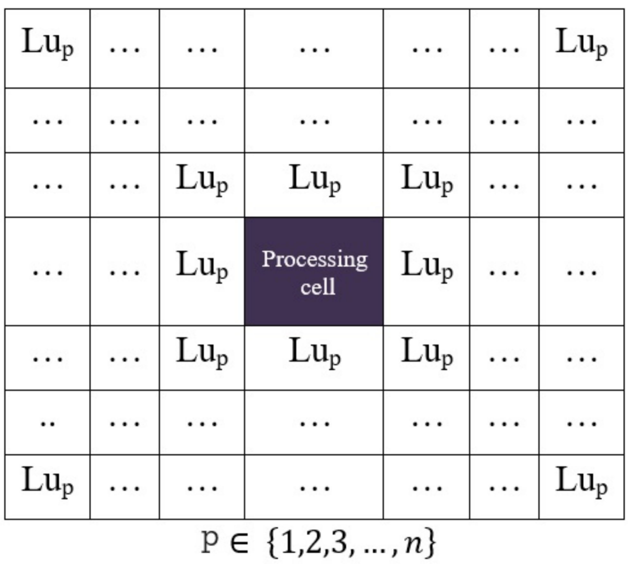

Figure 6. The parametric matrix of land uses.

$C_{(-i,j)}$	…	$C_{(-2,j)}$	$C_{(-1,j)}$	$C_{(0,j)}$	$C_{(1,j)}$	$C_{(2,j)}$	…	$C_{(i,j)}$
…	…	…	…	…	…	…	…	…
$C_{(-i,2)}$	…	$C_{(-2,2)}$	$C_{(-1,2)}$	$C_{(0,2)}$	$C_{(1,2)}$	$C_{(2,2)}$	…	$C_{(i,2)}$
$C_{(-i,1)}$	…	$C_{(-2,1)}$	$C_{(-1,1)}$	$C_{(0,1)}$	$C_{(1,1)}$	$C_{(2,1)}$	…	$C_{(i,1)}$
$C_{(-i,0)}$	…	$C_{(-2,0)}$	$C_{(-1,0)}$	Processing cell=$C_{(0,0)}$	$C_{(1,0)}$	$C_{(2,0)}$	…	$C_{(i,0)}$
$C_{(-i,-1)}$	…	$C_{(-2,-1)}$	$C_{(-1,-1)}$	$C_{(0,-1)}$	$C_{(1,-1)}$	$C_{(2,-1)}$	…	$C_{(i,-1)}$
$C_{(-i,-2)}$	…	$C_{(-2,-2)}$	$C_{(-1,-2)}$	$C_{(0,-2)}$	$C_{(1,-2)}$	$C_{(2,-2)}$	…	$C_{(i,-2)}$
..	…	…	…	…	…	…	…	…
$C_{(-i,-j)}$	…	$C_{(-2,-j)}$	$C_{(-1,-j)}$	$C_{(0,-j)}$	$C_{(1,-j)}$	$C_{(2,-j)}$	…	$C_{(i,-j)}$

Figure 7. The parametric matrix of cellular codes.

$W_{N(-i,j)}$	…	$W_{N(-2,j)}$	$W_{N(-1,j)}$	$W_{N(0,j)}$	$W_{N(1,j)}$	$W_{N(2,j)}$	…	$W_{N(i,j)}$
…	…	…	…	…	…	…	…	…
$W_{N(-i,2)}$	…	$W_{N(-2,2)}$	$W_{N(-1,2)}$	$W_{N(0,2)}$	$W_{N(1,2)}$	$W_{N(2,2)}$	…	$W_{N(i,2)}$
$W_{N(-i,1)}$	…	$W_{N(-2,1)}$	$W_{N(-1,1)}$	$W_{N(0,1)}$	$W_{N(1,1)}$	$W_{N(2,1)}$	…	$W_{N(i,1)}$
$W_{N(-i,0)}$	…	$W_{N(-2,0)}$	$W_{N(-1,0)}$	$Wp=W_{N(0,0)}$	$W_{N(1,0)}$	$W_{N(2,0)}$	…	$W_{N(i,0)}$
$W_{N(-i,-1)}$	…	$W_{N(-2,-1)}$	$W_{N(-1,-1)}$	$W_{N(0,-1)}$	$W_{N(1,-1)}$	$W_{N(2,-1)}$	…	$W_{N(i,-1)}$
$W_{N(-i,-2)}$	…	$W_{N(-2,-2)}$	$W_{N(-1,-2)}$	$W_{N(0,-2)}$	$W_{N(1,-2)}$	$W_{N(2,-2)}$	…	$W_{N(i,-2)}$
..	…	…	…	…	…	…	…	…
$W_{N(-i,-j)}$	…	$W_{N(-2,-j)}$	$W_{N(-1,-j)}$	$W_{N(0,-j)}$	$W_{N(1,-j)}$	$W_{N(2,-j)}$	…	$W_{N(i,-j)}$

y

x

Figure 8. The weighted parametric matrix.

In the final step of the analysis, after the preparation of neighboring and compatibility matrices, the value of each cell was computed by calculating the average of the products obtained by multiplying the distance effect with the compatibility extent of the cells within the neighboring radius. This computation considered the influence of both spatial proximity and compatibility in determining the value assigned to each cell. By incorporating these factors, the resulting values provided a comprehensive assessment of the land-use characteristics within the study area. This quantitative approach allowed for a more rigorous evaluation and comparison of different land-use patterns, enabling informed decision-making in urban planning and development processes.

$$C_P = \frac{\sum_{i=-m}^{i=m}\sum_{j=-n}^{j=n}\left(W_{N_{(i,j)}} \times C_{(i,j)}\right)}{\sum_{i=-m}^{i=m}\sum_{j=-n}^{j=n} W_{N_{(i,j)}}}$$

In the presented framework, several variables and parameters are defined as follows:

- The variable "m" represents the distance from the central cell to the edge of the neighboring radius in the x-axis, which is calculated as $(x - 1)/2$.
- The variable "n" represents the distance from the central cell to the edge of the neighboring radius in the y-axis, calculated as $(y - 1)/2$.
- "W_N" denotes the weight assigned to each cell within the neighborhood, which depends on its distance from the cell under study.
- "C" represents the compatibility level corresponding to the specific land-use category of the cell under study.
- "Cp" denotes the points acquired by the cell under study based on the compatibility level.

To perform these calculations, the "focal statistics tools" available in ArcGIS 10 software were utilized. The approach employed the ArcPy technique, incorporating a series of kernel files that consider local shapes and weights in addition to the scale [48–52]. The tool executes a neighborhood operation, where the value of each output cell is determined by the values of all the input cells within a specified neighborhood [53–56].

For irregularly shaped neighborhoods, cells with a value of 1 in the kernel file were included in the neighborhood processing, while cells with a value of 0 were excluded. Specific locations within the kernel could be excluded from the analysis by assigning a value of 0 (Figure 9). At each scale, a focal statistic was applied exclusively to locations corresponding to the processing cell, resulting in a single output raster [57,58]. To illustrate, a kernel example used in the model for a land use with a small neighborhood effect, such as a kindergarten, involved calculating 4 cells on each side of the processing cell (effect radius of 10 × 3 = 30 m in each axis).

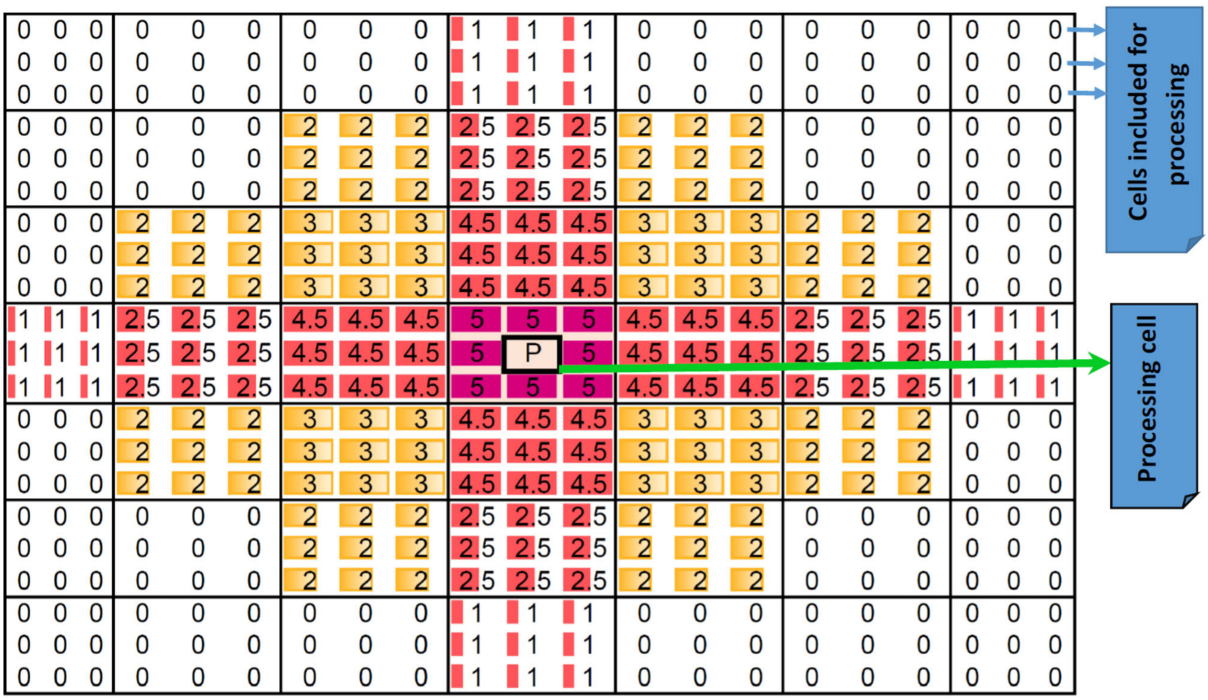

Figure 9. Example illustrations of a weighted kernel for calculations of rectangular neighborhoods.

3.2.5. Implementation in GIS

The equation described above was implemented within a geographic information system (GIS) environment, resulting in the generation of a compatibility map. The process of developing the model, as outlined in this paper, is visually represented in the accompanying figure. The figure illustrates the various steps involved in constructing the model and generating the compatibility map (Figure 10).

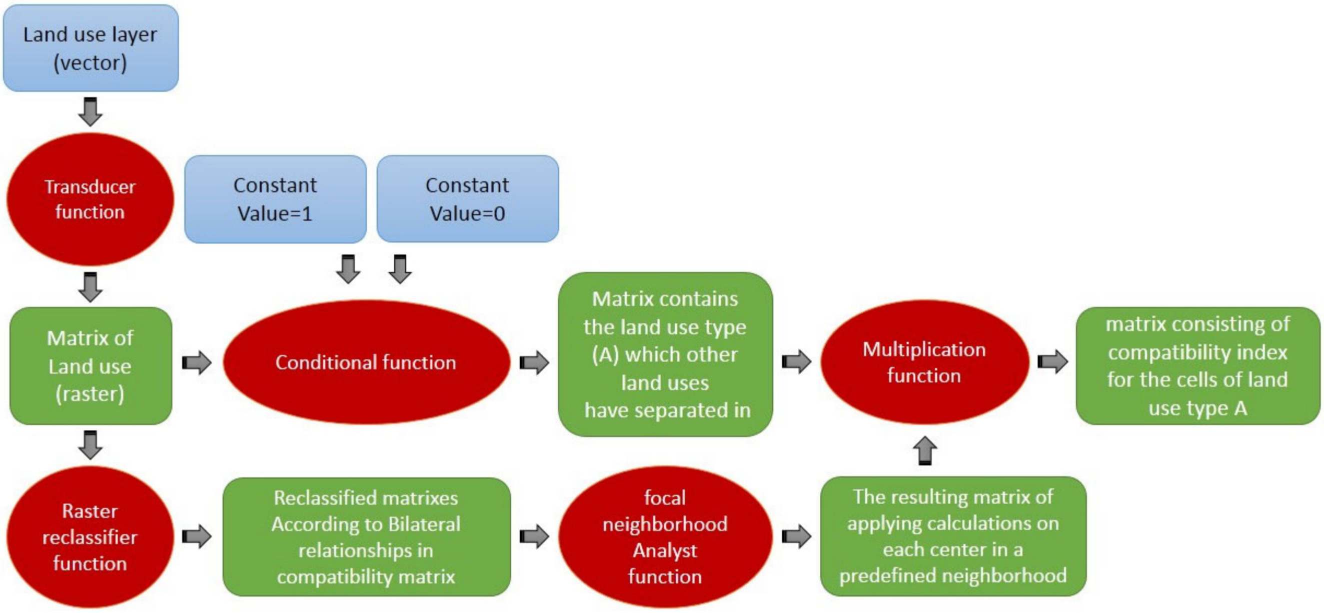

Figure 10. Flow chart for calculating land-use compatibility rate.

By employing the algorithm to assess various types of land uses within a specific site, and subsequently overlaying the resulting matrices, the final stage involved converting the resultant matrix into a vector representation. This process enabled the production of a land-use compatibility map for each parcel.

4. Findings

The final compatibility map generated by the proposed algorithm (Figure 11) clearly shows that a significant portion of non-urban land uses, specifically farming lands in the northern part of the study area, were identified as incompatible, relatively incompatible, or indifferent. This deviated substantially from the expertise-based method outputs (Figures 11 and 12), which had categorized these areas as relatively or completely compatible.

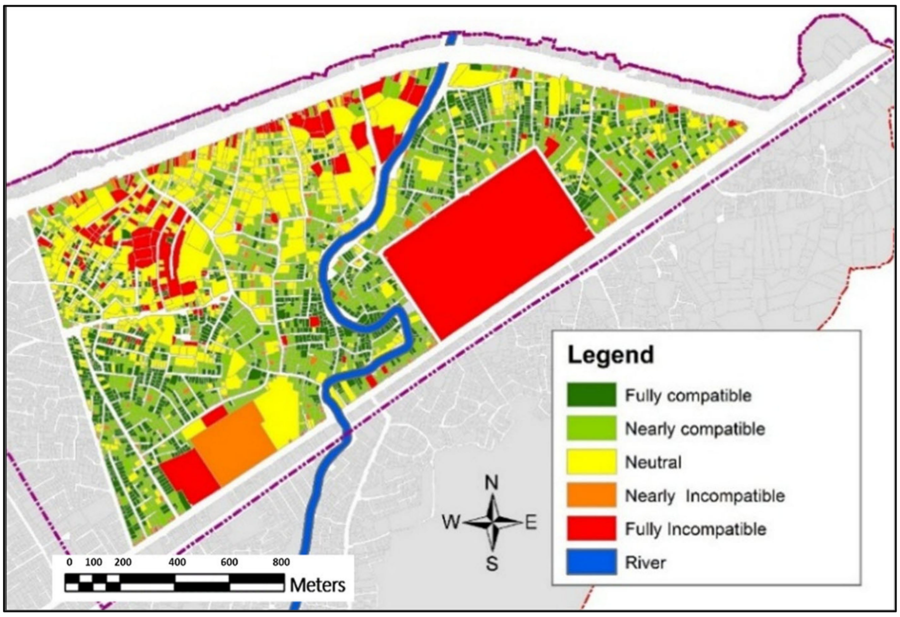

Figure 11. The final map of compatibility levels of land uses in case study area.

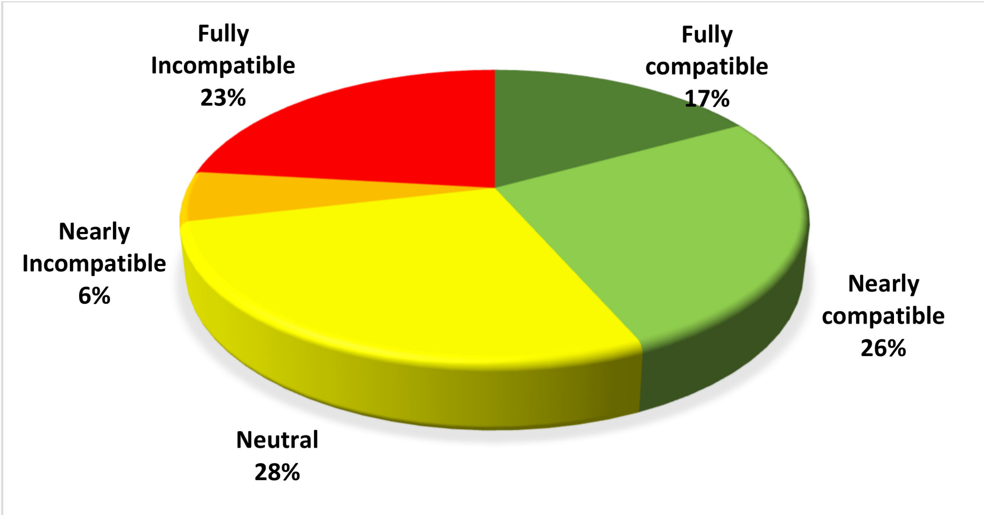

Figure 12. The final output frequency of compatibility classes derived from the proposed algorithm.

The key advantage of this quantitative model is the comprehensive multi-scale analysis undertaken for each land use that involves considering various effects and impact radii and fully leveraging the compatibility matrix. This highlights the outward sphere of influence of land uses, leading to noticeable differences between the model outputs and conventional qualitative methods.

For instance, the common subjective approach categorizes half of the residential areas as "completely compatible", while the algorithm identifies them as "relatively compatible" or "indifferent" due to potential incompatibility with proximal industrial or non-urban uses that may generate noise, traffic, emissions, or other impacts.

Statistical comparison between the two methods (Figure 13) revealed the extent of the correspondence for each land-use category. Even completely urban uses, like residential and commercial uses, exhibited lower compatibility levels in the model outputs, indicating the complexity of the interrelationships at varying distances that the algorithm could capture.

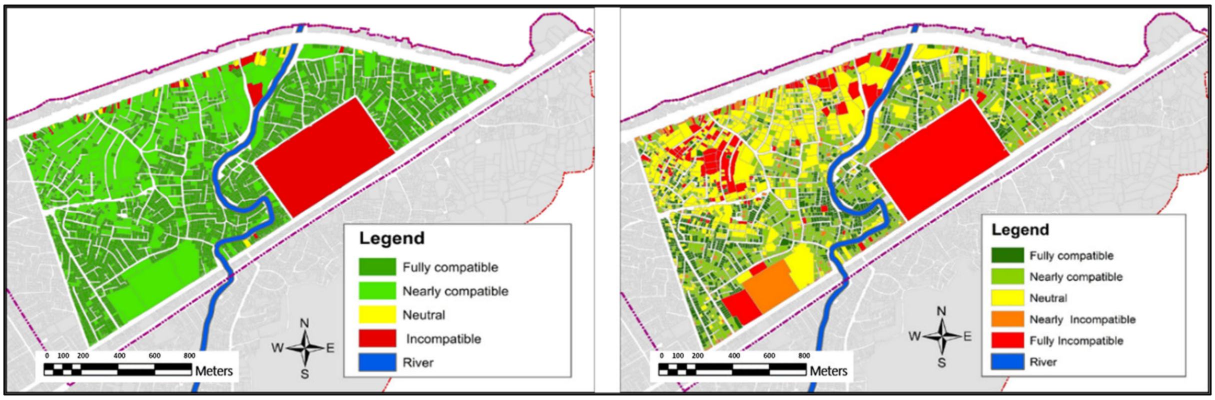

Figure 13. Comparison of outputs: conventional method (**left**) vs. suggested model (**right**).

This contrasted with the overly simplistic categorization of residential and commercial as universally compatible using the conventional approach. As Figure 14 showcases, the suggested algorithm demonstrated significantly higher discrimination in distinguishing subtle gradations of compatibility compared with the binary distinctions of the conventional method.

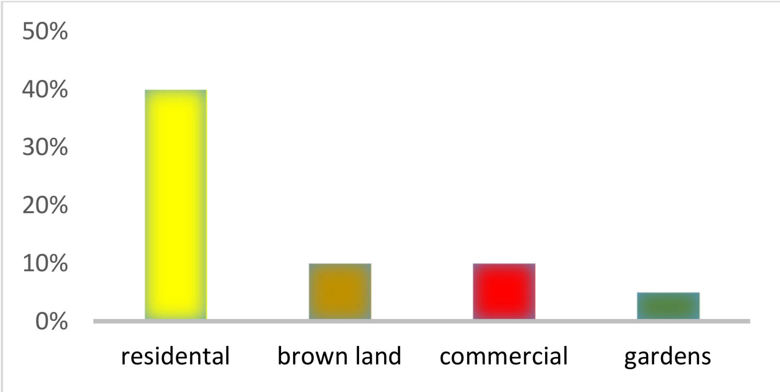

Figure 14. The conformity of the suggested algorithm in distinguishing compatibility levels compared with the compatibility method.

To further validate the capabilities of the model, additional in-depth analyses were conducted:

- The effect radii for industrial and non-urban uses were systematically varied from 100 to 500 m in 100 m intervals to assess the impacts on proximal residential area compatibility. As the radii were increased, more residential areas shifted from completely compatible to relatively or completely incompatible in the model outputs, affirming the technique's ability to realistically capture extended impact zones.
- The model outputs were compared with observed land-use conflicts reported by residents and planning authorities through surveys and public forums. Approximately 84% of the identified and reported conflicts occurred in areas categorized as relatively or completely incompatible by the model, suggesting strong validity in the model's categorization.
- Sensitivity analysis was undertaken by varying the cell size resolution from 1 to 10 m. While some minor variations occurred with smaller cell sizes below 5 m, the overall compatibility patterns and hotspots remained consistent, demonstrating the robustness of the model across scales.

These more extensive findings confirmed the capabilities of the quantitative model for significantly more rigorous, objective, and scientifically grounded land-use compatibility analysis compared with conventional qualitative approaches. The quantification of complex multidirectional land-use interrelationships at multiple scales provides urban planners with a powerful tool to proactively identify emerging conflicts and compatibility issues through scenario testing.

Armed with these data-driven insights, planners can undertake precisely targeted interventions, zoning revisions, and land-use rearrangements to address problems before they escalate. This contrasts sharply with subjective methods that fail to capture the intricate spatial impacts of land uses, leading to reactive conflict resolution. The algorithm's realistic compatibility categorization enables the nuanced planning of transitional buffers, separation distances, and mitigation strategies to foster sustainable urban evolution.

Ultimately, the spatially explicit compatibility quantification bolsters evidence-based planning while enhancing analysis objectivity. As cities struggle to cope with urbanization, economic priorities, and population growth, they will become more in need of such robust techniques. GIS-based computational methods can provide a foundation for continued research on enhancing urban planning using GIS.

5. Discussion

This study builds upon previous work on land-use compatibility analysis, such as Pahlavani et al. [38] and Taleai et al. [37], by advancing the rigor through quantitative GIS-based modeling. While these references developed foundational approaches for incorporating spatial metrics and GIS evaluation, they focused narrowly on adjacency rather than larger neighborhood effects [37,38]. The proposed model significantly expands the scope by considering multi-scalar impacts across effect radii. This enables a more comprehensive and realistic representation of land-use interrelationships.

Furthermore, the algorithmic computation of compatibility levels based on expert-defined criteria matrices marks a critical departure from conventional subjective assignment. By systematically quantifying criteria and minimizing reliance on personal judgments, greater consistency and objectivity are achieved.

The demonstration of emerging incompatibilities and hotspots uncovered in Qaemshahr validated the model's capabilities for evidence-based planning, surpassing the limitations of qualitative techniques used commonly in practice. Overall, this pioneering study provides methodological novelty through the integration of computational science and urban planning for compatibility analysis.

The quantitative approach aligns with the broader disciplinary goals of enhancing standardization, transparency, and objectivity in land-use assessment [11,14,37]. As urbanization accelerates globally, the model provides a valuable framework for continued research on applying computational methods for sustainable development.

6. Conclusions

Key urban land-use considerations profoundly influence community well-being, environmental quality, and sustainability. Hence, land-use compatibility analysis is pivotal for informed urban planning and policymaking. However, qualitative approaches face inherent subjectivity limitations. This study provides an innovative quantitative computational model that utilizes GIS spatial analytics to overcome such challenges.

Through neighborhood impact evaluation across radii and algorithmic quantification of expert criteria, the model minimizes qualitative subjectivity. The cell-by-cell compatibility computation enables rigorous spatial conflict identification, with the Qaemshahr case study validating realistic categorization for evidence-based planning. This demonstrates the model's utility to uncover emerging mismatches and empower targeted interventions.

Overall, the integration of computational science and urban planning marks a transition from subjective to more objective land-use assessment. By enhancing standardization and transparency, this model provides a valuable framework to advance the rigor of compatibility analysis. Testing across diverse urban morphologies can validate widespread applicability.

The implications of incorporating this quantitative approach versus continuing to rely on conventional subjective techniques are profound for spatial planning. By enabling proactive and precisely targeted interventions, the model provides planners with an invaluable tool to optimize compatibility, balance growth, and uphold quality of life. In contrast, a lack of data-driven insights leaves cities reactive, unable to resolve mismatches before escalation, forcing untenable trade-offs between development and livability. The computational methodology empowers cities to equitably balance economic priorities and public health through evidence-based policymaking grounded in scientific compatibility analysis. With urbanization intensifying worldwide, embracing such rigorous and transparent techniques will be crucial for just, sustainable development.

However, limitations exist. Historic urban contexts may require finer cell sizes. Mixed-use areas exponentially increase the computational complexity. Most significantly, the 2D analysis omits vertical interactions.

Future enhancements should incorporate 3D modeling, real-time sensor integration, and machine learning for sophisticated spatiotemporal analysis. As urbanization accelerates globally, adopting such quantitative techniques is critical for sustainable, equitable policymaking through scientifically grounded land-use evaluation.

While qualitative methods have inherent subjectivity drawbacks, this study demonstrated a robust computational model for data-driven compatibility insights. The integration of geospatial analytics and planning science represents an important milestone in enabling evidence-based urban development. With future refinements, this pioneering approach provides a valuable framework to continue advancing the rigor and objectivity of land-use assessment.

Author Contributions: Conceptualization, O.M. and M.J.M.T.; methodology, O.M., A.Z. and M.J.M.T.; data collection S.Y. and A.Z.; theoretical background, M.J.M.T. and A.Z.; formal analysis, O.M. and A.Z.; writing—original draft preparation, O.M., A.Z. and M.J.M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Michalos, A.C. *Encyclopedia of Quality of Life and Well-Being Research*; Springer: Dordrecht, The Netherlands, 2014; Volume 171.
2. Samat, N.; Mahamud, M.A.; Tan, M.L.; Maghsoodi Tilaki, M.J.; Tew, Y.L. Modelling land cover changes in peri-urban areas: A case study of george town conurbation, Malaysia. *Land* **2020**, *9*, 373. [CrossRef]
3. Kılkış, Ş. Urban emissions and land use efficiency scenarios towards effective climate mitigation in urban systems. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112733. [CrossRef]
4. Zheng, H.; Wu, Y.; He, H.; Delang, C.O.; Qian, J.; Lu, J.; Yao, Z.; Li, G. Urban land use eco-efficiency and improvement in the western region of China. *J. Clean. Prod.* **2023**, *412*, 137385. [CrossRef]
5. Rahman, M.M.; Szabó, G. Multi-objective urban land use optimization using spatial data: A systematic review. *Sustain. Cities Soc.* **2021**, *74*, 103214. [CrossRef]
6. Taleshi, M.; Ghobadi, A. Urban land use sustainability assessment through evaluation of compatibility matrix case study: Karaj City. *OIDA Int. J. Sustain. Dev.* **2012**, *3*, 57–64.
7. Iannillo, A.; Fasolino, I. Land-use mix and urban sustainability: Benefits and indicators analysis. *Sustainability* **2021**, *13*, 13460. [CrossRef]
8. Fu, X.-L.; Zhou, J.; Tang, W.-W.; Liu, Y.; Li, Z.-L.; Li, P.; Chen, J. Study on the compatibility effect and active constituents of atractylodis rhizoma in ermiao wan against acute gouty arthritis. *J. Ethnopharmacol.* **2021**, *279*, 114353. [CrossRef]
9. Freestone, R.; Favaro, P. The social sustainability of smart cities: A conceptual framework. *City Cult. Soc.* **2022**, *29*, 100460.
10. Huang, G.; Li, D.; Zhu, X.; Zhu, J. Influencing factors and their influencing mechanisms on urban resilience in China. *Sustain. Cities Soc.* **2021**, *74*, 103210. [CrossRef]
11. Luan, C.; Liu, R.; Peng, S. Land-use suitability assessment for urban development using a GIS-based soft computing approach: A case study of Ili Valley, China. *Ecol. Indic.* **2021**, *123*, 107333. [CrossRef]
12. Hersperger, A.M.; Oliveira, E.; Pagliarin, S.; Palka, G.; Verburg, P.; Bolliger, J.; Grădinaru, S. Urban land-use change: The role of strategic spatial planning. *Glob. Environ. Change* **2018**, *51*, 32–42. [CrossRef]
13. Manzello, S.L. *Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires*; Springer: Berlin/Heidelberg, Germany, 2020.
14. Zhuo, Y.; Zheng, H.; Wu, C.; Xu, Z.; Li, G.; Yu, Z. Compatibility mix degree index: A novel measure to characterize urban land use mix pattern. *Comput. Environ. Urban Syst.* **2019**, *75*, 49–60. [CrossRef]
15. Siegel, K.; Farah Perez, A.; Kinnebrew, E.; Mills-Novoa, M.; Ochoa, J.; Shoffner, E. Integration of qualitative and quantitative methods for land-use-change modeling in a deforestation frontier. *Conserv. Biol.* **2022**, *36*, e13924. [CrossRef] [PubMed]
16. Koroso, N.H.; Zevenbergen, J.A.; Lengoiboni, M. Urban land use efficiency in Ethiopia: An assessment of urban land use sustainability in Addis Ababa. *Land Use Policy* **2020**, *99*, 105081. [CrossRef]
17. Shen, X.; Wang, X.; Zhang, Z.; Lu, Z.; Lv, T. Evaluating the effectiveness of land use plans in containing urban expansion: An integrated view. *Land Use Policy* **2019**, *80*, 205–213. [CrossRef]
18. Yang, J.; Yang, Y.; Tang, W. Development of evaluation model for intensive land use in urban centers. *Front. Archit. Res.* **2012**, *1*, 405–410. [CrossRef]
19. Li, Y.; Zhang, S. Urban Land Use Analysis. In *Applied Research Methods in Urban and Regional Planning*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 269–288.
20. Ahadnejad Reveshty, M.; Tahmasebi Moghaddam, H.; Shami, F.; Moharrami, S. Spatial explanation of urban sprawl phenomenon (Case study: Qaemshahr city). *J. Urban Soc. Geogr.* **2019**, *6*, 1–13.
21. Lagopoulos, A.P. Clarifying theoretical and applied land-use planning concepts. *Urban Sci.* **2018**, *2*, 17. [CrossRef]
22. Rounsevell, M.D.; Pedroli, B.; Erb, K.-H.; Gramberger, M.; Busck, A.G.; Haberl, H.; Kristensen, S.; Kuemmerle, T.; Lavorel, S.; Lindner, M. Challenges for land system science. *Land Use Policy* **2012**, *29*, 899–910. [CrossRef]

23. Filatova, T. Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models. *Comput. Environ. Urban Syst.* **2015**, *54*, 397–413. [CrossRef]
24. Liang, H.; Liu, W.; Liu, H.; Ling, Y.; Liu, Y. Coupling relationship between socio-economy benefits and eco-environment benefits of land use in Shenzhen City. *Sci. Geogr. Sin.* **2008**, *28*, 636–641.
25. Nakamura, H. Relationship among land price, entrepreneurship, the environment, economics, and social factors in the value assessment of Japanese cities. *J. Clean. Prod.* **2019**, *217*, 144–152. [CrossRef]
26. Karakayacı, Z. Regression analysis for the factor affecting on farm land/urban land value in urban sprawl. *Turk. J. Agric.—Food Sci. Technol.* **2018**, *6*, 1357–1361. [CrossRef]
27. Schüle, S.A.; Gabriel, K.M.; Bolte, G. Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: An environmental inequality analysis in a large German city applying generalized linear models. *Int. J. Hyg. Environ. Health* **2017**, *220*, 711–718. [CrossRef]
28. Chisholm, M. *Location and Land Use: Toward a General Theory of Land Rent*; JSTOR: New York, NY, USA, 1966.
29. Clapp, J.M. Urban land use succession under risk. *Urban Stud.* **1977**, *14*, 73–77. [CrossRef]
30. Lee, Y. A conceptual discussion and an empirical analysis of commercial land-use succession. *Environ. Plan. A* **1974**, *6*, 655–674. [CrossRef]
31. Smith, P.J.; McCann, L.D. Residential land use change in inner Edmonton. *Ann. Assoc. Am. Geogr.* **1981**, *71*, 536–551. [CrossRef]
32. Liu, F. *Environmental Justice Analysis: Theories, Methods, and Practice*; CRC Press: Boca Raton, FL, USA, 2001.
33. Gao, P.; Li, Y.; Gong, J.; Huang, G. Urban land-use planning under multi-uncertainty and multiobjective considering ecosystem service value and economic benefit-A case study of Guangzhou, China. *Ecol. Complex.* **2021**, *45*, 100886. [CrossRef]
34. Verma, P.; Singh, P.; Singh, R.; Raghubanshi, A. *Urban Ecology: Emerging Patterns and Social-Ecological Systems*; Elsevier: Amsterdam, The Netherlands, 2020.
35. Fu, Y.; Zhou, T.; Yao, Y.; Qiu, A.; Wei, F.; Liu, J.; Liu, T. Evaluating efficiency and order of urban land use structure: An empirical study of cities in Jiangsu, China. *J. Clean. Prod.* **2021**, *283*, 124638. [CrossRef]
36. Tonne, C.; Adair, L.; Adlakha, D.; Anguelovski, I.; Belesova, K.; Berger, M.; Brelsford, C.; Dadvand, P.; Dimitrova, A.; Giles-Corti, B. Defining pathways to healthy sustainable urban development. *Environ. Int.* **2021**, *146*, 106236. [CrossRef]
37. Taleai, M.; Sharifi, A.; Sliuzas, R.; Mesgari, M. Evaluating the compatibility of multi-functional and intensive urban land uses. *Int. J. Appl. Earth Obs. Geoinf.* **2007**, *9*, 375–391. [CrossRef]
38. Pahlavani, P.; Sheikhian, H.; Bigdeli, B. Evaluation of residential land use compatibilities using a density-based IOWA operator and an ANFIS-based model: A case study of Tehran, Iran. *Land Use Policy* **2020**, *90*, 104364. [CrossRef]
39. Sadiq, F.K.; Ya'u, S.L.; Aliyu, J.; Maniyunda, L.M. Evaluation of land suitability for soybean production using GIS-based multi-criteria approach in Kudan Local Government area of Kaduna State Nigeria. *Environ. Sustain. Indic.* **2023**, *20*, 100297. [CrossRef]
40. Maleki, J.; Hakimpour, F.; Masoumi, Z. A parcel-level model for ranking and allocating urban land-uses. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 273. [CrossRef]
41. Wang, A.; Wang, H.; Chan, E.H. The incompatibility in urban green space provision: An agent-based comparative study. *J. Clean. Prod.* **2020**, *253*, 120007. [CrossRef]
42. Shi, H.; Zhao, M.; Chi, B. Behind the land use mix: Measuring the functional compatibility in urban and sub-urban areas of China. *Land* **2021**, *11*, 2. [CrossRef]
43. Chakraborty, A.; McMillan, A. GIS and scenario analysis: Tools for better urban planning. In *Comprehensive Geographic Information Systems*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 371–380.
44. Cai, G.; Zhang, J.; Du, M.; Li, C.; Peng, S. Identification of urban land use efficiency by indicator-SDG 11.3.1. *PLoS ONE* **2020**, *15*, e0244318.
45. Brown, G.; Raymond, C.M. Methods for identifying land use conflict potential using participatory mapping. *Landsc. Urban Plan.* **2014**, *122*, 196–208. [CrossRef]
46. De Jong, L.; De Bruin, S.; Knoop, J.; van Vliet, J. Understanding land-use change conflict: A systematic review of case studies. *J. Land Use Sci.* **2021**, *16*, 223–239. [CrossRef]
47. Pourmohammadi, M.R. *Urban Land Use Planning*; SAMT Publications: Tehran, Iran, 2003. (In Persian)
48. Wei, R.; Ye, C.; Sui, T.; Ge, Y.; Li, Y.; Li, J. Combining spatial response features and machine learning classifiers for landslide susceptibility mapping. *Int. J. Appl. Earth Obs. Geoinf.* **2022**, *107*, 102681. [CrossRef]
49. Chakir, R.; Le Gallo, J. Spatial Autocorrelation in Econometric Land Use Models: An Overview. In *Advances in Contemporary Statistics and Econometrics: Festschrift in Honor of Christine Thomas-Agnan*; Springer: Cham, Switzerland, 2021; pp. 339–362.
50. Overmars, K.d.; De Koning, G.; Veldkamp, A. Spatial autocorrelation in multi-scale land use models. *Ecol. Model.* **2003**, *164*, 257–270. [CrossRef]
51. Li, L.; Tang, H.; Lei, J.; Song, X. Spatial autocorrelation in land use type and ecosystem service value in Hainan Tropical Rain Forest National Park. *Ecol. Indic.* **2022**, *137*, 108727. [CrossRef]
52. Kangas, K.; Brown, G.; Kivinen, M.; Tolvanen, A.; Tuulentie, S.; Karhu, J.; Markovaara-Koivisto, M.; Eilu, P.; Tarvainen, O.; Similä, J. Land use synergies and conflicts identification in the framework of compatibility analyses and spatial assessment of ecological, socio-cultural and economic values. *J. Environ. Manag.* **2022**, *316*, 115174. [CrossRef] [PubMed]

53. Lozada, A.; Bertin, A. Spatial autocorrelation signatures of ecological determinants on plant community characteristics in high Andean wetlands. *Sci. Rep.* **2022**, *12*, 13770. [CrossRef] [PubMed]
54. Tang, X.; Li, C.Z.; Jiang, L.; Lai, X.; Zhang, L. A Spatial Autocorrelation Analysis for Land Use Change in the Guangdong-Hong Kong-Macao Greater Bay Area. In Proceedings of the 26th International Symposium on Advancement of Construction Management and Real Estate, Beijing, China, 20–22 November 2021; Springer: Berlin/Heidelberg, Germany, 2021.
55. Wang, Z.; Han, Q.; De Vries, B. Land use spatial optimization using accessibility maps to integrate land use and transport in urban areas. *Appl. Spat. Anal. Policy* **2022**, *15*, 1193–1217. [CrossRef]
56. Yang, Q.; Pu, L.; Jiang, C.; Gong, G.; Tan, H.; Wang, X.; He, G. Unveiling the spatial-temporal variation of urban land use efficiency of Yangtze River Economic Belt in China under carbon emission constraints. *Front. Environ. Sci.* **2023**, *10*, 1096087. [CrossRef]
57. Burghardt, K.; Uhl, J.H.; Lerman, K.; Leyk, S. Road network evolution in the urban and rural United States since 1900. *Comput. Environ. Urban Syst.* **2022**, *95*, 101803. [CrossRef]
58. Sun, S.; Parker, D.C.; Brown, D.G. From an agent-based laboratory to the real world: Effects of "neighborhood" size on urban sprawl. *Comput. Environ. Urban Syst.* **2023**, *99*, 101889. [CrossRef]