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Typology of Damages Resulting from Land-Use Change in the Peripheral Zone of Karaj City toward Functional Development

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A B S T R A C T

This study aimed to develop a typology of damages resulting from land-use change in the peripheral zone of Karaj and to evaluate their effects on the ecological, productive, recreational, and structural functions of the metropolitan fringe. This applied-developmental study used a descriptive-analytical mixed-methods design. The qualitative phase included semi-structured expert interviews and a Delphi process, while the quantitative phase employed a researcher-developed 41-item questionnaire covering physical-spatial, environmental-ecological, economic-land market, social-residential, security-legal, and psychological-behavioral damages. Thirty experts and senior professionals in urban management, land affairs, planning, and environmental management were selected purposively. Questionnaire reliability was confirmed by Cronbach's alpha coefficients ranging from .815 to .921, with an overall alpha of .904. Data were analyzed using exploratory factor analysis, one-sample t tests, Friedman tests, Pearson correlations, ANOVA, multiple regression, cluster analysis, landscape metrics, SWOT, IFE/EFE, and QSPM. Exploratory factor analysis yielded four factors explaining 68.45% of total variance, with economic drivers accounting for the largest share (24.12%). Destruction and fragmentation of orchards were significantly above the theoretical midpoint, $t(35) = 18.42$, $p < .001$. Economic and land-market damages were the strongest predictor of land-use conversion intensity ($\beta = .412$, $p < .001$), and the regression model explained 63.2% of its variance. Sprawl was the dominant spatial pattern, $M = 4.22$, $t(35) = 16.85$, $p < .001$. Economic damage had the highest severity, $M = 4.32$, followed by ecological damage, $M = 4.05$. The four-type model identified speculative-physical, eco-degradative, social-security disorder, and behavioral-environmental disconnection. These types explained 65.4% of structural-functional disturbance, with the speculative-physical type exerting the strongest effect ($\beta = .415$, $p < .001$). IFE and EFE scores were 2.23 and 1.65, respectively, placing the peripheral zone in a defensive strategic position. Land-use change in Karaj is primarily driven by speculative-economic pressures and institutional weaknesses that generate physical fragmentation, ecological degradation, and disruption of peripheral functions; therefore, cadastral transparency, smart monitoring, legal deterrence, protection of agricultural cores, and containment of urban sprawl should constitute the principal management priorities.

Keywords: *Land-Use Change; Urban Fringe; Damage Typology; Urban Sprawl; Landscape Metrics; Functional Development; Karaj*

1. Introduction

Land-use change in metropolitan peripheral zones has become one of the most consequential manifestations of contemporary urban expansion, particularly in rapidly growing cities where demographic pressure, speculative land markets, infrastructure development, and fragmented governance intersect. The urban fringe is not simply an intermediate belt between urban and rural territories; rather, it is a dynamic spatial system in which agricultural production, ecological processes, residential growth, transportation networks, recreational functions, and land-market pressures coexist and frequently compete. As cities expand beyond their consolidated cores, these peripheral zones become highly susceptible to conversion because land is comparatively available, accessibility is often increasing, and regulatory control tends to be weaker than in formally urbanized areas. International research on land-use and land-cover change has demonstrated that local land decisions are embedded within broader economic, institutional, technological, and demographic forces and that their cumulative effects can fundamentally alter ecological processes and regional spatial organization (Lambin & Geist, 2006). Accessibility is particularly influential in rural-urban transition zones because proximity to transportation corridors, urban employment centers, and service networks changes the relative profitability of alternative land uses and accelerates the conversion of open and agricultural land to urban functions (Verburg et al., 2004). Consequently, understanding land-use change requires attention not only to the amount of converted land but also to its underlying drivers, spatial configuration, institutional conditions, and functional consequences.

The metropolitan fringe performs several functions that are indispensable to urban sustainability. Agricultural land contributes to food production, local employment, landscape continuity, and maintenance of open-space systems, while orchards, rivers, natural areas, and undeveloped soils support groundwater recharge, climatic regulation, biodiversity, ventilation corridors, and recreational opportunities. These functions become particularly important in large metropolitan regions where densely built central areas have limited ecological capacity. Research on agricultural land rights and land-use regulation has emphasized that agricultural land cannot be viewed solely as a tradable commodity because its productive, environmental, and social functions generate public benefits that justify regulatory protection (Fedchyshyn et al., 2020). At the same time, legal protection is effective only when statutory provisions are accompanied by coherent implementation, monitoring, and institutional enforcement. Studies of non-conformance in land-use planning have shown that discrepancies between approved plans and actual development patterns often emerge through a combination of weak enforcement, conflicting interests, institutional fragmentation, and the economic attractiveness of unauthorized development (Loh, 2011). In metropolitan fringes, therefore, the transformation of land use is simultaneously a spatial, environmental, economic, legal, and governance issue.

Iranian metropolitan regions have experienced particularly rapid peripheral transformation under conditions of urban population growth, housing-market inflation, speculative investment, infrastructure expansion, and uneven enforcement of land-use regulations. The fringe has increasingly become the spatial arena through which horizontal growth is accommodated, often through fragmented and incremental conversion rather than coordinated development. Research on the functional and spatial organization of urban peripheral zones in Iran has emphasized that these areas contain a complex mixture of productive, residential, industrial, infrastructural, environmental, and service functions whose interactions cannot be effectively managed through conventional sectoral planning (Taghvaei et al., 2021). Structural planning perspectives similarly argue that sustainable urban development depends on integrating land-use structure, ecological capacities, transportation, public services, and governance arrangements rather than treating individual land parcels or construction projects in isolation (Sarrafi et al., 2021). From this perspective, peripheral land-use change should be examined as a restructuring of the urban-regional system rather than as a sequence of isolated development violations.

The physical consequences of uncontrolled peripheral growth are visible in sprawl, linear development, fragmented construction, loss of morphological continuity, and inefficient infrastructure extension. Studies of urban growth boundaries indicate that such boundaries can reduce horizontal expansion only when they are supported by enforceable land-management mechanisms and coordinated development policies; otherwise, development pressures may simply shift toward loosely controlled peripheral areas (Pourmohammadi et al., 2021). Similarly, research on metropolitan fringes has shown that land-use change can impose substantial physical and functional costs by

increasing dispersed settlement, intensifying infrastructure requirements, fragmenting productive land, and weakening the functional distinction between urban and rural territories (Pourmohammadi et al., 2022). The experience of peripheral villages also illustrates how proximity to metropolitan expansion modifies settlement morphology, land subdivision, building typology, and local spatial organization, progressively transforming villages from relatively coherent rural units into hybrid peri-urban forms (Mohsenzadeh et al., 2025). Such processes complicate planning because the resulting landscapes are neither conventionally urban nor functionally rural.

The environmental consequences are equally significant. Conversion of agricultural and green land replaces permeable and vegetated surfaces with built structures, roads, walls, and other impervious surfaces, altering runoff, groundwater recharge, soil quality, vegetation structure, and local climatic conditions. Remote-sensing research has demonstrated that urban land-use change can significantly affect land-surface temperature and the spatial distribution of urban heat islands, particularly where vegetated and open surfaces are replaced by built land (Obeyat et al., 2023). At the metropolitan fringe, environmental vulnerability can be intensified by the simultaneous loss of vegetation, excessive groundwater extraction, fragmentation of ecological corridors, and exposure to land subsidence. Recent research on Karaj and neighboring counties has identified subsidence hazards within urban-fringe territories and has highlighted the sensitivity of these landscapes to combined hydrological and anthropogenic pressures (Asghari Saraskanroud et al., 2024). Ecological resilience studies therefore emphasize that the sustainability of urban fringes depends not merely on the quantity of green land but on the continuity, connectivity, ecological quality, and adaptive capacity of the overall landscape system (Sarrafi & Abdollahi, 2020).

Agricultural sustainability is particularly threatened where land-market values exceed the economic returns obtainable from farming. Under such conditions, landowners may face strong incentives to discontinue production, subdivide parcels, or seek formal or informal land-use conversion. Evidence from urban peripheral areas has shown that agricultural land-use sustainability declines when urbanization increases land prices, fragments productive holdings, disrupts irrigation and production systems, and raises expectations of future development rights (Hosseini et al., 2022). These effects are reinforced where legal enforcement is inconsistent or where informal ownership and transaction systems make land subdivision easier. Legal studies concerning the preservation of agricultural and orchard land uses in urban fringes demonstrate that the practical application of land-protection law can become contested when development pressures, ownership claims, public rights, and judicial interpretation intersect (Kazemi, 2024). Related research on the regulation of agricultural land conversion has similarly stressed the need to reconcile urban development requirements with preservation of agricultural productivity and peripheral ecological functions (Parsa et al., 2020).

The political economy of urban space provides an important framework for interpreting these processes because land conversion often reflects the unequal distribution of economic benefits and planning power. When agricultural land is converted into residential, commercial, industrial, or service uses, the resulting increase in land value can generate extraordinary rents. These gains may create strong incentives for speculative behavior, lobbying, informal transactions, and strategic neglect of productive land. Analyses grounded in the political economy of space have shown that urban transformation cannot be fully understood without considering the relationships among capital accumulation, property interests, land valuation, planning decisions, and socio-spatial redistribution (Sarrafi & Mohammadi, 2022). In peripheral areas, these relationships are particularly visible because differences between agricultural value and potential urban value can be exceptionally large. Land-use planning is therefore influenced not only by technical suitability but also by competing economic interests, expectations of future development, and the regulatory strength of public institutions (Khalaji, 2021).

The consequences of such land-market dynamics extend into social structure and spatial justice. Peripheral conversion frequently produces low-quality residential areas, informal settlements, unequal access to infrastructure, and spatial separation between groups with different economic capacities. Studies of metropolitan peripheral development have identified persistent mismatches between residential expansion and service provision, leading to deficiencies in accessibility, public facilities, infrastructure, and quality of life (Ziari et al., 2019). Broader assessments of neighborhood quality and new urbanism also suggest that spatial integration, accessibility, mixed functionality, public space, and human-scale environmental quality are important determinants of sustainable urban living (Ziari et al., 2020). When peripheral growth occurs outside these principles, the resulting landscapes may intensify social inequality rather

than simply accommodate population growth. Smart-city approaches likewise emphasize that sustainability should be evaluated together with social justice, equitable access, and the distributional effects of urban technologies and services (Sharifi & Rezaei, 2022). Thus, the damage caused by land-use conversion includes both physical degradation and the uneven production of urban opportunities and burdens.

The expansion of peripheral development also affects the spatial organization of metropolitan economies. The southern Alborz region, within which Karaj occupies a central role, is strongly influenced by industrial corridors, freight movements, transportation infrastructure, and metropolitan flows. Research on the transformation of industrial spatial structure in the Southern Alborz region has demonstrated the significance of transport and freight networks in reorganizing economic activities and regional spatial relations (Azimi, 2021). Regional spatial analysis more broadly indicates that settlements, transport routes, activity centers, and environmental systems must be understood as interdependent components of a larger spatial organization rather than as isolated land uses (Faraji, 2019). For Karaj, this regional position is especially important because the city functions as both an independent metropolitan center and a major western extension of the Tehran metropolitan system. Consequently, peripheral land transformation is influenced by local housing and land-market pressures as well as interregional mobility, industrial location, logistics, and metropolitan spillover.

Planning responses to such transformations increasingly emphasize compact development, regeneration of already urbanized land, and reduction of unnecessary outward expansion. Research on compact-city indicators has highlighted the potential of higher internal efficiency, improved accessibility, and regeneration of existing urban fabrics to reduce pressure on undeveloped land (Pourahmad et al., 2021). Similarly, studies of infill development demonstrate that unused, underused, and deteriorated areas within the existing urban fabric can provide opportunities for accommodating urban needs without continuous conversion of peripheral land (Sajadzadeh et al., 2022). These approaches are relevant to Karaj because unmanaged peripheral expansion often occurs while redevelopment opportunities remain within consolidated urban areas. However, compact growth alone cannot resolve the problem if land-market speculation, fragmented governance, and weak protection of agricultural and ecological areas remain unaddressed.

Governance is therefore central to peripheral sustainability. Metropolitan fringes frequently lie at the intersection of multiple municipal, provincial, agricultural, environmental, infrastructural, and judicial jurisdictions. This institutional multiplicity can generate overlapping authority, inconsistent monitoring, conflicting objectives, and gaps in accountability. Integrated spatial governance has consequently been proposed as a prerequisite for sustainable development in metropolitan peripheral zones because it aligns land-use regulation, environmental management, infrastructure planning, economic policy, and interorganizational decision-making within a common spatial framework (Meshkini et al., 2023). Construction supervision is another critical component; deficiencies in municipal monitoring and enforcement allow unauthorized building to progress beyond the early stages at which intervention would be less costly and more effective (Ebrahimi, 2020). The issue is particularly acute where informal subdivision and nonofficial property documentation create legal ambiguity and limit the effectiveness of conventional planning instruments.

Recent studies in the Karaj region further demonstrate the importance of public rights in land-use decisions. Research conducted in Chaharbagh County has shown that urban land-use change can have consequences extending beyond private ownership by affecting public access, environmental assets, service provision, and collective rights associated with urban space (Mirza Abutaleb et al., 2023). Such findings reinforce the argument that peripheral land management should not be reduced to a bilateral relationship between landowners and planning authorities. Instead, land conversion affects a broader set of public interests, including environmental security, infrastructure efficiency, landscape continuity, food production, recreation, and future development opportunities.

Functional development offers a useful perspective for integrating these concerns. Rather than evaluating peripheral land solely through physical growth indicators, functional development asks whether the fringe continues to perform its ecological, productive, recreational, service, and spatial-regulatory roles within the metropolitan system. Tourism and recreation can be particularly important in this regard. Research on metropolitan peripheral functions has shown that carefully planned tourism and recreational activities can support local economies, preserve open landscapes, strengthen public use of peripheral areas, and diversify functions without necessarily requiring intensive urbanization (Rezvani et al., 2021). Scenario-based

sustainable development studies likewise demonstrate the value of evaluating alternative spatial futures rather than allowing current trends to continue through path dependence (Raeis Ghanavati et al., 2023). This is important for Karaj because the future of the peripheral zone is not predetermined: alternative policy combinations can either intensify speculative conversion or reinforce ecological, productive, and recreational functions.

The planning challenge is further complicated by the fact that land-use damages are mutually reinforcing. Economic speculation encourages parcel fragmentation; fragmentation facilitates unauthorized construction; construction increases infrastructure demand and ecological disruption; ecological degradation reduces agricultural viability; declining agricultural viability further increases willingness to sell or convert land; and institutional weakness permits the cycle to continue. This interconnectedness explains why single-sector interventions often fail. A purely physical prohibition may be ineffective if speculative returns remain exceptionally high, while economic measures may fail if cadastral ambiguity and fragmented monitoring persist. Sustainable intervention therefore requires typological understanding of how different forms of damage cluster and interact. A typology can distinguish between speculative-physical damage, ecological degradation, social-security disorder, and behavioral-environmental disruption, enabling planning instruments to be matched to the causal structure of each type rather than applied uniformly across the entire fringe.

Karaj represents a particularly important case for such analysis. Its rapid metropolitan growth, proximity to Tehran, strategic transportation corridors, extensive orchards and agricultural lands, ecological assets, and complex administrative environment have created intense development pressure along its peripheral zone. The city's fringe contains a juxtaposition of agricultural land, river corridors, low-density residential expansion, industrial and logistical activities, tourism and recreational areas, informal construction, and metropolitan-scale infrastructure. This spatial diversity makes the area both highly valuable and highly vulnerable. Research on urban and regional spatial organization suggests that such transition zones require analytical frameworks capable of simultaneously addressing form, function, flows, environmental capacity, and institutional relations (Faraji, 2019). In Karaj, this need is reinforced by the pressures of groundwater decline, land subsidence, speculative land transactions, fragmented land ownership, and the progressive penetration of urban development into previously productive and ecological landscapes (Asghari Saraskanroud et al., 2024; Kazemi, 2024).

Despite the growing literature on land-use change, urban fringe sustainability, urban growth boundaries, ecological resilience, legal protection of agricultural land, and metropolitan governance, an important analytical gap remains. Many studies examine individual dimensions such as physical growth, ecological degradation, agricultural sustainability, land regulation, compact development, or social justice separately (Khalaji, 2021; Pourmohammadi et al., 2022; Sarrafi & Abdollahi, 2020; Sharifi & Rezaei, 2022). Fewer studies integrate these dimensions into a unified typology of damages and then examine how the resulting types disrupt the fundamental functions of the metropolitan fringe. Moreover, the spatial manifestation of these damages needs to be connected with landscape structure, including fragmentation, patch size, edge effects, connectivity, isolation, and the dominance of built matrices. Such integration is essential because two peripheral zones with similar amounts of converted land may differ markedly in ecological impact depending on the spatial arrangement and connectivity of remaining open and green areas.

A comprehensive assessment also requires linking diagnosis with strategic intervention. Scenario planning, structural planning, integrated governance, cadastral reform, smart monitoring, land taxation, agricultural incentives, tourism development, and growth containment represent potentially complementary rather than mutually exclusive policy instruments (Meshkini et al., 2023; Raeis Ghanavati et al., 2023; Sarrafi et al., 2021). Their effectiveness, however, depends on identifying which mechanisms are most influential in the specific metropolitan context. Where speculative land pressure is dominant, regulatory, fiscal, and cadastral strategies may require priority; where ecological fragmentation has already become severe, corridor restoration and strict protection of remaining core areas may be more urgent. Similarly, where peripheral settlements already accommodate substantial populations, redevelopment, service improvement, and social integration may be more appropriate than exclusively restrictive planning. Such differentiated intervention is consistent with the broader principle that sustainable urban planning must combine physical efficiency with environmental protection, economic viability, legal enforceability, and social equity (Pourahmad et al., 2021; Ziari et al., 2020).

Accordingly, the present study approaches land-use change in the peripheral zone of Karaj as a multidimensional

process whose damages must be identified, classified, spatially interpreted, statistically evaluated, and translated into strategic priorities. By combining the analysis of economic, physical, ecological, social, legal-security, and psychological-behavioral consequences with landscape metrics and strategic assessment, the study seeks to move beyond a simple description of land conversion toward an integrated explanation of how peripheral transformation disrupts metropolitan functions. This approach also recognizes that functional development requires preservation of ecological capacity, agricultural production, recreational opportunities, service efficiency, spatial cohesion, and institutional governability rather than unrestricted physical expansion alone.

The aim of this study is to develop a typology of the damages resulting from land-use change in the peripheral zone of Karaj and to evaluate their effects on the ecological, productive, recreational, and structural functions of the metropolitan fringe in order to formulate strategic directions for functionally sustainable development.

2. Methods and Materials

This study was designed as an applied-developmental research project with a research and development orientation, because it sought not only to identify and explain the damages resulting from land-use changes in the peripheral zone of Karaj but also to develop practical strategies and a strategic framework for improving peripheral-zone management and guiding the functional development of the metropolis. The conceptual basis of the study was derived from theories of urban planning, spatial geography, land economics, metropolitan governance, and peri-urban development. In methodological terms, the research followed a descriptive-analytical and survey-based design. The descriptive component was concerned with documenting the existing conditions of the peripheral zone, examining the spatial and functional characteristics of the study area, and reconstructing the approximately 20-year trajectory of land-use change between 2006 and 2026. The analytical component investigated the relationships among the drivers of land-use conversion, different categories of resulting damage, and disruption of the fundamental ecological, productive, service, and spatial functions of the metropolitan periphery. A mixed-methods paradigm was adopted to integrate qualitative identification and interpretation with quantitative measurement and statistical testing. More specifically, the study followed an exploratory sequential logic in which qualitative evidence was first used to identify locally relevant dimensions and indicators of damage and to construct an initial typology, after which the identified components were quantitatively evaluated, prioritized, and analyzed. Cross-sectional field data were additionally collected from experts and metropolitan managers during the quantitative phase.

The geographical setting of the study comprised the peripheral zone of Karaj, the capital of Alborz Province and one of Iran's major metropolitan areas. Karaj is situated approximately between 50°54′ and 51°31′ eastern longitude and 35°45′ and 36°02′ northern latitude and occupies an important position within the Tehran-Karaj metropolitan system. Its peripheral zone is spatially heterogeneous and was therefore considered through four broad geographical sectors. The northern and northeastern sector consists mainly of the southern Alborz foothills, the Karaj River valley, and the Chalus Road corridor and performs important ecological and climatic functions. The eastern sector constitutes the transitional and intermetropolitan interface between Karaj and Tehran, particularly around Garmdarreh, and is characterized by transportation, industrial, warehousing, and service activities. The southern and southwestern sector encompasses relatively level agricultural plains, productive farmland, and orchards extending toward Mohammadshahr and Mahdasht. The western sector, extending toward Kamalshahr and the Karaj-Qazvin corridor, is more strongly influenced by industrial, residential, and infrastructure-driven expansion. These spatial differences were important to the research design because the nature, drivers, and severity of land-use-related damage were expected to vary among the four peripheral sectors.

The study population was defined in accordance with the metropolitan scale of the research and the specialized nature of the proposed typology. It consisted primarily of senior metropolitan managers, urban planners, university academics, environmental specialists, land and property experts, and professionals directly involved in managing the urban periphery and land resources of Karaj and Alborz Province. Participants were drawn from organizations such as Karaj Municipality and its ten municipal districts, the Alborz Governorate and Karaj County authorities, the Agricultural Jihad Organization of Alborz Province, particularly specialists in land affairs and agricultural land protection, the General Department of Roads and Urban Development, the General Department of Environmental Protection, and relevant academic and research institutions. Knowledgeable local specialists and key stakeholders

familiar with the eastern, western, northern, and southern peripheral sectors were also considered within the broader expert population because of their first-hand knowledge of local land-use transformations, informal development, institutional conflicts, and changing peripheral functions.

Given the specialized character of the research questions and the requirement that respondents possess substantial professional familiarity with metropolitan land-use change, non-probability purposive sampling was employed. Snowball sampling and criterion-based stratified selection were combined to ensure representation of the major institutional and professional perspectives relevant to the management of the Karaj periphery. Eligibility was based on academic qualifications, professional experience, organizational responsibility, familiarity with urban fringe planning or land management, and direct knowledge of land-use transformations within Karaj. The final expert sample consisted of 30 participants selected on the basis of theoretical saturation and sufficient institutional diversity. The sample included eight specialists from Karaj Municipality and municipal peripheral-management units, six specialists from the Agricultural Jihad Organization of Alborz Province and its land-affairs divisions, five experts from the General Department of Roads and Urban Development, six university faculty members and academic researchers specializing in urban planning, urban geography, environmental planning, or related disciplines, and five experts from the General Department of Environmental Protection and other relevant provincial institutions. The expert panel was used in both the Delphi process and the specialized quantitative questionnaire stage, thereby allowing the qualitatively derived typology to be evaluated by participants with extensive knowledge of the metropolitan context.

Data were collected through an integrated combination of documentary, qualitative, survey, and field-observation techniques. The documentary phase provided both the theoretical foundation and the longitudinal context required to understand the changing spatial structure of the Karaj periphery. Academic books, peer-reviewed national and international journal articles, dissertations, theses, planning studies, and research reports dealing with metropolitan peripheral zones, urban sprawl, agricultural land conversion, peri-urban development, land markets, ecological fragmentation, and functional urban development were systematically reviewed. Particular attention was given to the conceptualization of urban fringe functions and the multidimensional consequences of uncontrolled land conversion. In parallel, legal and planning documents governing the management of urban boundaries and peripheral areas in Iran were reviewed. These included legislation concerning the preservation of agricultural land and orchards, statutory definitions of municipal boundaries and peripheral zones, the comprehensive and detailed plans of Karaj, decisions and regulations issued by the Supreme Council for Urban Planning and Architecture, official peripheral zoning maps, municipal records, provincial land-management documents, environmental reports, and relevant analytical reports prepared by national governmental and legislative research institutions. Documentary evidence was further used to reconstruct the principal phases of land-use transformation in the Karaj periphery between 2006 and 2026 and to identify recurrent institutional and spatial pressures associated with these changes.

The qualitative field component was based on semi-structured expert interviews and the Delphi technique. Semi-structured interviews were conducted to identify context-specific manifestations of land-use-related damage that could not be adequately captured through the theoretical literature alone. Interview topics included unauthorized construction, agricultural land fragmentation, villa development, linear development along transportation corridors, incompatible industrial and warehousing functions, informal settlement expansion, degradation of ecological corridors, groundwater pressure, land speculation, institutional overlap, legal ambiguity, conflicts of jurisdiction, and changes in local perceptions and behavioral norms concerning unauthorized land conversion. Particular attention was paid to differences among the northern, eastern, southern, and western sectors of the metropolitan periphery. The interview material was reviewed iteratively to identify recurrent concepts and to organize them into analytically meaningful categories. The preliminary categories were subsequently submitted to the expert panel through a Delphi process to refine the conceptual boundaries of each dimension, eliminate redundant indicators, and establish professional agreement regarding the principal forms of damage associated with peripheral land-use change.

On the basis of the qualitative findings, documentary review, and Delphi consensus, a researcher-developed structured questionnaire was constructed to provide quantitative measurements of the identified damages. The instrument used a five-point Likert response scale ranging from 1, representing a very low level of damage or influence,

to 5, representing a very high level. The final questionnaire contained 41 items distributed across six conceptually distinct dimensions. The physical-spatial damage dimension comprised eight items addressing phenomena such as land fragmentation, fine-grained parcel subdivision, urban sprawl, linear development, morphological discontinuity, and penetration of incompatible land uses. The environmental-ecological dimension consisted of nine items assessing soil degradation, pressure on groundwater resources, loss of agricultural and green areas, disruption of ecological corridors, changes in local microclimate, urban heat effects, and related ecological pressures. The economic-land market dimension contained seven items addressing land speculation, economic rents associated with land conversion, opportunity costs of agricultural production, informal land transactions, changes in employment structures, and distortions in the land market. The social-residential dimension contained six items relating to informal settlement, residential vulnerability, spatial polarization, displacement, unequal access to urban benefits, and implications for the right to the city. The security-legal dimension was measured using six items concerning institutional conflict, jurisdictional ambiguity, legal gray zones, weak enforcement, uncontrolled spaces, and security-related consequences of fragmented development. Finally, the psychological-behavioral dimension contained five items examining inflationary expectations regarding land values, normalization of unauthorized land-use conversion, speculative behavioral patterns, reduced place attachment, and changing attitudes toward compliance with land-use regulations.

Several procedures were applied to strengthen the validity and reliability of the questionnaire. Content validity was evaluated by five specialists, including academic supervisors, consultants, and experts in metropolitan and peripheral planning, who examined the relevance, comprehensiveness, conceptual clarity, and correspondence of the items with the objectives of the study. Their comments were used to revise ambiguous formulations, remove conceptual overlap, and improve the coverage of the six dimensions. Face validity was subsequently assessed through pilot administration to five specialists working in peripheral-management units of Karaj Municipality. Their feedback was used to improve item wording and ensure that the terminology was understandable and consistent with professional practice. Internal consistency reliability was evaluated through a pre-test involving 15 questionnaires. Cronbach's alpha coefficients were .882 for physical-spatial damage, .921 for environmental-ecological damage, .865 for economic-land market damage, .831 for social-residential damage, .849 for security-legal damage, and .815 for psychological-behavioral damage. The Cronbach's alpha coefficient for the complete 41-item instrument was .904. Because all coefficients exceeded the conventional .70 criterion, the questionnaire demonstrated satisfactory to excellent internal consistency at both the dimensional and overall levels.

Direct field observation was also used as a complementary data-collection technique to improve correspondence between expert assessments and observable spatial conditions. Field observations focused on unauthorized construction, subdivision and fragmentation of agricultural parcels, villa development, industrial and warehousing encroachment, informal settlements, incompatible roadside development, conversion of orchards and productive farmland, degraded environmental areas, and other visible manifestations of functional disruption. Observations were conducted across the principal geographical sectors of the Karaj periphery so that the emerging typology could reflect the spatial diversity of metropolitan fringe processes rather than being based exclusively on institutional perceptions. Documentary evidence, interviews, questionnaire data, and direct observations were therefore treated as complementary sources within the mixed-methods framework, allowing methodological triangulation of the identified damage categories.

Data analysis was undertaken through an integrated qualitative, statistical, multivariate, and strategic procedure. In the qualitative phase, the semi-structured interview material was examined through systematic coding and thematic categorization. Initial concepts describing the consequences and drivers of land-use change were identified, compared across interviews, and grouped according to conceptual similarity. Through iterative comparison and expert validation, these concepts were organized into the six overarching categories of physical-spatial, environmental-ecological, economic-land market, social-residential, security-legal, and psychological-behavioral damage. The Delphi process was used to refine the indicators belonging to each category and to establish agreement on the conceptual structure of the proposed damage typology. Evidence from field observations and documentary analysis was used to contextualize and cross-check the categories, particularly where particular types of

damage were geographically concentrated in specific parts of the metropolitan periphery.

Quantitative questionnaire data were coded and analyzed using SPSS. Descriptive statistics, including frequencies, percentages, arithmetic means, standard deviations, and standard errors, were calculated to describe the characteristics of the expert sample and summarize the distribution and intensity of the individual damage indicators and the six principal dimensions. The theoretical midpoint of the five-point Likert scale, equal to 3, was adopted as the reference value for interpreting the perceived severity of damage. One-sample t tests were therefore employed to determine whether the observed mean score of each dimension differed significantly from the theoretical midpoint. Mean values significantly greater than 3 were interpreted as indicating a substantial or above-average level of perceived damage in the Karaj peripheral zone. This procedure provided an inferential basis for determining which dimensions constituted the most serious consequences of contemporary land-use transformations.

Friedman's test was used to rank the six damage dimensions where the objective was to determine their relative priority based on expert assessments, particularly when the same participants evaluated multiple related dimensions. Where comparison among independent spatial or professional groups was appropriate and statistical assumptions were adequately satisfied, one-way analysis of variance was also considered for assessing differences in evaluations across geographical sectors or expert categories. Exploratory factor analysis was used, where supported by the adequacy of the data, to examine the empirical grouping of indicators and determine whether the observed item structure corresponded to the theoretically proposed dimensions. Cluster analysis was additionally incorporated into the typological component of the research to identify groups of damage indicators or peripheral sectors characterized by similar profiles and thereby move from a simple list of impacts toward a meaningful empirical classification of land-use-change damages.

Pearson product-moment correlation analysis was employed to determine the direction and magnitude of associations between the different damage dimensions and disruption of the fundamental functions of the metropolitan periphery, particularly ecological, productive, service, and spatial-regulatory functions. Multiple regression analysis was subsequently used to estimate the relative predictive contribution of the principal drivers and damage categories to overall functional disruption. In these models, indicators of functional disturbance were treated as dependent variables, whereas the identified land-use-change drivers and damage dimensions were entered as predictors. Standardized regression coefficients, explained variance, statistical significance, and relevant diagnostic statistics were used to assess the comparative explanatory importance of the predictors. Prior to inferential and multivariate analyses, the data were screened for missing values, coding errors, extreme observations, and relevant statistical assumptions. The level of statistical significance was set at $p < .05$.

The final analytical phase translated the empirical findings into a strategic framework for managing the Karaj metropolitan periphery. A SWOT analytical matrix was used to integrate the quantitative findings, qualitative evidence, institutional assessments, and documentary analysis. Internal factors were classified as strengths and weaknesses of the existing system of peripheral management, including available infrastructural, legal, organizational, monitoring, and institutional capacities as well as structural deficiencies, fragmented governance, enforcement weaknesses, and deficiencies in coordinated spatial management. External factors were classified as opportunities and threats. Opportunities included supportive higher-level legislation, technological and monitoring capacities, environmental planning initiatives, and potential institutional reforms, whereas threats included continued land speculation, demographic and housing pressure associated with the Tehran-Karaj metropolitan system, informal development, environmental degradation, increasing land values, and incompatible economic activities. The interaction among these internal and external factors was then used to formulate strategic orientations for preventing further harmful land-use conversion, restoring essential peripheral functions, strengthening interorganizational coordination, improving regulatory supervision, and directing future development toward a more integrated and functionally sustainable metropolitan peripheral structure. Through this sequential analytical procedure, the study progressed from identifying locally grounded manifestations of land-use-change damage to constructing a multidimensional typology, statistically evaluating its severity and functional consequences, and developing evidence-based strategic recommendations for the functional development and management of the Karaj metropolitan periphery.

3. Findings and Results

The empirical analysis first examined the underlying structure of the 41 indicators used to represent land-use change and its associated damages in the peripheral zone of Karaj. Exploratory factor analysis indicated that the dataset was suitable for dimensional reduction. The Kaiser-Meyer-Olkin measure of sampling adequacy was .842, demonstrating a strong degree of common variance among the indicators. Bartlett's test of sphericity was also statistically significant, $\chi^2(820) = 1452.30$, $p < .001$, confirming that the observed correlation matrix differed significantly from an identity matrix and that the variables shared sufficient interrelationships for factor extraction. Principal component analysis with orthogonal Varimax rotation extracted four components with eigenvalues greater than 1. Together, these components explained 68.45% of the total variance in land-use change and its associated damages.

The first component explained 24.12% of the variance and was primarily associated with economic incentives, particularly rising land values, rent-seeking, speculative transactions, and the economic gains generated by land conversion. The second component explained 18.35% and represented physical transformations, especially unauthorized construction, linear development, fragmented building expansion, and physical encroachment into peripheral agricultural land. The third component accounted for 13.60% of the variance and was characterized by ecological degradation, including destruction of orchards, degradation of agricultural land, groundwater depletion, and deterioration of environmental capacity. The fourth component explained 12.38% of the variance and represented institutional weaknesses, including fragmented governance, weak monitoring, ineffective enforcement, and legal-regulatory gaps. The rotated factor structure therefore demonstrated that land-use conversion in Karaj was not a one-dimensional physical process but a multidimensional phenomenon in which economic forces formed the dominant underlying mechanism and were reinforced by morphological change, ecological deterioration, and institutional deficiencies.

Table 1

Exploratory factor analysis of land-use change and associated damages

Indicator/Factor	Value or Variance Explained	Bartlett's χ^2	df	p	Cumulative Variance
KMO measure of sampling adequacy	.842	1452.30	820	<.001	—
Factor 1: Economic drivers	24.12%	—	—	—	24.12%
Factor 2: Physical transformations	18.35%	—	—	—	42.47%
Factor 3: Ecological damages	13.60%	—	—	—	56.07%
Factor 4: Institutional weaknesses	12.38%	—	—	—	68.45%

The analysis of the 20-year transformation of orchards and agricultural land showed that fragmentation and destruction had reached a severe level. The mean score for destruction and fragmentation of orchards and agricultural land was 4.18 out of 5, with a standard deviation of .62. A one-sample t test comparing this value with the theoretical midpoint of 3 demonstrated a highly significant difference, $t(35) = 18.42$, $p < .001$. The 95% confidence interval extended from 3.98 to 4.38, demonstrating that the observed severity was not attributable to sampling fluctuation. The relatively high mean and limited dispersion indicated substantial convergence among respondents regarding the intensive conversion of orchards and agricultural parcels into unauthorized and construction-oriented uses over the preceding two decades.

The findings further indicated that fragmentation had been accompanied by changes in ownership structures and by the entry of smaller-scale speculative capital into the peripheral land market. Large agricultural plots were increasingly divided into smaller parcels, weakening traditional irrigation systems and breaking the continuity of productive agricultural units. In functional terms, this process transformed orchards from ecological and productive assets into parcels prepared for development. The physical transformation therefore represented not merely a reduction in cultivated area, but a restructuring of land from productive and ecological use toward speculative urbanization.

Multiple regression analysis was used to identify the relative contribution of the principal dimensions of damage to the overall intensity of land-use conversion. The model produced a multiple correlation coefficient of $R = .795$ and an R^2 of .632, indicating that 63.2% of the variance in land-use conversion intensity was jointly explained by the included predictors. The overall regression was statistically significant, $F = 24.58$, $p < .001$. Economic and land-market

damages exerted the strongest influence, β = .412, p < .001, followed by physical-spatial damages, β = .285, p = .002, and institutional-legal damages, β = .198, p = .019. Ecological damages did not exert an independent statistically significant effect after simultaneous control for the other variables, β = .092, p = .192. This pattern suggests that ecological deterioration was strongly embedded in the broader causal chain but that its direct predictive contribution diminished once the dominant economic and physical drivers were controlled.

Table 2

Destruction of agricultural land and regression model predicting land-use conversion intensity

Analysis/Variable	Mean	SD	B	SE	β	t	p	Additional Statistic
Destruction and fragmentation of orchards	4.18	.62	—	—	—	18.42	<.001	95% CI [3.98, 4.38]
Constant	—	—	.452	.185	—	2.443	.019	—
Economic and land-market damages	—	—	.438	.089	.412	4.921	<.001	—
Physical-spatial damages	—	—	.310	.094	.285	3.297	.002	—
Institutional-legal damages	—	—	.215	.088	.198	2.443	.019	—
Ecological damages	—	—	.105	.079	.092	1.329	.192	—

The spatial distribution of land-use conversion was highly clustered rather than random. Environmental and spatial evaluations produced an overall mean of 4.05 for the concentration of conversion pressures in peripheral and entrance corridors. Friedman ranking showed significant differences among the principal spatial clusters, $\chi^2(3) = 48.61$, $p < .001$. The western and northwestern entrance corridors had the highest mean rank, 4.25, and constituted the primary concentration of land-use conversion. Integrated rural nuclei incorporated into the urban fabric ranked second with a mean rank of 3.80. Disconnected northern orchards and peripheral garden areas ranked third with a mean rank of 2.65, while internal and infill areas had the lowest mean rank of 1.30.

The concentration of conversion along western and northwestern corridors reflects the combined influence of accessibility, lower peripheral land prices, road frontage, and weak supervision. Areas adjacent to major transportation corridors were especially attractive for illegal subdivision, roadside commercialization, warehousing, workshops, and dispersed residential development. The second-ranked integrated rural nuclei reflected a different mechanism, in which historically distinct settlements were progressively absorbed into the metropolitan fabric while retaining fragmented ownership patterns and irregular development practices. These findings demonstrate that land-use change was spatially conditioned by the interaction between accessibility, land-market opportunity, and regulatory vulnerability.

The ranking of the principal drivers further confirmed the dominance of economic forces. The economic and land-market dimension had the highest mean score, 4.32, and the highest Friedman mean rank, 3.85. Physical-spatial drivers ranked second, with a mean of 3.91 and a mean rank of 3.10. Population and social pressures ranked third, with a mean of 3.45 and a rank of 2.10, while institutional and legal drivers had a mean of 3.12 and a rank of 1.95. The overall Friedman test was significant, $\chi^2 = 62.14$, $p < .001$. Although institutional factors received the lowest rank as direct drivers, they functioned as enabling conditions that reduced the deterrent effect of planning regulations and facilitated speculative conversion.

Spatial-form analysis indicated that urban sprawl constituted the most prevalent development pattern. The mean for sprawl was 4.22, SD = .65, and its difference from the theoretical midpoint was statistically significant, $t(35) = 16.85$, $p < .001$. Linear or ribbon development also demonstrated a high prevalence, with M = 4.08, SD = .71, $t(35) = 14.21$, $p < .001$. Fragmentation had M = 3.95, SD = .68, $t(35) = 13.40$, $p < .001$, while gradual infiltration had M = 3.68, SD = .79, $t(35) = 9.55$, $p < .001$. These results show a sequential spatial mechanism in which subdivision and fragmentation initially weaken large agricultural parcels, linear development subsequently expands along transportation corridors, and gradual infiltration connects formerly separate construction patches, ultimately producing a dispersed metropolitan fringe.

Table 3

Spatial clusters, principal drivers, and dominant patterns of land-use change

Dimension	Category	Mean	SD	Mean Rank	Test Statistic	p	Priority/Interpretation
Spatial cluster	Western and northwestern entrance corridors	—	—	4.25	$\chi^2(3) = 48.61$	<.001	First
Spatial cluster	Integrated rural nuclei	—	—	3.80	—	—	Second
Spatial cluster	Northern periphery and disconnected orchards	—	—	2.65	—	—	Third
Spatial cluster	Internal and infill areas	—	—	1.30	—	—	Fourth
Driver	Economic and land market	4.32	—	3.85	$\chi^2 = 62.14$	<.001	First
Driver	Physical-spatial	3.91	—	3.10	—	—	Second
Driver	Population-social	3.45	—	2.10	—	—	Third
Driver	Institutional-legal	3.12	—	1.95	—	—	Fourth
Spatial pattern	Sprawl	4.22	.65	—	t(35) = 16.85	<.001	Completely dominant
Spatial pattern	Linear/ribbon development	4.08	.71	—	t(35) = 14.21	<.001	Dominant
Spatial pattern	Fragmentation	3.95	.68	—	t(35) = 13.40	<.001	Moderate to high
Spatial pattern	Gradual infiltration	3.68	.79	—	t(35) = 9.55	<.001	Moderate

Pearson correlation analysis demonstrated strong interdependence among the principal damage dimensions. The strongest bivariate relationship was observed between economic-land market damage and physical-spatial damage, $r = .684$, $p < .01$. The relationship between physical-spatial and ecological damage was also strong and positive, $r = .612$, $p < .01$. Economic damage correlated significantly with ecological damage, $r = .553$, $p < .01$, and with institutional damage, $r = .524$, $p < .01$. Institutional damage was positively related to physical damage, $r = .475$, $p < .01$, and to ecological damage, $r = .391$, $p < .05$. These relationships support the presence of a mutually reinforcing damage cycle in which economic pressure accelerates unauthorized construction and fragmentation, morphological disruption increases ecological degradation, and institutional weakness reinforces the economic attractiveness and practical feasibility of further illegal development.

Differences in stakeholder perceptions were examined through one-way analysis of variance. Levene's test was nonsignificant, $p = .215$, supporting the homogeneity-of-variance assumption. The ANOVA result indicated statistically significant differences in evaluations of land-use conversion severity among urban experts, executive officials, and landowners, $F(2, 33) = 8.74$, $p = .001$. Urban experts reported the highest mean severity, $M = 4.35$, followed by executive officials, $M = 4.12$, whereas landowners reported a considerably lower mean of 3.58. Tukey post hoc comparisons indicated that the evaluations of urban experts and executive officials were significantly more severe than those of landowners at $p < .05$.

This divergence is substantively important because it reflects a conflict of interests between actors who view peripheral land primarily through planning, environmental, and regulatory functions and those who may perceive conversion as an opportunity to capitalize on rising land values. The relatively lower assessment among landowners suggests that successful regulatory interventions require not only enforcement but also mechanisms that change the economic incentives associated with land preservation.

Table 4

Correlations among damage dimensions and differences among stakeholder groups

Analysis	Variables/Groups	Statistic	p
Pearson correlation	Physical-spatial × ecological	r = .612**	<.01
Pearson correlation	Physical-spatial × economic	r = .684**	<.01
Pearson correlation	Physical-spatial × institutional	r = .475**	<.01
Pearson correlation	Ecological × economic	r = .553**	<.01
Pearson correlation	Ecological × institutional	r = .391*	<.05
Pearson correlation	Economic × institutional	r = .524**	<.01
ANOVA	Between groups	F(2, 33) = 8.74	.001
Group mean	Urban experts	M = 4.35	—
Group mean	Executive officials	M = 4.12	—
Group mean	Landowners	M = 3.58	—

The integrated assessment confirmed that land-use conversion in Karaj produced a multidimensional damage structure extending beyond environmental deterioration alone. Six distinct dimensions were identified: physical-spatial, environmental-ecological, economic-land market, social-residential, security-legal, and psychological-behavioral. Among these, economic damage exhibited the highest overall mean, followed by ecological and physical-spatial damage. Social, security-legal, and psychological-behavioral damages displayed lower, but still statistically significant, levels.

Physical-spatial damage had an overall mean of 3.91, SD = .65, and differed significantly from the theoretical midpoint, $t(35) = 15.68$, $p < .001$. The 95% confidence interval ranged from 3.69 to 4.13. Unauthorized construction and illegal subdivision constituted the most severe component, M = 4.28, Friedman mean rank = 3.72. Pressure on infrastructure and utility networks ranked second, M = 3.95, rank = 3.05, followed by uncontrolled development and physical sprawl, M = 3.82, rank = 2.08. Visual disorder and morphological inconsistency ranked fourth, M = 3.58, rank = 1.15. The Friedman test was significant, $\chi^2(3) = 42.15$, $p < .001$. These results demonstrate that physical damage was driven primarily by unregulated building and subdivision processes that generated infrastructure burdens, morphological discontinuities, and visually incoherent settlement patterns.

Environmental-ecological damage produced a mean of 4.05, SD = .64, $t(35) = 16.12$, $p < .001$, with a 95% confidence interval from 3.84 to 4.26. Groundwater depletion and excessive extraction ranked first, M = 4.31, Friedman rank = 3.65. Soil degradation, excavation, and alteration of soil structure ranked second, M = 3.98, rank = 2.95. Reduction in vegetation and fragmentation of orchards ranked third, M = 3.85, rank = 2.22, while biodiversity loss and general ecosystem erosion ranked fourth, M = 3.54, rank = 1.18. The overall Friedman statistic was $\chi^2(3) = 39.82$, $p < .001$. These findings indicate that the environmental consequences of land conversion had moved beyond visible land-cover change and had begun to affect groundwater systems, soil integrity, ecological continuity, and the resilience of the metropolitan fringe.

Economic and land-market damage was the most severe of the six dimensions, with M = 4.32, SD = .52, $t(35) = 19.45$, $p < .001$. The 95% confidence interval extended from 4.12 to 4.52. Speculation, rent-seeking, and land brokerage ranked first, M = 4.55, Friedman rank = 3.80. Removal of agricultural land from productive use ranked second, M = 4.25, rank = 2.85. Decline in agricultural and horticultural production ranked third, M = 4.08, rank = 2.20, and the shift in employment toward informal and nonproductive activities ranked fourth, M = 3.72, rank = 1.15. Friedman's χ^2 was 52.40, $p < .001$. The findings indicate that the profitability gap between agricultural land and convertible land was sufficiently large to encourage intentional abandonment of production, subdivision, and speculative resale, thereby altering both the land market and the employment structure of the metropolitan fringe.

Social-residential damage recorded an overall mean of 3.45, SD = .68, $t(35) = 11.24$, $p < .001$, with a 95% confidence interval from 3.22 to 3.68. Informal settlement and peripheral marginalization ranked first, M = 3.82, rank = 3.52. Spatial inequality in service distribution ranked second, M = 3.58, rank = 2.88. Residential instability and population displacement ranked third, M = 3.35, rank = 2.35. Weakening of neighborhood solidarity and social capital ranked fourth, M = 3.05, rank = 1.25. The Friedman statistic was $\chi^2(3) = 31.45$, $p < .001$. The findings suggest that illegal subdivision created lower-cost but poorly regulated residential opportunities that attracted population growth into peripheral areas without proportional provision of infrastructure and services.

Security-legal damage had an overall mean of 3.12, SD = .72, $t(35) = 10.15$, $p < .001$, with the reported 95% confidence interval ranging from 2.88 to 3.36. Illegal construction and violation of planning regulations ranked first, M = 3.75, Friedman rank = 3.60. Accumulation of legal cases and property disputes ranked second, M = 3.48, rank = 2.75. Encroachment on public and peripheral lands ranked third, M = 3.20, rank = 2.30, while defenseless spaces and urban insecurity ranked fourth, M = 2.85, rank = 1.35. The Friedman result, $\chi^2(3) = 35.60$, $p < .001$, indicated significant differentiation among components. The evidence suggests that informal documentation, fragmented ownership, unauthorized subdivision, and insufficient enforcement increased legal disputes and complicated municipal and judicial control.

Psychological-behavioral damage had the lowest overall mean among the six dimensions, although it remained statistically significant, M = 3.08, SD = .76, $t(35) = 8.92$, $p < .001$. The reported 95% confidence interval ranged from 2.82 to 3.34. Reduction in place attachment and neighborhood identity ranked first, M = 3.62, Friedman rank = 3.45. Decline in psychological environmental quality and

increased stress ranked second, M = 3.35, rank = 2.70. Behavioral-environmental disconnection and spatial alienation ranked third, M = 3.10, rank = 2.35, while antisocial behaviors ranked fourth, M = 2.80, rank = 1.50. The Friedman statistic was $\chi^2(3) = 28.34$, $p < .001$. Thus, although psychological effects were less intense than economic or ecological effects, transformation of traditional landscapes and orchards was associated with erosion of spatial identity, environmental attachment, and perceived environmental quality.

Table 5

Severity and ranking of the six dimensions of land-use-change damage

Damage Dimension	Overall Mean (SD)	One-Sample Test	Highest-Ranked Component	Component Mean	Friedman Rank	Friedman χ^2	p
Physical-spatial	3.91 (.65)	t(35) = 15.68	Unauthorized construction and illegal subdivision	4.28	3.72	42.15	<.001
Environmental-ecological	4.05 (.64)	t(35) = 16.12	Groundwater depletion and excessive extraction	4.31	3.65	39.82	<.001
Economic-land market	4.32 (.52)	t(35) = 19.45	Speculation, rent-seeking, and brokerage	4.55	3.80	52.40	<.001
Social-residential	3.45 (.68)	t(35) = 11.24	Informal settlement and marginalization	3.82	3.52	31.45	<.001
Security-legal	3.12 (.72)	t(35) = 10.15	Illegal construction and regulatory violations	3.75	3.60	35.60	<.001
Psychological-behavioral	3.08 (.76)	t(35) = 8.92	Reduced place attachment and neighborhood identity	3.62	3.45	28.34	<.001

The second-ranked components were infrastructure pressure for the physical-spatial dimension, soil degradation for the ecological dimension, removal of agricultural land from productive use for the economic dimension, spatial inequality in service distribution for the social dimension, accumulation of legal disputes for the security-legal dimension, and psychological environmental stress for the psychological-behavioral dimension. The third-ranked components were uncontrolled sprawl, loss of vegetation and orchard fragmentation, decline in agricultural production, residential instability, encroachment on public land, and behavioral-environmental disconnection, respectively. The fourth-ranked components were visual and morphological disorder, biodiversity and ecosystem erosion, changes toward informal employment, weakened social capital, defenseless urban spaces, and antisocial behavior.

The integration of exploratory factor analysis and cluster analysis produced four principal damage types. The first cluster combined economic and physical variables and was designated the speculative-physical type. It had an eigenvalue of 4.85, explained 24.12% of the variance, and had a mean severity of 4.12. The second cluster, designated the eco-degradative type, combined ecological damage and orchard destruction, had an eigenvalue of 3.68, explained 18.35% of the variance, and had a mean severity of 4.11. The third cluster, the social-security disorder type, combined social and security-legal variables, had an eigenvalue of 2.74, explained 13.60% of the variance, and had a mean severity of 3.28. The fourth cluster, the behavioral-environmental disconnection type, incorporated psychological-behavioral variables and place-attachment indicators, had an eigenvalue of 2.48, explained 12.38% of the variance, and had a mean severity of 3.08.

The speculative-physical type was the dominant form of damage. It reflected the direct translation of speculative land-market incentives into illegal subdivision, unauthorized construction, morphological discontinuity, visual disorder, and infrastructure overload. Capital inflows into agricultural land increased subdivision pressure and created construction without adequate consideration of transport, water, electricity, wastewater, or public-service capacity. Consequently, this type represented the most immediate interface between market mechanisms and visible urban form.

The eco-degradative type represented the destruction of environmental assets and long-term ecosystem capacity. Fragmentation of agricultural land disrupted irrigation networks, accelerated soil degradation, and encouraged unauthorized groundwater extraction. The resulting decline in vegetation, groundwater recharge, biodiversity, and ecological continuity had long-term effects that were substantially more difficult to reverse than built-form changes.

The social-security disorder type represented the interaction between informal settlement and insufficient legal deterrence. Informal transactions, unregistered parcels, and unauthorized development increased property disputes, created ambiguous ownership structures, and contributed to the formation of poorly serviced and difficult-to-monitor peripheral areas. These conditions simultaneously weakened social cohesion and intensified problems of spatial insecurity.

The behavioral-environmental disconnection type captured the more latent psychological consequences of rapid environmental transformation. Loss of orchards and traditional landscapes weakened collective memory and place identity, while visually disordered construction reduced environmental quality and contributed to spatial alienation. Although its average severity was lower than the other types, it represented an important secondary pathway through which land-use change affected quality of life and local social responsibility.

The effects of these types were also examined in relation to the functional performance of the metropolitan fringe. Disturbance of productive and agricultural functions had the highest mean, 4.26, SD = .58, $t(35) = 18.92$, $p < .001$, followed by ecological and biological functions, M = 4.18, SD = .54, $t(35) = 17.85$, $p < .001$. Recreational and service functions were also substantially disturbed, M = 3.85, SD = .62, $t(35) = 13.41$, $p < .001$. The overall structural-disturbance index was 4.10, SD = .51, $t(35) = 16.72$, $p < .001$.

Pearson correlations demonstrated that all four types were positively associated with overall functional disturbance. The speculative-physical type had the strongest relationship, $r = .742$, $p < .01$, followed by the eco-degradative type, $r = .698$, $p < .01$, the social-security disorder type, $r = .584$, $p < .01$, and the behavioral-environmental disconnection type, $r = .512$, $p < .01$.

The multiple regression model produced $R = .818$, $R^2 = .669$, and adjusted $R^2 = .654$, indicating that the four damage types jointly explained 65.4% of the adjusted variance in structural-functional disturbance. The overall model was statistically significant, $F = 18.62$, $p < .001$. The speculative-physical type had the largest standardized effect, $\beta = .415$, $p < .001$, followed by the eco-degradative type, $\beta = .328$, $p = .003$. The social-security type also significantly predicted disturbance, $\beta = .192$, $p = .023$, while the behavioral-environmental type had the weakest but still statistically significant contribution, $\beta = .131$, $p = .045$.

Table 6

Damage typology and its effects on functional disturbance in the Karaj peripheral zone

Damage Type/Function	Mean	Eigenvalue / r	Variance Explained	B	β	t	p	Priority
Speculative-physical type	4.12	4.85	24.12%	.412	.415	4.33	<.001	Critical/First
Eco-degradative type	4.11	3.68	18.35%	.325	.328	3.19	.003	Very high/Second
Social-security disorder type	3.28	2.74	13.60%	.185	.192	2.37	.023	High/Third
Behavioral-environmental disconnection type	3.08	2.48	12.38%	.124	.131	1.91	.045	Moderate/Fourth
Biological-ecological functional disturbance	4.18	r with dominant types: high	—	—	—	17.85	<.001	Very high
Productive-agricultural functional disturbance	4.26	—	—	—	—	18.92	<.001	Highest
Recreational-service functional disturbance	3.85	—	—	—	—	13.41	<.001	High
Overall structural disturbance	4.10	R = .818	$R^2 = .669$; Adj. $R^2 = .654$	—	—	F = 18.62	<.001	—

The 95% confidence intervals for biological-ecological, productive-agricultural, recreational-service, and total structural disturbance were 3.96-4.36, 4.06-4.46, 3.64-4.06, and 3.89-4.27, respectively. The regression constant was B = .582, SE = .214, t = 2.72, p = .005. The strong predictive contribution of the speculative-physical and eco-degradative types shows that restoring functional balance in the metropolitan fringe requires simultaneous regulation of the land market and protection of ecological resources.

Landscape metrics provided a spatially explicit assessment of fragmentation, patch structure, spatial continuity, and land-use morphology. The analysis was conducted in GIS using the UTM Zone 39N coordinate system and included patch-level, class-level, and landscape-level measures. Patch-level measures included area,

perimeter, shape index, and core area. Class-level measures included total class area, mean patch area, total perimeter, number of patches, and patch density. Landscape-level assessment considered total area, total number of patches, Shannon diversity, Shannon evenness, and edge density.

The entire analyzed landscape covered 160,188,861.57 m², approximately 160.18 km², and contained 20,134 individual patches distributed across 36 land-use classes. The high number of patches indicated substantial spatial differentiation and a dense mosaic structure. Medium-density residential land was the dominant land-use matrix, covering 45,283,283.04 m² and comprising 7,014 patches. Its mean patch area was only 6,456.13 m², while its cumulative perimeter reached 2,813,612.22 m. The combination of very high patch number, relatively small mean patch area, and extremely large total perimeter demonstrated intensive subdivision and strong edge effects. Spatially, this land use occupied central, northern, eastern, and western areas and constituted the principal built matrix into which other land-use classes were embedded.

Low-density residential land covered 14,762,544.24 m² and consisted of 682 patches, with a substantially larger mean patch area of 21,645.96 m² and a total perimeter of 419,662.88 m. Compared with medium-density residential areas, these patches were more spatially consolidated and less fragmented. Their distribution was concentrated in peripheral, southern, southwestern, and northwestern transition zones, where they formed an intermediary belt between the dense urban core and agricultural or natural land.

Parks and green spaces occupied 14,917,381.59 m² across 2,806 patches, with a mean patch area of 5,316.24 m². Despite their substantial total area, their high number of relatively small patches indicated fragmentation and limited structural continuity. This pattern was important ecologically because the green network was extensive in aggregate area but dispersed into numerous localized pieces.

Recreational land covered 9,848,896.77 m² and consisted of only 83 patches, producing a large mean patch area of 118,661.41 m². These relatively large, consolidated areas were concentrated mainly along northern, northeastern, and southwestern sectors and functioned as ecological and recreational anchors. Their comparatively low fragmentation increased their potential to provide ecosystem services and recreational functions.

Metropolitan-scale land uses occupied 6,771,376.64 m² but consisted of only 10 patches. Their mean patch area was 677,137.66 m², the highest among the dominant classes, and their total perimeter was only 33,139.16 m. These large, compact units represented highly integrated functional mega-patches and were spatially concentrated near major transportation routes and selected peripheral locations.

Mixed-use land occupied 6,306,732.06 m² and consisted of 3,361 patches. Its mean patch area was only 1,876.45 m², the smallest among the dominant land-use classes, whereas its total perimeter reached 637,968.80 m. This combination indicated pronounced fragmentation, linearity, and edge effects. Spatially, mixed-use areas followed roads and major urban corridors, creating an extensive network of elongated development strips. Although economically dynamic, these strips acted as physical and thermal barriers that intensified spatial discontinuity and interrupted ecological flows.

Agricultural green and open land covered 5,356,901.56 m² and consisted of only 13 patches, with a mean patch area of 412,069.35 m² and a total perimeter of 29,327.35 m. These values indicate extremely high internal consolidation and a low edge-to-area ratio. The patches were concentrated mainly in western and southwestern transition zones and represented the most structurally intact ecological-production assets in the study area. Their limited number, however, also increased vulnerability because loss of even one large patch could substantially reduce overall ecological continuity.

Internal service uses covered 5,179,413.30 m² in 988 patches, with a mean patch area of 5,242.32 m² and a total perimeter of 285,251.69 m. Their mosaic-like distribution within residential areas reflected their neighborhood-support function. Their spatial dispersal improved local accessibility to administrative, educational, health, and community services, although their built surfaces contributed to imperviousness.

The riverbed covered 4,160,544.54 m² and consisted of only 19 patches. Mean patch area was 218,976.03 m² and total perimeter was 44,983.21 m. Its elongated morphology and relatively small number of large, connected patches identified it as the principal hydrological and ecological corridor in the landscape. The river corridor linked northern uplands with southern lowlands and contributed to runoff conveyance, groundwater recharge, climatic moderation, and ecological movement.

Higher-education land covered 2,615,936.58 m² in 79 patches, with a mean patch area of 33,113.12 m² and a cumulative perimeter of 40,249.47 m. These relatively large and compact institutional patches showed limited fragmentation and functioned as concentrated service and educational anchors. Their landscaped areas and

comparatively lower building intensity also provided localized ecological benefits.

Table 7

Landscape metrics for dominant land-use classes and advanced structural interpretation

Land-Use Class	Total Area (m^2)	Mean Patch Area (m^2)	Total Perimeter (m)	No. of Patches	Structural Interpretation
Medium-density residential	45,283,283.04	6,456.13	2,813,612.22	7,014	Dominant urban matrix; highly fragmented, high edge density
Park and green space	14,917,381.59	5,316.24	1,773,523.16	2,806	Substantial area but fragmented; moderate-to-low connectivity
Low-density residential	14,762,544.24	21,645.96	419,662.88	682	Consolidated peripheral transition patches
Recreational	9,848,896.77	118,661.41	112,602.92	83	Large ecological-recreational anchor patches
Metropolitan-scale	6,771,376.64	677,137.66	33,139.16	10	Very large, compact and highly integrated mega-patches
Mixed use	6,306,732.06	1,876.45	637,968.80	3,361	Highly fragmented, linear network along major corridors
Agricultural green/open	5,356,901.56	412,069.35	29,327.35	13	Large core ecological-production patches; spatially isolated
Internal services	5,179,413.30	5,242.32	285,251.69	988	Dispersed neighborhood-support patches
Riverbed	4,160,544.54	218,976.03	44,983.21	19	Principal continuous hydrological-ecological corridor
Higher education	2,615,936.58	33,113.12	40,249.47	79	Compact institutional anchor patches
Entire landscape	160,188,861.57	—	—	20,134	Highly differentiated metropolitan mosaic
Estimated contagion index	—	—	—	—	Moderate, approximately 55-62%

At the landscape level, the simultaneous dominance of medium-density residential development and the high total number of patches generated a structurally complex and anthropogenic mosaic. Shannon diversity and evenness were interpreted as reflecting considerable land-use heterogeneity across the 36 classes, while high edge density indicated intensive interpenetration between built and natural land. The structural condition of the Hesar area and the wider Karaj periphery was particularly influenced by the interaction between the dense residential matrix, linear mixed-use strips, large agricultural core patches, recreational land, and the river corridor.

Advanced metrics further clarified the spatial structure. Connectivity was highest for the riverbed because its 19 elongated patches retained longitudinal continuity and acted as the principal ecological corridor. Parks and green spaces displayed moderate-to-low connectivity despite comprising 2,806 patches because many were small neighborhood parks separated by built development. Agricultural green/open land displayed low connectivity and high isolation because only 13 large patches remained and these were separated by urbanized land. Conversely, medium-density residential and mixed-use land had very low nearest-neighbor distances and high structural continuity, demonstrating the strong consolidation of the built matrix.

The contagion index for the entire landscape was estimated at approximately 55%-62%, indicating an intermediate condition in which a relatively continuous urban core coexisted with fragmented service and green land around its margins. This pattern signifies neither complete spatial dispersion nor complete aggregation. Instead, it reveals a metropolitan landscape with dense residential cores, fragmented ecological components, and strongly linear mixed-use development.

The Hesar area and the broader peripheral zone showed especially clear signs of structural pressure. Medium-density residential development increasingly enclosed natural and garden patches, while low-density residential development occupied transitional ecotones between the hard urban core and open land. Agricultural green/open land remained relatively intact internally, but its isolation exposed it to future subdivision and encroachment. The Karaj River corridor retained its role as the principal hydrological and ecological spine, but interaction with recreational and linear mixed-use development created points of functional discontinuity. The structural evidence therefore corroborated the survey findings: the principal spatial damage was not simply reduction in green land area, but progressive fragmentation, edge intensification, and

isolation of ecologically important patches within a dominant built matrix.

4. Strategic Assessment of the Existing Peripheral-Zone Management System

The strategic assessment integrated the statistical, spatial, ecological, institutional, and functional results within a SWOT framework. Internal strengths included the ecological capacity of orchards and natural corridors, the productive value of agricultural land, recreational and tourism potential, and the existence of formal planning and legal instruments for controlling development. Internal weaknesses included institutional and supervisory fragmentation, informal and shared ownership documents, inadequate infrastructure capacity, and declining place attachment and social capital.

The ecological function of orchards represented a particularly important strength, with a mean functional value of 4.18. Recreational-service capacity also remained substantial, with a mean of 3.85. Agricultural productivity and the presence of statutory planning rules constituted additional strengths. However, these capacities were counterbalanced by major weaknesses. Institutional and legal deficiencies accounted for 12.38% of the extracted variance in the factor analysis, while unauthorized construction associated with informal documentation had a mean of 3.75 and Friedman rank of 3.60. Infrastructure pressure had a mean of 3.95, and decline in place attachment had a mean of 3.62.

External opportunities included growing demand for nature-based recreation, application of remote sensing, GIS, cadastral systems, and smart monitoring technologies, implementation of taxation instruments targeting capital gains and land-value increases, and participation of landowners through incentives for preservation of green land. External threats were dominated by speculation and land rent, M = 4.32, Friedman rank = 3.85; groundwater decline, ecological rank = 3.65; sprawl, M = 4.22, t = 16.85; and informal settlement expansion, Friedman rank = 3.52.

The Internal Factor Evaluation matrix produced a total weighted score of 2.23. Because this value was below the conventional midpoint of 2.50, the internal management system was characterized by a predominance of weaknesses over strengths. The ecological function of orchards had the highest weighted strength score, .56, followed by recreational capacity, .33, agricultural potential, .27, and formal legal-planning foundations, .24. Institutional weakness had the greatest relative weight among weaknesses, .18, but because it received the lowest performance rating, its weighted score was .18. Informal/shared documentation had a weighted score of .15, infrastructure pressure .28, and weakening social capital/place attachment .22.

The External Factor Evaluation matrix produced a markedly lower total score of 1.65. This result indicated that the peripheral management system had a limited capacity to use available opportunities or neutralize major external threats. Nature-based tourism demand yielded a weighted score of .30, landowner participation .24, smart monitoring .18, and tax instruments .16. Among threats, speculation received the highest relative weight, .22, followed by sprawl and linear development, .16, groundwater depletion, .15, and informal settlement expansion, .12. The simultaneous IFE score of 2.23 and EFE score of 1.65 positioned the Karaj peripheral zone in a defensive/contractionary strategic condition in which WT strategies required immediate priority.

Cross-combination of the SWOT dimensions produced four strategic orientations. SO strategies emphasized development of nature-based tourism campuses and public recreational areas within ecological corridors and the application of smart monitoring to protect high-value agricultural land. ST strategies focused on using statutory peripheral boundaries and ecological assets to establish green containment belts and on increasing the economic viability of agricultural production to reduce land-conversion incentives. WO strategies prioritized cadastral registration, smart monitoring, formalization of informal documentation, and fiscal incentives for landowners who retained green land uses. WT strategies focused on immediate legal suppression of unauthorized construction and speculative subdivision, together with strict controls on groundwater extraction and infrastructure provision in vulnerable areas.

Quantitative Strategic Planning Matrix analysis was subsequently used to rank the principal strategic options. WT1, focused on legal enforcement against speculative and unauthorized development, and WO1, focused on cadastral reform and smart RS/GIS monitoring, both achieved the highest total attractiveness score of 6.31. ST1, involving stabilization of the legal peripheral boundary and establishment of a green belt, ranked second with a total attractiveness score of 5.52. SO1, involving development of public recreational and tourism campuses, ranked third with a score of 4.00. This ordering indicates that regulatory and cadastral reforms constitute necessary preconditions for ecological and recreational development.

Table 8

Integrated strategic assessment, priority strategies, and implementation roadmap

Strategic Element	Key Result / Strategy	Quantitative Basis	Priority / Time Horizon
IFE	Internal management position	Total weighted score = 2.23	Weak internal position
EFE	External strategic position	Total weighted score = 1.65	High external vulnerability
Main strength	Ecological and air-purification function of orchards	M = 4.18; weighted score = .56	Strategic ecological asset
Main weakness	Institutional and supervisory deficiency	12.38% explained variance; weight = .18	Critical weakness
Main opportunity	Nature-based tourism and urban recreational demand	Weighted score = .30	High opportunity
Main threat	Land speculation and rent-seeking	M = 4.32; Friedman rank = 3.85; weight = .22	Primary threat
WT1	Legal enforcement and criminal deterrence against speculative unauthorized development	STAS = 6.31	Joint first; immediate
WO1	Integrated cadastre and online RS/GIS monitoring	STAS = 6.31	Joint first; years 1-2
ST1	Stabilization of peripheral boundary and green containment belt	STAS = 5.52	Second; years 2-3
SO1	Public ecological-tourism campuses and recreational corridors	STAS = 4.00	Third; years 4-5
WT2	Closure of illegal wells and restriction of unauthorized utilities	—	Medium term; years 2-4
WO2	Fiscal incentives for owners preserving active orchards	—	Medium term; years 3-4
KPI for WT1	Reduction in new unauthorized construction	Target: 80%	First year
KPI for WO1	Smart cadastral coverage of peripheral land	Target: 100%	Years 1-2
KPI for ST1	Length of stabilized green belt and native planting	Physical implementation indicator	Years 2-3
KPI for WT2	Groundwater stabilization and cessation of subsidence	Environmental performance indicator	Years 2-4
KPI for WO2	Proportion of owners withdrawing from conversion	Behavioral/economic indicator	Years 3-4
KPI for SO1	Hectares converted to public ecological-recreational use	Land-management indicator	Years 4-5

The first implementation phase therefore concerns legal clarification, cadastral integration, and smart monitoring. This phase requires establishment of an integrated peripheral cadastre connecting Karaj Municipality, the Registry of Deeds and Properties, and the Agricultural Jihad Organization. A smart peripheral observatory based on satellite imagery, GIS, and drone monitoring is required to identify unauthorized development at its earliest stages. A specialized judicial and enforcement mechanism is also required to address organized speculative subdivision, unauthorized construction, and violations involving informal or nonregistered land documents.

The second implementation phase concerns physical stabilization and ecological containment. Acquisition and protection of strategically important parcels along development fronts should be combined with establishment of a green belt in corridors exposed to sprawl and linear growth. Fiscal incentives and development-transfer mechanisms can be directed toward owners who preserve orchards and green uses. Illegal wells should be closed, groundwater abstraction monitored, and unauthorized water and electricity supply to newly converted parcels restricted. These actions directly address the identified interaction between land speculation, groundwater decline, physical fragmentation, and infrastructure pressure.

The third phase concerns ecological regeneration and sustainable recreational development. Once the immediate regulatory and cadastral conditions have been stabilized, remaining mature orchards, ecological corridors, and open spaces can be integrated into public natural parks, garden pathways, and low-density recreational campuses. Private-sector participation may be appropriate where development is compatible with ecological carrying capacity and where public access and environmental protection are institutionally guaranteed.

Taken together, the findings demonstrate that land-use conversion in the peripheral zone of Karaj is driven primarily by an economic-institutional mechanism that becomes visible through fragmented and linear physical development and subsequently produces ecological, productive, social, legal, and psychological consequences. The quantitative analyses identified economic and land-

market pressure as the strongest direct driver, while the landscape metrics revealed the spatial expression of this pressure through the expansion of the residential matrix, fragmentation of mixed and green land uses, isolation of agricultural core areas, and growing pressure on the Karaj River ecological corridor. The strategic analyses further demonstrated that the current management system lacks sufficient internal capacity and external responsiveness to counter these processes. Consequently, the highest-priority interventions are legal enforcement against speculative conversion, cadastral transparency, intelligent monitoring, preservation of large agricultural core patches, protection of the river corridor, and containment of peripheral sprawl before recreational and developmental opportunities can be sustainably realized.

5. Discussion and Conclusion

The findings of this study demonstrate that land-use change in the peripheral zone of Karaj is a multidimensional process driven primarily by economic pressures and expressed through physical fragmentation, ecological degradation, institutional weakness, and functional disruption. Exploratory factor analysis reduced the 41 indicators to four major dimensions explaining 68.45% of the total variance, with economic drivers accounting for the largest share at 24.12%. This result indicates that rising land values, speculative transactions, rent-seeking behavior, and expectations of future development constitute the principal mechanisms behind land conversion in the metropolitan fringe. The dominance of economic forces is consistent with the political-economy interpretation of urban transformation, according to which land-use change cannot be understood merely as a technical planning issue but must also be interpreted through the interaction of capital accumulation, property interests, land valuation, and the unequal distribution of development benefits (Sarrafi & Mohammadi, 2022). The result also agrees with studies emphasizing that accessibility and the changing economic value of peripheral land strongly influence land-use conversion at the rural-urban interface (Verburg et al., 2004). In Karaj, therefore, physical expansion is better interpreted as the spatial manifestation of economic incentives than as a simple response to demographic growth.

The severity of agricultural and orchard fragmentation provides further evidence of this mechanism. The mean score of 4.18 for destruction and fragmentation of orchards and agricultural land was significantly higher than the theoretical midpoint, while sprawl and linear development recorded means of 4.22 and 4.08, respectively. These findings reveal that the transformation of the Karaj fringe is occurring through a sequence of parcel subdivision, fragmented construction, roadside expansion, and gradual infiltration into productive and ecological land. This pattern closely corresponds with previous research showing that metropolitan fringes are particularly vulnerable to horizontal development when urban growth boundaries are weakly enforced or disconnected from land-market controls (Pourmohammadi et al., 2021). It also supports findings that land-use change in metropolitan fringes produces both physical and functional consequences, including fragmented spatial structure, inefficient infrastructure extension, and disruption of the distinction between urban and rural functions (Pourmohammadi et al., 2022). The observed transformation of large agricultural parcels into smaller development-oriented units further parallels studies of peri-urban settlement transformation in which metropolitan influence alters parcel morphology, building patterns, and the physical organization of formerly coherent rural spaces (Mohsenzadeh et al., 2025).

The spatial concentration of land-use change in the western and northwestern entrance corridors of Karaj further confirms that accessibility is a critical conditioning factor. These areas received the highest Friedman rank of 4.25, followed by integrated rural nuclei. The concentration of conversion along major transport corridors suggests that road accessibility lowers the effective cost of development and increases the commercial attractiveness of peripheral land. This finding is strongly aligned with the observation that accessibility patterns shape land-use outcomes in transitional rural-urban landscapes by changing the relative attractiveness of competing land uses (Verburg et al., 2004). It is also consistent with analyses of the Southern Alborz region emphasizing the role of transportation corridors, freight movements, and metropolitan flows in restructuring spatial organization (Azimi, 2021). The results therefore suggest that transportation infrastructure in Karaj performs a dual role: it supports regional connectivity and economic exchange, but simultaneously creates development corridors along which unauthorized and speculative land conversion can become concentrated.

The results also showed that economic-land market damage was the most severe of the six damage dimensions, with a mean of 4.32, followed by environmental-ecological damage at 4.05 and physical-spatial damage at 3.91. Within the economic dimension, speculation and rent-seeking had

the highest mean and priority rank. This finding supports studies arguing that conversion pressure becomes especially intense when the market value of potentially developable land substantially exceeds the productive returns of agriculture (Hosseini et al., 2022). Under such conditions, continued agricultural production becomes economically disadvantaged relative to parcel subdivision and development. The present findings also correspond with legal and policy research indicating that preservation of agricultural and orchard land requires more than statutory prohibition because development pressure is sustained by powerful economic incentives and contested property rights (Kazemi, 2024; Parsa et al., 2020). The relatively strong correlation between economic and institutional damage further suggests that speculation becomes more consequential when regulatory deterrence is weak, property documentation is ambiguous, or enforcement is fragmented.

The environmental findings are particularly important because the ecological consequences of land-use conversion in Karaj extend well beyond the visible loss of green land. Groundwater depletion and excessive extraction ranked first among environmental damages, followed by soil degradation, vegetation loss, and biodiversity decline. The mean ecological damage score of 4.05 and the high level of disturbance in biological-ecological fringe functions indicate that the cumulative effects of peripheral development are altering the basic environmental processes that sustain the metropolitan system. This result is compatible with research showing that agricultural and open-land conversion affects environmental resilience by fragmenting ecological networks and weakening the adaptive capacity of peri-urban landscapes (Sarrafi & Abdollahi, 2020). It is also consistent with evidence from the wider Karaj and Alborz region regarding the growing hazard of land subsidence under conditions of groundwater depletion and human pressure (Asghari Saraskanroud et al., 2024). The observed relationship between physical and ecological damage further demonstrates that construction, soil sealing, parcel subdivision, and ecological decline are not separate processes but interconnected elements of the same spatial transformation.

The reduction of vegetated surfaces also has implications for urban climate. Although the present study focused primarily on functional and typological consequences, the loss and fragmentation of orchards and green areas can reasonably be interpreted in light of studies demonstrating significant relationships between land-use conversion, land-surface temperature, and urban heat-island formation (Obeyat et al., 2023). The landscape-metric analysis strengthens this interpretation. Medium-density residential land constituted the dominant urban matrix with more than 45 million m² and 7,014 patches, while mixed land uses displayed a highly fragmented and linear structure. In contrast, agricultural green/open land was concentrated in only 13 relatively large patches, and the riverbed consisted of 19 elongated patches functioning as the principal ecological corridor. The spatial structure therefore reveals a metropolitan landscape in which extensive built surfaces increasingly surround and isolate a limited number of large ecological core areas. This corresponds with theoretical perspectives on land-use and land-cover change that emphasize the importance of spatial configuration, not merely absolute area, in determining environmental consequences (Lambin & Geist, 2006).

The finding that productive-agricultural functions experienced the greatest level of disturbance, with a mean of 4.26, is likewise significant. Karaj's peripheral zone historically supported horticultural and agricultural functions, but the results suggest that speculative pressure has increasingly displaced productive land uses. This supports previous findings that urban-fringe agricultural sustainability deteriorates when fragmentation, rising land prices, development expectations, and urban pressure reduce the viability of farming (Hosseini et al., 2022). The observed shift from agricultural employment toward land brokerage, construction, and informal services also demonstrates that land conversion restructures the local economy rather than merely altering land cover. This outcome is consistent with broader spatial-planning approaches in which land-use change is understood as part of a transformation in the regional organization of production, settlement, transportation, and economic flows (Faraji, 2019). It also confirms that agricultural land protection should be interpreted as both an environmental and an economic-development issue.

The social and residential effects, although less severe than the economic and ecological dimensions, were also statistically meaningful. Informal settlement expansion ranked first among social damages, followed by spatial inequality in services and residential instability. These findings support earlier research showing that rapid peripheral expansion can create a mismatch between residential development and the provision of public services, infrastructure, and urban facilities (Ziari et al., 2019). They also align with sustainability frameworks emphasizing that urban quality cannot be assessed solely by physical

expansion or technological efficiency but must incorporate equity, accessibility, and spatial justice (Sharifi & Rezaei, 2022). The relatively lower mean reported by landowners compared with urban experts and executive officials is particularly noteworthy because it reflects divergent perceptions of land conversion. Landowners may view conversion primarily in terms of asset appreciation and individual economic opportunity, while planners and public officials are more likely to perceive the externalized infrastructural, environmental, and legal costs. This divergence confirms the importance of stakeholder-sensitive governance rather than relying exclusively on regulatory prohibition.

The security-legal findings further illustrate the relationship between informal land markets and institutional capacity. Illegal construction, accumulation of property disputes, encroachment on public land, and defenseless spaces were identified as significant components of security-legal damage. These findings are consistent with research emphasizing that the effectiveness of land-use regulation depends on implementation and that planning non-conformance may become structurally persistent when enforcement is inconsistent or institutional responsibilities are fragmented (Loh, 2011). They also support studies highlighting the role of municipal supervision in preventing unauthorized construction before violations become physically and legally entrenched (Ebrahimi, 2020). In the Iranian context, legal protection of agricultural land is especially complicated by overlapping ownership claims, informal agreements, and the tension between private property interests and public land-use objectives (Kazemi, 2024; Mirza Abutaleb et al., 2023). The present results demonstrate that these legal ambiguities have direct spatial consequences and can facilitate further fragmentation.

The psychological-behavioral dimension had the lowest overall mean but remained statistically significant. Reduced place attachment and neighborhood identity ranked as the most important component within this dimension. This finding suggests that rapid replacement of traditional orchards, agricultural landscapes, and familiar open spaces by irregular construction modifies not only physical structure but also residents' relationships with place. Although such effects are less immediately visible than land loss or infrastructure pressure, they are relevant to long-term urban sustainability because weakened attachment and spatial alienation may reduce collective responsibility for environmental stewardship. This interpretation is compatible with research on neighborhood development showing that the quality, legibility, accessibility, and human-scale character of urban environments influence perceptions of quality of life and social attachment (Ziari et al., 2020). It also reinforces the need to understand functional development as including social meaning and experiential quality rather than purely economic or physical performance.

The four-type damage model synthesized these interrelated consequences into speculative-physical, eco-degradative, social-security disorder, and behavioral-environmental disconnection types. The speculative-physical type recorded the highest mean of 4.12 and the strongest correlation with overall structural-functional disturbance, r = .742. The eco-degradative type followed closely, with a mean of 4.11 and r = .698. Together, these two types accounted for the largest proportion of explanatory influence in the regression model. The strong predictive contribution of the speculative-physical type confirms that land-market pressure becomes especially damaging when it directly translates into unregulated built development. The eco-degradative type demonstrates that the resulting spatial transformation subsequently reduces the capacity of the metropolitan fringe to perform ecological and productive functions. This typological relationship supports integrated-governance approaches that argue for simultaneous management of land, infrastructure, environment, and institutional responsibility in metropolitan fringes (Meshkini et al., 2023). It also corresponds with structural-planning perspectives in which sustainable development requires coordinated intervention across spatial systems rather than isolated responses to individual land-use violations (Sarrafi et al., 2021).

The landscape analysis provided independent spatial support for the survey-based typology. Medium-density residential land had the highest area and patch number and therefore acted as the dominant matrix, whereas mixed uses formed a highly fragmented linear network. Agricultural green/open land remained internally consolidated but spatially isolated, while the riverbed retained the highest longitudinal ecological connectivity. This structure indicates that the principal ecological risk in Karaj is not simply disappearance of all green land but isolation of remaining ecological assets within an increasingly dominant built matrix. The estimated intermediate contagion level of approximately 55%-62% also suggests coexistence of relatively cohesive urbanized cores with fragmented green and service structures. These findings reinforce the relevance of compact-city and infill-development

approaches that seek to accommodate urban needs within existing fabrics rather than extending development into peripheral ecological and agricultural lands (Pourahmad et al., 2021; Sajadzadeh et al., 2022). Reducing unnecessary outward expansion could therefore contribute directly to preservation of the 13 major agricultural patches and the river corridor identified in the spatial analysis.

The strategic analysis further showed that the present peripheral-management system is poorly positioned to respond to these pressures. The IFE score of 2.23 indicates that internal weaknesses exceed the effective use of internal strengths, while the EFE score of 1.65 demonstrates considerable vulnerability to external threats. The resulting defensive strategic position is consistent with the empirical evidence of fragmented governance, speculation, groundwater decline, informal development, and infrastructure pressure. Integrated spatial governance has been proposed precisely for situations in which multiple agencies possess partial authority over metropolitan fringes but no single institutional framework provides effective coordination (Meshkini et al., 2023). The findings also support the use of scenario-oriented planning because the continuation of existing trends would likely intensify fragmentation, whereas alternative combinations of monitoring, containment, ecological restoration, and economic incentives could produce markedly different futures (Raeis Ghanavati et al., 2023).

The QSPM results identified legal enforcement against speculative unauthorized development and integrated cadastral/smart monitoring as the joint first-priority strategies, each with an attractiveness score of 6.31. This result is coherent with the broader statistical analysis because economic speculation and institutional weakness were repeatedly identified as the principal drivers of conversion. The prioritization of cadastral reform and RS/GIS monitoring is also consistent with the need for more effective construction supervision and transparent land-management mechanisms (Ebrahimi, 2020). Establishing a green containment belt ranked second, which corresponds with evidence that urban growth boundaries can be effective when combined with enforcement and complementary land policies rather than implemented as purely cartographic limits (Pourmohammadi et al., 2021). Tourism and recreational development ranked lower and should therefore be regarded as a later-stage opportunity rather than an immediate response. Nevertheless, recreation remains important because metropolitan fringe tourism can support sustainable functions, public access, and local economic diversification when ecological integrity is preserved (Rezvani et al., 2021).

Overall, the study confirms that the peripheral zone of Karaj should be understood as a functional metropolitan system rather than as vacant land awaiting urbanization. Its orchards, agricultural patches, river corridor, open spaces, and recreational areas provide ecological, productive, hydrological, climatic, and social functions whose degradation generates costs that extend far beyond individual parcels. The results support a shift from reactive control of isolated violations toward integrated management of the causal chain linking speculative markets, fragmented ownership, weak institutional control, physical encroachment, and ecological decline. They are also consistent with approaches emphasizing that sustainable urban development requires the simultaneous protection of environmental capacity, public rights, social equity, spatial efficiency, and long-term functional performance (Mirza Abutaleb et al., 2023; Sharifi & Rezaei, 2022). Accordingly, preserving the Karaj fringe requires both containment of harmful conversion and active reinforcement of its ecological, agricultural, recreational, and public-service functions.

This study has several limitations that should be considered when interpreting its findings. First, the expert-based quantitative component relied on a relatively small specialized sample, which was appropriate for the Delphi and professional assessment design but limits the extent to which the numerical results can be generalized to all residents, landowners, informal developers, and institutional actors in the wider metropolitan region. Second, several indicators were based on expert perceptions rather than direct longitudinal measurement, and therefore the reported severity of some dimensions may reflect professional judgments in addition to objectively observed change. Third, although landscape metrics provided an important spatial validation of the survey results, the analysis was conducted primarily on the available land-use layer and did not include a fully standardized multi-date remote-sensing classification for every year across the 20-year period. Fourth, the cross-sectional nature of the questionnaire limited causal interpretation even though the regression and typological models revealed strong associations. Finally, institutional, legal, and market conditions in the Karaj fringe are highly dynamic, meaning that the relative importance of individual drivers may change following major policy reforms, infrastructure projects, macroeconomic fluctuations, or shifts in housing-market conditions.

Future studies should extend the present framework through longitudinal and multi-source designs. A particularly valuable direction would be to integrate satellite imagery from multiple benchmark years with cadastral records, building permits, land-price databases, groundwater measurements, and household-level surveys in order to reconstruct the temporal sequence through which agricultural parcels move from productive use to fragmentation and eventual construction. Future research could also apply spatial econometric models, geographically weighted regression, cellular automata, agent-based modeling, and machine-learning techniques to identify nonlinear relationships and predict future conversion hotspots. Comparative studies across the eastern, western, northern, and southern sectors of Karaj would help determine whether the same damage typology operates with equal intensity across different morphological and environmental contexts. Additional research should also incorporate residents, farmers, informal settlers, developers, and land brokers alongside experts so that conflicts in perceptions and incentives can be modeled more explicitly. Finally, testing the four-type damage model in other Iranian metropolitan fringes would clarify its external validity and determine whether the speculative-physical, eco-degradative, social-security, and behavioral-environmental types constitute a transferable analytical framework.

Urban and provincial authorities should prioritize intervention at the economic and institutional sources of land conversion rather than relying primarily on post-construction demolition or fragmented enforcement. An integrated digital cadastre should connect municipal, agricultural, environmental, judicial, and property-registration databases so that ownership changes, subdivision, construction activity, and environmental violations can be detected in near real time. Monitoring should be concentrated on the western and northwestern entrance corridors, integrated rural nuclei, major transportation axes, the remaining 13 large agricultural patches, and the Karaj River ecological corridor. Enforcement against unauthorized subdivision should be combined with economic measures that reduce speculative returns while improving the financial viability of maintaining agricultural and orchard uses. Infrastructure provision should not be extended automatically to newly converted parcels where it would legitimize irregular development. At the same time, green belts, ecological corridors, groundwater-protection measures, public recreational spaces, and incentive programs for landowners should be implemented as complementary instruments. The strategic sequence should therefore begin with cadastral transparency, legal deterrence, and monitoring, proceed to physical containment and ecological stabilization, and only then expand toward recreational development and long-term functional regeneration.

Authors' Contributions

Authors contributed equally to this article.

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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