urban science

MDPI

Article

Operationalizing Social–Ecological Systems Dynamics Through Spatial Metrics for Urban Waste Space Transformation in İzmir, Türkiye

Gurkan Guney

Department of City and Regional Planning, Faculty of Architecture, Middle East Technical University, Ankara 06800, Türkiye; gurkan.guney@metu.edu.tr; Tel.: +90-5413770557

Abstract

Unused, underutilized, abandoned, and residual urban spaces are increasingly recognized as potential resources for adaptive reuse, ecological improvement, and urban resilience. In this study, such areas are approached through the overarching concept of waste space, a term that captures both their underutilized condition and their transformation potential. While existing research has largely focused on the definition, classification, and emergence of such spaces, their potential for transformation across varying spatial and institutional contexts has received comparatively limited attention. Addressing this gap, this study operationalizes selected social–ecological system (SES) dynamics through spatial analysis in the metropolitan area of İzmir, Türkiye, offering a proxy-based assessment of transformation capacity rather than a direct transformation. Using district-level analysis across ten metropolitan districts, this research combines typological and morphological classification of waste spaces with four spatial indicators: the Density Index, Location Quotient, Shannon Diversity Index, and Typology Dominance Index. The results show that waste spaces are unevenly distributed across İzmir and form distinct district-level configurations shaped by infrastructure expansion, post-industrial transformation, speculative vacancy, and fragmented urban growth. This study concludes that waste spaces cannot be addressed through a uniform regeneration logic. By linking SES dynamics with measurable spatial indicators, the proposed framework offers a context-sensitive, proxy-based basis for indicating transformation capacity of waste spaces and supporting district-specific planning and policy decisions.

Keywords: waste spaces; social–ecological systems; İzmir; urban transformation; complex adaptability; nonlinearity; adaptive governance; resilience; sustainability

Check for updates

Academic Editor: Verónica Oliveira

Received: 17 March 2026
Revised: 17 April 2026
Accepted: 20 April 2026
Published: 22 April 2026

Copyright: © 2026 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Unused, underutilized, abandoned, and residual urban spaces have become a widespread and persistent feature of contemporary cities, reflecting long-term interactions between infrastructure development, planning processes, and institutional fragmentation. Once understood primarily as symptoms of urban decline and frequently stigmatized as blighted or unsafe, such spaces are increasingly recognized as potential resources for sustainable development, urban resilience, and adaptive reuse [1–6]. This shift is particularly relevant in metropolitan regions where rapid urbanization coexists with large areas of underutilized land, creating both spatial challenges and opportunities for transformation [7]. A diverse body of the urban literature conceptualizes these spaces under multiple terms, including brownfields, third

landscape, derelict land, vacant land, and urban voids, reflecting their spatial, social, and ecological attributes [8]. This research approaches such areas through the overarching concept of waste space. The term waste inherently carries a negative connotation, generally implying something unused, ruined, or residual. Meanwhile, the term waste in city planning and urban design refers to the outcome of natural and manmade urban processes [9]. One of the first urban theorists to frame this concept systematically was Kevin Lynch in the early 1990s [10]. Although Lynch did not coin the term, he gave it theoretical significance by moving beyond its conventional negative meaning to interpret waste space as a potential resource for rethinking and transforming the city. He characterized waste spaces as physically deteriorated, economically unproductive, socially marginalized or stigmatized, and temporally vacant, but also as potentially productive areas for reuse [10]. Similarly, Alan Berger (2006) [7] explains that contemporary modes of industrial production and consumption generate different forms of waste landscapes, including abandoned or contaminated sites as well as oversized or redundant urban developments, which may hold plural value and latent potential for reuse.

A significant body of the literature focuses on the drivers, origins, and categorizations of waste spaces, emphasizing processes such as deindustrialization, financial constraints, suburbanization, and speculative land practices [10–13]. Parallel studies highlight the social consequences of waste space, including socio-spatial inequality, environmental degradation, and neighborhood decline [14]. While these contributions are essential for understanding how waste spaces emerge, they offer limited guidance on a critical practical question faced by planners and policymakers: how should urban waste spaces be transformed under different spatial and institutional conditions?

More recent scholarship has sought to move beyond causal explanations by exploring reuse and regeneration strategies, such as adaptive reuse, temporary use, tactical urbanism, and nature-based solutions [15–19]. These studies demonstrate that urban waste spaces can support experimentation, community engagement, and ecological functions [20]. However, this literature often relies on very localized case studies and normative arguments, making it difficult to generalize findings or translate them into decision-support tools applicable at the metropolitan scale [21,22]. Nowadays, a central point of debate in the field concerns whether transformation outcomes are primarily shaped by policy and governance choices or by spatial and morphological configurations. Some scholars argue that institutional arrangements and actor coalitions are the decisive factors in successful regeneration [21]. In contrast, others emphasize the roles of urban form, land use, and spatial discontinuity in shaping transformation capacity [20]. This divergence has led to fragmented analytical approaches, with limited integration among social–institutional analysis, ecologically sensitive approaches, and spatially explicit methods [21,22].

Social–ecological systems (SES) theory offers a promising integrative framework for bridging these social, ecological, and spatial dimensions of urban change [23]. Originally developed to study coupled human–environment systems, SES theory conceptualizes cities as complex social–ecological systems shaped by interacting social, ecological, and spatial processes across multiple scales [23]. Within urban research, SES-based approaches have been increasingly employed to examine resilience, sustainability transitions, and governance dynamics [24]. However, these applications have largely remained conceptual, with limited efforts to translate SES dynamics into measurable, spatially explicit indicators that can inform empirical analysis [25,26]. As a consequence, the practical capacity of SES theory to guide planning and policy decisions, particularly those related to reuse strategies and spatial interventions, remains underdeveloped [27]. Accordingly, this study asks how SES-informed spatial indicators can provide proxy-based insights into the transformation capacity of waste spaces across metropolitan districts under varying spatial and institutional conditions.

The novelty of this study lies in three interrelated dimensions. First, it operationalizes SES dynamics—complex adaptability, adaptive governance, resilience, and nonlinear cross-scale dynamics—through spatial indicators derived from GIS-based analysis of typological and morphological configurations at the metropolitan district scale. This approach aims to translate SES concepts into proxy-based and interpretative spatial metrics, thereby extending beyond conceptual applications while maintaining an analytical framework [25,26]. While existing GIS-based studies have made significant contributions to the field, they have largely operated within different analytical boundaries. Mohamad Selamat et al. (2025) [28] developed a multi-tier GIS framework to assess the ecological suitability of vacant land parcels, Xu & Ehlers (2022) [29] applied remote sensing tools to automatically detect and typologically map urban vacant spaces, Luo et al. (2023) [6] spatially prioritized post-industrial waste spaces for green infrastructure based on site attributes and urban demand, and Newman et al. (2018) [30] modeled vacant parcels as potential ecological corridors through least-cost path analysis. While each of these studies advances spatial understanding of underutilized land, none connects spatial metrics to a systems-theoretical framework. This study takes a different analytical step by linking each spatial indicator to a specific SES dynamic, approaching spatial metrics as interpretative and indicative proxies for system-level properties such as adaptability, resilience, and governance complexity. Recent studies have begun to integrate spatial and multi-criteria approaches in urban regeneration and green infrastructure planning [31,32], yet these efforts remain limited in systematically linking SES dynamics with proxy-based frameworks across the metropolitan scale. Second, it introduces a combined typological and morphological classification of waste spaces explicitly grounded in SES theory and linked to an indicative framework. Third, it generates district-level diagnostic profiles—integrating density, concentration, diversity, and dominance—that provide proxy-based assessments for metropolitan planning and policy. Compared to parcel-scale indicator frameworks such as Kim et al. (2018) [22] and Lee & Newman (2019) [33], neighborhood-level social–ecological assessments such as Kremer et al. (2013) [21], and spatiotemporal vacancy mapping without SES integration such as Tu et al. (2024) [34], this study advances the analytical scale to the metropolitan district level, combining typological classification with SES-informed spatial metrics in a manner applicable to comparative planning practice.

This study addresses selected SES dynamics as a transformation-oriented analytical framework rather than a theory for explaining the emergence of waste space. It argues that the morphological and typological characteristics of waste spaces can be interpreted as practical spatial proxies for selected SES dynamics, particularly complex adaptability, adaptive governance, cross-scale dynamics, and resilience [35–41]. By translating these dynamics into a set of spatial indices [28,42–44], this study provides an evidence-based, exploratory approach for indicating relative transformation capacities and planning implications rather than prescribing uniform solutions [45].

Using the city of İzmir, Türkiye, as a metropolitan case study, this research develops and applies a morphology- and typology-based framework. For this purpose, waste spaces are classified into three main typologies: vacant parcels, post-industrial sites, and infrastructure-driven spaces. Then, the analysis integrates typological and morphological classification of waste spaces with spatial metrics, including density, Location Quotient, diversity, and dominance, to assess transformation capacity across districts. One of the main aims of this study is to demonstrate how SES dynamics can be operationalized through spatial analysis to indicate proxy-based transformation capacity for waste spaces in a context-sensitive, policy-relevant manner.

The principal conclusion is that waste spaces cannot be treated as a homogeneous category. Instead, their transformation potential depends on how spatial pressure, typo-

logical diversity, and structural lock-in interact within the urban system. By making these interactions measurable and comparable, the proposed framework helps bridge the gap between urban science and planning practice and offers a transferable decision-support tool for metropolitan regions facing persistent vacancy and uneven development.

2. Theoretical Background

2.1. Social–Ecological Systems Perspective

Urban waste spaces are increasingly evaluated not only as urban residuals but also as components of complex urban systems shaped by interactions among social, ecological, and spatial processes across multiple scales [46–48]. SES theory provides one of the most widely used frameworks for analyzing these interactions. SES theory emerged from interdisciplinary research to understand how human and non-human processes interact within shared systems [49,50]. Gradually, the theory has been adopted in urban science to analyze urban transformation, sustainability transitions, ecosystem services, and governance arrangements in cities [51–53].

Within the SES approach, urban areas are understood as hybrid socio-ecological environments where infrastructure networks, governance institutions, economic activities, and ecological processes co-evolve over time [47,54,55]. Waste spaces emerge from these intertwined processes. They are simultaneously shaped by planning failures, ownership conflicts, ecological cycles, and social practices [56]. This perspective highlights that when waste spaces are reused adaptively, they can restore ecological functions, improve well-being, and strengthen community and local economies; when neglected, they often generate environmental and social risks.

The SES framework emphasizes that urban areas cannot be understood through isolated variables alone, but through interactions among multiple components operating across spatial and temporal scales [23,48]. In the context of this study, SES theory is not used only as a theoretical framework for understanding the waste space phenomenon, but also as an analytical framework for operationalizing its transformation potential through spatial analysis. In this respect, resilience, complex adaptability, adaptive governance, and nonlinear cross-scale dynamics are selective dynamics of SES theory because they can be linked to measurable spatial indicators and used to explain how different waste space typologies and morphologies support or constrain transformation [35,36,57]. Their significance lies not only in their theoretical relevance but also in their capacity to guide us in the spatial interpretation of district-level morphological and typological patterns.

2.2. Key SES Dynamics for Waste Space Transformation

SES theory emphasizes resilience as the capacity of systems to absorb disturbances, reorganize, and adapt while retaining essential structures and functions [40,49]. In urban contexts, resilience is increasingly linked to the reuse of waste spaces for biodiversity, stormwater regulation, urban agriculture, recreation, and cultural activities, thereby enhancing community well-being and social value [39,58]. Hence, waste spaces become a distinctive urban context where resilience is tested and enacted, turning underutilized land into drivers of adaptive and sustainable urban futures.

SES theory also emphasizes the complex adaptability of systems. It means the built environment is a complex social–ecological system in which multiple metabolisms influence one another across different scales, and it calls for multiple disciplines and approaches to understand its complexity [59]. Waste spaces, when viewed through the lens of SES, become opportunities for complex adaptation and transformation. Hence, complex adaptability becomes a useful analytical tool for transforming degraded, blighted, and problematic spaces in urban landscapes within this conception of the built environment [36,60]. Com-

plex systems are characterized by scale-dependent effects, nonlinear behaviors, critical thresholds, intrinsic ambiguity or lack of predictability, innate self-structuring, interlinkages, reliance on past developments, and spontaneously arising properties. Within this perspective, waste spaces reveal a complex nature involving nonlinearities, planning and policy dimensions, economic conjunctures, and actor–stakeholder interactions across micro and macro scales [61].

Thirdly, adaptive governance within SES theory is a flexible, collaborative approach to managing complex urban areas, particularly in urban transformation [54,62,63]. Hence, it emphasizes experimentation, learning, and coordination among multiple actors to support collaboration and problem-solving in the management of resources, urban landscapes, and ecosystems [64]. In the context of waste space transformation, adaptive governance emphasizes the inclusive participation of communities, planners, landowners, decision-makers, and environmental systems to balance ecological, social, and economic goals, since these areas have been produced through complex interactions among such human and non-human actors [65]. Its polycentric, multi-level structure helps coordinate actors, institutions, and interventions across scales, thereby strengthening resilience and supporting more sustainable approaches to waste space transformation and reuse [54]. Thus, SES reframes waste spaces as dynamic landscapes of possibility, whose trajectories depend on adaptive governance structures coupled with ecological processes and social practices [57,66].

Ultimately, SES theory challenges urban planners and designers to embrace non-equilibrium, viewing cities as intrinsically unpredictable systems that are continuously evolving and shaped by numerous nonlinear interactions [67–69]. Within this system, changes occurring at one spatial scale may generate cascading effects across other scales, meaning that local spatial interventions can produce broader systemic consequences. Nonlinearity, therefore, underscores that responses within social–ecological systems are not always proportional to the changes introduced, meaning that small alterations in one component of the urban environment may generate disproportionately large, often unpredictable outcomes [38]. This dynamic is particularly important for understanding the waste space phenomenon, which often emerges from interactions between metropolitan and district-scale development processes, infrastructure-driven expansion, and land use transformations. For instance, urban sprawl may transform previously continuous natural landscapes into fragmented land cover structures, contributing to the emergence of residual or underutilized urban land [70]. From a transformation perspective, however, recognizing these cross-scale dynamics is equally important for waste space reuse, since interventions that overlook broader metropolitan and district-level processes may unintentionally reproduce similar conditions of vacancy in the future. Within the scope of this research, cross-scale and nonlinear dynamics are therefore interpreted through the relative spatial concentration of waste spaces across districts, allowing the analysis to capture how metropolitan-scale processes shape local patterns of waste space and influence the possibilities for their reuse.

2.3. Conceptual Framework

This study develops a conceptual framework (Figure 1) that links the morphological and typological characteristics of waste spaces with SES dynamics discussed above. Therefore, the morphological and typological characteristics of waste spaces are interpreted as spatial proxies of key SES dynamics, including resilience, complex adaptability, adaptive governance, and nonlinear cross-scale dynamics. Typological diversity reflects the system's adaptive capacity, while spatial concentration reveals cross-scale interactions shaping the uneven distribution of waste spaces. Structural dominance signals potential lock-in condi-

tions affecting resilience, whereas overall spatial intensity highlights governance-related processes influencing intervention priorities across districts.

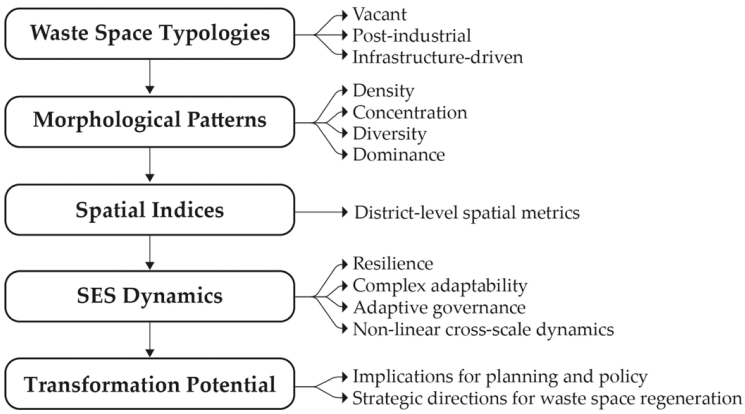


Figure 1. Conceptual framework linking waste space typologies, spatial indicators, and SES dynamics.

By translating these spatial characteristics into measurable indicators, the framework enables the operationalization of SES dynamics through spatial analysis. This operationalization, however, involves a deliberate distinction between two analytical perspectives. The spatial indicators produce directly measurable and comparable outputs: the Density Index quantifies the spatial intensity of waste spaces within each district; the Location Quotient measures relative concentration against the metropolitan sample; the Shannon Diversity Index calculates the evenness of typological distribution; and the Typology Dominance Index identifies the degree to which a single typology prevails. These are quantifiable, replicable outcomes. Their interpretation of SES dynamics operates at a conceptual level. These interpretative links are grounded in SES theory but are not themselves directly measurable or empirically demonstrable within the scope of this study. This distinction is maintained consistently throughout the analysis and discussion.

3. Materials and Methods

3.1. Study Area and Scale

This study focuses on the metropolitan area of İzmir, comprising ten major districts: Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Narlıdere, Karabağlar, Karşıyaka, and Konak (Figure 2). İzmir is Türkiye's third-largest city and a major economic, industrial, and transportation hub along the Aegean coast. As of the end of 2025, İzmir's total population is estimated at 4,504,185 [71]. The urban area extends along the İzmir Bay and inland to the north across the Gediz River Delta, eastward over an alluvial plain shaped by several small streams, and southward into more rugged topography [72]. İzmir's urban development has been shaped by successive sequences of new settlement and transformation processes, transportation infrastructure development, large-scale urban projects, the loss of previous functions, and plan amendments [73]. As a result, these processes have produced a heterogeneous urban landscape with a significant amount of waste spaces in İzmir [74,75]. Now, these waste spaces coexist with dense residential districts, commercial centers, and transportation corridors [74,76–79].

İzmir was selected as the study area for three interrelated methodological reasons. First, as a historically significant port and industrial city, İzmir exemplifies the metropolitan condition this study seeks to address: a large city where post-industrial transformation, infrastructure-led spatial fragmentation, and speculative vacancy coexist within a single metropolitan system, producing a typologically diverse waste space landscape that reflects the full range of formation processes central to this study [80]. Second, İzmir is one of

the few Turkish metropolitan areas fully covered by the Urban Atlas Land Cover/Land Use 2018 dataset, enabling the use of a standardized, high-resolution spatial dataset that supports methodological replicability and cross-city comparability. Third, the availability of multi-year field access between 2023 and 2025 and the observation of the locally documented planning trajectories enabled primary verification of the waste space inventory, strengthening the empirical reliability of the analysis.

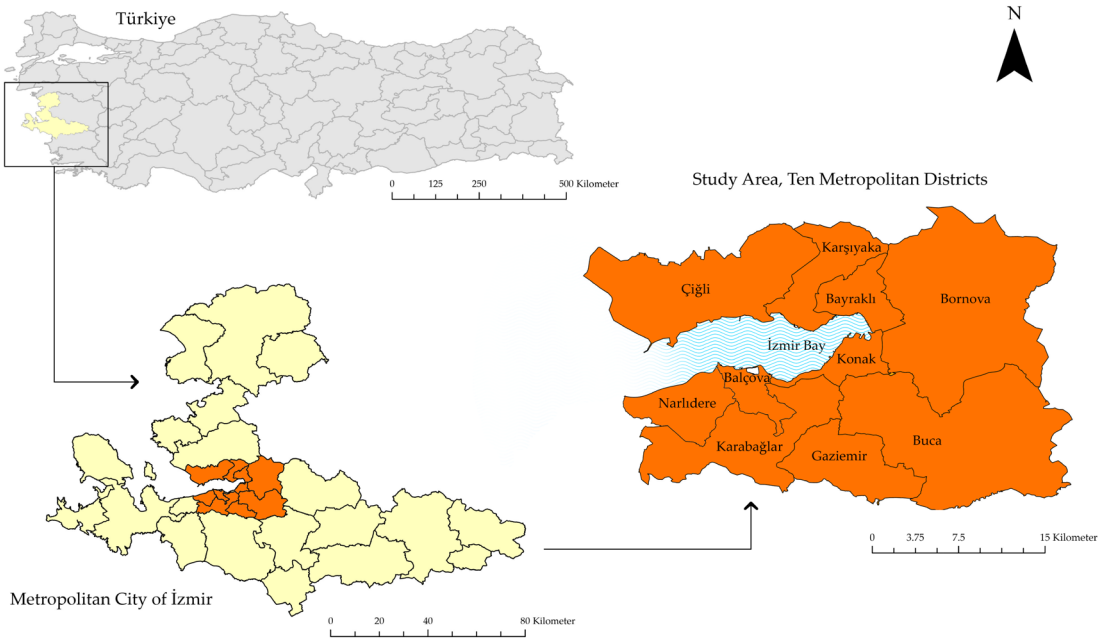


Figure 2. The location of the study area and selected districts within the İzmir metropolitan region.

İzmir's metropolitan structure is characterized by remarkable spatial differentiation among its historic core, central districts, and peripheral areas [11,81]. Central districts such as Konak, Bayraklı, and Karşıyaka, which also maintain the city's strongest relationship with the sea, are characterized by high development density and long-term exposure to infrastructure-led and post-industrial transformation processes [74,82]. In contrast, geographically larger districts such as Bornova, Buca, and Karabağlar encompass extensive urbanized areas with distinct land use histories, parcel structures, and planning trajectories [76,82,83]. Peripheral districts such as Gaziemir, Çiğli, and Narlıdere, meanwhile, provide contrasting conditions associated with speculative development, industrial transition, and fragmented urban expansion [80,84–86].

The analytical scale of this study is the district level, corresponding to İzmir's administrative districts. The analysis focuses on ten districts within the İzmir metropolitan area that align with the spatial coverage of the Urban Atlas Land Cover/Land Use 2018 dataset, which is used here as a standardized basis for district-level evaluation [87]. This scale is deliberately chosen for three reasons. First, district-level evaluation enables systematic comparison across the metropolitan area while capturing significant variation in urban form and waste space patterns. Second, districts serve as a critical governance scale for planning and policy implementation in Türkiye, aligning analytical outputs with decision-making processes for zoning, regeneration projects, and public investment. Third, identifying characteristics at the district level facilitates integrating spatial metrics with institutional and policy considerations without oversimplifying local conditions. Importantly, district-level aggregation is used as an analytical tool to identify dominant patterns and relative differences in waste space configurations. The underlying assumption is that district-scale morphological and typological profiles can function as indicators of broader

system behavior, revealing how the waste space phenomenon accumulates, diversifies, or becomes structurally locked-in over time. In this way, the district-level analysis enables comparison of how different configurations of urban form relate to waste space patterns within a single metropolitan system. This approach is consistent with SES perspectives that emphasize cross-scale interactions, for instance, whereby local spatial conditions both reflect and influence metropolitan-scale dynamics.

3.2. Data Sources

The spatial delineation of the study area is informed by both analytical objectives and data availability. The ten metropolitan districts were selected deliberately because they are included in the Urban Atlas Land Cover/Land Use 2018 dataset, which provides harmonized, high-resolution land use information for İzmir's core metropolitan area. Although the dataset was published in 2026, it represents land use/land cover conditions for the 2018 reference year [87]. This does not imply the absence of waste spaces in non-covered districts, but reflects a methodological choice to ensure consistency, comparability, and spatial accuracy in waste space classification. Urban Atlas's spatial extent corresponds to the most intensively urbanized districts, where processes of urban densification, infrastructure expansion, and post-industrial restructuring are most pronounced. To identify and analyze waste spaces within these districts, this study integrates multiple sources of evidence, including spatial datasets, remote sensing satellite imagery, and field-based observations. These data were compiled and analyzed in a Geographic Information System (GIS) environment using QGIS 3.34.11-Prizren version, enabling consistent spatial measurements, typological classification, and comparative analysis across districts.

3.2.1. Land Use and Waste Space Identification

This study draws on a combination of secondary spatial datasets and primary field observations to identify, classify, and quantify waste spaces across İzmir's districts. The main spatial dataset used to identify waste spaces was the Urban Atlas Land Cover/Land Use 2018 dataset, provided by the Copernicus Land Monitoring Service of the European Environment Agency (EEA) [87]. It provides reliable, high-resolution, and comparable land use and land cover information for 764 urban Areas with more than 50,000 inhabitants, covering the 2018 reference year across the 38 European Environment Agency (EEA) countries, including EU members, the Western Balkans, and Türkiye [87]. Thus, it is a digital thematic land use/land cover dataset with positional accuracy of approximately 2–4 m, making it suitable for district-scale spatial analysis in İzmir. Its nomenclature and vector-based land use classes provided the point of departure for identifying morphological assessments of waste spaces across the metropolitan area.

As elaborated in Figure 3 below, waste spaces were first identified through the Urban Atlas nomenclature *land without current use* (code 13400), which includes derelict, abandoned, and vacant areas without ongoing development or specified use. This category was selected as the primary departure point because it most directly corresponds to the theoretical and practical definition of waste space adopted in this study—areas characterized by vacancy, decay, obsolescence, or functional disconnection from active urban use. Beyond code 13400, three additional sets of Urban Atlas categories were incorporated based on explicit inclusion criteria. First, polygons within the categories *mineral extraction* and *dump sites* (13100) and *construction sites* (13300) were selectively included where field verification and satellite imagery cross-referencing jointly confirmed the absence of active operational use and a functionally residual or abandoned condition—for example, former industrial sites such as the old lead and casting factory in Gaziemir, which retain contaminated and derelict land despite their original classification. Sites exhibiting ongoing

activity, active construction, or temporary operational purposes were explicitly excluded from the inventory. Second, residual and underutilized areas associated with transportation infrastructure were included within the categories of *fast transit roads and associated land* (12210), *other roads and associated land* (12220), *railways and associated land* (12230), *port areas* (12300), and *airports* (12400), where satellite imagery and field observation confirmed that these spaces functioned as residual, disconnected, or inaccessible land rather than as active infrastructure. Spaces within these categories that remained in operational or active use were excluded. These categories were incorporated because many waste spaces in İzmir emerge adjacent to, beneath, or between major infrastructure systems. Accordingly, waste space was not treated as a single land use class but as an analytically reconstructed category derived from multiple Urban Atlas nomenclature classes.

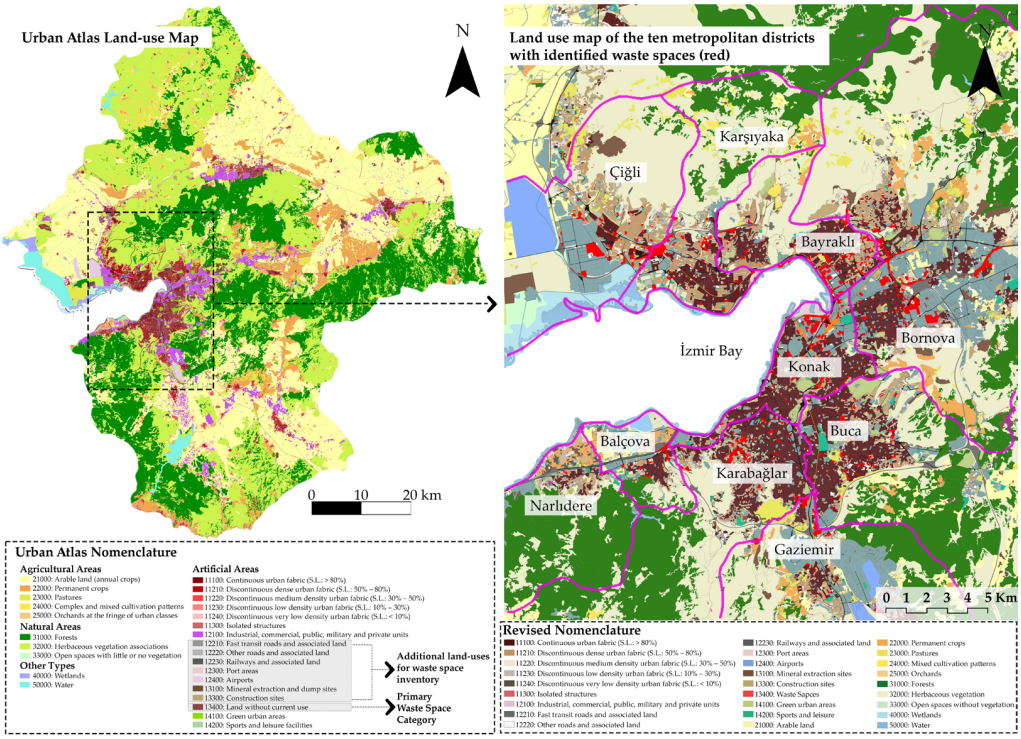


Figure 3. Urban Atlas land use map with original nomenclature, revised nomenclature, and identified waste spaces in the İzmir metropolitan area. The original Urban Atlas Land Use 2018 map is shown on the left, with the original nomenclature on the bottom left; the revised nomenclature used for waste space is identified on the bottom right; and the ten selected metropolitan districts with identified waste spaces are highlighted in red in the upper right.

To improve methodological transparency, the identification of waste spaces followed a structured three-stage classification protocol. In the first stage, a preliminary selection was conducted using the relevant Urban Atlas land use classes described above to establish an initial pool of potentially underutilized areas. In the second stage, these areas were systematically re-evaluated through high-resolution satellite imagery and cross-referenced with available planning documents to verify their current use status and exclude sites exhibiting active or temporary functions. In the third stage, each polygon was assigned to one of the three waste space typologies—vacant, post-industrial, and infrastructure-driven—based on morphological characteristics, spatial context, and observed land use conditions. To further enhance reliability and minimize potential overestimation, cases where field evidence was insufficient to confirm residual status were conservatively excluded from the final inventory.

This reinterpretation aligns with the broader conceptualization adopted in this study, which includes vacant parcels, post-industrial areas, and infrastructure-driven residual spaces. This also aligns with the production and emergence patterns of the waste space phenomenon in İzmir, reflecting five recurrent processes within the local urban conjuncture: new settlement and transformation processes, transportation infrastructure development, large-scale urban projects, the loss of previous functions, and plan amendments [82]. As with any study that reconstructs an analytical category from multiple standardized land use classes, some degree of classification ambiguity is unavoidable, given that the Urban Atlas nomenclature was not designed specifically to capture the waste space concept as defined here [88]. To enhance the reliability and consistency of the inventory, a three-step verification procedure was applied. Since the Urban Atlas represents land use/land cover conditions for the reference year 2018, its classifications were first further verified using high-resolution satellite imagery from Google Earth Pro 2025 (https://www.google.com/earth/ (accessed 26 January 2025)) [89], cross-referenced in QGIS to assess whether the identified spaces still existed and whether their land use status had changed. This step allowed the removal of polygons where active development or land use change had occurred since 2018 and the confirmation of continued vacancy or residual status in the remaining inventory. Second, targeted field visits were conducted to validate selected locations across 10 metropolitan districts and refine the final inventory. A total of four field visits were conducted: the first in November 2023, the second in April 2024, the third in July 2024, and the fourth in October 2025. The field visits covered all 10 municipal districts in the İzmir metropolitan area. During field visits, qualitative data were gathered through direct observations of the physical characteristics and conditions of each waste space. Field observations documented physical and social conditions, patterns of use, and the presence of spontaneous vegetation, thereby capturing the evolving characteristics of each waste space. Photographic documentation complemented these observations by providing a visual record of typologies and spatial configurations across the study areas [64]. Third, where variations arose between satellite imagery and field observations, on-site findings were generally prioritized in determining the final classification, given their capacity to capture ground-level conditions that remote sensing alone may not fully reflect. This multi-step procedure ensured that the waste space database combined the consistency of a standardized land use dataset with updated visual verification and site-based confirmation. Notwithstanding these verification steps, a residual classification ambiguity remains for some polygons at the boundary between active and residual use, and this limitation is acknowledged in the Conclusions. More broadly, the use of a 2018 base dataset alongside more recent verification sources introduces an inherent temporal tension: the inventory reflects waste space conditions as reconstructed across a multi-year window rather than at a single point in time. Sites undergoing gradual or partial transformation may therefore be underrepresented or inconsistently captured, a constraint that future studies could address through longitudinal or annually updated spatial datasets.

Beyond the temporal dimension, the reconstruction of waste spaces across multiple land-use categories introduces an interpretive dimension inherent to any study that operationalizes an analytically constructed category from standardized land use data. The distinction between unused and active use is not always clear-cut, and the classification is most sensitive at the interface between construction sites and derelict land, as well as between operational infrastructure and residual infrastructure-adjacent spaces. This challenge is also well recognized in the literature on waste space typology, where classification schemes have consistently been acknowledged as context-dependent and subject to interpretive variation [33,90]. The three-stage classification protocol and multi-source verification procedure adopted here are designed to minimize this sensitivity through

explicit criteria and conservative exclusion of ambiguous cases. The resulting inventory is best understood as a systematically verified reconstruction—consistent with established practice in waste space research—whose comparative value lies in its internal consistency across districts rather than in absolute completeness.

3.2.2. Spatial Data Processing and GIS-Based Mapping

All spatial data processing and subsequent analyses were conducted within a Geographic Information System (GIS) environment using QGIS, which served as the primary platform for data integration, measurement, and visualization. The Urban Atlas dataset was first imported and aligned with the İzmir administrative district boundaries from İzmir Metropolitan Municipality Open Data Portal (2024) [90]. To verify and update the latest land use situation, high-resolution satellite imagery from Google Earth Pro 2025 (https://www.google.com/earth/ (accessed 26 January 2025)) [89] was integrated and georeferenced within the same coordinate system. This overlay enabled the identification and verification of waste space polygons derived from Urban Atlas land use categories.

Waste space polygons were subsequently refined through manual digitization and spatial editing to ensure accurate delineation of site boundaries. Each identified polygon was then attributed according to the typological classification adopted in this study. Spatial measurements, including area and perimeter, were calculated in QGIS. Finally, waste space polygons were aggregated at the district level to enable comparative spatial analysis across the metropolitan area.

Spatial data processing prioritized transparency and replicability. All analytical steps, including data processing, polygon validation, and aggregation, were documented to facilitate reproducibility. While this study does not rely on proprietary datasets, some planning documents and detailed parcel-level information are subject to institutional access restrictions. These limitations are addressed explicitly in the Conclusion.

3.3. Typological Classification of Waste Spaces

A central component of the analytical framework is the typological classification of urban waste spaces. Typological classification is widely used in urban science and land use research to distinguish different production mechanisms and spatial characteristics of underutilized land [22,91,92]. As Hwang and Lee (2020) [92] demonstrate, the field has produced a wide spectrum of interchangeable terms and typologies, each developed for specific contexts, making comparative analysis and generalizable planning and policy tools a bit difficult to produce. Meanwhile, it should be noted that this typology is not proposed as a definitive framework for categorizing all waste spaces. Rather, it functions as a guiding reference and feedback mechanism to support planning and policy implication processes. Meanwhile, areas that remain undeveloped or unused primarily due to physical constraints, peripheral suburban location, or the absence of basic urban infrastructure—rather than as a direct outcome of urban abandonment, functional obsolescence, or planning fragmentation within an already urbanized context—fall outside the analytical scope of this study regarding typological identification and classification.

In this study, waste spaces were classified into three primary typologies based on their dominant formation processes and spatial characteristics. While this typological framework was not directly adopted from a single established classification scheme, it was informed by and developed in dialogue with the existing literature on urban waste land, vacancy, brownfields, and residual urban spaces, and subsequently adapted to reflect the specific formation processes documented in the İzmir metropolitan context. It draws on Kim et al.'s (2018) [22] field-based typology—which identifies post-industrial, derelict, unattended, natural, and transportation-related sites based on formation processes

and physical characteristics—and on Lee and Newman's (2019) [33] scheme, which links vacancy types to production mechanisms such as industrial decline, speculative holding, and institutional reserve. The three-category structure adopted in this study—vacant parcels, post-industrial sites, and infrastructure-driven waste spaces—represents a contextual consolidation of these precedents, adapted to the formation processes appropriate to İzmir: speculative vacancy and delayed development, post-industrial transformation, and infrastructure-led spatial fragmentation [75]. This is also consistent with Hwang and Lee's (2020) [92] reclassification, which groups similar conditions under post-industrial, residual/infrastructure-driven, and unused/underused categories.

Each identified waste space polygon was assigned to one of these typologies based on the combined interpretation of Urban Atlas land use classes, high-resolution satellite imagery, and field observations. In cases where polygons displayed overlapping characteristics or unclear cases, the dominant formation process, as confirmed by field observation, determined the final classification to ensure consistency. Field observations further supported the interpretation by verifying site conditions such as vacancy, residual infrastructure spaces, or the presence of former industrial structures. Based on this multi-source interpretation, each polygon was categorized as a vacant parcel, a post-industrial site, or an infrastructure-driven waste space, as shown in Table 1.

Table 1. The typological classification of waste spaces in İzmir.

Typology	Definition	Characteristics	Production Process
Vacant parcels	Undeveloped or long-term vacant parcels within the urban fabric that currently lacks active use	• Non-built surfaces • Irregular or odd-shaped parcels • Spontaneous vegetation • Publicly or privately owned	• Delayed urban development • Plan amendments • Demolition of previous structures • Speculative landholding
Post-industrial sites	Former industrial areas that have lost their original function and remain abandoned or underutilized	• Large parcels containing industrial structures, warehouses, and factories to smaller administrative buildings and utility structures • Potential soil contamination • Predominantly orthogonal or irregular surfaces	• Industrial decline • Relocation of production facility • Technological change • Economic restructuring • Changes in planning policies, or the abandonment of the old infrastructure elements
Infrastructure-driven spaces	Residual spaces emerging from large-scale transportation infrastructure and mobility systems	• Long, narrow, linear • Located adjacent to, beneath, or between transportation infrastructure • Passive green areas or informal usage	• Transport infrastructure expansion • Spatial fragmentation • Barrier effects • Buffer and right-of-way spaces

The three-category typological structure is considered transferable to other metropolitan contexts where land use datasets are available, and similar formation processes are documented. As Kim et al. (2018) [22] note, typologies of this kind are best understood as context-sensitive starting points rather than universal frameworks, and their direct

application should be assessed critically where land ownership regimes, planning systems, or urban processes differ substantially.

3.4. Spatial Metrics and Index Construction

To quantify the spatial structure and typological composition of waste spaces across İzmir's metropolitan districts, a set of spatial indicators was constructed based on a dataset generated in the previous steps. These indicators enabled systematic comparison of waste space configurations across districts by measuring spatial intensity, relative concentration, and composition. Rather than relying solely on descriptive statistics, this study employed four complementary spatial metrics that capture different dimensions of the waste space phenomenon: density, relative concentration, typological diversity, and dominance.

Together, these indices provided a multi-dimensional representation of waste space patterns. Density measures the overall spatial intensity of waste spaces within each district, while the Location Quotient evaluates whether waste spaces are disproportionately concentrated compared to the metropolitan average. Typological diversity captures the internal composition of waste space types within each district, reflecting the coexistence of different formation mechanisms. Finally, typology dominance identifies districts where a single waste space type strongly prevails, indicating structural specialization or potential lock-in conditions [22,93–101].

The selection of these four indicators follows a deliberate and constrained analytical strategy. Rather than constructing a composite index with a large number of variables, this study adopts a parsimonious indicator set designed to capture complementary and non-redundant dimensions of waste space structure at the district scale. The selection is guided by three criteria: each indicator must be derivable from consistently available area-based spatial data applicable across all districts without requiring additional socio-economic or governance datasets; each captures a distinct analytical dimension—spatial intensity (Density Index), relative metropolitan concentration (Location Quotient), internal typological heterogeneity (Shannon Diversity Index), and structural dominance (Typology Dominance Index); and all selected indicators are widely established in urban and landscape spatial analysis, ensuring interpretability, transparency, and comparability across cases. This approach aligns with recent research emphasizing multi-dimensional spatial analysis and indicator transparency in GIS-based urban studies [102,103], as well as systematic classification frameworks for brownfield and waste space identification [104].

However, several methodological sensitivities should be acknowledged. As area-based indicators calculated at the administrative district level, all four are subject to the modifiable areal unit problem (MAUP), in which index values can vary depending on the size and configuration of spatial units used, thereby affecting both the magnitude and interpretation of results [105,106]. The Shannon Diversity Index and Typology Dominance Index are additionally sensitive to the number of typological categories—here fixed at three—which bounds the differentiation capacity of H' relative to frameworks with finer typological distinctions. The Location Quotient is sensitive to the choice of reference area; calculated within the ten-district sample, its values reflect relative concentration within this bounded context rather than absolute metropolitan-scale measures. All indicators were calculated at the district levels using GIS-based spatial measurements of waste space polygons and district boundaries. Surface areas of waste spaces were first aggregated by typology and district, and the indices were then computed using standard spatial statistical procedures.

3.4.1. Density Index

The Density Index measures the spatial intensity of waste spaces within each district by normalizing the total area of waste spaces by the district's surface area. Similar density-based indicators are widely used in urban studies to quantify the spatial concentration of specific land use categories within a defined territory [94,107,108]. In the context of the waste space phenomenon, comparable measures have been used to assess the proportions of vacant, post-industrial, and infrastructure-driven waste spaces relative to total urban area [22,95]. The Density Index was calculated for each of the ten metropolitan districts using Equation (1) below.

$$D_i = \frac{WS}{A_d} \quad (1)$$

where

D_i: Density Index;

WS: Total Waste Space Area (km^2);

A_d: District Surface Area (km^2).

A key sensitivity of this indicator concerns its relationship to district size: larger districts may display relatively low density values despite containing substantial absolute waste space areas, while smaller districts may appear more intensive due to proportional effects. The Density Index is therefore interpreted as a relative measure of spatial intensity within the ten-district sample rather than as an absolute indicator of transformation priority.

3.4.2. Location Quotient (LQ)

The Location Quotient (LQ) is an indicator in regional and spatial analysis that measures the relative concentration of a specific factor within a sub-region compared to a larger reference area. Originally developed in economic geography to evaluate regional specialization, this method has been widely applied to examine spatial distributions of industries, social phenomena, and urban activities [96,109,110].

In this study, the Location Quotient (LQ) was employed to assess the spatial concentration of waste spaces across districts in the İzmir metropolitan area. The index compares the share of waste space area in a district to the district's share of the total metropolitan area. This indicator matters in showing structural specialization, not just size. Hence, it is significant for comparative urban policy. Equation (2) below shows the calculation formula:

$$LQ_i = \frac{\left(\frac{x_i}{\sum x_i}\right)}{\left(\frac{X_i}{\sum X_i}\right)} \quad (2)$$

where

LQ_i: Location Quotient;

x_i: Area of typology (i) within the analyzed sub-area (e.g., district);

$\sum x_i$: Total area of all typologies within the sub-area;

X_i: Area of typology (i) at the larger spatial scale (e.g., city/metropolitan area);

$\sum X_i$: Total area of all typologies at the larger spatial scale.

The Location Quotient (LQ) is a non-negative indicator. Values greater than 1 signify that factor i is more concentrated in a given district than in the reference area. In contrast, values equal to or below 1 indicate an average or lower-than-average presence. Increasing LQ values, therefore, reflect stronger spatial concentration of the factor. The resulting values indicate whether waste spaces are over-represented or under-represented in a district relative to the metropolitan structure:

- LQ > 1 → waste spaces are more concentrated than expected, indicating spatial clustering or specialization;

- LQ = 1 → waste space distribution is proportional to the district's share of metropolitan land;
- LQ < 1 → waste spaces are less concentrated than expected, indicating a relative deficit.

The Urban Atlas dataset covers the wider İzmir metropolitan area. However, the waste space categories relevant to this study—particularly code 13400 and the supplementary categories described in Section 3.2.1—are spatially concentrated in the ten core metropolitan districts, which therefore define the analytical boundary of the study. Accordingly, the LQ was calculated within this ten-district sample, and its values should be interpreted as within-sample concentration ratios rather than absolute measures of specialization across the full metropolitan area.

3.4.3. Shannon Diversity Index (H')

Originally developed in information theory [111,112] and gradually applied in ecology to measure species diversity [113], the Shannon–Wiener index, commonly referred to as the Shannon diversity index (H'), has also gradually been adopted across a range of spatial and environmental disciplines. In ecological research, Das et al. (2012) [114] demonstrated the index's potential as a GIS-based spatial indicator of environmental conditions and land cover heterogeneity. In urban studies, Cervero & Kockelman (1997) [115] adopted it as a measure of land use mix, a relationship later extended by Frank et al. (2005) [116] and Pattillo (2009) [117] to include physical activity and neighborhood composition. Baeza et al. (2017) [97] applied the index to measure spatial complexity and the homogeneity of urban economic activities at the district scale, while Ritsema van Eck & Koomen (2008) [118] demonstrated its utility as a policy-relevant indicator in scenario-based simulations of future land use at the metropolitan scale. In landscape ecology, McGarigal (1995, 2002) [99,119] and O'Neill et al. (1988) [120] established it as a standard tool for quantifying the richness and evenness of patch types within a given landscape. Taken together, these applications reflect a gradual convergence around the index as a flexible tool for characterizing the compositional heterogeneity of spatial systems—one that captures both the number of categories present and the evenness of their distribution. This study employs the index to assess and quantify the typological diversity—specifically, the relative proportions of vacant parcels, post-industrial sites, and infrastructure-driven spaces—of urban waste spaces within every ten districts. The index is calculated as shown in Equation (3) below:

$$H' = -\sum_{i=1}^{n} p_i \ln(p_i) \quad (3)$$

where

H': Shannon Diversity Index ($-(p_1 \ln p_1 + p_2 \ln p_2 + p_3 \ln p_3)$);

$-\Sigma$: Indicates that the calculation is performed for all typological categories (i) from 1 to n. The sign ($-$) ensures that the final index value is positive, since $\ln(p_i)$ is negative for $0 < p_i < 1$;

i: Typology category index (e.g., infrastructure-driven, vacant, post-industrial);

n: Total number of waste space typologies considered in the district (in this study, $n = 3$);

p_i: Corresponds to the proportion of each waste space typology ((i), e.g., infrastructure-driven, vacant, and post-industrial) relative to the total waste space area of the district;

$$p_i = \frac{\text{Area of Typology}_i}{\text{Total Waste Space Area in District}}$$

$\ln(p_i)$: Natural logarithm of the proportion of typology i.

The index takes non-negative values. The Shannon Diversity Index ranges between 0 and $\ln(n)$, where n represents the number of categories considered, as seen in the above

formula, with higher values indicating greater diversity and mixed typologies. In contrast, lower values suggest that one or a few categories dominate the system. In this study, typological diversity is interpreted through the lens of complex adaptability. This perspective draws on a well-established body of SES scholarship, where structural heterogeneity has been increasingly associated with a broader range of possible system responses [36,37]. In this context, the Shannon Diversity Index can be used as an analytical tool to differentiate district-level waste space configurations based on their indicative adaptive potential within the metropolitan system. Norberg et al. (2008) [121] conceptualized diversity as the availability of multiple functional responses within a system, enabling reorganization under changing conditions rather than being locked into a single trajectory. Wang et al. (2023) [122] applied the Shannon Diversity Index within a quantitative framework of urban ecological resilience across 48 Chinese cities, finding that more heterogeneous landscape configurations tend to be associated with higher performance across resilience dimensions. Similarly, in the context of leftover and vacant urban spaces, Naghibi et al. (2023) [123] identify diversity as a key feature of complex adaptability, showing that configurations with greater typological variety tend to offer more diverse intervention possibilities and greater socio-ecological flexibility.

Taken together, these studies suggest that higher H' values may correspond to a broader range of potential reuse opportunities, while lower values may indicate more structurally constrained spatial conditions. The Shannon Diversity Index is additionally sensitive to the number and definition of typological categories; its outputs are therefore bounded by the three-typology classification adopted in this study and should be understood as comparative indicators within this framework rather than universal measures of spatial complexity. In this study, with three waste space typologies and a theoretical maximum of $\ln(3) \approx 1.099$, H' values above 0.90 are interpreted as indicating high typological diversity, values between 0.60 and 0.90 as moderate diversity, and values below 0.60 as low diversity, following the proportional classification approach commonly used in landscape diversity analysis [99].

3.4.4. Typology Dominance Index (TDI)

The Typology Dominance Index (TDI) is widely used in landscape ecology for land use diversity and dominance analysis, where dominance is defined as the proportion of the largest class within a spatial unit [118,124]. In urban studies, dominance-based indices have been increasingly applied to characterize land use concentration and spatial imbalance—for instance, Ritsema van Eck & Koomen (2008) [118] employed dominance index alongside diversity indices to evaluate land use mixing in future urban scenarios, while Baeza et al. (2017) [97] used concentration measures to identify spatial homogeneity in urban economic activity patterns at the district scale. In this study, TDI complements the diversity analysis by capturing the relative concentration of a dominant waste space typology within each district, thereby providing an additional dimension to the understanding of spatial composition.

While the Shannon Diversity Index reflects the distribution and balance among multiple categories [125,126], TDI focuses specifically on the extent to which one typology prevails over others, as commonly applied in urban and landscape pattern analysis by McGarigal (1995) [119] and O'Neill et al. (1988) [120], signaling structural rigidity and path dependency. In this regard, Ricotta & Avena (2003) [126] demonstrated that dominance indices reveal spatial imbalances in land use structures and can inform planning priorities by identifying areas where a single function or land use type prevails. Similarly, Preston et al. (2023) [127] showed that post-industrial waste space typologies characterized by strong morphological dominance tend to correspond to narrower ecosystem service repertoires and more constrained intervention logics, while Naghibi et al. (2023) [123] found that

configurations with lower typological variety in abandoned urban spaces are associated with fewer transformation alternatives and reduced socio-ecological flexibility.

TDI values range between 0 and 1. Higher TDI values, with values approaching 1, indicate that a single typology overwhelmingly dominates the district's waste space structure, suggesting low typological diversity and high structural rigidity. Lower TDI values, closer to 0.33 (across three typologies), reflect a more balanced distribution, implying greater structural flexibility and multiple potential reuse opportunities.

From an SES-informed perspective, Walker et al. (2004) [36] established that systems dominated by a single component tend to exhibit reduced flexibility and greater vulnerability to lock-in—a condition Norberg et al. (2008) [121] further linked to the absence of multiple functional response pathways within the system. Translated into the spatial composition of waste spaces, this can suggest that districts with a single dominant typology may face fewer reuse options under changing planning conditions. This relationship is approached here as an interpretative linkage rather than a direct causal measurement, and TDI is accordingly employed as a heuristic spatial proxy that can support the identification of structurally concentrated configurations, providing indicative insights into potential constraints on transformation processes. The index is most informative when interpreted alongside the Shannon Diversity Index rather than in isolation; while high dominance values indicate strong typological concentration, they do not explain its underlying causes, which may relate to planning decisions, land-ownership structures, or historical functional specialization.

In this study, TDI values above 0.75 indicate high structural dominance, values between 0.50 and 0.75 indicate moderate dominance, and values below 0.50 indicate low dominance, consistent with the dominance classification used in land use diversity analysis [99,126]. The index formula is shown in Equation (4) below as

$$TDI_i = \max(p_i) \quad (4)$$

where

TDI_i: Typology Dominance Index, measuring the degree to which a single waste space typology dominates the overall typological structure within a district;

$\max(p_i)$: The largest typology share within the district (i.e., the dominant waste space typology).

$$p_i = \frac{\text{Area of Typology}_i}{\text{Total Waste Space Area in District}}$$

4. Results

4.1. Spatial Distribution and Concentration of Waste Spaces

The spatial analysis reveals substantial variations in the distribution of urban waste spaces across İzmir's ten metropolitan districts. As illustrated in Figure 4 below, waste spaces are not homogenously dispersed across the metropolitan territory. Instead, their spatial distribution, as seen in Scheme 1, displays clear clustering patterns associated with central urban areas, major infrastructure corridors, and historically industrialized districts. Concentrations are particularly visible in the northern and central parts of the metropolitan area, including Konak, Bayraklı, Karşıyaka, and Bornova, whereas peripheral districts contain comparatively smaller inventories.

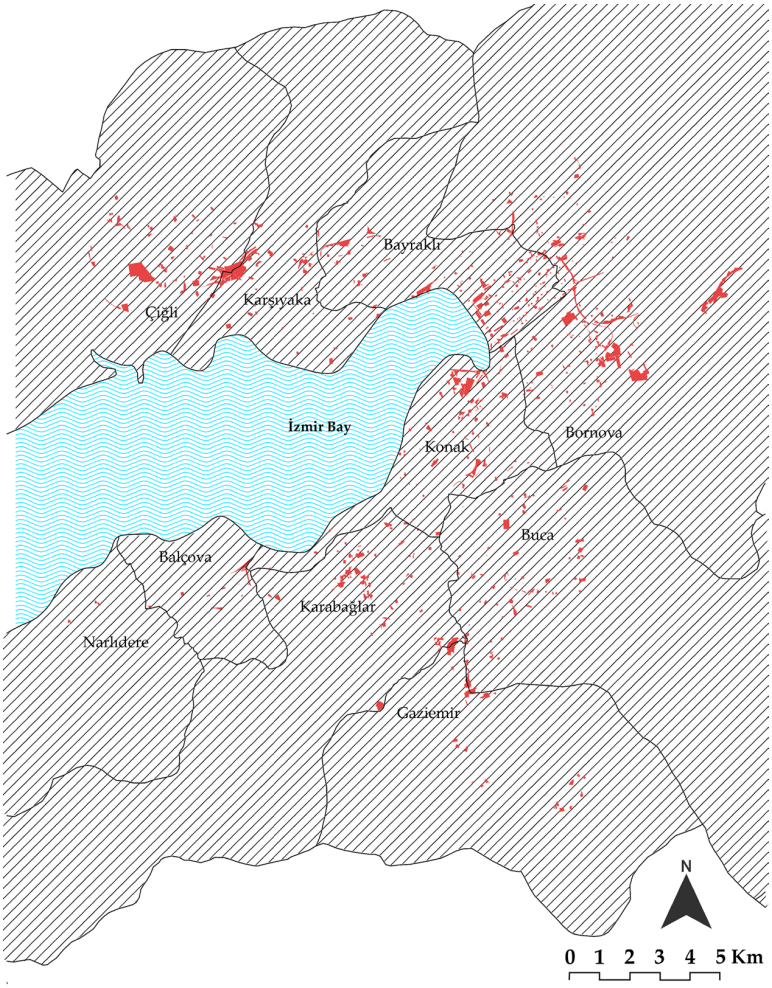
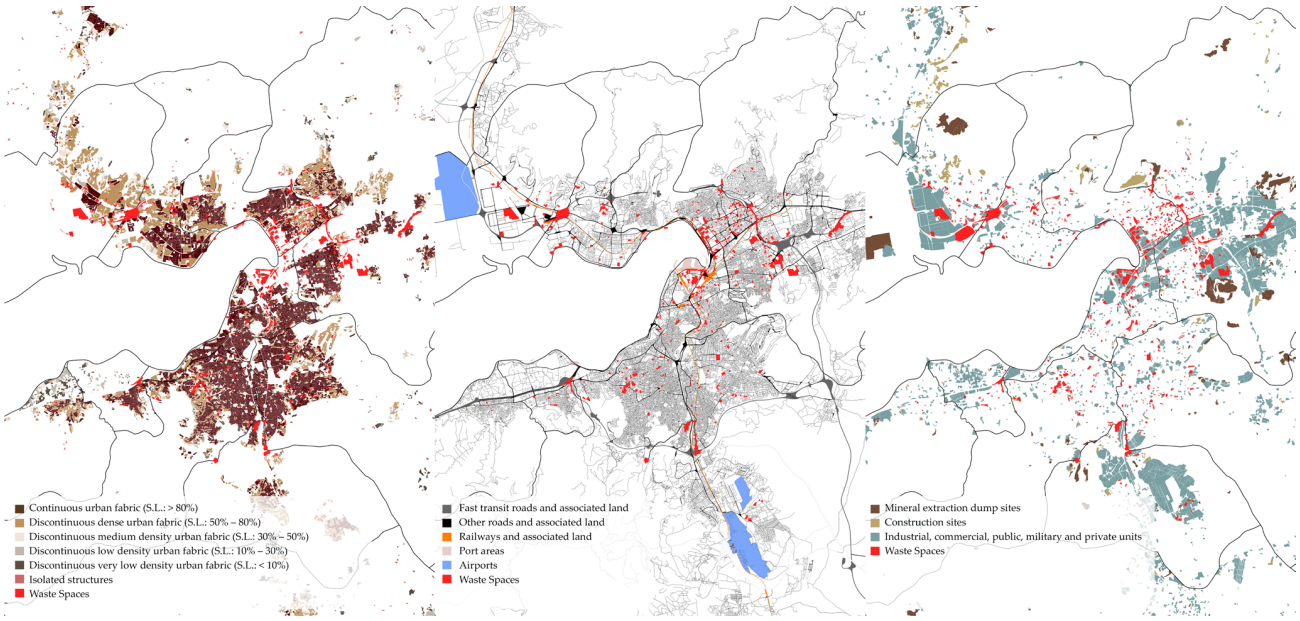


Figure 4. A waste space distribution map of the ten metropolitan districts of İzmir. Waste spaces are represented in red, district boundaries are shown with grey outlines, and İzmir Bay is depicted in blue.



Scheme 1. Waste space clustering patterns in relation to urban, industrial, and infrastructural uses across ten metropolitan districts of İzmir.

District-level comparison further highlights these spatial disparities. This variation becomes more explicit when visualized through a district-level choropleth representation (Figure 5), which highlights the relative intensity differences across the metropolitan structure. As summarized in Table 2 below, Bornova has the largest total waste space within the study sample (1.784 km^2), followed by Bayraklı (0.969 km^2), Çiğli (0.886 km^2), Karşıyaka (0.801 km^2), and Konak (0.789 km^2). On the other hand, Narlıdere has the smallest waste inventory (0.025 km^2), while Balçova (0.126 km^2) also displays a relatively limited amount of waste space. These differences reflect the contrasting development trajectories of the districts, as central and industrialized districts have experienced more intense infrastructure development, industrial restructuring, and redevelopment pressures than peripheral areas.

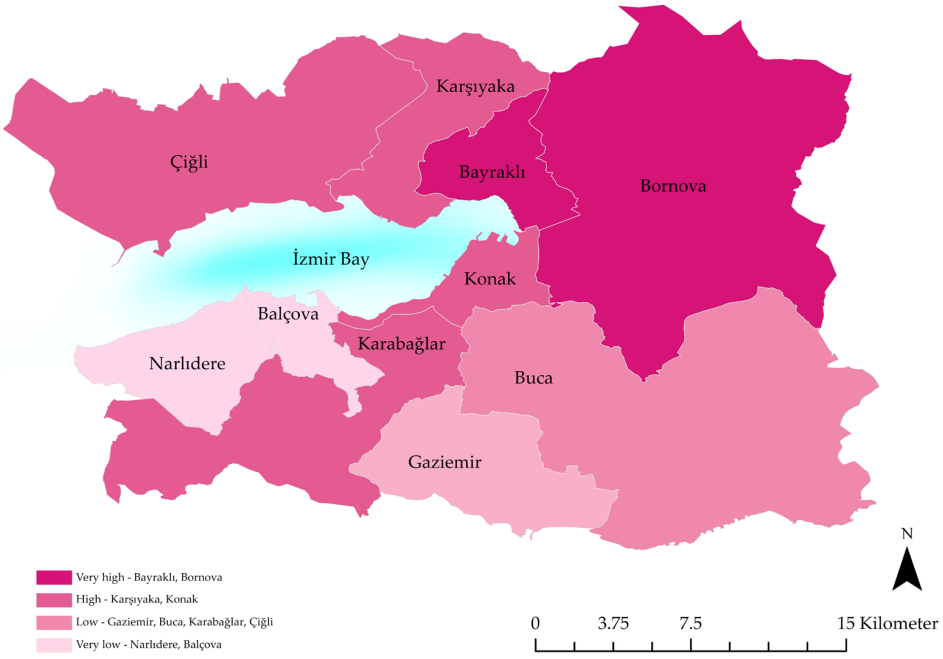


Figure 5. District-level choropleth map showing the relative variation in the selected waste space indicator across the ten metropolitan districts of the İzmir metropolitan area. Darker shades indicate higher values.

Table 2. District-level spatial indicators of waste spaces in İzmir.

District	District Area (km^2)	Waste Space (km^2)	Density (%)	Density Index	LQ *,1
Balçova	16	0.126	0.788	0.00788	0.98
Bayraklı *,2	30	0.969	3.230	0.03230	4.01
Bornova	220	1.784	0.811	0.00811	1.01
Buca	178	0.515	0.289	0.00289	0.36
Çiğli	139	0.886	0.637	0.00637	0.79
Gaziemir	70	0.471	0.673	0.00673	0.84
Narlıdere	50	0.025	0.050	0.00050	0.06
Karabağlar	89	0.616	0.693	0.00692	0.86
Karşıyaka	51	0.801	1.571	0.01571	1.95
Konak *,2	24	0.789	3.288	0.03287	4.08

*,1 The LQ was calculated within the ten-district sample because, although the Urban Atlas covers the broader metropolitan area, sufficient spatial data for waste space classification is available only for these districts. Values reflect within-sample concentration ratios rather than absolute metropolitan-scale measures. *,2 Bayraklı and Konak exhibit the highest density values across ten metropolitan districts.

To account for differences in district size, the spatial intensity of waste spaces was further evaluated using the Density Index, which normalizes the total area of waste spaces by the surface area of each district. The results indicate considerable variation in the relative spatial intensity of waste spaces across the metropolitan area. Konak and Bayraklı exhibit the highest density values, indicating that waste spaces occupy a relatively large proportion of the district's territory. Karşıyaka also shows a relatively high density, while Bornova, Balçova, Gaziemir, Karabağlar, and Çiğli exhibit moderate density, suggesting that waste spaces form a visible component of their spatial fabric. By contrast, districts such as Buca and Narlıdere display considerably lower density, indicating that vacant spaces occupy only a limited share of the district's territory. In these districts, waste spaces tend to appear more fragmented and spatially dispersed, reflecting different urbanization dynamics and lower levels of infrastructural or industrial restructuring.

The Location Quotient (LQ) analysis further refines this spatial interpretation by comparing the concentration of waste spaces in each district relative to the overall district sample. Districts with LQ values above 1, including Konak, Bayraklı, Karşıyaka, and Bornova, contain above-average concentrations of waste spaces within the metropolitan structure. Balçova presents a value close to 1, suggesting a near-average distribution of waste spaces within the district. Conversely, districts such as Buca, Narlıdere, Çiğli, Gaziemir, and Karabağlar display LQ values below 1, indicating that waste spaces are underrepresented relative to the overall distribution within the study area. These spatial concentration patterns suggest that waste spaces are not randomly distributed but are systematically associated with zones of intensified urban transformation. The disproportionate concentration in Konak and Bayraklı is particularly indicative in this regard: Konak, as İzmir's historic commercial and administrative core, has been subject to land speculation, fragmented ownership structures, and delayed redevelopment—conditions that generate waste spaces even under strong market pressure. Bayraklı, by contrast, represents a rapidly restructuring former industrial district now under intense CBD-driven development pressure, where the pace of transformation has outrun planning capacity, leaving significant areas of functional disconnection. Their exceptionally high indicator values—Konak: DI = 0.03287, LQ = 4.08; Bayraklı: DI = 0.03230, LQ = 4.01—suggest that waste space accumulation in these districts is not incidental but structurally produced by the intensity of urban restructuring itself [11,12].

Overall, these findings demonstrate that waste spaces in İzmir exhibit clear spatial concentration patterns rather than a uniform metropolitan distribution. However, the spatial concentration alone does not fully explain the internal structure of waste spaces across districts. The following section, therefore, examines the typological and morphological patterns through which waste spaces are formed within the metropolitan landscape.

4.2. Typological and Morphological Patterns of Waste Spaces

The typological classification of waste spaces reveals substantial variation in their internal composition of waste spaces across the ten metropolitan districts. As shown in Table 3 and Figure 6 below, three main typologies of vacant parcels, post-industrial sites, and infrastructure-driven waste spaces occur throughout the metropolitan area, but their relative proportions vary significantly between districts. Typological percentages were calculated based on the total waste space area within each district.

Table 3. The typological composition of waste spaces across districts.

District	Vacant (km^2)	Infrastructure-Driven (km^2)	Post-Industrial (km^2)	Total (km^2)	Vacant%	Infrastructure-Driven%	Post-Industrial%
Balçova	0.033	0.083	0.011	0.126	25.9	65.4	8.7
Bayraklı	0.539	0.187	0.244	0.969	55.6	19.3	25.1
Bornova	0.661	0.620	0.503	1.784	37.1	34.8	28.2
Buca	0.493	0.000	0.022	0.515	95.7	0.0	4.3
Çiğli	0.674	0.167	0.045	0.886	76.1	18.8	5.1
Gaziemir	0.182	0.070	0.218	0.470	38.8	14.9	46.4
Narlıdere	0.025	0.000	0.000	0.025	100	0	0
Karabağlar	0.493	0.000	0.123	0.616	80.0	0	20.0
Karşıyaka	0.229	0.501	0.071	0.801	28.6	62.5	8.9
Konak	0.205	0.146	0.438	0.789	26.0	18.4	55.5

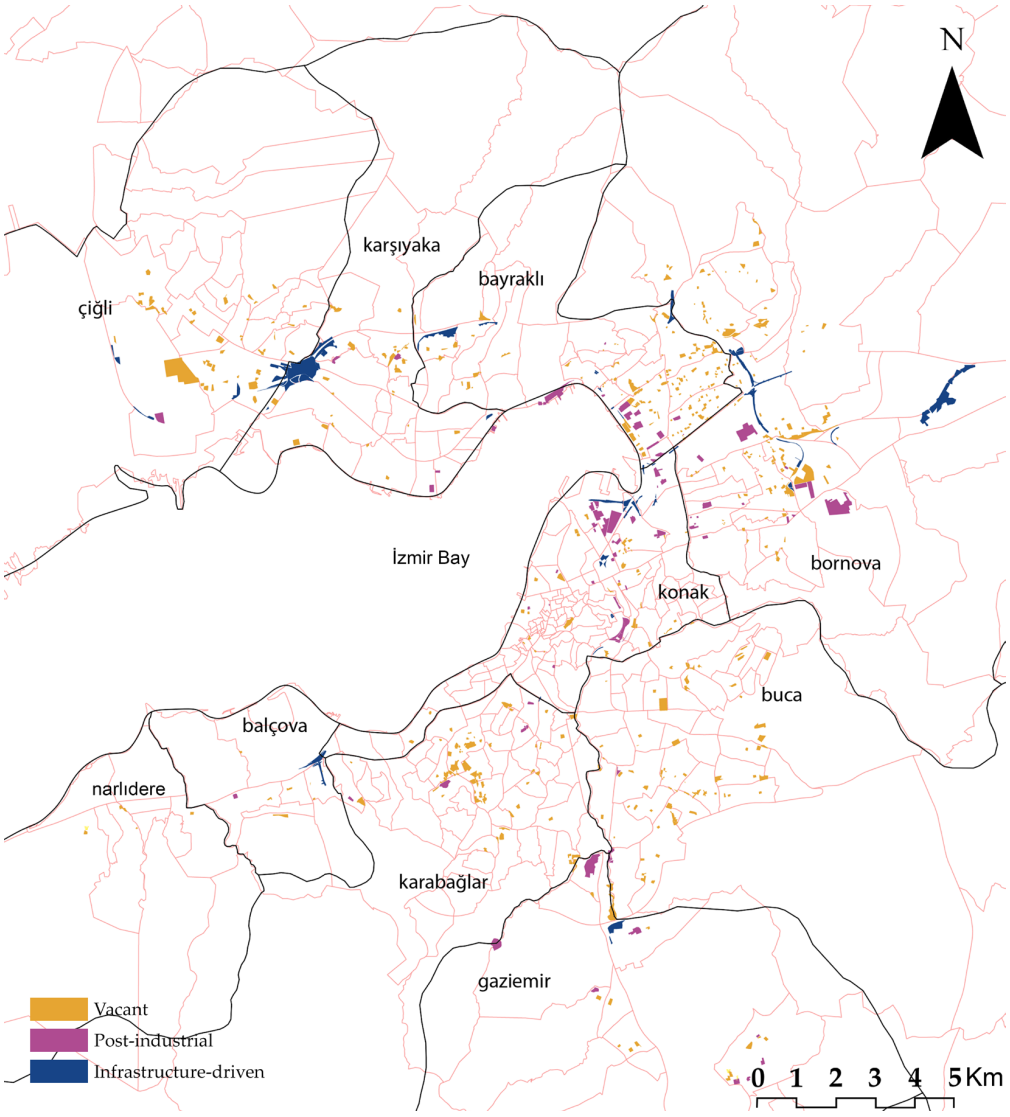


Figure 6. The typological distribution of waste spaces across the selected districts of the İzmir metropolitan area.

Vacant parcels constitute the dominant typology in most districts. This pattern is particularly evident in Buca (95.7%) and Narlıdere (100%), where vacant parcels account for the overwhelming majority of waste space, as well as in Karabağlar (80.0%) and Çiğli (76.1%), where vacancy also accounts for a large proportion of the waste space inventory. In Bayraklı, vacant parcels also comprise the largest share (55.6%), followed by significant post-industrial (25.1%) and infrastructure-driven typologies (19.3%).

Other districts have different typological structures. Karşıyaka (62.5%) and Balçova (65.4%) are primarily characterized by infrastructure-driven waste spaces, reflecting the strong influence of transportation corridors and infrastructural fragmentation within these districts.

In contrast, post-industrial waste spaces are particularly visible in (55.5%) and Gaziemir (46.4%), where former industrial facilities have left large underutilized areas within the urban fabric. These spaces tend to be larger and more spatially connected than vacant parcels, reflecting their origins in big former industrial and logistical activities.

Among all districts, Bornova represents the most balanced typological composition, with relatively similar shares of vacant (37.1%), infrastructure-driven (34.8%), and post-industrial waste spaces (28.2%). This balanced distribution distinguishes Bornova from districts such as Buca or Narlıdere, where a single typology clearly dominates the waste space structure.

These typological differences are also associated with distinct morphological patterns within the urban fabric. Vacant parcels often appear as fragmented and irregularly shaped spaces dispersed throughout residential or transitional urban areas. In contrast, post-industrial waste spaces typically form larger consolidated blocks, reflecting their historical association with large-scale production sites. Infrastructure-driven waste spaces, on the other hand, frequently display linear or corridor-based morphologies that emerge under viaducts and highways and adjacent to railways and other transportation infrastructures. These typological differences reflect distinct underlying urban processes. Vacancy-dominated districts such as Buca and Narlıdere are associated with speculative development dynamics and delayed planning implementation, while infrastructure-driven configurations in Karşıyaka and Balçova indicate spatial fragmentation produced by large-scale transport systems. Post-industrial concentrations in Konak and Gaziemir, by contrast, reflect the spatial legacy of industrial decline and the relocation of production within the metropolitan area. In this sense, typological composition is not merely a morphological characteristic but also an indicator of the specific urban processes that have shaped each district's waste space structure.

4.3. Typological Diversity and Structural Dominance

While the typological composition reveals which types of waste spaces exist in each district, additional insight can be obtained by examining the internal balance between these typologies. The Shannon Diversity Index was therefore calculated to evaluate the degree of typological diversity within each district.

As summarized in Table 4, Bornova exhibits the highest diversity value ($H' = 1.092$), indicating the most balanced distribution among the three waste space typologies (vacant—37.1%; infrastructure-driven—34.8%; post-industrial—28.2%). Relatively high diversity values are also observed in Gaziemir ($H' = 1.007$), Bayraklı ($H' = 0.991$), and Konak ($H' = 0.989$), where multiple types of waste spaces coexist within the district structure. These districts display more heterogeneous waste space configurations than those dominated by a single typology.

Moderate diversity levels are found in Karşıyaka ($H' = 0.867$) and Balçova ($H' = 0.840$), where one typology is clearly dominant but other categories still retain a visible presence (e.g., infrastructure-driven spaces account for 62.5% in Karşıyaka and 65.4% in Balçova).

Lower diversity values are observed in Çiğli (H' = 0.675) and Karabağlar (H' = 0.500), indicating greater concentration in a single typological category (vacant parcels represent 76.1% and 80.0%, respectively).

Table 4. The typological diversity and dominance of waste spaces by district.

District	Vacant (%)	Infrastructure-Driven (%)	Post-Industrial (%)	Shannon (H')	TDI	Dominant Typology
Balçova	25.9	65.4	8.7	0.840	0.654	Infrastructure-driven
Bayraklı	55.6	19.3	25.1	0.991	0.556	Vacant
Bornova	37.1	34.8	28.2	1.092	0.371	Vacant
Buca	95.7	0.0	4.3	0.177	0.957	Vacant
Çiğli	76.1	18.8	5.1	0.675	0.761	Vacant
Gaziemir	38.8	14.9	46.4	1.007	0.464	Post-industrial
Narlıdere	100.0	0.0	0.0	0.000	1.000	Vacant
Karabağlar	80.0	0.0	20.0	0.500	0.800	Vacant
Karşıyaka	28.6	62.5	8.9	0.867	0.625	Infrastructure-driven
Konak	26.0	18.4	55.5	0.989	0.555	Post-industrial

The lowest diversity levels are observed in Buca (H' = 0.177) and Narlıdere (H' = 0.000), where waste spaces are overwhelmingly dominated by a single typology (vacant parcels account for 95.7% in Buca and 100% in Narlıdere). In these districts, the internal structure of waste spaces is therefore considerably more homogeneous than in districts with higher diversity values.

In addition to diversity, the Typology Dominance Index (TDI) was calculated to identify districts in which a single typology strongly dominates the waste space structure. Higher dominance values indicate districts where waste spaces are primarily structured around a single typological category, while lower values suggest a more balanced internal composition. The highest dominance values occur in Narlıdere (TDI = 1.000) and Buca (TDI = 0.957), followed by Karabağlar (TDI = 0.800) and Çiğli (TDI = 0.761), confirming the strong prevalence of vacancy in these districts. By contrast, lower dominance values are observed in Bornova (TDI = 0.371), Gaziemir (TDI = 0.464), Bayraklı (TDI = 0.556), and Konak (TDI = 0.555), indicating more balanced typological structures.

Overall, the diversity and dominance indices demonstrate that waste spaces across İzmir exhibit significant variation in their internal typological structures. Some districts display heterogeneous configurations with multiple typologies coexisting (e.g., Bornova H' = 1.092), while others are characterized by strong specialization around a single waste space form (e.g., Narlıdere TDI = 1.000; Buca TDI = 0.957). Taken together, the diversity and dominance patterns suggest that districts differ not only in their typological composition but also in their structural flexibility for transformation. Districts with higher diversity values may accommodate a wider range of reuse pathways, whereas highly dominant structures indicate more constrained and path-dependent spatial conditions—a distinction explored further in relation to SES dynamics in Section 5 [36,37].

4.4. Synthesis of District-Level Waste Space Profiles

The combined analysis of spatial indicators and typological characteristics reveals several distinct district-level waste space configurations across the metropolitan area. As summarized in Table 5, the synthesis integrates spatial concentration indicators (Density In-

dex and location quotient), typological diversity (Shannon index), and structural dominance (TDI) to compare waste space structures across districts. The four configurations identified—diversified, vacancy-dominated, infrastructure-driven, and post-industrial—correspond to distinct positions within the SES dynamics framework: diversified districts exhibit spatial conditions associated with complex adaptability and resilience; vacancy-dominated districts reflect structural lock-in and governance challenges; infrastructure-driven districts highlight cross-scale fragmentation dynamics; and post-industrial districts signal conditions requiring targeted remediation-oriented governance.

Table 5. District-level waste space profiles in the İzmir metropolitan area. The table integrates spatial indicators (Density Index and location quotient), typological diversity (Shannon index), structural dominance (TDI), and typological composition to identify distinct configurations of waste spaces across districts.

District	Density Index	LQ	Shannon (H')	TDI	Configuration	Spatial Characteristics	Urban Processes
Balçova	0.00788	0.98	0.840	0.654	Infrastructure-driven district	Linear and underutilized residual spaces	Infrastructure expansion and spatial fragmentation
Bayraklı	0.03230	4.01	0.991	0.556	Mixed high-intensity district	Large inventory, multiple typologies	CBD formation, rapid urban transformation, and redevelopment pressures
Bornova	0.00811	1.01	1.092	0.371	Diversified waste space district	Coexistence of vacant parcels, infrastructure-driven spaces, and post-industrial sites	Interaction of industrial restructuring, infrastructure, and urban expansion
Buca	0.00289	0.36	0.177	0.957	Vacancy-dominated district	Highly fragmented vacant parcels dispersed in urban expansion areas	Development delays and speculative vacancy
Çiğli	0.00637	0.79	0.675	0.761	Vacancy-dominated district	The concentration of vacant land adjacent to industrial areas	Industrial land use transition
Gaziemir	0.00672	0.84	1.007	0.464	Post-industrial transition district	Large parcels associated with the former industrial activities	Industrial decline and relocation of production
Narlıdere	0.00050	0.06	0.000	1.000	Peripheral vacancy district	Scattered vacant parcels in low-density peripheral areas	Peripheral urbanization and speculative development pressure
Karabağlar	0.00692	0.86	0.500	0.800	Vacancy accumulation district	Concentration of vacant parcels within dense urban fabric	Urban restructuring and fragmented land ownership
Karşıyaka	0.01571	1.95	0.867	0.625	Infrastructure-driven district	Corridor-based residual spaces along transport networks	Infrastructure fragmentation
Konak	0.03287	4.08	0.989	0.555	Post-industrial core district	Large consolidated former industrial sites in central urban areas	Post-industrial transformation

The results indicate that districts differ not only in the amount of waste space they contain but also in their internal structural composition and dominant urban processes shaping these spaces. One configuration corresponds to diversified waste space districts, where multiple typologies coexist, and diversity values are relatively high. These districts exhibit balanced typological shares and lower dominance values, indicating heterogeneous waste space structures. In the study area, Bornova (H' = 1.092; TDI = 0.371) represents the distinct example of this configuration, reflecting the interaction of several urban processes, including infrastructure development, industrial restructuring, and urban expansion. A second configuration includes vacancy-dominated districts, where vacant parcels constitute the dominant share of waste spaces and diversity values remain comparatively low. These districts typically exhibit strong typological dominance and highly fragmented spatial structures associated with incomplete development processes and speculative landholding. Examples include Buca (TDI = 0.957) and Karabağlar (TDI = 0.800), where vacancy accumulation forms the dominant pattern. Çiğli also aligns with this configuration, displaying relatively high dominance (TDI = 0.761) and a strong concentration of vacant land.

A third configuration corresponds to infrastructure-driven districts, where waste spaces emerge primarily as residual areas associated with transportation infrastructure. These districts are characterized by corridor-based, linear spatial patterns aligned with highways, railways, and other transport networks. Karşıyaka and Balçova illustrate this configuration, where infrastructure-related fragmentation strongly influences the spatial formation of waste spaces. Particularly, Balçova exhibits a near-average level of spatial concentration (LQ $\approx$ 1), indicating that infrastructure-driven waste spaces are embedded within a relatively balanced district structure. Finally, post-industrial districts represent another distinct configuration, where large parcels associated with former industrial activities dominate the waste space landscape. These districts reflect the spatial legacy of industrial decline and the relocation of production within the metropolitan area. Konak and Gaziemir illustrate this pattern, where post-industrial transformation processes shape the current distribution of waste spaces.

5. Discussion

5.1. Waste Spaces as Social–Ecological Systems Components

The results of this study highlight that waste spaces in İzmir are not as isolated residual spaces or leftovers after planning anomalies. Rather, their metropolitan distribution, typological composition, and district-level structural differences indicate that they are embedded within complex social, ecological, and spatial processes. This interpretation is consistent with social–ecological systems (SES) theory, which conceptualizes urban environments as coupled and evolving systems shaped by interactions among infrastructure, governance, land use, ecological processes, and human activities [46–50]. In this sense, waste spaces in İzmir emerge not outside the urban system, but from within it.

This systemic and analytical perspective is particularly important because the results reveal that waste spaces are not distributed randomly across the metropolitan area. The Density Index and Location Quotient (LQ) indicate that districts such as Konak, Bayraklı, and Karşıyaka have more intense and concentrated waste space configurations than other districts, while Bornova also demonstrates an above-average concentration within a more balanced spatial structure. At the same time, typological composition varies markedly across districts. These patterns reflect distinct combinations of cumulative urban processes [11,12,27]: high-density and high-concentration districts such as Konak and Bayraklı are shaped by rapid redevelopment pressure and central business district formation, infrastructure-driven configurations in Karşıyaka and Balçova by large-scale transport investments and spatial fragmentation, and vacancy-dominated districts such as Buca

and Karabağlar by speculative landholding and delayed planning implementation. This process-based differentiation is what makes district-level profiling analytically meaningful: it shows that waste spaces are not simply spatial residues but are actively produced by distinct combinations of ongoing urban dynamics. This also supports the idea within urban science research arguing that the waste space concept should be approached as a strategic urban phenomenon rather than as leftovers with solely negative value [18,22,41].

When we approach through this lens, the district-level waste space patterns in İzmir point to different socio-spatial trajectories of waste space production and persistence. Central districts with high-density urban fabrics and strong redevelopment pressures tend to contain more concentrated, mixed waste space formations, whereas peripheral districts tend to display more fragmented waste space formations. Thus, the results establish the argument that waste spaces are spatial manifestations of broader urban system behavior and that their interpretation requires a framework capable of linking local morphology to wider metropolitan dynamics. SES theory offers a holistic and interdisciplinary framework because it allows these patterns to be understood not only in terms of land use but also in relation to adaptability, governance, resilience, and cross-scale interactions [52,53].

5.2. SES Dynamics and Transformation Capacity

5.2.1. Complex Adaptability

The district-level pattern identified in İzmir reveals fundamental heterogeneity in structural conditions with direct implications for the dynamics of complex adaptability. The variation in Shannon Diversity Index values—ranging from $H' = 1.092$ in Bornova to $H' = 0.000$ in Narlıdere—is not merely a descriptive outcome but suggests that metropolitan waste space systems are internally differentiated in ways consistent with SES theoretical predictions: districts with higher structural heterogeneity may retain a broader repertoire of adaptive responses, while those dominated by a single typology exhibit conditions associated with path dependency and reduced adaptive capacity [36,37]. It should be noted, however, that this interpretation is conceptual rather than directly measurable—the spatial indicators serve as theoretically grounded proxies rather than empirical demonstrations of adaptive capacity.

Here, the Shannon Diversity Index (H') and the Typology Dominance Index (TDI) are especially revealing. Districts such as Bornova, Gaziemir, Bayraklı, and Konak show relatively high diversity and lower dominance values. By contrast, districts such as Buca, Narlıdere, Karabağlar, and Çiğli are much more strongly dominated by a single typology. In the SES framework, this distinction is important because adaptability depends on systems' capacity to reorganize, accommodate different trajectories, and generate new configurations under changing conditions [36,37,59,60]. Typological diversity is therefore not merely a descriptive characteristic of waste space composition. It is employed here as a proxy-based spatial indicator, drawing on the converging body of the SES literature reviewed in Sections 3.4.3 and 3.4.4, to indicate whether a district may support multiple reuse options or is constrained by structural rigidity. Thus, a more heterogeneous waste space configuration is interpreted as suggesting a broader range of possible interventions, including adaptive reuse, ecological restoration, incremental redevelopment, and mixed public space strategies.

Conversely, high typological dominance points to stronger path dependency and lower structural flexibility. This interpretation aligns with studies emphasizing that waste spaces should be differentiated according to their internal conditions, production processes, and reuse capacities rather than treated as a single category [22,91,92]. More broadly, this aligns with SES scholarship linking the adaptive capacity of complex systems to the internal heterogeneity of their component.

5.2.2. Nonlinear Cross-Scale Dynamics

From a transformation perspective, the results also highlight the importance of nonlinear cross-scale dynamics. It emphasizes that urban systems are characterized by cross-scale interactions, feedbacks, thresholds, and nonlinear responses, meaning that transformation strategies for waste space reuse require a dedicated integration of local and larger urban processes [45,128]. In the study area, the Location Quotient shows that waste spaces are disproportionately concentrated in specific districts relative to the ten-district metropolitan sample. This indicates that the current distribution of waste spaces is shaped not only by parcel-specific conditions but also by broader metropolitan processes. In other words, waste spaces tend to accumulate where district-level conditions intersect with larger urban transformations, a very common urban trajectory in other Turkish metropolitan cities [11,64,81,82].

This spatial concentration pattern has important theoretical implications within the SES cross-scale dynamics framework. If interventions are designed only at the parcel scale, without considering the wider district-level and metropolitan processes that have produced these spaces, similar conditions of vacancy and underutilization may persist or re-emerge elsewhere [20,27,41]. Cross-scale dynamics are therefore substantial not only for understanding the uneven accumulation of waste spaces but also for framing more effective transformation strategies. The reuse approaches should then be considered through site-by-site interventions but should also engage with broader patterns of infrastructure development, industrial land transition, and spatial restructuring, particularly in districts such as Konak, Bayraklı, and Karşıyaka.

5.2.3. Adaptive Governance

The Density Index provides a significant spatial basis for discussing adaptive governance, although more indirectly. Districts with high density values, for instance, Konak, Bayraklı, and Karşıyaka, include waste spaces that occupy a significant share of the district fabric and where planning intervention is likely to require stronger coordination, prioritization, and institutional flexibility. This study does not claim to measure governance directly; rather, it identifies the spatial conditions under which governance complexity becomes more visible. This is consistent with the adaptive governance literature within SES theory, which emphasizes flexible, collaborative, and multi-level coordination in complex socio-ecological contexts [54,57,63]. In this context, districts with high density values may be seen as areas where stronger governance among planning institutions, municipalities, and other relevant actors is likely to be required.

5.2.4. Resilience

The TDI results reveal a spatially uneven distribution of structural dominance across the metropolitan area—a finding with significant theoretical discussions for resilience thinking. At the measurable level, the TDI identifies the degree to which a single typology structurally dominates each district's waste space composition. At the interpretative level, and consistent with SES resilience theory, lower dominance values are read as suggestive of greater structural flexibility and a broader capacity to reorganize, a link that is theoretically grounded but not empirically demonstrated within this study. In SES scholarship, resilience is understood not merely as recovery from disturbance but as the capacity of a system to reorganize while retaining essential functions [54]. Applied to waste spaces, this suggests that districts with lower TDI values (Bornova: 0.371; Gaziemir: 0.464) may retain greater structural flexibility for reorganization, while those with high TDI values (Narlıdere: 1.000; Buca: 0.957) exhibit conditions associated with structural lock-in—where transformation is less likely to occur without targeted external intervention to disrupt the dominant path.

As evident in the results, the Typology Dominance Index (TDI) identifies which districts are more constrained by a single waste space type and therefore require more focused and engaged transformation strategies. Districts with lower TDI values, such as Bornova and Gaziemir, have a more balanced typological structure and support a broader combination of interventions, including adaptive reuse, ecological improvement, and phased redevelopment. Bayraklı, Konak, and Karşıyaka have an intermediate position, since one typology is more visible in each district, while the coexistence of secondary typologies may still enable differentiated and combined interventions. On the other hand, districts with high TDI values, such as Buca, Narlıdere, Karabağlar, and Çiğli, are structured around one dominant typology, which narrows the range of feasible interventions and ties reuse more closely to a single production logic. This is important because transformation in these districts cannot rely on mixed or flexible strategies to the same extent. Instead, it can respond directly to the dominant form of waste space. From a practical angle, higher dominance means greater rigidity in the district-level waste space structure, while lower dominance provides a broader basis for change. This approach is also mentioned in the social–ecological resilience literature, which links the capacity to absorb change and reorganize to the diversity and structure of system components [24,40,129].

5.3. Planning and Policy Implications

The results show that the transformation of waste space in İzmir cannot be managed through a single metropolitan regeneration model. This is readable from the Density Index, Location Quotient, Shannon Diversity Index, and Typology Dominance Index. This means that the same planning and policy implications would not be feasible in Konak, Bayraklı, Bornova, Buca, Karşıyaka, and Gaziemir districts. For instance, waste spaces in high-density, high-concentration districts, e.g., Konak, Bayraklı, and Karşıyaka, can be considered priority intervention areas because they are a highly interwoven component of the urban fabric. In these districts, municipalities need coordinated district-scale programs rather than isolated parcel-level decisions that have become a common practice recently in the administrative agenda of decision makers [12,76,78]. This can involve the preparation of district inventories, which these typological and morphological outputs may help with; prioritization of strategic sites; and the use of phased redevelopment tools that combine adaptive reuse, temporary activation, and selective redevelopment within the same planning area. It should be noted, however, that district-level profiles function as diagnostic entry points rather than prescriptive planning tools. Intra-district spatial variations—including differences in ownership structure, accessibility, and site-level conditions that parcel-scale analysis would reveal—are not fully captured at this scale, and a complementary parcel-level investigation is therefore required before site-specific transformation decisions are made.

The typological results also point to different policy tools for different district profiles. In Buca, Karabağlar, and Narlıdere, where vacant parcels dominate and TDI is high, the main issue is not the heritage of post-industrial sites or infrastructure fragmentation, but the persistence of delayed development and speculative landholding. In such districts, transformation policy should focus on stronger implementation controls, negotiated acquisitions when inactivity is prolonged, temporary lease-based public use, and planning incentives tied to time-bound development. Pla Buits Vacant Lots Transformation project in Barcelona, the Dalston Curve Garden project in London, UK, and the Gardens in Between project in Istanbul, Türkiye, offer relevant precedents for this configuration, demonstrating how community-led temporary use programs and bottom-up activation strategies can incrementally bring dispersed vacant land into productive use without requiring comprehensive redevelopment [6,16,130]. The Gardens in Between project is particularly instructive in

the Turkish context, demonstrating how participatory design involving local stakeholders can transform vacant spaces in a very dense district where vacancy dominates the urban fabric into active community assets while simultaneously addressing ecological and social challenges at the neighborhood scale. By contrast, in Konak and Gaziemir, where post-industrial waste spaces play a major role, the policy problem is more complex. Here, reuse strategies to bring these spaces back to life depend on addressing large parcel structures, obsolete industrial functions, potential contamination, and high remediation costs. This is why these areas require very targeted redevelopment frameworks, brownfield remediation programs, and public–private financing models rather than generic planning policies [131]. The Duisburg-Nord Landscape Park project in Duisburg, Germany, and the Hasanpaşa Gasworks—Müze Gazhane transformation project in Istanbul, Türkiye, illustrate how such conditions have been addressed through heritage-sensitive adaptive reuse and multi-actor governance structures [132–134]. In Karşıyaka and Balçova, where infrastructure-driven spaces are more visible, the transformation should focus less on conventional redevelopment and more on corridor-level integration, accessibility, interconnectedness, green infrastructure development, landscape continuity, and the productive reuse of residual land adjacent to transport systems. Because such typological and morphological waste spaces have the potential to be repurposed as linear public spaces that support community use and ecological functions, thereby enhancing urban resilience and strengthening connections between surrounding neighborhoods, as evident in practices from Türkiye and the USA of the Nezahat Gökyiğit Botanical Garden, the Mecidiyeköy Under-Viaduct Transformation, and the Under the Elevated projects [135–137].

In more diverse districts such as Bornova, Bayraklı, Konak, and Gaziemir, the coexistence of several waste space types means that transformation cannot rely on a single tool. Here, the Shannon Diversity Index is especially useful for deciding whether planning should proceed through a single-track or a multi-track strategy. These districts are better suited to mixed strategies that combine ecological rehabilitation, adaptive reuse, temporary use, and parcel-scale redevelopment. The Ayamama Stream Green Valley project in Istanbul, Türkiye, and Fresh Kills Park in New York City, USA, illustrate how phased, multi-typology ecological restoration combined with adaptive governance across multiple actors can provide precisely this kind of integrated, flexible approach [138,139]. In more specialized districts such as Buca and Narlıdere, where one typology overwhelmingly dominates, the planning agenda is narrower and should be tied more directly to the dominant form of underutilization. Likewise, the Typology Dominance Index is not only descriptive; it can inform decision makers about where flexible combinations are realistic and where transformation will be constrained unless the dominant typology is addressed directly. In this sense, the indices are useful not just for diagnosis, but for selecting the scale and type of intervention. Across all district profiles, these international and national precedents suggest that the framework's diagnostic outputs are directionally consistent with established transformation practices, though this alignment does not constitute a formal validation.

The adaptive governance dynamic is also equally concrete. Districts with high Density Index values and high LQ values are the places where project-by-project action is least likely to be sufficient. In Konak, Bayraklı, and Karşıyaka, transformation requires stronger coordination between metropolitan and district municipalities, administrative infrastructural actors, landowners, and, obviously, local communities. This is where adaptive governance becomes an operational tool rather than a conceptual one. That means it turns out not to be a general institutional framework, but rather the need to build procedures that can coordinate fragmented responsibilities, sequence interventions over time, and keep sites from remaining inactive while long-term redevelopment is negotiated [65]. Where immediate redevelopment is blocked by ownership disputes, contamination, or financial

infeasibility, for instance, interim-use models should be treated as a planning instrument rather than as an informal exception. Temporary public access, lease agreements, low-cost ecological activation, and hybrid financing of public–private partnerships can keep waste spaces in public use while longer-term transformation is prepared [16,139].

An eventual consideration is metropolitan-level policy design. The Location Quotient results show that waste spaces are not simply a district problem, but they are unevenly concentrated outcomes of broader metropolitan development. This indicates that İzmir needs not only district-specific projects, but also a metropolitan policy framework that formally recognizes waste spaces as a distinct planning category. Such a framework can include a citywide inventory, legal recognition of interim uses, mechanisms for negotiated acquisition or land assembly, and incentives that can support remediation and temporary activation. Without such instruments, districts with a high waste space concentration will continue to reproduce underutilization even when individual sites are redeveloped or at least included in future master plans.

6. Conclusions

This study demonstrated that the waste space phenomenon in the İzmir metropolitan area does not represent a single urban condition but rather a set of distinct district-level configurations with different indicative transformation capacities, as interpreted through a proxy-based SES analytical framework. Their distribution, typological composition, and internal structure vary significantly across districts, producing different transformation conditions within the metropolitan system. By combining the Density Index, Location Quotient, Shannon Diversity Index, and Typology Dominance Index, this research demonstrated that waste spaces are shaped not only by local site conditions but also by broader processes of industrial restructuring, infrastructure expansion, speculative vacancy, and uneven urban development. In this sense, waste spaces in İzmir are better understood as differentiated district-level configurations rather than as a single metropolitan phenomenon.

The quantitative results further contextualize these spatial patterns by summarizing key district-level variations. For instance, the total waste space area ranges from 1.784 km^2 in Bornova to only 0.025 km^2 in Narlıdere, while density values reach their highest levels in Konak (3.288%) and Bayraklı (3.230%). Typological composition also varies significantly, with vacant parcels dominating in Buca (95.7%) and Narlıdere (100%), whereas post-industrial sites are most prominent in Konak (55.5%) and Gaziemir (46.4%), and infrastructure-driven spaces in Karşıyaka (62.5%) and Balçova (65.4%). Similarly, diversity and dominance indicators reveal strong contrasts, with Bornova exhibiting the highest diversity ($H' = 1.092$), while Narlıdere ($H' = 0.000$) and Buca ($H' = 0.177$) reflect highly homogeneous structures, and the highest dominance values are observed in Narlıdere (1.000) and Buca (0.957). These quantitative summaries reinforce the differentiated and non-uniform nature of waste space configurations across the metropolitan system.

Therefore, a central contribution of this study is the operationalization of four SES dynamics through measurable spatial indicators that serve as heuristic proxies rather than direct measurements. The results show that typological diversity is heuristically associated with a broader range of potential transformation options, whereas strong typological dominance is interpreted as indicating structural rigidity and more constrained reuse capacity. Likewise, the concentration of waste spaces across districts highlighted the importance of cross-scale metropolitan processes, suggesting that parcel-based interventions alone may be insufficient when underutilization is reproduced by broader urban dynamics. By linking morphology and typology to SES-based interpretation, this study aimed to serve as a decision-support and exploratory analytical framework—rather than a predictive model—to shift the discussion within urban science from why waste spaces emerge to how

their transformation capacity can be differentiated indicatively across varying spatial and institutional conditions. In doing so, it advances beyond parcel-scale typological studies and neighborhood-level social–ecological assessments by operating at the metropolitan district scale and aiming to link classification towards an SES-informed indicator framework applicable to comparative planning practice.

The findings in this study also provide a practical framework for planning and policy implications in metropolitan governance. Districts with high concentration and diversity require integrated and holistic strategies, whereas districts dominated by a single typology require more targeted responses tied to the prevailing form of underutilization. Post-industrial sites call for redevelopment frameworks sensitive to large parcels, remediation needs, and obsolete functions, while infrastructure-driven waste spaces require corridor-based strategies focused on connectivity, landscape continuity, and public use. In this respect, the framework offers a comparative basis for identifying priority areas, selecting appropriate intervention tools, and aligning district-level action with wider metropolitan policy.

This study also has some limitations. The district-level scale of analysis necessarily aggregates spatial conditions that may vary considerably within individual districts, which limits the direct applicability of the framework's outputs to site-specific planning decisions without further parcel-scale investigation. This study is based on a cross-sectional spatial dataset and therefore does not capture the temporal evolution of waste spaces and the full institutional complexity of governance processes. For this reason, future research could extend the framework by incorporating temporal change, ownership structure, and governance indicators. In addition, the interpretative and indicative linkages between spatial indicators and SES dynamics, particularly the proposed relationship between typological diversity and adaptive capacity, remain to be tested through systematic empirical comparison with observed transformation trajectories. However, even with these limitations, this study provides a transferable and spatially grounded foundation for evidence-based planning and policy direction in cities facing similar underutilization, fragmented urban growth, and uneven development. Rather than treating waste spaces as leftovers of urbanization, this research positions them as strategic components of metropolitan transformation—and the framework developed here, while interpretative in its SES linkages, offers a replicable and context-sensitive basis for differentiating district-level transformation priorities in metropolitan planning practice. The framework is considered most relevant in metropolitan contexts where harmonized land use datasets are available alongside field-verification capacity, and where urban processes such as post-industrial transformation, infrastructure-led fragmentation, and speculative vacancy are documented. In contexts where data availability or urban dynamics differ substantially, the typological categories and indicator thresholds should be critically assessed and adapted to reflect local conditions rather than applied directly.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting the findings of this study are derived from publicly available sources, which are cited throughout the article.

Acknowledgments: The author would like to thank Bahar Gedikli Bilgin (Middle East Technical University, Faculty of Architecture, Department of City and Regional Planning, Türkiye).

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

SES	Social–Ecological System
GIS	Geographical Information System
EEA	European Environment Agency
LQ	Location Quotient
H'	Shannon Diversity Index
TDI	Typology Dominance Index
MAUP	Modifiable Areal Unit Problem

References

1. Accordino, J.; Johnson, G.T. Addressing the Vacant and Abandoned Property Problem. *J. Urban Aff.* **2016**, *22*, 301–315. [CrossRef]
2. Burchell, R.W.; Listokin, D. Property abandonment in the United States. In *The Adaptive Reuse Handbook*; Rutgers University, Center for Urban Policy Research: New Brunswick, NJ, USA, 1981; pp. 386–410.
3. Kelling, G.L.; Wilson, J.Q. Broken windows. *Atl. Mon.* **1982**, *249*, 29–38.
4. Kunstler, J.H. *Geography of Nowhere: The Rise and Declineof America's Man-Made Landscape*; Simon and Schuster: New York, NY, USA, 1994.
5. Loukaitou-Sideris, A. Cracks in the city: Addressing the constraints and potentials of urban design. *J. Urban Des.* **2007**, *1*, 91–103. [CrossRef]
6. Luo, S.; de Wit, S. Augmenting socioecological dynamics in urban leftover spaces: Landscape architectural design as a foundation. *J. Landsc. Archit.* **2023**, *17*, 32–45. [CrossRef]
7. Berger, A. *Drosscape: Wasting Land in Urban America*; Princeton Architectural Press: New York, NY, USA, 2006.
8. Barron, P.; Mariani, M. *Terrain Vague: Interstices at the Edge of the Pale*; Routledge: Oxfordshire, UK, 2013.
9. Iodice, S.; De Toro, P. Waste and wasted landscapes: Focus on abandoned industrial areas. *Detritus* **2020**, *11*, 103–120. [CrossRef]
10. Lynch, K.; Southworth, M. *Wasting Away*; Sierra Club Books: San Francisco, CA, USA, 1990.
11. Esen, G. Deindustrialisation and Neoliberal Urbanisation: The Rear Port of İzmir, Alsancak. Master's Thesis, Izmir Institute of Technology, Urla, Turkey, 2019.
12. Tutar, Ö.; Bal, E. Transformation of the space in the context of neoliberal urbanization: The case of İzmir new city centre, Turkey. *ICONARP Int. J. Archit. Plan.* **2019**, *7*, 428–459. [CrossRef]
13. Ryan, B.D. *Design After Decline: How America Rebuilds Shrinking Cities*; University of Pennsylvania Press: Philadelphia, PA, USA, 2012.
14. Trancik, R. *Finding Lost Space: Theories of Urban Design*; John Wiley & Sons: Hoboken, NJ, USA, 1991.
15. Hasan, M.; Rahman, M.; Islam, S.; Siddika, T. Using the Lost Space–as an Urban Regeneration Strategy: A Case Study of Sylhet. *J. Civ. Constr. Eng.* **2018**, *4*, 1–8.
16. Capel, H. *El Modelo Barcelona: Un Examen Crítico*; Ediciones del Serbal Barcelona: Barcelona, Spain, 2005.
17. Lydon, M.; Garcia, A. The next American city and the rise of tactical urbanism. In *Tactical Urbanism: Short-Term Action for Long-Term Change*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 63–88.
18. Bowman, A.O.M. *Terra Incognita: Vacant Land and Urban Strategies*; Georgetown University Press: Washington, DC, USA, 2004.
19. Németh, J.; Langhorst, J. Rethinking urban transformation: Temporary uses for vacant land. *Cities* **2014**, *40*, 143–150. [CrossRef]
20. Lokman, K. Vacancy as a laboratory: Design criteria for reimagining social-ecological systems on vacant urban lands. *Landsc. Res.* **2017**, *42*, 728–746. [CrossRef]
21. Kremer, P.; Hamstead, Z.A.; McPhearson, T. A social–ecological assessment of vacant lots in New York City. *Landsc. Urban Plan.* **2013**, *120*, 218–233. [CrossRef]
22. Kim, G.; Miller, P.A.; Nowak, D.J. Urban vacant land typology: A tool for managing urban vacant land. *Sustain. Cities Soc.* **2018**, *36*, 144–156. [CrossRef]
23. Liu, F.; Dai, E.; Yin, J. A review of social–ecological system research and geographical applications. *Sustainability* **2023**, *15*, 6930. [CrossRef]
24. Meerow, S.; Newell, J.P.; Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* **2016**, *147*, 38–49. [CrossRef]
25. Nagel, B.; Partelow, S. A methodological guide for applying the social-ecological system (SES) framework: A review of quantitative approaches. *Ecol. Soc.* **2022**, *27*, 39. [CrossRef]
26. Partelow, S. A review of the social-ecological systems framework. *Ecol. Soc.* **2018**, *23*, 25. [CrossRef]
27. Nassauer, J.I.; Raskin, J. Urban vacancy and land use legacies: A frontier for urban ecological research, design, and planning. *Landsc. Urban Plan.* **2014**, *125*, 245–253. [CrossRef]
28. Mohamad Selamat, I.A.; Maruthaveeran, S.; Mohd Yusof, M.J.; Shahidan, M.F. A GIS-Based Multi-Tier Framework for Assessing the Ecological Potential of Urban Vacant Land. *Urban Sci.* **2025**, *9*, 218. [CrossRef]

29. Xu, S.; Ehlers, M. Automatic detection of urban vacant land: An open-source approach for sustainable cities. *Comput. Environ. Urban Syst.* **2022**, *91*, 101729. [CrossRef]
30. Newman, G.D.; Smith, A.L.; Brody, S.D. Repurposing Vacant Land through Landscape Connectivity. *Landsc. J.* **2018**, *36*, 37–57. [CrossRef]
31. Granados Aragonez, R.A.; Martinez Duran, A.; Martin, X. Green Infrastructure for Reintegrating Fragmented Urban Fabrics: Multiscale Methodology Using Space Syntax and Hydrologic Modeling. *Urban Sci.* **2025**, *9*, 208. [CrossRef]
32. Russo, A.; Baresi, U.; Cheshmehzangi, A. Nature-Based Solutions in Urban Regeneration: A Review of Methods, Governance, and Future Directions. *Urban Sci.* **2026**, *10*, 130. [CrossRef]
33. Lee, R.J.; Newman, G. A classification scheme for vacant urban lands: Integrating duration, land characteristics, and survival rates. *J. Land Use Sci.* **2019**, *14*, 306–319. [CrossRef] [PubMed]
34. Tu, T.; Wang, X.; Long, Y. Spatiotemporal changes of urban vacant land and its distribution patterns in shrinking cities on the globe. *Sci. Total Environ.* **2024**, *947*, 174424. [CrossRef]
35. May, C.K. Complex adaptive governance systems: A framework to understand institutions, organizations, and people in socio-ecological systems. *Socio-Ecol. Pract. Res.* **2022**, *4*, 39–54. [CrossRef]
36. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, adaptability and transformability in social–ecological systems. *Ecol. Soc.* **2004**, *9*, 5. [CrossRef]
37. Preiser, R.; Biggs, R.; De Vos, A.; Folke, C. Social-ecological systems as complex adaptive systems. *Ecol. Soc.* **2018**, *23*, 15. [CrossRef]
38. Mathias, J.-D.; Anderies, J.M.; Baggio, J.; Hodbod, J.; Huet, S.; Janssen, M.A.; Milkoreit, M.; Schoon, M. Exploring non-linear transition pathways in social-ecological systems. *Sci. Rep.* **2020**, *10*, 4136. [CrossRef]
39. Folke, C.; Colding, J.; Berkes, F. Synthesis: Building resilience and adaptive capacity in social-ecological systems. In *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*; Cambridge University Press: Cambridge, UK, 2003; Volume 9, pp. 352–387.
40. Walker, B.; Salt, D. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*; Island Press: Washington, DC, USA, 2012.
41. Burkholder, S. The new ecology of vacancy: Rethinking land use in shrinking cities. *Sustainability* **2012**, *4*, 1154–1172. [CrossRef]
42. Liehr, S.; Röhrig, J.; Mehring, M.; Kluge, T. How the social-ecological systems concept can guide transdisciplinary research and implementation: Addressing water challenges in central northern Namibia. *Sustainability* **2017**, *9*, 1109. [CrossRef]
43. Caniglia, B.S.; Vallée, M.; Frank, B. *Resilience, Environmental Justice and the City*; Routledge London: London, UK, 2016.
44. Frank, B.; Delano, D.; Caniglia, B.S. Urban systems: A socio-ecological system perspective. *Sociol. Int. J.* **2017**, *1*, 00001. [CrossRef]
45. Garmestani, A.; Ruhl, J.; Garcia, J.H.; Gilissen, H.K.; Allen, C.R.; Eason, T.; Gunderson, L.; van Rijswick, H.F.; Angeler, D.G. Opportunities and challenges for transformation of urban social-ecological systems. *Adv. Ecol. Res.* **2025**, *72*, 1–21.
46. Alberti, M.; Marzluff, J.M.; Shulenberger, E.; Bradley, G.; Ryan, C.; Zumbrunnen, C. Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. *BioScience* **2003**, *53*, 1169–1179. [CrossRef]
47. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global change and the ecology of cities. *Science* **2008**, *319*, 756–760. [CrossRef]
48. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J. Complexity of coupled human and natural systems. *Science* **2007**, *317*, 1513–1516. [CrossRef]
49. Berkes, F.; Folke, C. Linking social and ecological systems for resilience and sustainability. In *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*; Cambridge University Press: Cambridge, UK, 1998; Volume 1, p. 4.
50. Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
51. Barthel, S.; Colding, J.; Erixon, H.; Ernstson, H.; Grahn, S.; Kärsten, C.; Marcus, L.; Torsvall, J. *Principles of Social Ecological Design: Case Study Albano Campus, Stockholm*; School of Architecture and the Built Environment: Singapore, 2013.
52. Colding, J.; Barthel, S. Exploring the social-ecological systems discourse 20 years later. *Ecol. Soc.* **2019**, *24*, 10. [CrossRef]
53. McPhearson, T.; Cook, E.M.; Berbés-Blázquez, M.; Cheng, C.; Grimm, N.B.; Andersson, E.; Barbosa, O.; Chandler, D.G.; Chang, H.; Chester, M.V. A social-ecological-technological systems framework for urban ecosystem services. *One Earth* **2022**, *5*, 505–518. [CrossRef]
54. Folke, C.; Hahn, T.; Olsson, P.; Norberg, J. Adaptive Governance of Social-Ecological Systems. *Annu. Rev. Environ. Resour.* **2005**, *30*, 441–473. [CrossRef]
55. Grimm, N.B.; Grove, J.M.; Pickett, S.T.; Redman, C.L. Integrated approaches to long-term studies of urban ecological systems. In *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*; Springer: Berlin/Heidelberg, Germany, 2008; pp. 123–141.
56. Petrosillo, I.; Aretano, R.; Zurlini, G. Socioecological systems, reference module in earth systems and environmental sciences. In *Reference Module in Earth Systems and Environmental Sciences; Socioecological Systems*; Elsevier: Amsterdam, The Netherlands, 2015; Volume 10.

57. Armitage, D.R.; Plummer, R.; Berkes, F.; Arthur, R.I.; Charles, A.T.; Davidson-Hunt, I.J.; Diduck, A.P.; Doubleday, N.C.; Johnson, D.S.; Marschke, M. Adaptive co-management for social–ecological complexity. *Front. Ecol. Environ.* **2009**, *7*, 95–102. [CrossRef]
58. Du Plessis, C. Understanding cities as social-ecological systems. In Proceedings of the World Sustainable Building Conference–SB, Melbourne, Australia, 21–25 September 2008.
59. Moffatt, S.; Kohler, N. Conceptualizing the built environment as a social–ecological system. *Build. Res. Inf.* **2008**, *36*, 248–268. [CrossRef]
60. Levin, S.A. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* **1998**, *1*, 431–436. [CrossRef]
61. Schlüter, M.; Haider, L.J.; Lade, S.J.; Lindkvist, E.; Martin, R.; Orach, K.; Wijermans, N.; Folke, C. Capturing emergent phenomena in social-ecological systems. *Ecol. Soc.* **2019**, *24*, 26. [CrossRef]
62. Edwards, P.; Sharma-Wallace, L.; Wreford, A.; Holt, L.; Cradock-Henry, N.A.; Flood, S.; Velarde, S.J. Tools for adaptive governance for complex social-ecological systems: A review of role-playing-games as serious games at the community-policy interface. *Environ. Res. Lett.* **2019**, *14*, 113002. [CrossRef]
63. Karpouzoglou, T.; Dewulf, A.; Clark, J. Advancing adaptive governance of social-ecological systems through theoretical multiplicity. *Environ. Sci. Policy* **2016**, *57*, 1–9. [CrossRef]
64. Güney, G. Regenerative Power of Waste Spaces Through the Lens of Social-Ecological Systems: The Case of İzmir. Doctoral Dissertation, Middle East Technical University, Ankara, Turkey, 2025.
65. Muñoz-Erickson, T.A.; Campbell, L.K.; Childers, D.L.; Grove, J.M.; Iwaniec, D.M.; Pickett, S.T.; Romolini, M.; Svendsen, E.S. Demystifying governance and its role for transitions in urban social–ecological systems. *Ecosphere* **2016**, *7*, e01564. [CrossRef]
66. Virapongse, A.; Brooks, S.; Metcalf, E.C.; Zedalis, M.; Gosz, J.; Kliskey, A.; Alessa, L. A social-ecological systems approach for environmental management. *J. Environ. Manag.* **2016**, *178*, 83–91. [CrossRef] [PubMed]
67. Ahern, J.; Cilliers, S.; Niemelä, J. The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation. *Landsc. Urban Plan.* **2014**, *125*, 254–259. [CrossRef]
68. Heymans, A.; Breadsell, J.; Morrison, G.M.; Byrne, J.J.; Eon, C. Ecological urban planning and design: A systematic literature review. *Sustainability* **2019**, *11*, 3723. [CrossRef]
69. Pickett, S.T.; McGrath, B.; Cadenasso, M.L.; Felson, A.J. Ecological resilience and resilient cities. *Build. Res. Inf.* **2014**, *42*, 143–157. [CrossRef]
70. Alberti, M.; Marzluff, J.M. Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. *Urban Ecosyst.* **2004**, *7*, 241–265. [CrossRef]
71. Turkish Statistical Institute. The Results of Address Based Population Registration System. 2025. Available online: https://veriportali.tuik.gov.tr/en/press/53899 (accessed on 16 March 2025).
72. Salata, S.; Uzelli, T. Are Soil and Geology Characteristics Considered in Urban Planning? An Empirical Study in Izmir (Türkiye). *Urban Sci.* **2023**, *7*, 5. [CrossRef]
73. Ajansı, İ.K. *İzmir Ili Için Metropol ve Seçilmiş Ilçelerde Nüfus Projeksiyonları: Sonuç Raporu (2022–2050)*; İzmir Kalkınma Ajansı: İzmir, Turkey, 2024.
74. Akkar, Z.M. Kentsel dönüşüm üzerine Batı'daki kavramlar, tanımlar, süreçler ve Türkiye. *Planlama* **2006**, *2*, 29–38.
75. Yılmaz, E.S.; Yılmaz, S. A review on urbanization, pollution and biodiversity in İzmir. *Uluslararası Çevresel Eğilimler Derg.* **2019**, *3*, 31–38.
76. Tanış, F. Urban Scenes of a Port City: Exploring Beautiful İzmir Through Narratives of Cosmopolitan Practices. Doctoral Dissertation, Delft University of Technology, Delft, The Netherlands, 2022; pp. 1–274.
77. Cin, M.M.; Egercioğlu, Y. A critical analysis of urban regeneration projects in Turkey: Displacement of Romani settlement case. *Procedia-Soc. Behav. Sci.* **2016**, *216*, 269–278. [CrossRef]
78. Demirel Şanlı, Ş. Planning with Complexity: The Analysis of İzmir Uzundere Urban Transformation Project Through the Advocacy Coalition Framework. Doctoral Dissertation, Middle East Technical University, Ankara, Turkey, 2023.
79. Tekeli, P.D.İ. *İZMİR-TARİH Projesi Tasarım Stratejisi Raporu*, 3rd ed.; Dinç Ofset İzmir: İzmir, Türkiye, 2015; p. 130.
80. Okta, B.Y. Sustainable planning strategies for a port city: Rethinking the İzmir's Meles River Basin development in Turkey. In *Contemporary Regional Planning Issues*; IntechOpen: London, UK, 2024.
81. Acar, Y. Urban Transformation Within the Interface of Design and Administration: The Case of İzmir Harbor District. Master's Thesis, Middle East Technical University, Ankara, Turkey, 2011.
82. Çelik, M.; Doğrusoy, İ.T.; Zengel, R. İzmir'deki Kentsel Atıl Alanları Çözümlemeye Yönelik Bir Değerlendirme. *Mimarlık* **2015**, *383*, 60.
83. Egercioğlu, Y.; Çete, M.; Yalçıner, S. The effects of urban rail transportation projects on urban areas: Case study of Izmir. In Proceedings of the 2nd International Balkans Conference on Challenges of Civil Engineering (BCCCE), Tirana, Albania, 23–25 May 2013.
84. Yetiskul, E.; Kul, F. Agglomeration of population and employment in the urbanization-industrialization interaction: The case of Izmir. *J. Des. Resil. Archit. Plan.* **2023**, *4*, 16–30. [CrossRef]

85. Hepcan, S.; Hepcan, C.C.; Kilicaslan, C.; Ozkan, M.B.; Kocan, N. Analyzing landscape change and urban sprawl in a Mediterranean coastal landscape: A case study from Izmir, Turkey. *J. Coast. Res.* **2013**, *29*, 301–310.
86. Partigöç, N.S.; Tarhan, Ç. Spatial changes of land use pattern in Guzelbahce district (Izmir). *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *42*, 405–411. [CrossRef]
87. Service, C.L.M. Urban Atlas Land Cover/Land Use 2018 (Vector), Europe, 3-Yearly. 2018. Available online: https://sdi.eea.europa.eu/catalogue/srv/api/records/9911fe21-57f6-46fb-ae26-d76e7bb6378f?language=all (accessed on 26 January 2025).
88. Comber, A.; Fisher, P.; Wadsworth, R. You know what land cover is but does anyone else?. . .an investigation into semantic and ontological confusion. *Int. J. Remote Sens.* **2005**, *26*, 223–228. [CrossRef]
89. Google LLC. Google Earth Pro (Version 7.3). Available online: https://www.google.com/earth/ (accessed on 26 January 2025).
90. Municipality, İ.M. İzmir Open Data Portal. Available online: https://acikveri.bizizmir.com/tr/dataset/izmir-sehir-haritasi/resource/c4b1da96-c547-4cca-a9a7-4053d0fee54f (accessed on 7 March 2025).
91. Kim, G.; Newman, G.; Jiang, B. Urban regeneration: Community engagement process for vacant land in declining cities. *Cities* **2020**, *102*, 102730. [CrossRef] [PubMed]
92. Hwang, S.W.; Lee, S.J. Unused, underused, and misused: An examination of theories on urban void spaces. *Urban Res. Pract.* **2020**, *13*, 540–556. [CrossRef]
93. Herold, M.; Couclelis, H.; Clarke, K.C. The role of spatial metrics in the analysis and modeling of urban land use change. *Comput. Environ. Urban Syst.* **2005**, *29*, 369–399. [CrossRef]
94. Alexander, E.R. Density measures: A review and analysis. *J. Archit. Plan. Res.* **1993**, *10*, 181–202.
95. Pagano, M.A.; Bowman, A.O.M. *Vacant Land in Cities: An Urban Resource*; Brookings Institution: Washington, DC, USA, 2000; Volume 1.
96. Miller, R.E.; Blair, P.D. *Input-Output Analysis: Foundations and Extensions*; Cambridge University Press: Cambridge, UK, 2009.
97. Baeza, J.L.; Cerrone, D.; Männigo, K. Comparing two methods for urban complexity calculation using the Shannon-Wiener Index. *WIT Trans. Ecol. Environ.* **2017**, *226*, 369–378.
98. Zachary, D.; Dobson, S. Urban Development and Complexity: Shannon Entropy as a Measure of Diversity. *Plan. Pract. Res.* **2021**, *36*, 157–173. [CrossRef]
99. McGarigal, K.; Cushman, S.A.; Neel, M.C.; Ene, E. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Available online: https://www.fragstats.org/ (accessed on 15 March 2025).
100. Luck, M.; Wu, J. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. *Landsc. Ecol.* **2002**, *17*, 327–339. [CrossRef]
101. Schwarz, N.; Haase, D.; Seppelt, R. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. *Environ. Plan. B Plan. Des.* **2010**, *37*, 265–283. [CrossRef]
102. Ding, K.; Yu, M.; Mi, X.; Meng, Y.; Feng, J.; Li, Y. Exploring the spatial characteristics of abandoned mining sites at the urban scale using a case study of Handan, China. *Sci. Rep.* **2025**, *15*, 23115. [CrossRef]
103. Wu, X.; Liu, J.; Hou, Y. Data and methods for assessing urban green infrastructure using GIS: A systematic review. *PLoS ONE* **2025**, *20*, e0324906. [CrossRef]
104. Fu, Q.; Zhu, J.; Zheng, X.; Li, Z.; Chen, M.; He, Y. "Target–Classification–Modification" Method for Spatial Identification of Brownfields: A Case Study of Tangshan City, China. *Land* **2025**, *14*, 1213. [CrossRef]
105. Jiao, Z.; Wu, Z.; Luo, Y.; Wei, B.; Dai, Z.; Li, S. A framework for analyzing the effects of modifiable areal unit problem on ecological security pattern. *J. Clean. Prod.* **2024**, *458*, 142549. [CrossRef]
106. Openshaw, S. *The Modifiable Areal Unit Problem*; Geo Books: Norwich, UK, 1983.
107. Churchman, A. Disentangling the concept of density. *J. Plan. Lit.* **1999**, *13*, 389–411. [CrossRef]
108. Angel, S.; Lamson-Hall, P.; Blanco, Z.G. Anatomy of density: Measurable factors that constitute urban density. *Build. Cities* **2021**, *2*, 264–282. [CrossRef]
109. Xu, N.; Cheng, Y.; Xu, X. Using Location Quotients to Determine Public–Natural Space Spatial Patterns: A Zurich Model. *Sustainability* **2018**, *10*, 3462. [CrossRef]
110. Haggett, P. *Locational Analysis in Human Geography*; Edward Arnold: London, UK, 1965.
111. Shannon, C.E. A mathematical theory of communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
112. Weaver, W. *The Mathematical Theory of Communication*; University of Illinois Press: Champaign, IL, USA, 1963.
113. Magurran, A.E. *Measuring Biological Diversity*; John Wiley & Sons: Hoboken, NJ, USA, 2003.
114. Das, P.; Joshi, S.; Rout, J.; Upreti, D. Shannon diversity index (H) as an ecological indicator of environmental pollution-a GIS approach. *J. Funct. Environ. Bot.* **2012**, *2*, 22–26. [CrossRef]
115. Cervero, R.; Kockelman, K. Travel demand and the 3Ds: Density, diversity, and design. *Transp. Res. Part D Transp. Environ.* **1997**, *2*, 199–219. [CrossRef]
116. Frank, L.D.; Schmid, T.L.; Sallis, J.F.; Chapman, J.; Saelens, B.E. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *Am. J. Prev. Med.* **2005**, *28*, 117–125. [CrossRef] [PubMed]

117. Pattillo, M. *Design for Diversity: Exploring Socially Mixed Neighborhoods by Emily Talen*; Architectural Press: New York, NJ, USA, 2009.
118. Ritsema van Eck, J.; Koomen, E. Characterising urban concentration and land-use diversity in simulations of future land use. *Ann. Reg. Sci.* **2008**, *42*, 123–140. [CrossRef]
119. McGarigal, K. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure*; US Department of Agriculture, Forest Service, Pacific Northwest Research Station: Portland, OR, USA, 1995; Volume 351.
120. O'Neill, R.V.; Krummel, J.R.; Gardner, R.H.; Sugihara, G.; Jackson, B.; DeAngelis, D.; Milne, B.; Turner, M.G.; Zygmunt, B.; Christensen, S. Indices of landscape pattern. *Landsc. Ecol.* **1988**, *1*, 153–162. [CrossRef]
121. Norberg, J.; Wilson, J.; Walker, B.; Ostrom, E. Diversity and resilience of social-ecological systems. In *Complexity Theory for a Sustainable Future*; Columbia University Press: New York, NY, USA, 2008; pp. 46–80.
122. Wang, Y.; Cai, Y.; Xie, Y.; Zhang, P.; Chen, L. A quantitative framework to evaluate urban ecological resilience: Broadening understanding through multi-attribute perspectives. *Front. Ecol. Evol.* **2023**, *11*, 1144244. [CrossRef]
123. Naghibi, M.; Faizi, M.; Ekhlassi, A. Mapping a framework for social–ecological resilience in reimaging of abandoned spaces. *Urban Des. Int.* **2023**, *28*, 122–140. [CrossRef]
124. Civeira, G.I. Landscape structure in urban and peri urban areas in The metropolitan region of buenos aires (mrba). *J. Urban Landsc. Plan.* **2022**, *7*, 47–64.
125. Hulshoff, R.M. Landscape indices describing a Dutch landscape. *Landsc. Ecol.* **1995**, *10*, 101–111. [CrossRef]
126. Ricotta, C.; Avena, G. On the relationship between Pielou's evenness and landscape dominance within the context of Hill's diversity profiles. *Ecol. Indic.* **2003**, *2*, 361–365. [CrossRef]
127. Preston, P.D.; Dunk, R.M.; Smith, G.R.; Cavan, G. Not all brownfields are equal: A typological assessment reveals hidden green space in the city. *Landsc. Urban Plan.* **2023**, *229*, 104590. [CrossRef]
128. Chapin, F.S.; Mark, A.F.; Mitchell, R.A.; Dickinson, K.J.M. Design principles for social-ecological transformation toward sustainability: Lessons from New Zealand sense of place. *Ecosphere* **2012**, *3*, 1–22. [CrossRef]
129. Naghibi, M.; Faizi, M.; Yazdani, H.; Ekhlassi, A. From empty to empowering: Leveraging vacant land for urban socio-ecological resilience. *Front. Archit. Res.* **2025**, *14*, 1076–1089. [CrossRef]
130. Ideas, S.A.A. Gardens in Between. Available online: https://www.soistanbul.com/gardens-in-between (accessed on 5 April 2026).
131. Seo, K.H. Urban Resilience through Design: A Holistic Framework for Sustainable Redevelopment of Brownfield Sites. *J. Environ. Earth Sci.* **2025**, *7*, 395–413. [CrossRef]
132. Braae, E. *Beauty Redeemed: Recycling Post-Industrial Landscapes*; Ikaros Press Aarhus: Aarhus C, Danmark, 2015.
133. Leblebici, E. Impact of Intermediate and Informal Adaptations on the Reuse of Postindustrial Sites: From Hasanpaşa Gasworks to Müze Gazhane. Master's Thesis, Bilkent Universitesi, Ankara, Turkey, 2023.
134. Yüksel, Ş.; Savaş Demir, H. Socially Oriented Approaches in Cities—Hasanpasa Gasworks and Gasworks Environmental Volunteers. *Sustainability* **2023**, *15*, 12924. [CrossRef]
135. Karaşah, B.; Var, M. Botanik Bahçelerinde Ziyaretçi Tercihlerinin Belirlenmesi 'Nezahat Gökyiğit Botanik Bahçesi Örneği'. *Kastamonu Univ. J. For. Fac.* **2016**, *16*, 120–130. [CrossRef]
136. KAAT. Mecidiyeköy Sanat ve İstanbul Kitapçısı. Available online: https://www.kaat.co/works-item/mecidiyekoy-art (accessed on 12 March 2025).
137. Bauer, C.; Drake, S.C.; Fletcher, R.; Travieso, C.; Woodward, D. *Under the Elevated: Reclaiming Space, Connecting Communities*; Design Trust for Public Space: New York, NJ, USA, 2015; p. 129.
138. Delibas, M.; Tezer, A. 'Stream Daylighting'as an approach for the renaturalization of riverine systems in urban areas: Istanbul-Ayamama Stream case. *Ecohydrol. Hydrobiol.* **2017**, *17*, 18–32. [CrossRef]
139. Loures, L.; Horta, D.; Santos, A.; Panagopoulos, T. Strategies to reclaim derelict industrial areas. *WSEAS Trans. Environ. Dev.* **2006**, *2*, 599–604.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.