Interpreting the Spatial Characteristics of the Dike-Pond System through Deep Learning and Digital Mapping Techniques: A Case Study of Foshan Sangyuanwei

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Abstract

The Dike-Pond System in China’s Pearl River Delta is a distinctive form of agricultural heritage, renowned for its integrated land-water production, ecological adaptability, and embedded cultural practices. Despite growing recognition of its heritage value, there remains a lack of a spatially grounded framework capable of decoding its internal structure and landscape heterogeneity. This study develops an intersubjective approach to identify, quantify, and interpret the spatial characteristics of the Dike-Pond System from a landscape perspective. Taking Sangyuanwei in Foshan as a case study, the research first extracts four core landscape characters, production and livelihood, ecological networks, water management, and transportation connectivity, through systematic literature review. A deep learning model, trained on high-resolution satellite imagery, was employed to detect pond morphologies and, together with hydrological, infrastructural, and land-use data, construct a comprehensive spatial database. Spatial indicators were then computed and visualized using digital mapping and geostatistical techniques, supporting the classification of five distinct landscape types. These typologies reflect the system’s coexisting patterns of resilience and transformation, offering insights into its spatial logic under urban-rural integration. The framework bridges qualitative interpretation and quantitative analysis, providing a replicable method for spatially grounded heritage evaluation and landscape-informed planning.

1. Introduction

Agricultural heritage systems are dynamic landscapes shaped by traditional land-use practices that sustain rich biodiversity, ecological resilience, and cultural continuity (FAO, n.d.). The Dike-Pond System, a representative case in the Pearl River Delta, exemplifies a circular integration of land and water through its spatially interwoven configuration of dikes, ponds, farmlands, and settlement (Weng, 2007). This spatial arrangement gives rise to distinct landscape characters, such as nutrient cycling, aquaculture-agriculture synergy, hydrological mediation, and spatial circulation, that are shaped and sustained by underlying spatial characteristics, including the hierarchical organization of water bodies, the layout of embankments and fields, and the articulation between built and natural element (Liang et al., 2020; Sun et al., 2019). Together, these features contribute to the system’s ecological, productive, hydraulic, and connective dimensions (Guo & Xu, 2011; Lin et al., 2014). However, rapid urbanization has disrupted this spatial coherence, threatening the continuity of these functions. This underscores the need for spatially explicit analysis to uncover the structural logic of the Dike-Pond System, forming a critical foundation for landscape-informed conservation, restoration, and sustainable development.

Existing research on the Dike-Pond System has primarily focused on its historical evolution, vernacular functions, and broader landscape significance. A substantial body of scholarship, grounded in archival maps, local gazetteers, and traditional literature, has examined the system’s long-term development and cultural relevance (Chi et al., 2024; Xu et al., 2024). Particular attention has been given to its ecological structure, especially the closed-loop “mulberry-silkworm-fish-mud” cycle, which is widely regarded as a model of sustainable resource use and was praised by the United Nations as a representative example of positive ecological feedback (Hou & Li, 2018; Zhong, 1980). Other studies have examined its historical evolution, tracing the transformation from fragmented dike enclosures in the Song Dynasty to integrated agro-aquatic landscapes in the Ming and Qing periods. The case of Sangyuanwei, in particular, exemplifies how hydraulic engineering and agricultural innovation jointly shaped the landscape’s spatial configuration (Wang et al., 2023). Additional research has explored the system’s hydraulic logic, noting that traditional Dike-Pond areas developed multi-tiered water infrastructures combining dikes, sluices, and interlaced canals to perform integrated functions of flood control, drainage, and irrigation (Xie et al., 2023). There is also growing attention to the interaction between settlement development and production organization. Scholars have found that the Dike-Pond System fostered an integrated spatial model of agriculture, trade, and habitation. Water-based transportation and rural marketplaces supported the co-evolution of production and exchange, influencing not only land-use patterns but also local industrial structures (Liang et al., 2023). While these high-impact studies contribute richly to our understanding of the system’s origins and typological evolution, they remain primarily qualitative in nature and seldom examine the internal spatial characteristics that structure its multifunctional performance. Their focus on broad narratives and generalized typologies often results in limited analytical resolution, making it difficult to systematically capture spatial heterogeneity or to decode the structural logic embedded within localized configurations of the Dike-Pond landscape.

In parallel with the growing recognition of the Dike-Pond System’s heritage value, recent research has increasingly turned toward quantitative spatial analysis, enabled by advancements in geospatial technologies and data availability. Early GIS-based investigations leveraged Landsat TM/ETM+ imagery to map regional pond distribution, wetland loss, and urban expansion, establishing a macro-scale spatial context (Cheng et al., 2021; Wang et al., 2011). As satellite imagery resolution improved, researchers adopted deep learning models to extract pond and embankment features with greater accuracy, leading to breakthroughs such as Xu et al. (2024), which presented the first global mapping of dike-pond systems and underscored their significance in food production and wetland conservation. In addition, UAV and LiDAR technologies have enabled fine-resolution mapping of terrain and embankment morphology, facilitating more nuanced spatial interpretations across vertical and horizontal dimensions (Kim & Hong, 2024; Liu & Li, 2022; Ma et al., 2022). Despite these methodological advances, most studies remain discipline-specific and feature-centric, rooted in agricultural, hydrological, or environmental science. They tend to emphasize classification and monitoring of individual features while overlooking the broader spatial compositions and configurations that define landscape characters. It always constrains the ability of existing research to inform regionally specific conservation strategies or landscape design interventions, thereby weakening its practical relevance in guiding sustainable development.

Together, these prior studies reveal a key gap: while traditional research provides valuable historical and cultural context, and recent quantitative approaches have advanced the identification of individual features of the Dike-Pond System, there remains a lack of an integrated, landscape-based perspective capable of decoding its internal spatial logic and structural complexity. To bridge this gap, the present study proposes an intersubjective approach for identifying, interpreting, and evaluating the system's spatial characteristics as expressions of its core structural principles, such as productivity patterns, ecological relationships, water infrastructure, and spatial connectivity. Taking Sangyuanwei in Foshan as a case study, the research aims to decode how spatial form reflects and mediates the underlying operational logic of this historically evolved system. By translating these spatial expressions into structured landscape knowledge, the study provides a foundation for more adaptive, differentiated, and spatially grounded strategies in heritage conservation and sustainable rural planning.

2. The Spatial Characteristics of the Dike-Pond System

To identify the core spatial characteristics of the Dike-Pond System, this study conducted a systematic content analysis of 109 academic publications, policy documents, and technical reports. Drawing on both qualitative interpretation and quantitative coding, the analysis synthesized recurring descriptions related to spatial form, functional logic, and land-water configurations. Through iterative classification, cross-validation among researchers, and expert review, a set of high-frequency descriptors was distilled and thematically grouped. As a result, four primary landscape characters were identified as consistently shaping the spatial logic of the Dike-Pond System: Production and Livelihood, Transportation Connectivity, Ecological Networks, and Water Management. Each of these landscape characters was further refined into a series of specific spatial characteristics, providing a structured basis for indicator development and for interpreting spatial structure in subsequent analysis.

- Production and livelihood are reflected in the close spatial coupling of settlements with productive land, where ponds and croplands alternate in a rational pattern. This configuration enables integrated aquaculture and agriculture, supports efficient use of land and water, and embodies a co-adaptive human-environment relationship (Pan et al., 2022; Tian, 2019; Lu & Pan, 2009; Hou & Guo, 2015; Astudillo et al., 2015).

- Transportation connectivity is primarily expressed through multifunctional dikes that double as roads. These structures form a connected internal circulation network, linking settlements with farmland and facilitating the flow of people and goods while reinforcing the integrated character of the landscape (Sun et al., 2024).

- Ecological networks emerge from the mosaic arrangement of aquatic and terrestrial elements including ponds, dikes, and vegetation. This structure creates extensive edge habitats and supports ecological processes such as nutrient cycling, species movement, and microclimatic regulation, contributing to biodiversity and system resilience (Chang et al., 2019; Chi et al., 2024; Wang et al., 2022; Zhou & Tang, 2024).

- Water management is organized through a hierarchical and integrated hydraulic system. Water flow is directed by dikes, regulated by sluices, and distributed through a network of ponds and channels, enabling precise control of irrigation, drainage, and reuse within the landscape (Hou & Li, 2018; Sun et al., 2019; Duan & Liang, 2020; Xie et al., 2023; Guo & Hou, 2015).

Following the identification and synthesis of the spatial characteristics, each qualitative descriptor was translated into a standardized, quantifiable indicator to support objective measurement and comparative analysis. Drawing on relevant theories from graph analysis, landscape morphology, and computer vision, each characteristic was mapped to specific spatial metrics with clearly defined mathematical expressions. For example, boundary morphology was quantified using length-width ratios and shape indices; internal spatial structure was assessed through fractal dimension; and transportation configuration was evaluated using connectivity measures derived from spatial syntax analysis. To ensure consistency and scientific rigor, indicator definitions were standardized across the dataset, and expert consultation was conducted to validate their conceptual clarity and practical applicability. The resulting indicator system enables multi-dimensional and multi-scalar analysis of the Dike-Pond landscape, providing a structured foundation for subsequent statistical evaluation, regional comparison, and spatial planning support (Table 1).

Table 1. Landscape characters, spatial characteristics, and the translated indicators of the Dike-Pond System

Landscape Character	Spatial Characteristic	Indicator (Abbr.)	Formula
Ecological Network	Diverse ecological services with strong ecological stability	Dike-Pond Connectivity Index (DPCI)	$DPCI = \left(\frac{\sum\sum c_{ijk}}{\frac{n_i(n_i-1)}{2}}\right) \times 100$
		Patch Diversity Index (PDI)	$PDI = \sum_{i=1}^{n} p_i \log(p_i)$
		Splitting Index (SPLIT)	$SPLIT = \frac{A^2}{\sum_{i=1}^{n} A_i^2}$

		Shape Index (SI)	$SI = \frac{P}{2\sqrt{\pi A}}$
		Fractal Dimension Index (FD)	$FD = \frac{2\log(P)}{\log(A)}$
		Biodiversity Support Index (BSI)	$BSI = f(A_i, C_i)$
	The ecological cycle at the water-land interface	Water-Land Interlacing Ratio (WLI)	$WLI = \frac{L_{wl}}{L_{total}}$
		Land-Water Ratio（LWR）	$LWR = \frac{A_{land}}{A_{water}}$
	Polder layout under environmental influences	Pond Orientation (PO)	$PO =$ Dominant azimuth of ponds
		Angle to River Axis (ARA)	$ARA = \angle(\text{Pond axis,River axis})$
		Angle to Road Axis (ARA-Road)	$ARA\text{-}Road = \angle(\text{Pond axis,Road direction})$
Production & Livelihood	Pond surfaces are typically delineated using geometric shapes, facilitating measurement, management, and cultivation.	Pond Area (AREA)	$AREA = A_p$
		Rectangular Compactness (RC)	$RC = \frac{A_p}{A_r}$
		Elongation (EL)	$EL = \frac{L_{long}}{L_{short}}$
		Convex Compactness Ratio (CCR)	$CCR = \frac{A_p}{A_c}$
		Related Circumscribing Circle（RCC）	$RCC = 1 - \frac{a_{ij}}{a_{ij}^c}$
	A rational alternation of pond and dike surfaces maximizes the use of land and water resources, supporting diversified agricultural production models.	Water-Adjacent Pond Ratio (WAPR)	$WAPR = \frac{A_{adj}}{A_{total}}$
		Land-Water Ratio (LWR)	$LWR = \frac{A_{land}}{A_{water}}$
	The spatial arrangement of settlements maintains a strong interactive relationship with surrounding farmland.	Proximity Index (PI)	$PI = \frac{1}{n}\sum_{i=1}^{n} d_i$
		Accessibility Index（ACI）	$ACI = \frac{1}{n}\sum_{i=1}^{n} t_i$
		Hydrological Interaction Density (HID)	$HID = \frac{N_{inter}}{A}$
Water Management	The water system is hierarchically structured, forming a connected network for irrigation and drainage.	Water Network Integration (WNI)	$WNI = \frac{\sum w_i}{n}$
		Water Network Choice (WNC′)	$WNC' = \sum\left(\frac{f_i}{F}\right)$
	Sluice gates, including primary and secondary types, regulate internal water levels by leveraging tidal differences.	Main Sluice Control Index (MSCI)	$MSCI = \frac{N_{main}}{N_{total}}$
		Subsidiary Sluice Control Index (SCI)	$SSCI = \frac{N_{sub}}{N_{total}}$
Transportation Connectivity	Multi-level dikes function as roads connecting settlements and the outside.	Road Integration (RIN)	$RIN = \frac{1}{\sum d_i}$
		Road Choice (RCH)	$RCH = \sum_{i,j}\frac{\sigma_{ij}(v)}{\sigma_{ij}}$

3. Methods

3.1 Study Area

This study focuses on Sangyuanwei, a representative Dike-Pond region located in the middle-upper reaches of the Pearl River Delta, southern China. Enclosed on three sides by waterways and protected by a historically fortified dike system, Sangyuanwei exhibits strong spatial integrity and relative isolation. Its enduring mosaic of fishponds, farmlands, and embankments exemplifies the structural logic of circular agriculture and integrated water management, making it one of the best-preserved embodiments of the region's agricultural heritage.

The selected research area covers approximately 153.53 km² within the core of Sangyuanwei. This subregion was chosen for its landscape representativeness, availability of high-resolution spatial data, and marked internal heterogeneity. While it retains a largely intact Dike-Pond structure, the area also faces increasing urban development pressures, especially along its peripheries. This juxtaposition of preservation and transformation offers a valuable context for examining how agricultural heritage systems respond spatially to urbanization and evolving land-use demands (Figure 1).

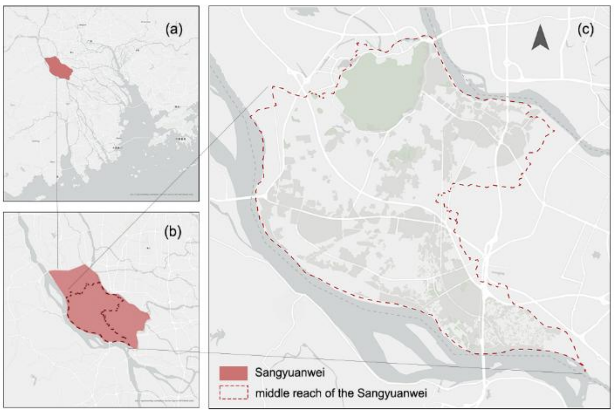

Figure 1. Study area
(a) estuarine area of the Pearl River Delta; (b) Sangyuanwei; (c) middle reach of the Sangyuanwei

3.2 Dataset Construction

To support fine-grained spatial analysis of the Dike-Pond System in Sangyuanwei, this study constructed a comprehensive, multi-source geospatial database integrating high-resolution imagery, vector layers, and historical materials. The database was structured to capture the morphological, topological, and functional dimensions of the landscape and consists of six core data modules: pond morphology, road infrastructure, water networks, land-use patterns, hydrological nodes, and settlement boundaries (Figure 2).

(1) Polder Morphology
High-resolution satellite imagery (JL1KF01C, 0.5 m resolution, 2024) was processed as the primary source for delineating pond surfaces. A deep learning model based on ArcGIS Pro was trained using 1350 manually annotated samples and achieved approximately 84% accuracy. The model adopted a Mask R-CNN architecture with a ResNet-50 backbone and Feature Pyramid Network (FPN), which enabled instance-level pond extraction with high boundary precision and adaptability to varying pond scales. This process generated a detailed pond layer capturing geometric features and spatial distributions essential for subsequent morphological and connectivity analysis.

(2) Road and Hydrological Networks
Road infrastructure and hydrological network data were acquired from OpenStreetMap. After initial extraction, datasets underwent topological correction and network structuring within ArcGIS Pro, followed by manual calibration to ensure accuracy and functional integrity. These refined datasets were subsequently converted into axial maps, creating a comprehensive foundation for detailed network analysis.

(3) Land-use Classification
Land-use types was generated through supervised classification methods in ArcGIS Pro, based on the high-resolution satellite imagery from 2024. Various classification algorithms, including Support Vector Machines (SVM), Random Forest, and Object-Based Image Analysis (OBIA), were comparatively tested and optimized. The finalized classification delineated key landscape elements, such as ponds, woodland, mulberry bases, water bodies, wastelands, and farmland, significantly improving spatial resolution and typological clarity.

(4) Hydrological Node Network
To capture the internal logic of water management, a hydrological node network was developed using Cytoscape. Key hydraulic control points, including sluices, drainage gates, and channel intersections, were identified, encoded, and analysed to reveal system-wide connectivity and flow regulation structures.

(5) Settlement Boundary Delineation
Settlements were identified as essential organizational units in the Dike-Pond System, linking production and habitation. This study adopted a spatial proximity-based approach to associate each pond with its nearest residential cluster, forming coherent settlement units. Industrial or non-productive urban areas were excluded to ensure analytical consistency. This method offers a more accurate spatial representation of socio-agricultural coupling in the heritage landscape.

3.3 Digital Mapping Techniques and Spatial Analysis

To identify and interpret the landscape characters of the Dike-Pond System, this study employed a set of digital mapping techniques and spatial analysis methods to decode its structural logic from a landscape perspective. The approach combined GIS-based grid analysis, landscape metrics, space syntax, and geostatistical methods to reveal spatial patterns and character interactions.

First, spatial indicators aligned with the four identified landscape characters, including production and livelihood, ecological networks, water management, and transportation connectivity, were computed to capture their structural expressions. For production-related characteristics, pond geometry (e.g., shape index, compactness, elongation) and settlement adjacency were calculated in ArcGIS Pro to reflect agricultural regularity and functional clustering. Ecological attributes were assessed using FRAGSTATS through metrics such as patch diversity, splitting index, and fractal dimension, indicating biodiversity potential and habitat stability. Hydrological structure was analyzed using spatial syntax values (integration and choice) derived from the water network in DepthmapX, alongside pond orientation and land-water interface metrics computed in GIS. Road network accessibility and connectivity measures were extracted using DepthmapX and network analysis tools in ArcGIS Pro to evaluate transportation efficiency and spatial reach.

Building on these quantified attributes, spatial analysis techniques were employed to investigate spatial heterogeneity within and across character dimensions. Indicators were aggregated thematically, and spatial distribution patterns, such as clustering intensity, spatial gradients, and transitional boundaries, were visualized through kernel density analysis, choropleth mapping, and overlay techniques in ArcGIS Pro. These analyses enabled the identification of localized concentrations, dispersal trends, and composite spatial morphologies characteristic of the Dike-Pond System. Spatial autocorrelation tests (e.g., Moran’s I, Getis-Ord Gi*) were conducted to detect statistically significant clusters, revealing spatial dependencies and directional biases within landscape character distributions, and helping to elucidate the structural coherence or fragmentation of different spatial functions.

To synthesize spatial insights across dimensions, entropy-weighted overlay analysis was applied within each character to generate composite spatial value maps. These maps revealed zones of high functional intensity, transitional belts, and areas of peripheral attenuation, reflecting spatial differentiation in ecological, productive, and hydraulic performance. This step enabled a unified interpretation of landscape heterogeneity and supported the classification of spatial zones sharing coherent internal structures and functions.

To further identify spatial typologies, a spatially constrained clustering approach was employed to delineate contiguous landscape units based on their quantified attributes. The SKATER algorithm (Spatial ‘K’luster Analysis by Tree Edge Removal), implemented in ArcGIS Pro, was used to construct a minimum spanning tree that respects both attribute similarity and spatial adjacency. Cluster boundaries were defined by iteratively removing high-dissimilarity edges, preserving spatial contiguity. The number of clusters was determined through a combination of within-group variance evaluation and expert consultation, ensuring both statistical robustness and spatial interpretability. This process produced five spatial types characterized by distinctive internal logic, providing a robust basis for scenario-specific planning strategies in traditional agricultural landscapes.

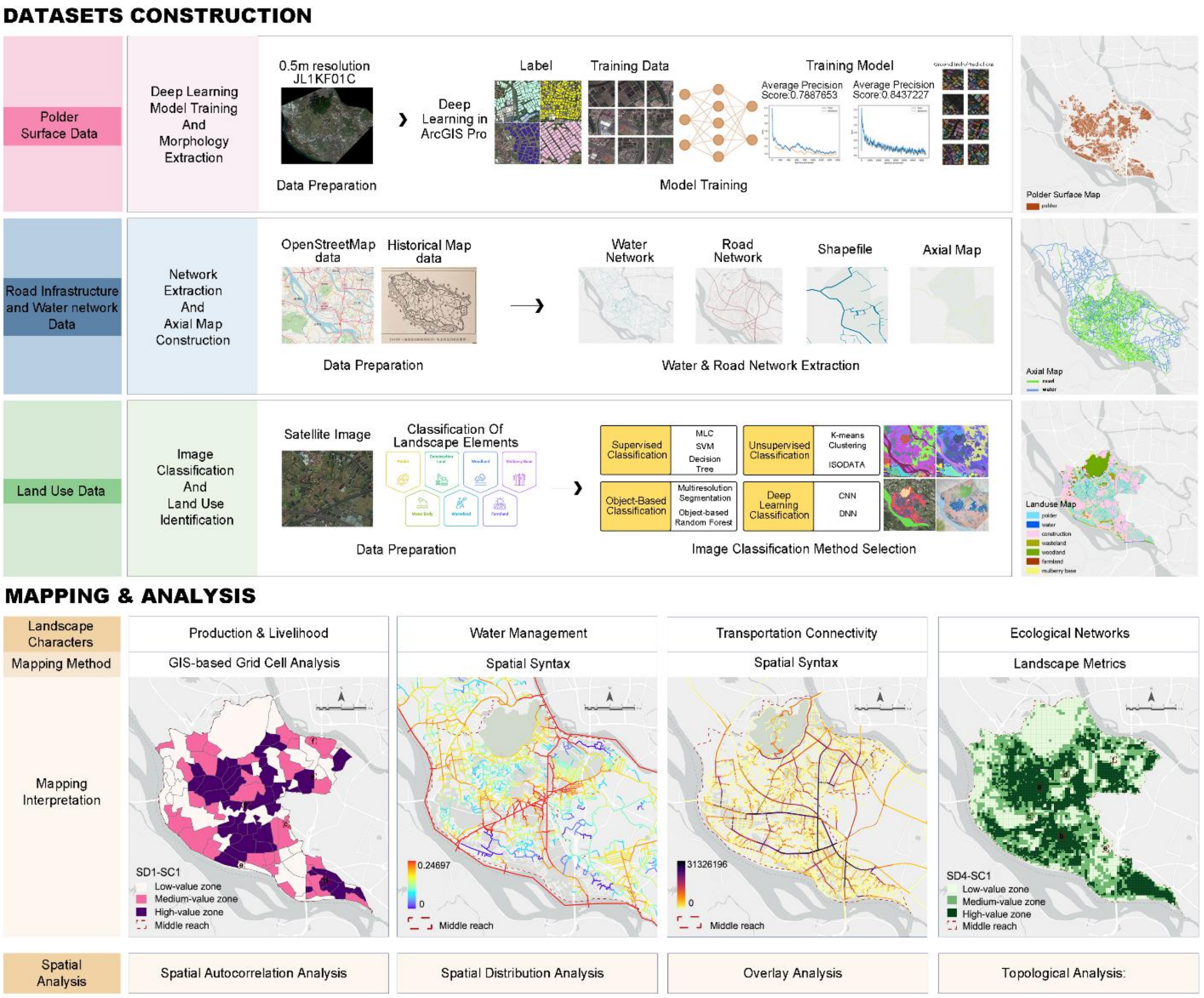

Figure 2. Integrated workflow of dataset construction, mapping, and spatial interpretation in the Sangyuanwei Dike-Pond System

4. Results

4.1 Overview of the Spatial Characteristics of the Dike-Pond System

The production space of the Dike-Pond landscape is dominated by small and relatively regular ponds, supporting high land-use efficiency. About 60% of pond areas are smaller than 1,583.95 m², and only 20% exceed 3,511.41 m², confirming the prevalence of small-sized units (Figure 3). Shape-related indicators, including Rectangular Compactness (RC), Elongation (EL), Convex Compactness Ratio (CCR), and Related Circumscribing Circle (RCC), suggest that while 60% of ponds deviate from ideal geometric forms, they retain a generally regular spatial structure. The water-adjacent pond ratio (WAPR) shows no uniform spatial trend but reaches up to 80% in areas such as Shatou, Datong, and Xiajin’ou Forts (mean=0.58), supporting water exchange for composite agricultural activities. The optimal dike-to-pond ratio range (0.6-1.0) accounts for 36% of the landscape, with a mean of 0.73. Meanwhile, accessibility levels are generally high: proximity index (PI) averages 0.66, and accessibility index (ACI) reaches 0.96. Settlement-river interaction (HID) remains low but is spatially consistent across most areas, suggesting uniform hydraulic detachment of settlements.

The hydrological network of the Dike-Pond system exhibits a relatively homogeneous structure, with connectivity and resilience relying on a limited number of critical water channels. Global choice values are skewed toward the lower end: over 71% of segments fall below 1,000,000, and only about 1% exceed 10,000,000, indicating that most water paths contribute little to overall flow mediation, while a few act as major conduits. Global integration values show a similar concentration, with 76% of the network scoring below 0.20, suggesting moderate levels of spatial cohesion in hydraulic circulation. In terms of control infrastructure, primary sluices demonstrate significantly higher control capacity (mean = 0.46) compared to secondary sluices (mean = 0.13), highlighting their dominance in regulating hydraulic connectivity and water distribution across the system.

The road network of the Dike-Pond landscape exhibits a core-periphery configuration, with overall efficiency heavily dependent on a limited number of key routes. Choice values are highly skewed, with approximately 70% of road segments falling below the mean (231,701), while a small number exceed 4,770,000, substantially raising the average. This pattern reveals that a limited number of roads concentrate shortest-path flows and function as backbone connections for the entire system. In contrast, integration values are more evenly distributed, though the majority of segments remain below the mean (0.32). This suggests the presence of structural backbone routes with higher centrality, while most secondary roads demonstrate relatively consistent integration levels.

The ecological characteristics of the Dike-Pond system exhibit evident spatial heterogeneity and localized clustering. The Dike-Pond Connectivity Index (DPCI) shows a near-uniform distribution across quintile intervals, indicating balanced spatial potential for material and energy exchange. Similarly, Patch Diversity Index (PDI) and Splitting Index (SPLIT) are evenly distributed, reflecting high variability in landscape composition and fragmentation. Shape Index (SI, mean = 2.47) and Fractal Dimension (FD, mean = 1.17) also show relatively balanced distributions. In contrast, the Biodiversity Support Index (BSI) is highly skewed: 60% of areas fall below 620, while only 20% exceed 2,276, suggesting that most zones provide limited ecological potential, with only a few functioning as biodiversity cores. Water-Land Interlacing (WLI) is low in 40% of samples (<0.011), dominated by simple pond-land edges. Yet values above the mean (0.04) form clear clusters, indicating localized zones of complex aquatic-terrestrial boundaries. Over 80% of ponds align orthogonally or parallel to hydrological axes and road networks, demonstrating a high degree of spatial coordination that reflects both ecological adaptation and anthropogenic regulation.

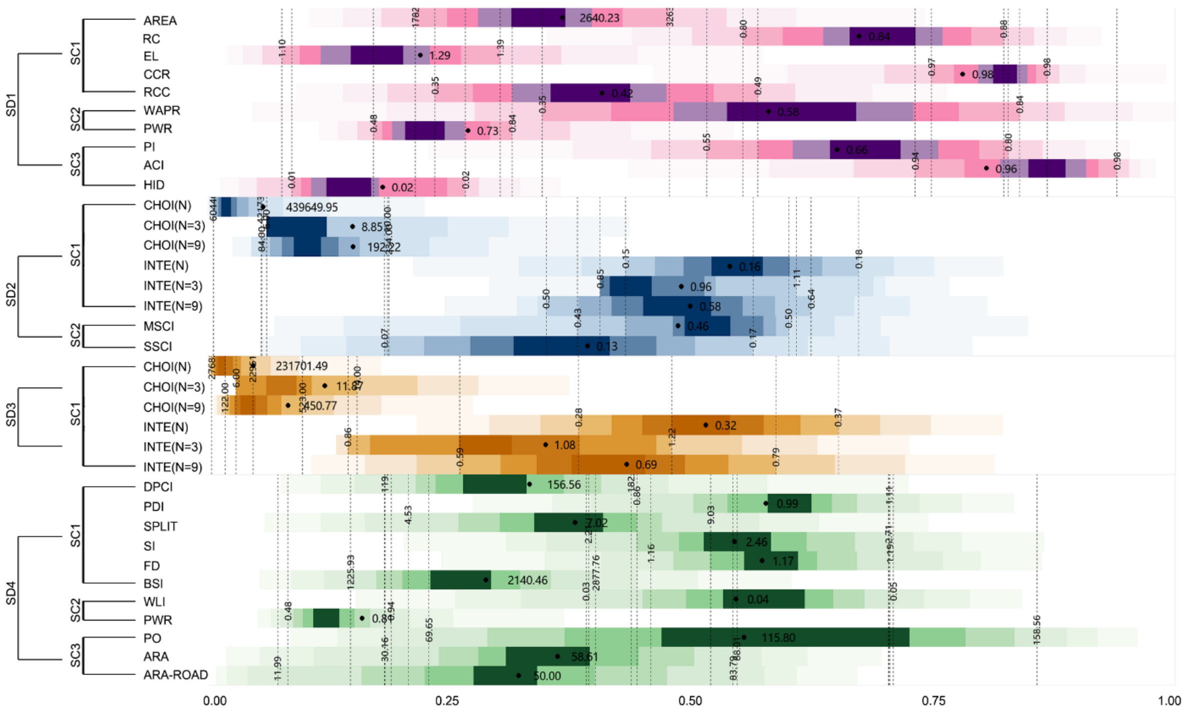

Figure 3. Normalized distributions of indicators representing spatial characteristics

4.2 Typological Classification and Strategic Interpretation

Based on a clustering analysis of quantified spatial indicators associated with the four core landscape characters, this study systematically identified five typologies within the Sangyuanwei Dike-Pond landscape: Integrated Ecological-Dominant Zone, Urban Built-Up Cluster, Productivity-Integrated Area, Aesthetic-Oriented Landscape Cluster, and Transitional Mosaic Zone. These types reflect the heterogeneous spatial structures and functional roles of contemporary Dike-Pond systems, ranging from ecological conservation and agricultural production to aesthetic experience and urban adaptation, while also revealing the spatial logic of transformation under urban-rural integration (Figure 4).

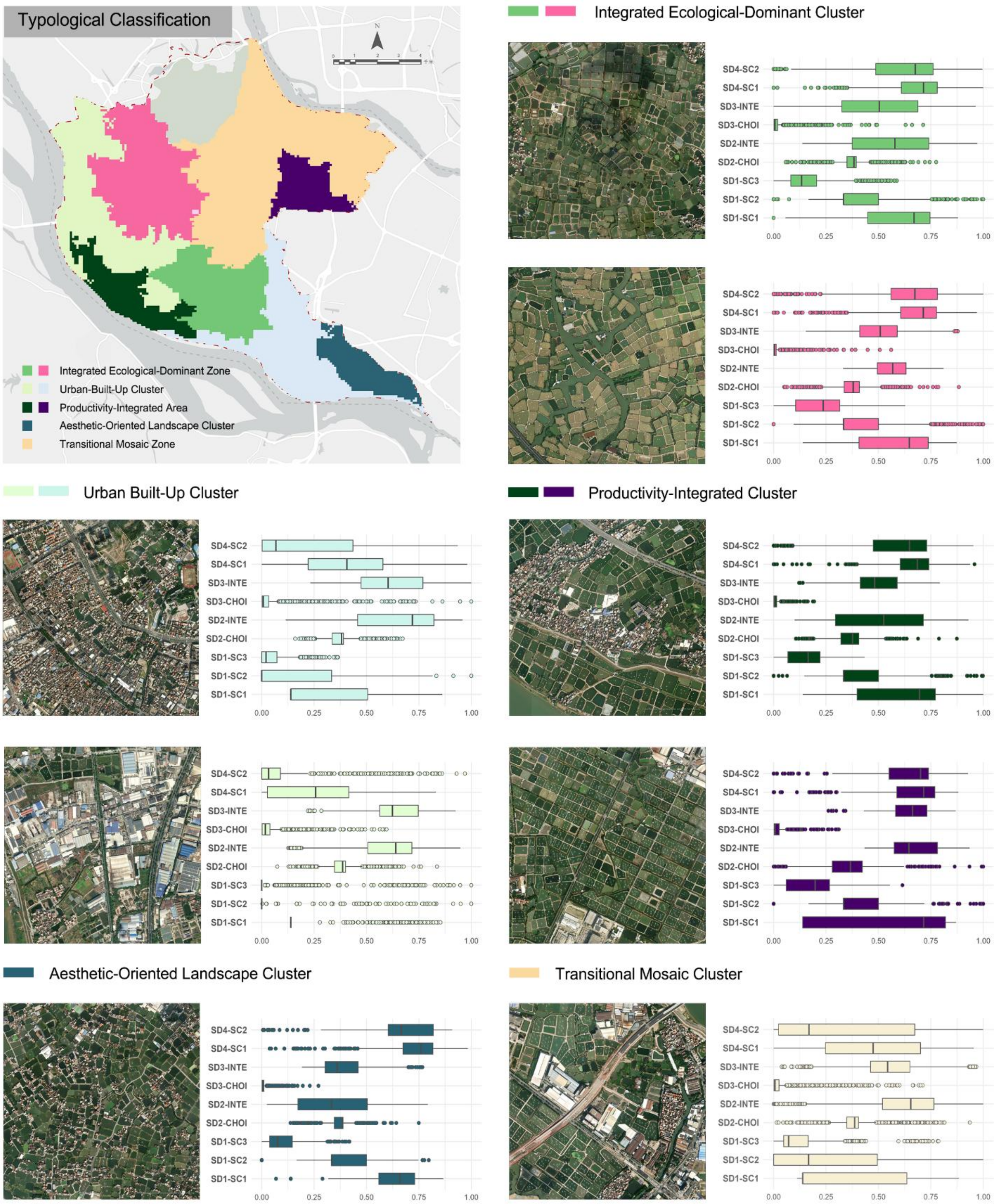

Figure 4. Spatial typology of the Dike-Pond System derived from clustering of normalized indicators

The **Integrated Ecological-Dominant Cluster** exemplifies a crucial spatial model for preserving and sustainably managing agricultural heritage. Its dense and interconnected pond-dike networks, extensive water-land interfaces, and robust ecological corridors form core spatial features that underpin ecological resilience and sustained agricultural productivity. Conservation strategies should prioritize preserving these spatial characteristics to safeguard the traditional ecological and cultural values intrinsic to the Dike-Pond system.

In contrast, the **Urban Built-Up Cluster** represents challenges posed by rapid urban expansion, highlighting issues such as fragmented ecological spaces and disrupted traditional water networks. This underscores the critical need for integrated landscape restoration and planning interventions. Implementing green infrastructure to reconnect isolated ecological patches can help restore traditional spatial structures, ensuring the continuity of heritage landscapes within urbanizing contexts.

The **Productivity-Integrated Cluster** characterized by an intensive agricultural layout and efficient spatial organization, demonstrates how traditional spatial patterns of the Dike-Pond landscape effectively support modern agricultural productivity. Future spatial planning in this cluster should emphasize the retention of these efficient configurations, enhancement of ecological buffer zones, and strengthening of heritage identities embedded within productive landscapes.

The **Aesthetic-Oriented Landscape Cluster** highlights the recreational, aesthetic, and cultural dimensions of agricultural heritage landscapes. This cluster features dispersed and organically structured settlements closely interwoven with water bodies and greenery. Its spatial configuration prioritizes landscape heterogeneity, visual corridors, and varied interactions between built and natural elements. Meandering pathways, irregularly shaped ponds, and open spaces collectively enrich spatial experiences and reinforce cultural identity. Such spatial compositions offer valuable insights for developing heritage-oriented rural tourism and for conserving landscape aesthetics.

Finally, the **Transitional Mosaic Cluster** encapsulates the complex interplay between heritage conservation and contemporary development pressures. Defined by heterogeneous land uses and transitional spatial structures, this zone demands adaptive planning approaches capable of delicately balancing heritage preservation, ecological integrity, and urban-rural integration. Sensitive and nuanced policy-making is necessary to guide the sustainable transformation of this landscape amid evolving urbanization pressures.

Overall, this typological classification captures the spatial complexity of the Dike-Pond System and distills it into actionable categories. These typologies offer a practical basis for differentiated conservation zoning, agricultural land-use planning, and integrated landscape management amid ongoing urban-rural transition.

5. Conclusion

This study proposed and validated an intersubjective framework for identifying, quantifying, and interpreting the spatial characteristics of the Dike-Pond System from a landscape perspective. Focusing on the case of Sangyuanwei, the research systematically extracted four core landscape characters, including production and livelihood, ecological networks, water management, and transportation connectivity, through content analysis, and refined them into measurable spatial characteristics and indicators via digital mapping and spatial analysis. This enabled a nuanced decoding of the internal spatial logic of the Dike-Pond landscape and its heterogeneity across scales.

The resulting five-fold spatial typology reveals how traditional spatial configurations, shaped by vernacular knowledge and ecological adaptation, are now interacting with contemporary processes of urban-rural transformation. By linking spatial form to underlying structural logic, the study provides a differentiated spatial basis for conservation zoning, adaptive landscape planning, and heritage-sensitive development.

Beyond its empirical findings, the study contributes methodologically by bridging qualitative landscape interpretation with quantitative geospatial analysis. It demonstrates how integrating tools from landscape morphology, ecological metrics, and spatial syntax can enhance the analytical depth and operational relevance of heritage studies. Additionally, a deep learning model was trained using high-resolution satellite imagery to automatically extract pond features, providing a scalable and transferable technique for identifying Dike-Pond structures in large and heterogeneous regions. In doing so, the study offers a replicable approach for interpreting complex spatial systems, advancing landscape-based planning frameworks that support sustainable management, spatial governance, and cultural continuity in living heritage contexts.

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