

Spatial Generation Mechanism of Traditional Settlements Based on the Triple Coupling of "Industry–Power–Topography": A Case Study of the Historic Salt Village of Nuodeng

Tianyun Zhang

School of Architecture and Design, Southwest Minzu University, Chengdu 610225, China
Email: 422668644@qq.com

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Abstract

The morphological evolution of traditional mountain production settlements is subject to multiple complex factors. Taking the historic salt village of Nuodeng as an empirical case, this paper integrates field surveys, GIS spatial analysis, and architectural typology to explore its spatial generation mechanism under the dual constraints of a complex mountainous environment and a high-intensity well-salt industry. The research findings reveal that: first, the vertical elevation difference of the natural topography and the industrial logistics limit collectively define the rigid boundary of the settlement's physical expansion. Second, conditioned by the social division of labor within the salt industry chain, the settlement has evolved into low, middle, and high-level terraces adapting to the contour lines. These terraces correspond respectively to a high-density, centripetally aggregated core production cluster; a logistics and commercial cluster with highly permeable interfaces; and a defensively enclosed administrative and control cluster. Finally, with the deep intervention of the national taxation management system, the spatial center of gravity within the settlement shifted from the bottom-level resource core to the high-level tax administration hub. The managerial class monopolized absolute elevation to construct a viewshed monitoring network, achieving the spatial materialization of institutional thresholds through the use of steep steps and ritualistic plazas. The conclusion indicates that the spatial morphology of the Nuodeng settlement is not a result of natural organic sprawl, but rather a physical manifestation of the deep coupling among macro-political-economic forces, clan-based division of labor, and micro-geographical contexts. This study provides a theoretical foundation for the heritage conservation and spatial cognition of traditional industrial settlements.

Keywords

Traditional Settlement; Spatial Generation Mechanism; Spatial Political Economy; Architectural Morphology; Nuodeng Village

1. Introduction

The spatial morphology of traditional settlements is not merely a physical result of adapting to the natural geographical environment; rather, it serves as a material-spatial carrier where regional economic models, social clan networks, and macro-national management systems interact during specific historical periods[1]. In recent years, settlement studies in the fields of architecture and urban-rural planning have gradually broken through the limitations of singular superficial morphological descriptions, shifting towards the exploration of deep-seated "spatial generation mechanisms"[2]. For "production-oriented settlements" centered on specific resource extraction and processing, the evolution of their spatial structures often exhibits stronger industry-driven dynamics and hierarchical differentiation characteristics compared to traditional agricultural settlements. Located in the hinterland of the canyon in the southern section of the Hengduan Mountains, Nuodeng Village—a historic core well-salt production site in Southwest China—profoundly records the entire process of the well-salt industry from spontaneous extraction to a highly institutionalized system through the evolution of its settlement morphology[3]. However, existing research on traditional salt industry settlements like Nuodeng mostly focuses on historical text verification or singular architectural detail mapping, lacking a systematic analysis of the triple coupling mechanism of "industrial production—cultural belief—spatial morphology" at the meso-scale. Based on this, this paper adopts the perspectives of urban-rural morphology and spatial political economy to examine the settlement as an intricately interlocked "production-society" megastructure. By overlaying GIS topographic elevation analysis, slope and hydrological analysis, and historical settlement figure-ground extraction, this article reveals the spatial development logic of the Nuodeng settlement under complex mountainous constraints. It aims to ascertain how specific economic models and political orders are ultimately translated into concrete, stable architectural clusters and settlement spatial hierarchical structures in an extremely confined mountainous environment through road network topology reconstruction, interface permeability regulation, and absolute elevation control.

2. Boundary Demarcation under Natural Landforms and Industrial Energy Limits

The external spatial boundary of the Nuodeng settlement is by no means an outcome of natural organic sprawl, but rather a spatial morphology collectively defined by a complex mountainous terrain and high-intensity well-salt production. Its village boundary is not merely an ordinary geographic demarcation; it objectively manifests the physical result of the reciprocal interaction between topographic constraints and industrial evolution.

2.1. Vertical Elevation and the Physical Rigid Boundaries of Construction Land

From the macro-geographical context, Nuodeng Village is deeply embedded in the canyon hinterland of the southern Hengduan Mountains. The outer perimeter of the settlement is physically enclosed by surrounding mountain ranges: anchored to the north by Manchong Mountain, flanked by Xiang Mountain and Dong Mountain on either side, and facing South Mountain as an enframing foreground mountain (Anshan), forming a relatively enclosed canyon space [4]. As shown in the topographic elevation analysis in Figure 1, the region exhibits a substantial vertical elevation difference. While the broader regional altitude spans from 1659 meters to 2925 meters, the core settlement itself is situated on a steep slope where the lowest and highest points within the village boundaries differ by approximately 180 meters. Under the effect of this marked vertical relief, the core built-up area of Nuodeng Village is clustered within the valley corridor. Beyond this elevation range, the natural slope gradients of the mountain undergo abrupt steepening. As illustrated in Figure 2, slope analysis reveals that the inhabited zone of Hedong Village is predominantly concentrated on gentle slopes below 15°, while its surrounding areas mostly exceed 30°, resulting in an acute scarcity of developable construction land. In contrast, to optimize production accessibility, Hexi Village exhibits a dense distribution of courtyards across steep-slope zones ranging from 15° to 30°. On slopes exceeding 30°, conventional construction techniques for leveling building sites become unviable, causing cut-and-fill shoring costs and geological safety hazards to escalate drastically. Consequently, the steep topographic contours form a physical threshold for architectural expansion in three-dimensional space, restricting the outward growth of the settlement toward higher elevations..

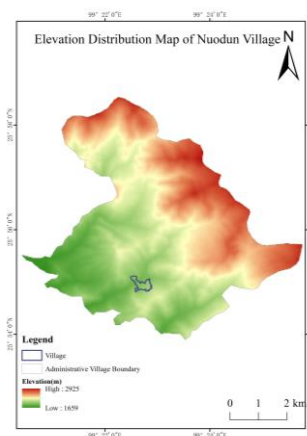


Figure 1. Topographic elevation analysis of Nuodeng Village.

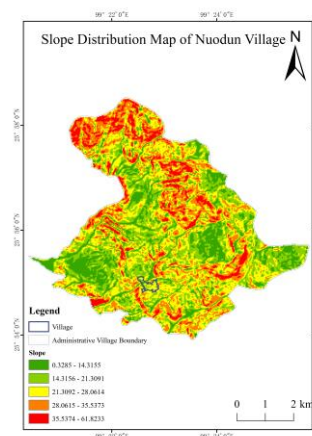


Figure 2. Slope analysis of Nuodeng Village.

2.2. Hydrological Faults and Discrete Substrate Segmentation

Hydrogeological conditions likewise constitute natural defining elements of the settlement boundary. The Nuoshui River originates from the Manchong Mountain range in the northeast, traverses the village along the canyon towards the southwest, and ultimately discharges into the Bijiang River three kilometers outside the village[5]. This hydrological axis physically bifurcates the residential area into two administrative and natural entities: Hedong Village and Hexi Village[6]. In addition, two mountain streams traverse the village from north to south; their riverbed elevations are significantly lower than the surrounding terrain, forming incised gullies that disrupt the morphological continuity of the settlement. To mitigate the risks of seasonal flash floods and debris flows during the rainy season, the site selection and spatial extension of architectural clusters necessitate terraced setbacks from the hydrological centerlines. The dissection caused by these gullies partitions the limited buildable land into several discrete terraces, endowing the settlement perimeter with discrete morphological characteristics that converge along the edges of the gullies.

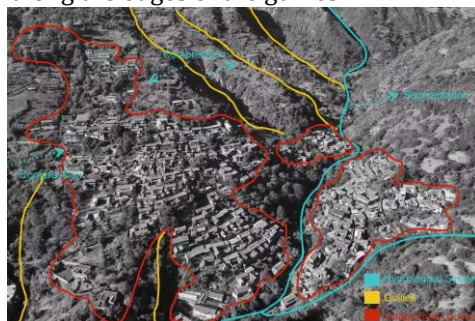


Figure 3. Substrate Segmentation by Gullies and the Hydrological System

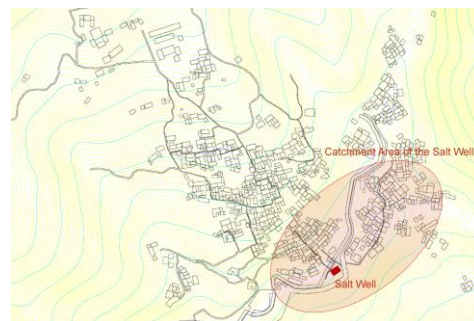


Figure 4. Catchment Radius of Salt Production and Building Density Distribution

2.3. Well-Salt Production Circulation and Settlement Economic Boundaries

As a quintessential production-oriented settlement, the morphological compactness of Nuodeng directly reflects the spatial demands of the well-salt production chain. The complete salt manufacturing cycle encompasses brine extraction, transport, and boiling. During the historical period reliant on human portage and draught animal transport, physical labor capacity and the transport costs of fuelwood demarcated an effective operational radius along the village periphery. Spatial buffer analysis centered on the primary salt well demonstrates that a 400-meter catchment radius covers the predominant residential zones of both natural villages, with only sporadic structures distributed beyond this threshold. Peripheral zones exceeding 400 meters from the core well were excluded from the primary production circulation due to prohibitive transport costs and reduced operational efficiency, subsequently transitioning into non-construction land. Consequently, the settlement boundary was intrinsically determined by the economic threshold of industrial

transport costs.

3. Spatial Pattern Evolution and Clan-Based Social Division of Labor

The macro-spatial pattern of the Nuodeng settlement is the physical outcome of long-term interactions between topographic constraints and the well-salt industry[7]. Conditioned by hydrological incision and steep slope constraints, the settlement developed a distinct directional and hierarchical organization[8], ultimately forming a topological structure characterized by "one river, two banks, and three terraced platforms". The spatial distribution of clans within the settlement serves as a direct meso-scale mapping of the three primary segments of the salt industry chain: "resource extraction, logistics transshipment, and administrative regulation". This spatial differentiation, grounded in a clan-based division of labor, provides the structural foundation for the settlement's morphological stability. As illustrated in Figure 5, the following subsections elaborate on the spatial generation mechanisms across these three distinct terraces.



Figure 5. Spatial Pattern Analysis of the Settlement

3.1. Core Production Cluster: Low-Elevation Terraces and Gravity Flowlines

The core production cluster is situated on the low-elevation terraces adjacent to the riverbed and the historic brine well. The logic of its spatial generation strictly adheres to the principles of minimizing transport distance and reducing operational energy consumption. To mitigate the substantial energy expenditure required for

anti-gravity brine transport, salt-making workshops were compelled to cluster tightly around the brine source, densely packing the limited gentle slopes into a compact, fine-grained architectural fabric. The vertical configuration of the building massing follows the downhill gradient, effectively establishing an early gravity-fed industrial production sequence. Regarding its boundaries and circulation, the perimeter facing the brine well lacks defensive enclosure walls, transitioning instead into open-air brine-curing decks and operational platforms that ensure uninterrupted resource conveyance. The internal fabric developed a centripetal pathway network structured around "brine-carrying routes," where lane clear widths are strictly constrained within an engineering threshold of 1.2 to 1.8 meters—calibrated precisely to the spatial clearances of single-file porters or pack animals—while adopting stepped ramps in vertical profile to conserve human physical labor.

3.2. Logistics and Commercial Cluster: Mid-Elevation Terraces and High-Permeability Interfaces

Decoupled from the centripetal pull of the valley-bottom brine well, the logistics and commercial cluster was organized around network accessibility, deploying linearly along the transit corridors of the Ancient Tea Horse Road on the mid-elevation terrace. In terms of architectural layout, this cluster maximizes its physical contact interface with the primary thoroughfare while providing functional buffer zones for transit operations, resulting in pronounced spatial permeability and edge openness. Substantial portions of private forecourts were set back to function as semi-public transitional spaces ("gray spaces") capable of accommodating caravan staging, assembly, and bulk cargo storage. Within the circulation topology, the arterial thoroughfare expands locally at critical intersections into market squares, decelerating transit logistics and effectively transforming linear throughput into concentrated areal commerce. By strategically avoiding the harsh industrial environment of the lower terraces, the merchant class anchored itself at key spatial bottlenecks, cultivating a resilient, highly permeable urban fabric.

3.3. Administrative and Governance Cluster: High-Elevation Terraces and Defensive Enclosures

Occupying the upper terraces and the highest topographical ridge of the settlement, the administrative and governance cluster embodies the intertwined authority of imperial salt monopolies and local elite governance. In three-dimensional space, it establishes an absolute visual command over the industrial operations on the lower terraces, with its boundary treatments exhibiting pronounced defensiveness and spatial introversion. Massive masonry retaining walls coupled with steep stone staircases erect distinct physical barriers and perceptual thresholds, thereby consolidating administrative hierarchy and sovereign authority. The internal

circulation system completely excludes heavy freight transit, instead exhibiting a deliberate geometric clarity, formal axuality, and ritualistic character within an introverted architectural setting. This planning strategy—hierarchically compartmentalizing production, circulation, and regulatory governance across vertical elevations—resolved the physical constraints of mountainous terrain and structured an enduring spatial hierarchy.

4. Spatial Materialization of Hierarchy and Mapping of Power Order

Settlement morphology is inherently dynamic; as the economic windfalls of the well-salt industry attracted imperial state intervention, the spatial center of gravity and hierarchical order of Nuodeng underwent structural reconfiguration[9]. In the vertical profile, a spatial order is manifested ranging from the salt well and salt production to administrative governance and religious belief, as illustrated in Figure 6.

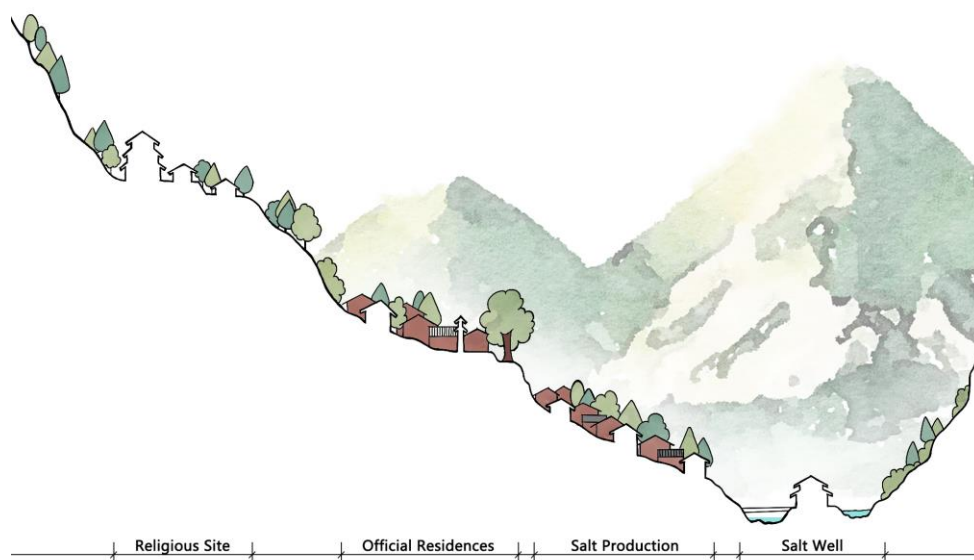


Figure 6. Vertical Section Mapping of Power Order

4.1. Shift in the Spatial Center of Gravity: From Resource Extraction Core to Fiscal-Administrative Hub

In the early stages of salt production, the settlement's spatial layout was characterized by a pronounced monocentric centripetality, with the low-elevation ancient brine well serving as the absolute spatial focus[5]. The circulation network converged in a unipolar pattern, lacking overarching spatial governance and formal coordination. However, with the institutional penetration of imperial salt monopoly apparatuses, newly constructed salt administrative bureaus (Yanju) and local gentry estates deliberately separated from the congested industrial zone to seek building sites on

the middle and upper terraces[10]. This macro-level variable necessitated a restructuring of the settlement's arterial circulation. Pathways ascending to the elevated administrative cluster were imbued with ceremonial and axial characteristics, showing marked improvements in lane width, geometric regularity, and pavement quality. The administrative buildings strictly followed orthodox typological canons and symmetrical layouts, occupying larger footprints with rectilinear courtyard configurations that visually and formally dominated the production fabric below in figure-ground relationships. Moving through the settlement sequence—transitioning from secular, bustling activities at the valley bottom to an increasingly solemn and introverted realm along the upward vertical axis—signaled a successful displacement of the spatial locus from a resource extraction node to an elevated fiscal-administrative center.

4.2. Political Economy of Absolute Elevation: Viewshed Dominance and Spatial Regulation

The deliberate appropriation of absolute vertical elevation by the managerial elite served as a spatial strategy to allocate scarce land resources and reduce governance transaction costs. Across an extreme topography where local slope gradients reach 0.33, the finished grade of upper administrative complexes and sacred temples sits well above the roof ridge-lines of dwellings on the lower and middle terraces, providing an unobstructed panoramic viewshed. This topographical advantage was leveraged into an omnipresent spatial surveillance network: officials maintained continuous visual command over the extraction basins along the riverbed and the caravan logistics hubs on the central terrace without descending into the lower fabric, substantially augmenting tax auditing efficiency and deterring illicit trade. Concurrently, this geometry established an asymmetrical visual dynamic—the upper tier possessed absolute visual transparency, whereas observers from the lower terraces faced occluded sightlines fragmented by retaining walls, stepped terrace escarpments, and monumental plinths. This unidirectional visual dominance reinforced a psychological sense of deference among the working classes. By situating Confucian temples and Daoist shrines alongside secular yamen complexes at the topographical zenith, the imperial administration secured moral and ideological legitimacy, embedding an inviolable socio-ethical hierarchy within the three-dimensional terrain.

4.3. Spatial Materialization of Institutional Thresholds: Physical Disruption and Ritual Plazas

To protect social distance and administrative authority, the ruling class engineered deliberate physical obstructions within the circulation fabric. Pathways leading to the high-elevation administrative sector departed from contour-hugging, gentle grades in favor of continuous, steep stone stairs flanked by massive ashlar retaining

walls. In terms of space syntax, this pronounced vertical relief increased topological depth and demanded substantial physical exertion from ascending visitors, filtering out mundane commercial flows and establishing an explicit spatial access threshold. Furthermore, against the backdrop of acute land scarcity and a compact figure-ground pattern on the lower slopes, the ruling class executed extensive cut-and-fill terracing to carve out expansive open spaces on the upper slopes, such as the Great Banyan Plaza (Daqingshu Plaza) and the Salt Bureau Plaza. Stripped of profane market and transshipment functions, the Great Banyan Plaza deployed broad flagstone paving and an extensive tree canopy to offer spatial pause and psychological decompression following the arduous vertical ascent, functioning as an architectural threshold mediating secular dwelling areas and sacred precincts. Conversely, the Salt Bureau Plaza was bounded by introverted, defensive perimeters designed for official convocations and fiscal inspections. Through this integration of vertical movement barriers and ceremonial spatial expansion, the imperial governance framework materialized class boundaries and institutional thresholds within an otherwise constrained mountainous terrain.

5. Conclusion

Through the meso-scale spatial analysis of the historic salt village of Nuodeng, this study confirms that the morphological generation of traditional production-oriented mountain settlements is not governed by singular geographical determinism, but is rather a spatial manifestation of the profound interaction among micro-geographical contexts, clan-based social divisions of labor, and macro-political-economic forces. The primary conclusions are as follows: First, the extreme vertical elevation relief, hydrological incision, and the 400-meter industrial logistics threshold determined by manual portorage collectively established the dual rigid boundaries—both physical and economic—of settlement expansion, dictating its compact yet discrete morphological fabric. Second, the complete industrial supply chain of well-salt "extraction-logistics-governance" directly steered the social division of labor among the three predominant clans (Yang, Xu, and Huang). Across the constrained mountainous section, this evolved into a highly integrated three-tiered spatial configuration: low-elevation gravity-driven production, mid-elevation high-permeability commerce, and high-elevation enclosed administrative governance. Third, propelled by the accumulation of mercantile capital and the institutional penetration of the imperial salt administration, the spatial order of the settlement underwent structural reconfiguration. The power center representing the state apparatus and local gentry secured absolute topographical elevation to construct an overarching viewshed monitoring network. Concurrently, it established distinct institutional thresholds through steep stone stairways and large-scale ritual plazas, completing a profound transition of the spatial hierarchy from spontaneous aggregation to an institutionalized system. The findings demonstrate that an

interdisciplinary framework integrating architectural morphology and spatial political economy offers an accurate lens for decoding the generative logic of traditional industrial settlements. This provides a scientific theoretical basis for the value identification, spatial fabric conservation, and organic renewal strategies of historic cultural villages.

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