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NEAREST NEIGHBOR ANALYSIS OF BALI'S EDUCATIONAL FACILITIES DISTRIBUTION AND SPATIAL POLICY COMPLIANCE

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ABSTRAK

Ketimpangan spasial fasilitas pendidikan dan ketidaksesuaiannya dengan rencana tata ruang merupakan tantangan kritis di wilayah yang berkembang pesat seperti Bali. Namun, penelitian yang mengintegrasikan analisis pola distribusi spasial dengan evaluasi kesesuaian terhadap Rencana Tata Ruang Wilayah (RTRW) masih terbatas. Penelitian ini menganalisis pola distribusi spasial fasilitas pendidikan di Provinsi Bali dan mengevaluasi kesesuaiannya dengan RTRW. Menggunakan pendekatan kuantitatif dengan desain analisis spasial, penelitian ini memanfaatkan data sekunder fasilitas pendidikan dan data pola ruang RTRW. Analisis pola distribusi menggunakan metode *Average Nearest Neighbor* (ANN) dengan uji signifikansi *z-score* ($p < 0,05$), sementara evaluasi kesesuaian dilakukan melalui teknik *overlay* spasial. Hasil penelitian menunjukkan bahwa seluruh kabupaten/kota di Provinsi Bali memiliki pola distribusi mengelompok secara signifikan (ANN < 1, $p < 0,001$). Kabupaten Buleleng menunjukkan pengelompokan paling intensif (ANN = 0,463445), sementara Kota Denpasar mendekati pola acak (ANN = 0,856465). Evaluasi kesesuaian mengungkapkan bahwa 55,75% fasilitas berada di Kawasan Permukiman (sesuai ketentuan), tetapi 44,25% berada di zona tidak sesuai, termasuk Kawasan Pertanian (14,10%), Kawasan Pariwisata (5,46%), serta Kawasan Lindung dan Kawasan Pertahanan dan Keamanan. Temuan ini menyoroti ketimpangan spasial sistemik dan kesenjangan antara kebijakan perencanaan dengan implementasi di lapangan, yang disebabkan oleh faktor historis, tekanan urbanisasi, dan lemahnya penegakan hukum tata ruang. Penelitian ini merekomendasikan revisi RTRW berbasis bukti, penguatan mekanisme pengendalian pemanfaatan ruang, dan integrasi partisipasi masyarakat.

Kata Kunci: Average Nearest Neighbor, Fasilitas Pendidikan, Pola Distribusi Spasial

ABSTRACT

Spatial inequality in educational facilities and their non-compliance with spatial planning remain critical challenges in rapidly developing regions such as Bali. However, research integrating spatial distribution pattern analysis with compliance assessment against the Regional Spatial Plan (Rencana Tata Ruang Wilayah/RTRW) remains limited. This study analyzes the spatial distribution patterns of educational facilities in Bali Province and evaluates their compliance with the RTRW. Employing a quantitative approach with spatial analytical design, this study utilized secondary data on educational facilities and RTRW spatial pattern data. Distribution pattern analysis employed the Average Nearest Neighbor (ANN) method with z-score significance testing ($p < 0.05$), while compliance evaluation was conducted using spatial overlay techniques. The results reveal that all regencies and the city in Bali Province exhibit statistically significant clustered distribution patterns (ANN < 1, $p < 0.001$). Buleleng Regency demonstrates the most intensive clustering (ANN = 0.463445), while Denpasar City approaches a random pattern (ANN = 0.856465). Compliance evaluation reveals that 55.75% of facilities are appropriately situated in Residential Zones, while 44.25% occupy non-suitable zones,

including Agricultural Zones (14.10%), Tourism Zones (5.46%), as well as Protected Areas and Defense and Security Zones. These findings highlight systemic spatial inequities and gaps between planning policy and implementation, driven by historical factors, urbanization pressures, and weak spatial planning law enforcement. This research recommends evidence-based RTRW revision, strengthening of spatial utilization control mechanisms, and integration of community participation.

Keywords: Average Nearest Neighbor, Educational Facilities, Spatial Distribution Pattern

INTRODUCTION

The provision of educational facilities represents one of the most fundamental manifestations of spatial justice and sustainable regional development. In tandem with global efforts to achieve Sustainable Development Goal 4 (Quality Education) and Goal 11 (Sustainable Cities and Communities), the equitable distribution of educational infrastructure has emerged as a critical determinant in shaping human capital and fostering socio-economic development (United Nations, 2023). In archipelagic and developing nations such as Indonesia, the challenge of ensuring equitable access to education is compounded by complex geographical conditions and historical disparities. Furthermore, there exists an inherent tension between centralized planning paradigms and localized socio-cultural realities.

The decentralization policy implemented in Indonesia during the early 2000s transferred significant authority over public service provision to local governments. This regulatory shift mandated that regencies and the city assume primary responsibility for ensuring the availability and accessibility of educational facilities across all levels, from primary to secondary education. Concurrently, the Spatial Planning Law requires all local governments to formulate Regional Spatial Plans (*Rencana Tata Ruang Wilayah*/RTRW) that designate specific zones for public facilities. Collectively, these legal instruments create a framework in which the geographic placement of educational facilities should, in theory, align with both population needs and logical planning principles.

Bali Province exhibits pronounced spatial heterogeneity in terms of population density, economic activity, and urbanization rates. The southern region has experienced relatively rapid growth compared to other regencies within the province (Utomo, 2024). This uneven development trajectory raises important questions regarding the spatial distribution of public services: Are educational facilities distributed equitably across this diverse landscape? Furthermore, do the existing spatial patterns align with the normative

framework mandated in the regional spatial plans?

Despite the legal mandates for equitable service provision and adherence to spatial planning, significant gaps persist between policy aspirations and ground realities in many regions of Indonesia. Previous studies have documented substantial disparities in educational access between urban and rural areas across the archipelago (Suryadarma and Jones, 2013; World Bank, 2020); however, systematic spatial analyses at the provincial level remain relatively scarce. In the specific context of Bali, the existing literature has predominantly focused on the historical-institutional dimensions of education or the philosophical-architectural conceptions of space, thereby leaving a conspicuous void in the understanding of the contemporary spatial configuration of educational infrastructure and its relationship with formal planning instruments.

The relevant body of literature for this study can be categorized into two primary thematic domains: educational development in Bali, and the concepts of space and land utilization. With regard to the education domain, scholarly inquiries have largely concentrated on historical-institutional analyses and the gender dimensions of educational participation. For instance, research by Suryawati and Jayanti (2010) examined the role of Bagi Darma Laksana as a pivotal educational organization during the 1935–1942 period, which contributed to educational progress in the late colonial era. Similarly, the study by Suartini and Yuniarika (2020) highlighted the participation of Balinese women in education between 1930 and 1950, framing it as both a response to and a catalyst for social transformation. While these studies provide robust socio-historical insights, their predominantly qualitative and historical approaches offer limited perspectives on contemporary spatial configurations. More recent educational literature has shifted focus toward pedagogical innovations, such as the preservation of the Balinese language through popular media (Andayani and Dwiyani, 2022), and linguistic aspects of Balinese language use in radio broadcasts (Supriyanti, Wirani and Indriani, 2015).

In terms of geographic distribution and land utilization, the literature reveals a different set of concerns. Although the studies mentioned above emphasize pedagogical methods and cultural preservation, they largely neglect the spatial dimensions of educational infrastructure provision. This gap highlights the need for research that directly addresses how educational facilities are distributed across Bali's geographic landscape, including variations

between urban, rural, and remote areas, as well as the implications of land use patterns for equitable access to education.

Meanwhile, within the domain of space and land utilization, the literature on Bali is profoundly influenced by local philosophical traditions concerning space and place. This is exemplified by Raharja (2011), who elucidated the cosmological conception of traditional Balinese space, rooted in both terrestrial and celestial environments. These principles are practically manifested in contemporary architecture, as demonstrated by Antaryama and Ananto (2013) through their investigation of the harmonious integration of exterior and interior design in Balinese cultural centers. The sustainability of culturally-based spatial sensibilities within modern development practices (Rembulan, 2025).

The critical gap that has emerged is twofold. First, educational research in Bali remains largely disconnected from spatial analysis, focusing predominantly on historical, institutional, pedagogical, and linguistic dimensions. Second, spatial research in Bali emphasizes philosophical concepts, architectural applications, and community processes, with minimal attention devoted to the empirical distribution of public facilities and their compliance with formal planning instruments. This study bridges these two parallel trajectories by integrating quantitative spatial pattern analysis with regulatory compliance assessment through spatial plan overlay against the provincial RTRW zoning regulations, thereby addressing a significant interdisciplinary void in the empirical evaluation of education infrastructure provision within culturally distinct, rapidly urbanizing developing regions.

This research aims to investigate the spatial distribution patterns of educational facilities across Bali Province and to evaluate their alignment with spatial utilization policies as articulated in the RTRW. This study focuses on primary and secondary educational facilities using recent spatial data, with an emphasis on their locational configuration, clustering tendencies, and compliance with designated zoning regulations at both district and provincial levels. Accordingly, this study addresses the following questions: (a) what is the spatial distribution pattern of educational facilities at both the regency/city and provincial levels in Bali? and (b) to what extent do the locations of existing educational facilities conform to the spatial allocations stipulated in the regional spatial plans?

These findings are expected to contribute theoretically, methodologically, and practically to scholarly knowledge and

policy practice. Theoretically, it advances understanding of how normative planning frameworks intersect with empirical spatial outcomes in a culturally rich yet rapidly transforming developing country context. Methodologically, it integrates pattern analysis with compliance assessment to provide a replicable template for evaluating public facility distribution, moving beyond descriptive approaches to identify both empirical configurations and governance gaps. Practically, the findings offer Bali's provincial, regencies, and city planning agencies empirically-grounded evidence to inform RTRW revisions and educational infrastructure investments amid intensifying land-use competition and urbanization, ultimately supporting more equitable educational access for sustainable human development in one of Indonesia's most culturally significant provinces.

RESEARCH METHODOLOGY

This research was conducted in Bali Province, Indonesia, which comprises eight regencies (Badung, Bangli, Buleleng, Gianyar, Jembrana, Karangasem, Klungkung, and Tabanan) and one city (Denpasar) (Figure 1). The study area exhibits marked spatial heterogeneity in population density, economic activity, and urbanization, making it an appropriate setting for analyzing educational facility distribution and spatial policy compliance.

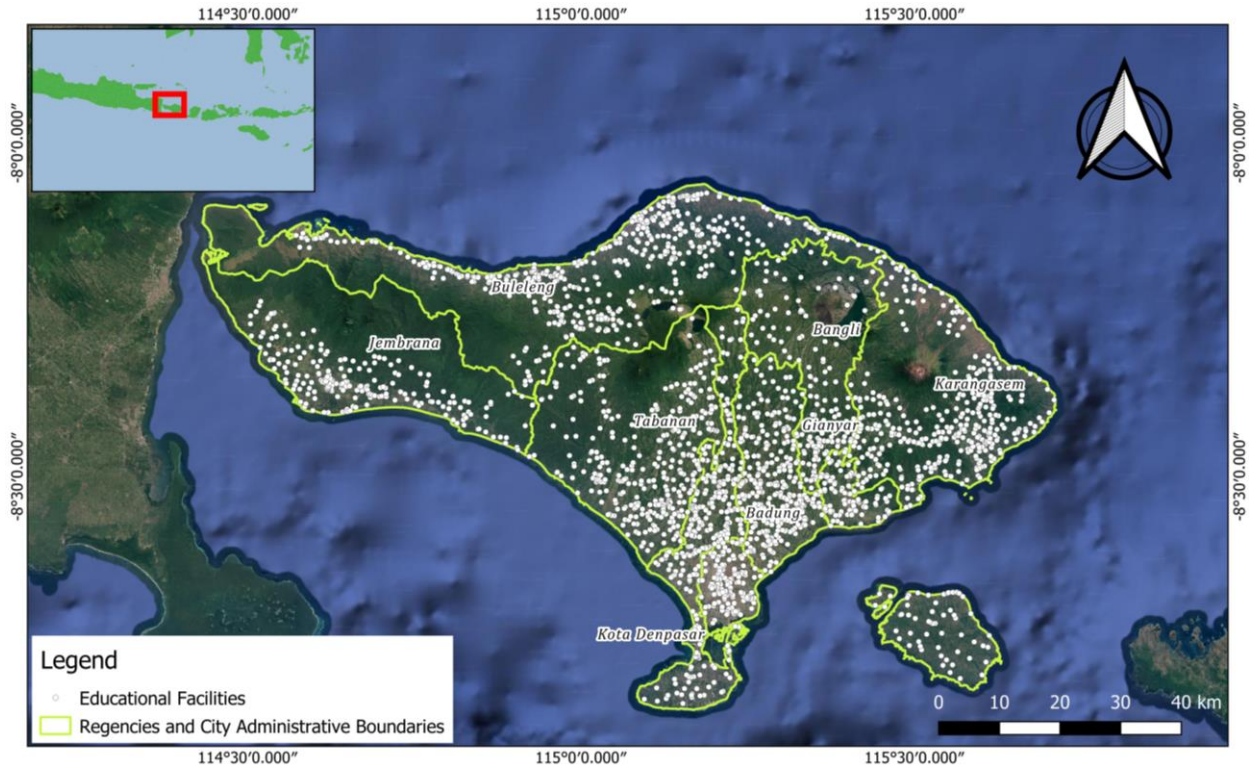


Figure 1. Study location and educational facilities
Source: BIG and Google Satellite Imagery (2026)

This study utilized two primary secondary datasets. First, the educational facilities dataset was obtained from the Geospatial Information Agency (*Badan Informasi Geospasial*/BIG), Indonesia's national mapping agency. The data represent point locations of formal educational institutions (primary and secondary levels) across Bali Province. The dataset's temporal reference is the release of the BIG database, around 2024–2025. The dataset indicates that there are 3,333 units of educational facilities in Bali Province, including formal primary and secondary schools, as well as higher education institutions and non-formal education providers.

Second, spatial pattern dataset: obtained from the Bali Provincial Public Works, Spatial Planning, Housing, and Residential Areas Office (*Dinas Pekerjaan Umum, Penataan Ruang, Perumahan dan Kawasan Permukiman Provinsi Bali*). This dataset is the official RTRW zoning map of Bali Province for the years 2023–2043 (Bali Provincial Regulation No. 2 of 2023).

To address the first research question, this study employed the Average Nearest Neighbor (ANN) method. This method measures the distribution pattern of point locations by comparing the observed mean distance between nearest neighboring points with the expected mean distance in a perfectly random pattern (Huang *et al.*, 2021).

The ratio is expressed as:

$$ANN = \frac{\overline{D}_O}{\overline{D}_E}$$

where $\overline{D}_O$ is the observed mean distance between each point and its nearest neighbor, and $\overline{D}_E$ is the expected mean distance for a random pattern given the study area and number of points. The interpretation of the ANN value is as follows: ANN < 1: Clustered pattern; ANN = 1: Random pattern; and ANN > 1: Dispersed pattern. Statistical significance is assessed via a z-score, with $p < 0.05$ indicating a pattern significantly different from random.

The ANN method was chosen for three main reasons. First, ANN produces a single interpretable summary statistic (the nearest-neighbor ratio) that directly answers the research question regarding whether the facilities are clustered, randomly distributed, or dispersed, without requiring parameter selection. Second, ANN is computationally efficient for medium-sized datasets and robust to boundary effects when the study area is well-defined. Third, ANN is the most widely used method in comparative spatial analysis of public facility distributions, which enhances comparability across studies. However, ANNs have limitations: they do not capture multiscale clustering patterns and assume isotropy (directional

independence) (Thompson *et al.*, 2022; Vidanapathirana *et al.*, 2022). These limitations are acknowledged, and the interpretation of ANN results is restricted to global clustering trends at the study area scale.

To address the second research question, a spatial overlay technique was employed. This method superimposes the educational facility point layer onto the RTRW zoning polygon layer using a point-in-polygon operation. Each facility point was assigned the zone attribute of the polygon within which it falls. Suitable was defined as any educational facility that complies with the regulations and was located within Residential Zones as designated by the RTRW. Other zones (Agricultural, Tourism, Protected, Defense/Security, and Mixed/Commercial/Other) were classified as non-suitable, with varying degrees of regulatory severity (prohibited vs. discouraged). Overlay analysis was conducted using QGIS. The analytical workflow in this study is described in Figure 2.

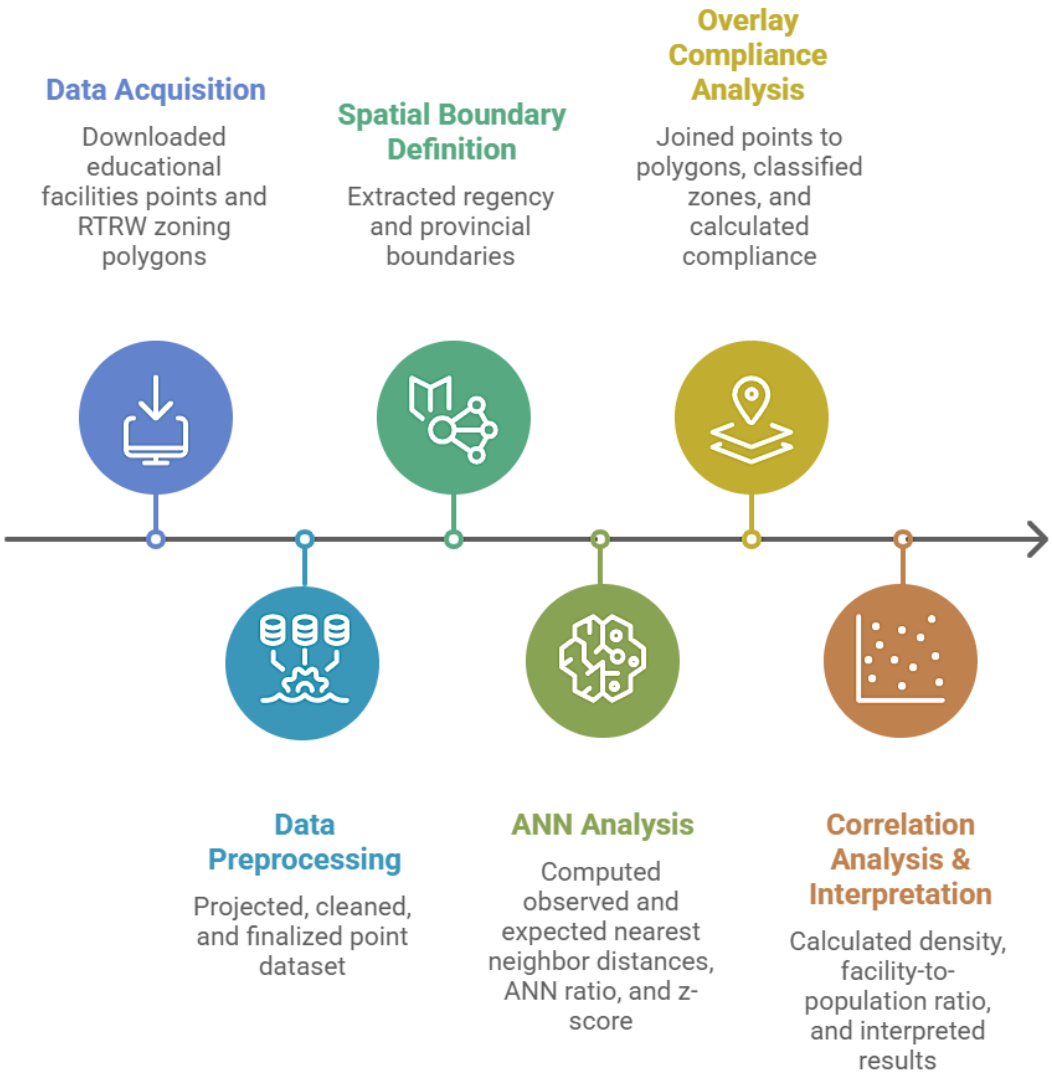


Figure 2. Step-by-Step Analytical Workflow
Source: author's processed results (2026)

This study has several methodological limitations. First, educational facilities are represented only as points, not building floor plans, which may lead to misclassification of compliance for facilities located on the boundaries of zones. Second, the ANN provides a global measure of clustering but cannot capture multiscale or local variations in distribution patterns. Third, there is a temporal mismatch between facility data and the RTRW, which potentially overestimates non-suitable for facilities built. Fourth, this study does not include accessibility metrics or demand-side factors, meaning zoning compliance does not automatically equate to equitable access. Finally, these findings are specific to the socio-cultural and tourism context of Bali and may not be generalizable to other provinces in Indonesia, although the methodological framework can be replicated. These limitations constrain but do not invalidate the core findings.

RESULT

1. Spatial Distribution Patterns of Educational Facilities in Bali Province

The analysis of educational facility distribution patterns in Bali Province was conducted using the ANN method at two spatial scales: the regencies or city level and the provincial level. The results, as presented in Table 1, reveal consistent findings across all regions: every regency or city in Bali Province exhibits a clustered distribution pattern with a very strong statistical significance.

Buleleng Regency demonstrated the most pronounced clustering ratio of educational facilities among all regencies and the city, with a value of 0.463445 (z-score = -22.721823). This was followed by Badung Regency (0.544342, z-score = -14.99738), Tabanan Regency (0.708871, z-score = -10.389787), and Karangasem Regency (0.722785, z-score = -10.24239 5).

Table 1. Summary of ANN

Administrative Region	Quantity	Observed Mean Distance (m)	Expected Mean Distance (m)	ANN	z-score	p-value	Distribution Type
Regency/Municipal							
Badung	296	477.7418	877.6495	0.544342	-14.99738	0.000000	Clustered
Bangli	161	894.1099	1117.9669	0.799764	-4.860551	0.000001	Clustered
Buleleng	490	547.9451	1182.3303	0.463445	-22.721823	0.000000	Clustered
Denpasar	155	397.8117	464.4812	0.856465	-3.418658	0.000629	Clustered
Gianyar	303	519.3696	615.7971	0.84341	-5.214533	0.000000	Clustered
Jembrana	214	722.9651	900.4337	0.802908	-5.515787	0.000000	Clustered
Karangasem	373	672.4679	930.384	0.722785	-10.242395	0.000000	Clustered
Klungkung	156	677.5257	941.6277	0.719526	-6.70171	0.000000	Clustered
Tabanan	348	639.2003	901.7166	0.708871	-10.389787	0.000000	Clustered
Province							
Bali	2496	599.3578	1050.0909	0.570768	-41.024733	0.000000	Clustered

Source: author's processed results (2026)

These findings indicate that educational facilities in these regencies are highly significantly concentrated in specific locations, particularly in urban settlement centers.

Conversely, Denpasar City exhibited the weakest clustering ratio of educational facilities, at 0.856465 with a z-score of -3.418658. Although statistically still classified as clustered, this comparatively higher ratio indicates that the distribution of educational facilities in Denpasar and Gianyar is relatively closer to a random pattern than in other regencies. This can be explained by Denpasar's characteristics as the provincial capital with the highest urbanization rate, where the development of educational facilities tends to be more evenly distributed to serve the high population density across all areas of the city.

At the provincial scale, the analysis of 2,496 educational facilities yielded a Nearest Neighbor Ratio of 0.570768 with a z-score of -41.024733. This confirmation affirms that, in aggregate, educational facilities in Bali Province also follow a clustered pattern. Notably, the provincial ratio value is lower (more clustered) compared to the average ratio value across all regencies and the city. This indicates that when viewed from a macro perspective, the clustering of educational facilities in Bali becomes increasingly pronounced. This phenomenon confirms the concentration of educational facilities in specific regions that serve as growth centers, particularly in the southern corridor (Denpasar-Badung-Gianyar) and parts of the northern region (Buleleng). That is why in the southern corridor, the GRDP and community welfare have a very positive impact on education (Putri and Purwanti, 2026) and serve as a major center of influence in the Province of Bali (Bharata, 2024).

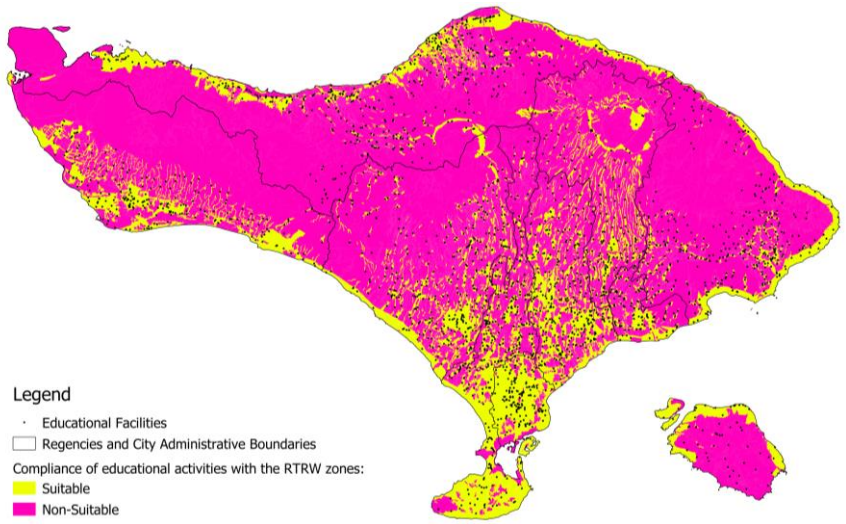


Figure 3. Distribution of educational facilities and RTRW zones suitable for educational activities
Source: author's processed results (2026)

2. Compliance with Spatial Utilization

Spatial overlay analysis reveals a substantial mismatch between the location of educational facilities and the zoning stipulated in Bali's RTRW (Figure 3). Across the province, only 124,560.5 ha (22.28%) of land is designated as suitable for educational activities, yet 1,858 out of 3,333 units (55.75%) fall within these suitable zones, while 1,475 units (44.25%) occupy areas deemed non-suitable. By zone, the majority reside in Residential Zones (1,818 units; 54.57%), which is normatively appropriate (Table 2). However, 470 units (14.10%) are in Agricultural Zones, where non-agricultural development threatens productive farmland, and 182 units (5.46%) are in Tourism Zones, creating land-use conflicts. Critically, four facilities lie in Protected Areas and one in a Defense and Security Zone, constituting clear regulatory violations.

Educational facility density varies dramatically across regencies, strongly mirroring population distribution. Denpasar City exhibits the highest density (749 facilities per 100 km^2), nearly 13 times the provincial average (57.7 per 100 km^2), while Jembarana and Bangli have the lowest densities (21.3 and 31.7 per 100 km^2, respectively). Pearson correlation analysis confirms a very strong positive relationship between facility density and population density ($r = 0.974$, $p < 0.001$), indicating that 94.9% of the variation in facility distribution is explained by population concentration. This responsiveness to demographic demand is a positive aspect of service provision, but simultaneously perpetuates spatial inequities, as sparsely populated rural areas remain underserved.

Table 2. Spatial Compliance of Educational Facilities by Zoning Category in Bali

RTRW Zones	Number of Facilities	Percentage (%)	Compliance Status	Key Implications
Residential Zone	1818	54.57	✓ Suitable	Normatively aligned, supports neighborhood-based access
Agricultural Zone	470	14.10	✗ Non-Suitable	Potential conversion of productive farmland
Tourism Zone	182	5.46	✗ Non-Suitable	Land use conflict, high economic pressure for relocation
Protected Areas	4	0.12	✗ Non-Suitable	Serious ecological/regulatory violation
Defense & Security Zone	1	0.03	✗ Non-Suitable	Critical regulatory breach
Mixed/Commercial/Other Zones	858	25.74	Varies	Area-specific compliance varies
Total	**3333**	**100**		

Source: author's processed results (2026)

Furthermore, a strong positive correlation exists between the percentage of suitable facilities (those in Residential Zones) and the urbanization rate per regency ($r = 0.817$, $p < 0.01$). More urbanized regions, such as Denpasar and Badung, display higher compliance, likely due to better planning enforcement and the historical alignment of schools with formal residential zones. Conversely, less urbanized regencies show lower compliance, reflecting the historical establishment of schools in agricultural and traditional village settings before RTRW formalization. This finding underscores that urbanization not only drives facility density but also enhances spatial planning adherence.

Three interconnected drivers explain these compliance gaps: (1) historical factors – many schools predate current RTRW regulations; (2) urbanization and tourism-driven land conversion, which has encroached onto agricultural zones; and (3) weak spatial law enforcement, as evidenced by facilities in protected and security zones. These patterns reveal a fundamental tension between empirical reality and normative planning, requiring evidence-based RTRW revision, strengthened enforcement mechanisms, and participatory planning (Budiman, Dialog and Anugrah, 2020; Pransisto, 2025) that integrates local spatial wisdom such as *Tri Hita Karana* (Wardana, 2024).

DISCUSSION

The finding that all administrative regions in Bali Province exhibit clustered patterns of educational facility distribution reflects complex geographical and socio-economic realities. Several studies of cities and regencies in China, Iran, and Indonesia have identified clustered patterns for educational facilities, particularly in urban areas or centers of activity, while outlying areas tend to be underserved (Ghodousi *et al.*, 2020; Huang, Cui, and Ma, 2023; Sitompul and Siagian, 2025). From a positive perspective, the clustered pattern demonstrates the responsiveness of educational service provision to population concentration. The majority of facilities located in residential zones indicates an effort to bring educational access closer to population settlements, aligning with the principle of efficient public resource allocation (Agbabiaka, Aguda, and Nzere, 2020; Al Fanatseh, 2024). Within this framework, clustering in urban areas such as Denpasar, Badung, and Gianyar constitutes a logical consequence of population concentration in Bali's southern corridor, known as the Sarbagita region.

However, a clustered distribution pattern is not equivalent to equitable access. While

clustering indicates that facilities are concentrated in certain locations, it does not measure whether all population groups, particularly those in peripheral or rural areas, can reach those facilities within reasonable travel time or distance (Wang and Zhou, 2022; Gu, Li, and Zheng, 2025). In Bali, the very low ANN values in Buleleng (0.463) and Karangasem (0.723) suggest that facilities are heavily concentrated in a few urban nodes, leaving vast rural areas with sparse coverage. This spatial configuration creates geographical barriers: children living outside these clustered centers may face long commutes, unsafe travel conditions, or prohibitive transportation costs, ultimately leading to lower enrollment and higher dropout rates (Todaro and Smith, 2024). Thus, statistical clustering, while methodologically robust, should not be misinterpreted as spatial justice.

The finding of clustered patterns in Bali is consistent with international evidence from other developing regions. In sub-Saharan Africa, studies in Nigeria have shown that primary schools are heavily concentrated in urban cores, with rural areas experiencing severe shortages (Agbabiaka, Aguda, and Nzere, 2020). Similarly, in India, educational mobility tends to be higher among upper-caste communities, who are more likely to be found in urban areas (Iversen *et al.*, 2026). In China, despite rapid educational expansion, the distribution of primary schools remains clustered around regency seats, where the effects of elevation and the varied topography of rural areas pose significant challenges, leading to school consolidation policies that have increased travel distances for rural children (Huang, Cui, and Ma, 2023; Zhu *et al.*, 2023). These international parallels suggest that clustered educational facility distribution is not unique to Bali but rather a common challenge in rapidly developing, tourism-driven, or agrarian economies where urbanization outpaces spatial planning. Bali's case, however, is distinctive because the clustering is exacerbated by the intense pressure of tourism-related land conversion, which has transformed agricultural zones into built-up areas.

The presence of educational facilities outside designated appropriate zones reflects a significant discrepancy between normative planning and empirical reality. Three interconnected drivers explain this gap. First, historical factors: many educational facilities were established long before the RTRW was formulated and enacted, and subsequent zoning changes did not retroactively relocate them. Similarly, in Russia and Europe, early educational facilities were shaped more by religion, politics, or community initiative than by formal planning models (Sirazeev

and Shuvaeva, 2025). Second, urbanization and tourism-driven land conversion: the rapid transformation of Bali's landscape has prompted the conversion of productive agricultural land into built-up areas, including for educational facilities. This phenomenon aligns with the findings of Ogiana and Dewi (2021) that spatial utilization dynamics often fall out of sync with formal planning documents. Third, weak spatial planning law enforcement: the presence of educational facilities in explicitly prohibited zones, such as protected areas (4 units) and defense and security zones (1 unit), indicates weaknesses in spatial utilization control mechanisms. The failure to control development in protected areas carries potential ecological impacts, confirming critiques that Indonesian spatial planning often remains trapped in normative aspects without adequate enforcement (Hudalah and Woltjer, 2007; Utami *et al.*, 2023).

It is intriguing to reflect on these findings within the framework of traditional Balinese spatial philosophy. The *Tri Hita Karana* concept, which emphasizes harmony between humans and God, among humans, and with the natural environment, inherently contains principles of harmonious spatial arrangement (Senastri, 2023; Mildawani *et al.*, 2024). In traditional conceptions, the determination of locations for various functions considered cosmological balance, reflected in the *Tri Mandala* pattern (Nurmala *et al.*, 2025). However, the unsuitability of educational facility locations reflects a tension between traditional spatial philosophy and the dynamics of modernity. Economic pressures, particularly from the tourism sector, have driven spatial transformations that often disregard local wisdom. As noted by Antaryama and Ananto (2013) and Abd Manaf *et al.* (2025), efforts to harmonize contemporary design with traditional values still face significant implementation challenges.

Methodological limitations and boundary effects inherent to this study warrant explicit discussion. While ANN provides a robust global measure of spatial clustering, it simplifies complex spatial patterns into a single ratio and does not capture multi-scale clustering nor local variations within a study area. For instance, a regency with a moderately clustered ANN value may contain both highly concentrated urban pockets and completely empty rural zones. Additionally, ANN assumes isotropy, which may not hold in a geographically constrained island province like Bali, where mountain ranges and coastal boundaries influence facility siting. To ensure the model's reliability, boundary effects were mitigated by using study area

polygons divided by area in accordance with the provisions set forth in Bali Provincial Regulation No. 2 of 2023. Data constraints include the point-only representation of facilities, which may misclassify compliance for facilities straddling zone boundaries, and the temporal mismatch between facility data and the RTRW. Despite these limitations, the core findings, that all regencies exhibit statistically significant clustering and that 44.25% of educational facilities are spatially non-suitable, remain valid.

The methodological framework combining ANN with spatial overlay compliance assessment is directly transferable to other Indonesian provinces and to developing countries facing similar challenges of rapid urbanization, weak spatial planning enforcement, and competition between agriculture, tourism, and public infrastructure. Any region with georeferenced facility points data and official zoning maps can replicate this analysis. However, the substantive findings are context-specific to Bali. Researchers applying this framework elsewhere should anticipate different drivers of non-suitability and adapt the interpretation accordingly.

Based on the research findings, three policy recommendations can be formulated. First, zoning flexibility and a school siting model based on GIS. The Bali Provincial Government should revise the RTRW to accommodate existing educational facilities in Agricultural and Tourism Zones through a zoning flexibility mechanism. Furthermore, future school siting should be guided by a GIS-based school siting model that incorporates: (a) population density thresholds; (b) maximum travel distance; (c) land suitability; and (d) alignment with RTRW residential zone designations. Digital spatial planning data used in GIS-based site selection will certainly help prevent the exploitation of space in protected areas, productive agricultural areas, and indigenous lands (Siregar, Nurlinda, and Priyanta, 2021; Ma'sura, Suparji, and Sadino, 2022; Susanto *et al.*, 2026).

Second, relocation policy for non-suitable facilities in high-risk zones. For the four educational facilities located in Protected Areas and the one in a Defense and Security Zone, the government should mandate a time-bound relocation of these facilities in accordance with the provisions set forth in Indonesian Government Regulation (*Peraturan Pemerintah*/PP) No. 39 of 2023 on Implementation of Land Acquisition for Development in the Public Interest.

Third, strengthening of spatial utilization control mechanisms. Beyond audits and enforcement, this requires: (a) establishing a provincial spatial compliance task force comprising National Land Agency (*Badan*

Pertanahan Nasional/BPN) and provincial government personnel to conduct annual spatial audits of all new educational facility permits; (b) mandating pre-construction spatial compliance verification; (c) integrating community-based spatial monitoring through the *Banjar* (traditional village) system, where village heads report any non-suitable construction to the task force. This participatory mechanism aligns with local wisdom while also strengthening spatial control and empowering the community (Abeng *et al.*, 2023; Utomo, Mulyanto, and Panuju, 2026).

CONCLUSION AND SUGGESTIONS

This study aimed to examine the spatial distribution patterns of educational facilities and evaluate their compliance with spatial planning policies in Bali Province. By integrating ANN analysis with spatial overlay compliance assessment, the study provides empirical evidence on both the clustering tendencies of educational infrastructure and their alignment with RTRW zoning regulations.

The findings reveal that all regencies and cities in Bali exhibit statistically significant clustered distribution patterns. At the provincial level, the ANN ratio of 0.571 indicates that educational infrastructure is heavily concentrated in population centers, particularly in the southern Sarbagita corridor and parts of northern Bali. A very strong positive correlation between facility density and population density confirms that facility distribution is responsive to demographic demand. However, a critical distinction must be emphasized: clustered patterns are not equivalent to equitable access. Communities outside these concentrated nodes likely face greater geographical barriers to accessing educational services, perpetuating spatial inequities.

Regarding compliance with spatial policies, the study uncovered a complex reality. 55.75% facilities are appropriately situated in Residential Zones, yet 44.25% facilities occupy areas inconsistent with the RTRW, including Agricultural Zones, Tourism Zones, and critically, Protected Areas and a Defense and Security Zone. The strong positive correlation between compliance rates and urbanization levels suggests that more urbanized regencies benefit from better planning enforcement. These discrepancies stem from three interconnected drivers: historical factors predating current regulations, rapid tourism-driven land conversion, and weak spatial law enforcement mechanisms.

Future research directions should extend this analysis in several ways. First, incorporating population data at finer spatial scales would enable a more precise assessment of whether facility locations

match actual population distribution, moving beyond regency-level aggregates. Second, temporal analysis examining changes in distribution patterns and compliance rates over multiple RTRW revision periods would reveal whether spatial planning effectiveness is improving or deteriorating. Third, integrating accessibility metrics and demand-side variables would transform the current compliance-focused diagnostic into a comprehensive spatial equity assessment. Fourth, applying multi-scale clustering methods would capture local variations that global ANN measures may obscure, particularly in topographically complex regions like Bali. Finally, comparative studies across multiple Indonesian provinces or other developing countries would test the transferability of the methodological framework and identify context-specific drivers of non-compliance. These findings highlight the broader challenge of balancing rapid urban development with equitable service provision in developing regions. In Bali, the tension between tourism-driven land conversion, *Tri Hita Karana* philosophies, and formal spatial planning has produced a landscape where nearly half of educational facilities operate outside designated zones. This paradox suggests that normative planning frameworks, if not regularly updated and enforced, risk becoming disconnected from empirical realities. For Bali and analogous regions worldwide, achieving spatial justice requires not only evidence-based RTRW revisions and strengthened enforcement but also participatory planning that integrates local wisdom and community needs into the formal spatial allocation process.

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