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SPATIAL DISTRIBUTION ANALYSIS OF ELEMENTARY SCHOOL POINTS USING GIS-BASED POISSON MODEL

Rahmat Idhami[1]*, Rian Farta Wijaya[2], Andri Saputra[3], Taufa Fadly[4], Hengki Gunawan[5], Ryan Fahreza Pasaribu[6]
Magister Teknologi Informasi, Universitas Pembangunan Panca Budi, Medan, Indonesia
E-mail: idhami531@gmail.com, rianfartawijaya@gmail.com, asaputra14183@gmail.com, taufan.fadly@gmail.com, hengkigunawan1591@gmail.com. ryanfahreza16@gmail.com.

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Abstract
The equitable distribution of basic education facilities is an important indicator of fair regional planning. This study analyzes the spatial distribution pattern of Elementary School (SD) points in Bener Meriah Regency, Aceh Province, and models the number of schools against regional sub-district characteristics using a Geographic Information System (GIS) approach integrated with Poisson regression. School data were obtained from the Indonesian Ministry of Education's reference database (Dapodik), covering a full census of 143 SD-equivalent schools across 10 sub-districts, with a stratified random sub-sample of 34 geocoded schools used for point pattern analysis. Spatial pattern was assessed using Average Nearest Neighbor (ANN) analysis, while the effect of population on school count per sub-district was modeled using Poisson regression with area as an exposure offset. The ANN result yielded a ratio of $R = 0.80$ ($z = -2.24$; $p < 0.05$), indicating a statistically significant clustered pattern. The Poisson model across 10 sub-districts showed population to be a significant positive predictor of school count (IRR = 1.086 per 1,000 people; $p < 0.001$), although overdispersion was detected (deviance/df = 6.93), suggesting a Negative Binomial model for future work with a larger number of analysis units. These findings indicate spatial inequality in elementary school provision across sub-districts that warrants attention in education facility planning in Bener Meriah Regency.

Keywords: spatial distribution, elementary school, Poisson model, GIS, Bener Meriah

INTRODUCTION

The availability and equitable distribution of basic education facilities is a crucial indicator of successful human resource development. Basic education serves not only as a means to improve students' literacy, numeracy, and character, but also as a key foundation for building a competitive society. Therefore, providing adequate and proportionally distributed educational facilities across all regions is the government's responsibility, as mandated by the constitution and various national education policies. Equitable access to education is crucial for realizing social justice, reducing disparities between regions, and supporting the achievement of the Sustainable Development Goals (SDGs), particularly the fourth goal on inclusive and equitable quality education. Elementary schools (SD), as the first level of formal education, play a strategic role in ensuring the continuity of the compulsory education program and in developing the academic, social, and character skills of students. Accessible SDs will increase school enrollment rates, reduce the risk of dropping out, and provide equal opportunities for all school-age children to receive adequate education. Conversely, the uneven distribution of schools can lead to various problems, such as increasing distances for students to school, disparities in the quality of educational services, and even limited access to education for people living in remote areas. Therefore, evaluating the distribution of basic education facilities is a crucial aspect in supporting effective and equitable educational development planning.

Bener Meriah Regency is a regency in Aceh Province with quite complex geographic and demographic characteristics. This region covers an area of approximately 1,454–1,942 km² according to various official sources, with topography dominated by mountainous areas, hills, and highlands. The physical characteristics of this region cause uneven distribution of population settlements, influenced by both geographic conditions and transportation networks. Most of the population is concentrated in several sub-districts with better accessibility, while other areas have relatively small populations and geographical conditions that are more difficult to reach. Based on population data, there are significant differences in population density between sub-districts, ranging from Wih Pesam District with a density of approximately 404 people/km² to Syiah Utama District with only around 3 people/km². These differences in regional characteristics have the potential to affect the need for and provision of basic education facilities in each sub-district. Differences in population, area, and geographic conditions mean that the need for educational facilities cannot be equalized in each region. Districts with large populations tend to require more schools to accommodate their students, while districts with large areas but small populations still require schools to ensure access to educational services without having to travel long distances. Therefore, an analysis of the distribution of educational facilities requires more than just considering the number of schools available; it must also consider the spatial characteristics of the region, population distribution, and the scope of services provided by each school.

The development of information technology provides enormous opportunities to support data-driven development planning processes. One technology widely used in regional analysis is the Geographic Information System (GIS). GIS is a system capable of integrating spatial and attribute data, enabling users to visualize, map, analyze, and model various spatial phenomena. In the field of education, GIS has been widely used to map the distribution of educational facilities, evaluate the level of accessibility of educational services, identify areas experiencing a shortage of educational facilities, and support the decision-making process in the construction of new schools. The advantage of GIS lies in its ability to present information visually, facilitating an understanding of the distribution patterns of educational facilities and the relationship between geographic conditions and community needs. In addition to the spatial approach through GIS, statistical analysis is also needed to understand the factors that influence the number of educational facilities in a region. One data characteristic often encountered in research on public facilities is count data , which is data in the form of non-negative integers, such as the number of schools, the number of health facilities, or the number of other service facilities. For this type of data, the Poisson regression model is one of the most appropriate statistical approaches because it belongs to *the Generalized Linear Model* (GLM) family, specifically designed to model count data. Unlike classical linear regression, which assumes a normally distributed response variable and can produce negative predictive values, Poisson regression uses a logarithmic relationship function, so the resulting predictive value is always positive and more in line with the characteristics of the number of schools as the response variable. Furthermore, this model allows the use of *exposure variables* , such as area size, so the analysis can take into account differences in the size of the areas covered by educational services.

In spatial studies, the distribution pattern of an object can also be analyzed using *the Average Nearest Neighbor Analysis (ANN) method* . This method is used to determine whether school locations have a clustered, dispersed, or random pattern . Information about *this* distribution pattern is very important because it can provide an overview of the level of equality of educational facilities in a region. If schools tend to be clustered in certain areas, there is a possibility that other areas have not received optimal educational services. Conversely, a more even distribution pattern indicates that the provision of educational facilities has taken into account the aspect of equal community access to educational services. Based on this description, this study integrates spatial analysis using GIS with a statistical approach through a Poisson regression model to provide a more comprehensive picture of the distribution of elementary schools in Bener Meriah Regency. The integration of these two approaches is expected to not only be able to explain the geographical distribution pattern of schools but also identify the relationship between population size and the intensity of the existence of elementary schools in each sub-district by considering the area as an *exposure factor* . This approach provides advantages because it combines spatial information and quantitative analysis so that research results can be used as a basis for formulating more targeted educational development policies.

Specifically, this study aims to answer two main questions, namely: (1) how is the spatial distribution pattern of Elementary School location points in Bener Meriah Regency based on the *Average Nearest Neighbor analysis* , and (2) how does the population influence the intensity or number of Elementary Schools at the sub-district level by considering the area as an *exposure factor* in the Poisson regression model. The results of the study are expected to provide scientific contributions in the development of educational spatial analysis methods, as well as being a practical reference for local governments in planning the development and distribution of basic education facilities more effectively, efficiently, and based on evidence (*evidence-based policy*), so that access to quality education can be felt evenly by all people of Bener Meriah Regency.

LITERATURE REVIEW

2.1 Point Pattern Analysis and *Average Nearest Neighbor*

Point pattern analysis *is* a method in spatial analysis used to identify the distribution characteristics of objects represented as points in a region. This analysis aims to determine whether a phenomenon has a tendency to be clustered , spread uniformly (*dispersed*), or spread randomly (*random*). In various studies of geography, regional planning, health, and education, point pattern analysis is an important approach because it is able to describe the relationship between the location of an object and the characteristics of the space it occupies. In research on educational facilities, point pattern analysis can provide information on the level of distribution of school locations and thus can serve as a basis for evaluating the effectiveness of the provision of educational services to the community.

One of the most widely used methods in point pattern analysis is *Average Nearest Neighbor Analysis* (ANN). This method works by comparing the average distance of the nearest neighbor obtained from the observation results with the average distance expected if the points were distributed randomly (*Complete Spatial Randomness* or CSR). In other words, ANN evaluates whether the distance between the observed objects is closer or further compared to the theoretically generated random pattern. This analysis produces an index called *the Nearest Neighbor Ratio* (R), which is the comparison between the average distance from the observation results with the average distance expected in a random distribution.

Mathematically, the ANN ratio value is expressed as

$$R=\frac{\bar{d}_o}{\bar{d}_e}$$

where ($\bar{d}_o$) is the average nearest neighbor distance from the observed results, while ($\bar{d}_e$) is the average expected distance based on a random distribution. The ratio value is the main indicator in determining the distribution pattern of objects. If the value ($R<1$), then the points tend to be close together, thus forming a clustered pattern . Conversely, if the value ($R>1$), then the points tend to be far apart, thus indicating a uniformly distributed pattern (*dispersed*). Meanwhile, an (R) value approaching one indicates that the distribution of objects follows a random *pattern* .

In addition to calculating the ratio value, ANN also uses a statistical test in the form of *a z-score* to determine whether the obtained pattern is significantly different from the random pattern. The *z-score value* is calculated based on the difference between the average observed distance and the average expected distance, then divided by the standard deviation of the theoretical distribution. At a significance level of 5%, the value ($|z| > 1.96$) indicates that the distribution pattern is significantly different from the random pattern. A negative *z-score value* indicates a tendency for the pattern to be clustered, while a positive value indicates a pattern that is more spread out than the random distribution. Thus, the interpretation of ANN results is not only based on the ratio value (R), but also considers the *z-score* and *p-value* to ensure the statistical significance of the observed pattern. In the context of this study, the ANN method was used to analyze the distribution pattern of elementary school locations in Bener Meriah Regency. The results of the analysis are expected to be able to show whether school locations have been distributed proportionally following the distribution of the population or are still concentrated in certain areas. This information is very important in evaluating the level of equity of basic education services, especially considering that Bener Meriah Regency has geographical characteristics in the form of a mountainous region with an uneven population distribution. If a clustered pattern is found, this could indicate that there is still an imbalance in the provision of educational facilities which needs to be taken into account in planning future educational development.

2.2 Poisson Regression and *Exposure/Offset Models*

Poisson regression is a statistical analysis method belonging to *the Generalized Linear Model* (GLM) family and is specifically designed to model response variables in the form of count data . Count data is data in the form of non-negative integers, such as the number of schools, the number of hospitals, the number of poor people, the number of disease cases, or the number of other public facilities. Unlike linear regression, which assumes a normally distributed response variable, Poisson regression uses the Poisson distribution, which is more appropriate for the characteristics of count data, thus producing more accurate parameter estimates.

In the Poisson regression model, the response variable is assumed to follow a Poisson distribution with parameter (μ_i), which states the expected value or average number of events in the i-th observation unit. One of the main characteristics of the Poisson distribution is that the mean and variance have the same value (*equidispersion*), so that

$$E(Y_i)= Var(Y_i)=\mu_i.$$

The relationship between the expected value and the independent variable is formed using a logarithmic link function *to* obtain a model.

$$\ln(\mu_i)= \beta_0+\beta_1X_{1i}+\beta_2X_{2i}+\cdots+\beta_pX_{pi},$$

where (β_0) is the intercept, while (β_j) is the regression coefficient that shows the magnitude of the influence of each independent variable on the change in the average number of events. The use of the logarithmic function ensures that the predicted value generated by the model is always positive, in accordance with the characteristics of count data which cannot have negative values.

In many spatial studies, each unit of analysis often has a different area size. This condition causes the number of observed events to be influenced not only by the explanatory variables, but also by the size of the observation area. Therefore, the Poisson regression model can be developed by including *exposure* or *offset variables* . The *offset variable* is a variable whose coefficient is set equal to one, thus functioning as an adjustment for differences in the size of the analysis unit. In this study, the area of the sub-district is used as the *offset variable* because each sub-district has a different area, so the probability of the existence of an elementary school is also influenced by the size of the area to be served.

The Poisson regression model with *offset* can be written as

[\ln(\mu_ i)= \ln(\text{Area} *i)+\beta_0+\beta_1X* {1i},]

where (\mu_i) is the expected number of elementary schools in the i-th sub-district, while (\ln(\ text{ Area}_i)) is the *offset component* that represents the size of the area. By including this component, the model no longer estimates the absolute number of schools, but rather the intensity or rate of *the* number of schools relative to the area. This approach produces a more proportional interpretation because it takes into account differences in geographic size between regions.

The regression coefficients in the Poisson model are interpreted using an exponential function. The value (e^{\beta_j}) is known as *the Incidence Rate Ratio* (IRR), which indicates the relative change in incidence rate due to a one-unit increase in the independent variable, assuming other variables remain constant. If the IRR is greater than one, then an increase in the independent variable will increase the incidence rate. Conversely, if the IRR is less than one, then an increase in the independent variable will decrease the incidence rate.

One of the important assumptions in Poisson regression is the fulfillment of the condition *of equidispersion* , namely the mean and variance of the data have relatively equal values. However, in practice, it is often encountered in conditions where the variance is much greater than the mean (*overdispersion*). Overdispersion can cause the standard deviation of the coefficient to be biased, so that hypothesis testing produces less accurate conclusions. Therefore, it is necessary to examine the *deviance value* and *Pearson Chi-Square* compared to the degrees *of freedom* . If the *deviance/df* or *Pearson Chi-Square/df ratio* is much greater than one, then the Poisson model is considered to be overdispersion.

When overdispersion occurs, a more appropriate model is Negative Binomial Regression . This model is an extension of Poisson regression by adding a dispersion parameter to accommodate variances greater than the mean. Using the Negative Binomial model results in more stable parameter estimates, more accurate standard deviations, and more reliable statistical tests. Therefore, in the analysis of count data, evaluating the equidispersion assumption is a crucial step before drawing conclusions about the influence of the analyzed variables.

In this study, a Poisson regression model was used to analyze the relationship between population as the independent variable and the number of elementary schools as the response variable in each sub-district in Bener Meriah Regency. Sub-district area was included as an *offset variable* to obtain a more proportional estimate of the intensity of the number of schools. Furthermore, the model results were evaluated through parameter significance testing, *Incidence Rate Ratio* (IRR) interpretation, and overdispersion checks to ensure that the model was appropriate to the characteristics of the research data.

METHOD

3.1 Research Location

The research was conducted in Bener Meriah Regency, Aceh Province, which consists of 10 sub-districts: Timang Gajah, Bukit, Bandar, Permata, Pintu Rime Gayo, Wih Pesam, Syiah Utama, Bener Kelipah, Mesidah, and Gajah Putih.

3.2 Data Sources and Scope

- Data on elementary school/equivalent education units (complete census of 143 schools) is sourced from the Ministry of Education and Culture's Education Reference Data (referensi.data.kemendikdasmen.go.id), including school name, NPSN, sub-district, village, and status (public/private).
- A subsample of geographic coordinates (latitude/longitude) for 34 schools, randomly stratified proportional to the number of schools in each sub-district, was sourced from each school's profile page on the same site.
- Data on area, population, and population density per sub-district in 2024 are sourced from the Central Statistics Agency (BPS) of Bener Meriah Regency, as published in the official regional profile.

3.3 Analysis Stages

1. Compilation of school data per sub-district from all 10 sub-districts to obtain the number of elementary schools/equivalent in a full census (n = 143).
2. Sub-sampling of 34 school coordinate points was randomly stratified proportionally per sub-district for point pattern analysis.
3. Projection of geographic coordinates onto a flat plane (equirectangular, km) with the reference point being the mean latitude of the study area, for the purpose of calculating Euclidean distances.
4. The Average Nearest Neighbor Analysis calculation uses the kd tree algorithm (k=2) to obtain the nearest neighbor distance for each point, the R ratio, and the z-score, with the district area (1,454.09 km², BPS) as the basis for calculating the expected distance of the random pattern.
5. The construction of a Poisson regression model at the sub-district unit (n = 10), with the number of elementary schools as the dependent variable, the population as the independent variable, and the logarithm of the area as the offset (exposure), was estimated using the Iteratively Reweighted Least Squares (IRLS) algorithm.
6. Model evaluation through residual deviance, deviance/df ratio (overdispersion test), pseudo R^2 (McFadden), and visualization of observed vs. predicted values.

3.4 Analysis Tools

Spatial data processing and visualization using Python (pandas, NumPy, SciPy for kd tree calculation and nearest neighbor analysis; Matplotlib for visualization), with Poisson model estimation calculated manually via the IRLS algorithm following the Generalized Linear Model framework.

RESULTS AND DISCUSSION

4.1 Distribution of Elementary Schools per District

The results of the Ministry of Education and Culture's data compilation show that there are 143 elementary schools (SD/equivalent) (including State Islamic Elementary Schools) spread across 10 sub-districts in Bener Meriah Regency. Pintu Rime Gayo Sub-district has the largest number of schools (23 units), followed by Timang Gajah, Bandar, and Wih Pesam (19 units each), while Syiah Utama (4 units) and Bener Kelipah (5 units) have the fewest number of schools, in line with their low population densities and their very large (Syiah Utama) or very small (Bener Kelipah) areas.

Subdistrict	Number of elementary schools	Area (km²)	Population (people)	Density (people/km²)
Rime Gayo Gate	23	223.56	16,583	74
Holding an Elephant	19	98.28	23,730	241
port	19	82.10	30,573	372
Wow, Pesam	19	66.28	26,786	404
Hill	18	110.95	32,840	296
Gemstone	17	159.66	23,758	149
White Elephant	11	75.57	10,231	141
Messiah	8	286.83	6,029	21
True Kelipah	5	26.75	5,701	213
Main Shia	4	814.63	2,775	3

Table 1. Number of Elementary Schools/Equivalent and Regional Characteristics per District, Bener Meriah Regency (Source: Ministry of Elementary and Secondary Education, processed; BPS Bener Meriah Regency 2025)

4.2 Results of Spatial Pattern Analysis (Average Nearest Neighbor)

The analysis was conducted on a subsample of 34 schools distributed proportionally across 10 sub-districts. The sample distribution map is shown in Figure 1.

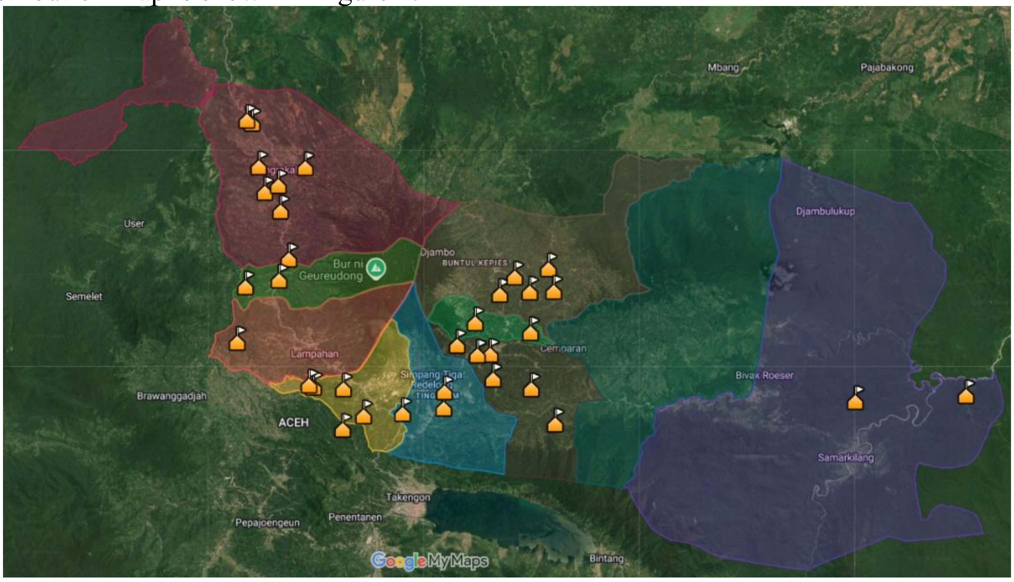

Figure 1. Distribution Map of Elementary School Sample Points (n=34), Bener Meriah Regency

The calculation results show that the average nearest neighbor distance from the observed results is 2.61 km, while the expected average distance under random conditions (based on an area of 1,454.09 km² and n = 34) is 3.27 km. The resulting nearest neighbor ratio is R = 0.80 with a z-score = -2.24. Since |z| > 1.96, this result is statistically significant at the 5% level of significance and indicates that the distribution pattern of elementary school points in Bener Meriah Regency is clustered, neither random nor uniform.

Parameter	Mark
Number of sample points (n)	34
Reference area (km²)	1,454.09
Average observation distance (km)	2,6131
Average expected/random distance (km)	3,2698
Nearest Neighbor Ratio (R)	0.7992
z-score	-2.2403
Interpretation	Clustered, significant ($p<0.05$)

Table 2. Results of Average Nearest Neighbor Analysis

This clustering pattern is in line with the characteristics of settlements in Bener Meriah Regency which are concentrated in areas with relatively flat topography and main road access (such as the Lampahan–Simpang Tiga Redelong–Pondok Baru corridor), while hilly and remote areas such as Syiah Utama have much greater distances between schools, as seen from the distance value of the nearest neighbors of Amor State Elementary School and Samar Kilang State Elementary School which reaches around 9.97 km, far above the district average.

4.3 Results of the Poisson Regression Model at the District Level

A Poisson regression model was constructed in 10 sub -districts with the number of elementary schools as the dependent variable, the population (in thousands) as the independent variable, and the logarithm of the area as the offset/exposure. The parameter estimation results are presented in Table 3.

Variables	Coefficient (β)	Std. Error	z	p-value	IRR = exp(β)
Constant	-3.9955	0.1929	-20,708	<0.001	0.0184

Population (per 1,000 people)	0.0828	0.0080	10,386	<0.001	1,0864

Table 3. Results of Poisson Regression Model Parameter Estimation (offset = log area)

The coefficient of the population variable is positive and statistically significant ($p < 0.001$), with an Incidence Rate Ratio (IRR) of 1.0864. This means that, with area controlled as exposure, every 1,000 additional residents in a sub-district is associated with an average increase in the number of elementary schools of 8.64%. This result is substantively in line with the logic of educational facility planning, namely that the number of schools tends to follow the size of the population to be served.

The model evaluation yielded a residual deviance of 55.46 with degrees of freedom (df) = 8, resulting in a deviance/df ratio of 6.93. This value far exceeds 1, indicating significant overdispersion in the model—the variance of the elementary school count data across sub-districts is greater than that assumed by a pure Poisson distribution. A pseudo R^2 (McFadden) value of 0.548 indicates the model is able to explain some of the variation in the data, but the detected overdispersion indicates the presence of other factors (e.g., topography, road accessibility, or past school placement policies) that are not captured by the population variable alone.

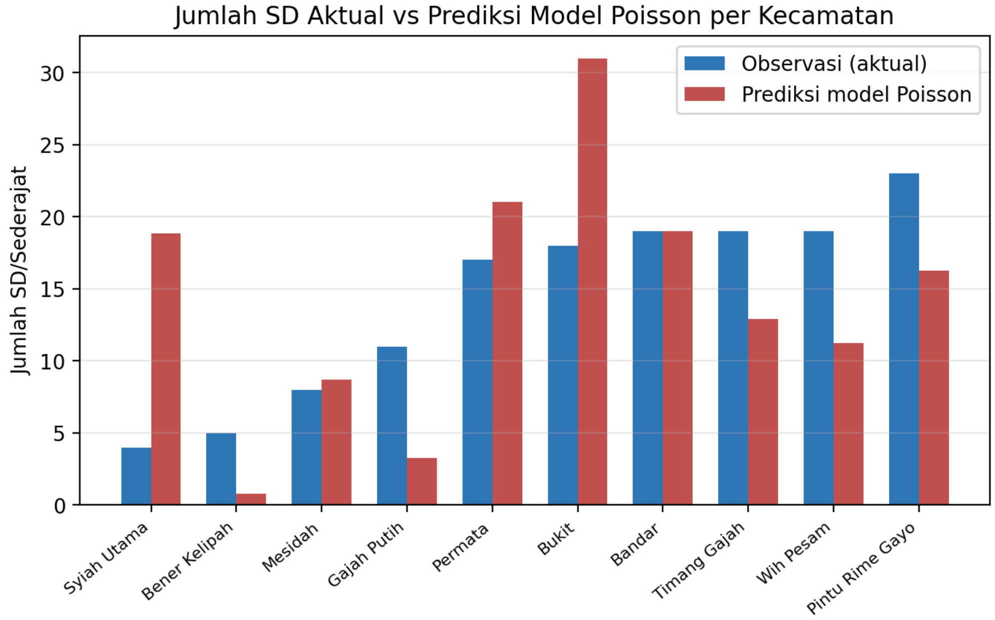

Figure 2. Comparison of the Actual Number of Elementary Schools and the Predicted Results of the Poisson Model per District

Figure 2 shows that the model under-predicts the Timang Gajah, Gajah Putih, Pintu Rime Gayo, and Wih Pesam sub-districts—these sub-districts have a higher number of elementary schools than would be expected based solely on population, likely due to historical school development or widespread settlement dispersion. Conversely, the model over-predicts Bukit and Syiah Utama. Bukit sub-district, despite its large population (32,840), has a relatively lower number of elementary schools (18 units) than the model predicts, indicating potential school capacity pressures and making it a priority candidate for facility expansion. The over-predictions for Syiah Utama are due primarily to its very large area (814.63 km²) which dominates the offset value, despite its very small population (2,775 people)—underscoring the model's limitations when area variation across units is extreme.

4.4 Implications for Educational Facilities Planning

The combination of clustering pattern (ANN) findings and sub-district-level Poisson models indicates that the distribution of elementary schools in Bener Meriah Regency generally follows the population distribution, but with significant deviations in some sub-districts. Bukit Sub-district, with the largest negative residual (the actual number of schools far below population-based predictions), can be a priority for evaluating the capacity and needs of new schools, while very large and sparsely populated sub-districts such as Syiah Utama and Mesidah require different strategies, such as one-roof schools or student transportation, because the population-to-school ratio approach alone does not account for the challenges of distance and geographic accessibility in these areas.

CONCLUSION

Based on the results of the analysis of real data of 143 elementary schools/equivalent and a sub-sample of 34 coordinate points in Bener Meriah Regency, it can be concluded: (1) the spatial distribution of elementary school points is significantly clustered ($R = 0.80$; $z = -2.24$; $p<0.05$), concentrated in residential corridors and main roads; (2) population has a positive and significant effect on the number of elementary schools per sub-district (IRR = 1.086 per 1,000 people; $p<0.001$) with area as exposure, but the model shows overdispersion (deviance/df = 6.93) which indicates the presence of other explanatory factors beyond population; and (3) Bukit sub-district is identified as a priority candidate for evaluation of additional elementary school facilities based on the residual model, while large, sparsely populated sub-districts such as Syiah Utama and Mesidah require a planning approach that takes into account distance and accessibility, not just population ratio.

Further research is recommended to: (a) use the full census coordinates of 143 schools (not a sub-sample) to improve the accuracy of the point pattern analysis; (b) add units of analysis (e.g., at the village/grid level, not just 10 sub-districts) so that Poisson and Negative Binomial models can be estimated with greater degrees of freedom; and (c) add topography and road network variables to explain variations not captured by the population variables.

DATA AVAILABILITY

Data on the number of schools are sourced from the Education Reference Data, Ministry of Primary and Secondary Education of the Republic of Indonesia (referensi.data.kemendikdasmen.go.id), accessed June 2026. Data on area, number, and population density per sub-district are sourced from the Central Statistics Agency of Bener Meriah Regency (2025 publication, as cited in the official area profile). The coordinates of the sub-sample of 34 schools and the analysis program code are available upon request to the authors.

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