Original Research

Indonesian Journal of Health Administration
(Jurnal Administrasi Kesehatan Indonesia)
p-ISSN 2303-3592, e-ISSN 2540-9301
10.20473/jaki.v13i1.2025.68-81

SPATIAL ANALYSIS FOR MICROPLANNING TO ADDRESS IMMUNIZATION INEQUALITIES IN INDONESIA

Analisis Spasial terhadap Perencanaan Mikro untuk Mengurangi Ketimpangan Cakupan Imunisasi di Indonesia

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Abstract

Background: To achieve high and equitable immunization coverage, it is important to understand the access and utilization barriers, as well as the influencing determinants among population groups.
Aims: This study aims to identify high-risk regencies and explore the application of spatial analysis to support microplanning in immunization programs.
Methods: This study employed an implementation research design conducted in Aceh Province, Indonesia. Secondary datasets on immunization coverage, health human resources, facilities, and socio-economic parameters were analyzed. Focus group discussions (FGDs) and training sessions were conducted with health workers.
Results: The average coverage of universal child immunization (UCI) across villages was 24.18%, while complete basic immunization (CBI) reached 55.85%. In general, regencies with low UCI and CBI often had limited human resources, inadequate health facilities, and a high proportion of high-risk populations. This study identified hot spots and cold spots in the study area. Additionally, participants reported that mapping using the application was easier and beneficial for supporting the preparation of immunization micro-planning.
Conclusion: Spatial analysis can help address inequalities in immunization services and support resources during immunization. Qualitative approaches provided a deeper understanding of undocumented information. The use of mapping applications facilitated more effective microplanning in immunization programs.

Keywords: Child mortality, health risk, immunization, microplanning, vaccine.

Abstrak

Latar Belakang: *Untuk mencapai cakupan imunisasi yang tinggi dan merata, penting untuk memahami hambatan akses dan pemanfaatan serta faktor penentu yang memengaruhi di antara kelompok populasi.*
Tujuan: *Penelitian ini mengidentifikasi daerah berisiko tinggi dan mengeksplorasi penerapan analisis spasial dalam mendukung perencanaan mikro dalam program imunisasi.*
Metode: *Penelitian ini menggunakan desain penelitian implementasi yang dilakukan di Provinsi Aceh, Indonesia. Data sekunder yang digunakan adalah data cakupan imunisasi, sumber daya manusia di bidang kesehatan, fasilitas, dan parameter sosial ekonomi. Diskusi kelompok terarah (FGD) dan pelatihan dilakukan bersama petugas kesehatan.*
Hasil: *Rata-rata cakupan UCI di desa yaitu 24,18%, sedangkan cakupan imunisasi dasar lengkap (CBI) yaitu 55,85%. Secara umum, kabupaten dengan cakupan UCI dan CBI rendah sering ditemukan memiliki sumber daya manusia yang rendah, fasilitas kesehatan yang tidak memadai, dan proporsi masyarakat berisiko tinggi yang tinggi. Penelitian ini mengungkap adanya* hot spot *dan* cold spot *di wilayah penelitian. Selain itu, para peserta berpendapat bahwa pemetaan menggunakan aplikasi lebih mudah digunakan dan diperlukan untuk mendukung kegiatan perencanaan mikro terkait imunisasi.*
Kesimpulan: *Analisis spasial dapat membantu mengurangi ketimpangan layanan imunisasi dan sumber daya pendukung selama imunisasi. Pendekatan kualitatif dapat memberikan pemahaman yang lebih baik tentang informasi yang tidak terdokumentasi. Penggunaan aplikasi pemetaan membuat perencanaan mikro terkait imunisasi lebih efektif.*

Kata kunci: *Imunisasi, kematian anak, perencanaan mikro, risiko kesehatan, vaksin.*

Indonesian Journal of Health Administration (*Jurnal Administrasi Kesehatan Indonesia*)
p-ISSN 2303-3592, e-ISSN 2540-9301, Volume 13 No.1 2025, DOI: 10.20473/jaki.v13i1.2025.68-81
Received: 2025-03-26, Revised: 2025-06-02, Accepted: 2025-06-16, Published: 2025-06-30.
Published by Universitas Airlangga in collaboration with *Perhimpunan Sarjana dan Profesional Kesehatan Masyarakat Indonesia (Persakmi)*.
How to cite:
Astutik, E., Hargono, A., Artanti, K. D., Hidajah, A. C., Husnina, Z., Sari, S. S. N., Sitohang, R. V., Surya, A., Hapsari, R. B., and Feletto, M. (2025). Spatial Analysis for Microplanning to Address Immunization Inequalities in Indonesia. *Indonesian Journal of Health Administration*, 13(1), pp. 68–81. https://doi.org/10.20473/jaki.v13i1.2025.68-81

Indonesian Journal of Health Administration
(Jurnal Administrasi Kesehatan Indonesia)
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Introduction

The National Health System is a health management initiative carried out by all components of the Indonesian nation in an integrated and mutually supportive manner to ensure the achievement of public health programs. According to the Presidential Regulation of the Republic of Indonesia Number 72 of 2012, the National Health System serves as a reference in the preparation and implementation of health development, including planning, monitoring, and evaluation. Achieving the highest standard of public health requires initiatives to prevent the occurrence of diseases, including through immunization (Regulation of the Minister of Health of the Republic of Indonesia Number 12 of 2017).

Despite these efforts, immunization-preventable diseases continue to pose a significant public health challenge in many developing countries, including Indonesia. The immunization program is regarded as a crucial effort to prevent the occurrence of these diseases (WHO, 2025). In 2018, approximately 19.7 million children worldwide did not receive routine immunization services, with approximately 60% of them residing in 10 countries, including Indonesia (WHO, 2020).

In Indonesia, only 35.8% of children aged 12 to 23 months received complete basic immunization. Compared to 2018, the coverage of complete basic immunization for this age group in 2023 did not met the target and even declined (Indonesian Ministry of Health, 2023).

The coverage of the comprehensive immunization program (CIP) in Indonesia remains challenging to achieve, despite being provided free of charge. In 2023, an estimated 14.5 million infants did not receive their first dose of the DTP vaccine, while an additional 6.5 million were only partially vaccinated. This situation is primarily due to a lack of access to immunization and other essential health services. Of the total 21 million children, less than 60% reside in just 10 countries, one of which is Indonesia (WHO, 2024). The geographical disparities within the country can significantly hinder the complete immunization coverage (Rajaonarifara *et al*., 2022; Dimitrova *et al*., 2023). Additionally, long distance to health facilities contributes to delays in immunization (Sriatmi *et al*., 2023). A study has shown that regions with limited health infrastructure are associated with lower rates of childhood immunization coverage (Allan, Adetifa and Abbas, 2021).

Aceh is the province with the lowest rate of CIP coverage (3.9%) (Indonesian Ministry of Health, 2023). Additionally, debates over the halal and haram status of vaccines—whether they are permissible or prohibited according to Islamic law—remain a significant issue in Indonesia (Harapan *et al.*, 2020), particularly in Aceh Province (Andika, Rayyanis and Suanda, 2020). Furthermore, in 2022, a positive case of polio was reported in Pidie Regency, Aceh. This province remains one of the provinces with the lowest vaccination coverage in Indonesia (Indonesian Ministry of Health, 2022).

The eradication of infectious diseases necessitates location-specific information, allowing for the mapping of disease incidence in relation to the surrounding environment and infrastructure. This approach serves as a valuable tool for assessing disease risk and identifying patterns of disease distribution, as each region possesses unique characteristics. Consequently, understanding spatial variations in vaccination coverage, particularly in the context of diverse vaccine delivery strategies, is crucial for evaluating the effectiveness of vaccination programs (Dimitrova *et al.*, 2023). Despite various implementations and interventions aimed at addressing immunization coverage issues and enhancing immunization programs and services, the application of spatial analysis remains limited in Indonesia.

Further research is needed to explore geographical patterns and analyze the role of adjacency associations (both temporal and spatial) among the determining factors. Such analyses would be valuable for providing comprehensive recommendations to support microplanning in immunization programs. Microplanning in immunization programs can be employed to identify local issues and develop effective solutions. Successful microplanning necessitates

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10.20473/jaki.v13i1.2025.68-81

accurate population estimates and maps that depict health facilities, village locations, and target populations (Ali *et al.*, 2020). Studies conducted in Nigeria have demonstrated that the effectiveness of microplanning in immunization programs could be enhanced through the use of geographic information system (GIS) software. GIS software enables the integration of multiple datasets and facilitates geospatial data analysis, allowing for the development of immunization strategies tailored to community needs (Dougherty *et al.*, 2019). Another study in Nigeria also showed that the use of maps generated by GIS could improve the quality of microplanning and optimize vaccination planning (Oteri *et al.*, 2021).

Maps has previously been used in the preparation of microplanning in immunization programs. However, these maps were created by manual hand drawing, and the information provided was limited to the number of villages in a service area, total population, and distances from villages to health facilities. This study examines the distribution of variables of health resources and identify relevant socioeconomic factors. Additionally, this study investigates the application of spatial analysis to support microplanning efforts aimed at reducing inequalities in immunization coverage.

Method

This implementation study employed a mixed methods approach that integrated both quantitative and qualitative methodologies. Implementation research refers to the scientific investigation of questions concerning implementation—the process of putting an intention into practice, which in health research may involve policies, programs, or individual practices (Peters *et al.*, 2013).

The first stage involved quantitative analysis utilizing secondary data, with the unit of analysis at the regency level, conducted in Aceh Province. This stage aimed to describe the distribution of immunization resources, assess capacity, and evaluate service coverage, as well as identify the risks and quantify their correlations with influencing factors.

The second stage involved qualitative analysis through focus group discussions (FGDs) aimed at investigating additional underlying issues related to the immunization program that were not documented in routine data. Findings from the FGDs were presented in a narrative report. In addition, spatial analysis training was provided to health workers to enable them to apply these skills in the preparation of micro planning. This study was conducted from June to October 2020.

Data Sources

Secondary data on immunization coverage, the number of infants receiving vaccines, the incidence of immunization-preventable diseases, adverse events following immunization, target populations, health facilities, health workers (human resources), and socioeconomic status (including unemployment rate, impoverished population, and average monthly expenditure per capita) were collected from health profiles, immunization surveillance reports, routine data from the Ministry of Health, the Provincial Health Office, and the Central Bureau of Statistics (*Badan Pusat Statistik*/ BPS) for 2019.

Primary data were collected through focus group discussions (FGDs). The FGDs were conducted virtually with relevant staff members at the Provincial Health Office, including immunization and surveillance officers, health service officers, data and information center officers, and family health officers, totaling seven informants. FGD topics included human resources, health facilities, logistics availability, immunization schedules, recording and reporting systems, community cultures, issues faced by high-risk communities, and the monitoring and evaluation of the immunization program. Additionally, spatial analysis training was conducted online via Zoom to four provincial health workers in Aceh Province.

Study Variables and Data Measurement

Village coverage of universal child immunization (UCI) was measured as the percentage of villages in each regency that

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achieved UCI status. Complete basic immunization (CBI) was defined as the condition in which a child received complete routine immunizations. Booster immunization was defined as a condition where a child received booster immunizations. The number of infants receiving immunizations was recorded based on the type of vaccine or antigen administered. This study also included various variables, including coverage of pentavalent basic and booster immunizations, as well as the number of vaccines administered for preventing diseases. Data on health facilities and health human resources were calculated from the ratios of available integrated health service posts (*posyandu*), community health centers (*puskesmas*), hospitals, doctors, midwives, and nurses to the population. Socioeconomic data were measured by the levels of poverty, unemployment rates, human development index (HDI), poor population, and average monthly expenditure.

Quantitative Approach

All variables were summarized in the frequency distribution table. RStudio version 4.0.3 was used to perform the analysis. A choropleth map was generated to visually present the geographic distribution of immunization service coverage, resources (facilities and professionals), as well as to identify risk based on socioeconomic indicators. The map was generated GIS software.

Global Moran's I test was employed to detect global structure and spatial autocorrelation with each dataset being. The assessment was conducted by examining visual curves, Moran's index, z-score, and p-value. The test yielded three possible outcomes: clustered, random, or dispersed patterns. The values of Moran's I range from -1 to 1. Positive value indicates positive spatial autocorrelation (clustering) and negative value indicates negative spatial autocorrelation (dispersion). Meanwhile, a value of zero indicates no spatial autocorrelation, suggesting that the value is randomly distributed.

Local Indicators of Spatial Association (LISA) tests were used to identify local clusters and outliers, highlighting hot spots of autocorrelation. This method aims to determine the specific regencies or patterns of variable distribution values. The LISA test classifies the spatial units into five categories: hot spots (areas with high values similar to their neighbors, denoted as high–high), cold spots (areas with low values similar to their neighbors, denoted as low–low), hot outliers (areas with high values adjacent to low-value neighbors, denoted as high–low), cold outliers (areas with low values adjacent to high-value neighbors, denoted as low- high), and non-significant areas (locations with no significant local autocorrelation).

Ordinary least squares (OLS) was applied to analyze the linear relationship between outcomes of interest (UCI and CBI as continuous data) and explanatory variables, assuming stationarity, which indicates that the association is constant across the geographical surface. The model quality was assessed using R^2. Multicollinearity was evaluated using the variance inflation factor (VIF) for all explanatory variables. The OLS regression analysis was conducted using RStudio version 4.0.3.

Qualitative Approach

The qualitative analysis was conducted through focus group discussions (FGDs) to obtain further information about the implementation of the immunization program, as well as the influencing factors that were not documented in the official data sources. The results of the FGDs were presented descriptively in a narrative report. The purpose of the FGDs was to finalize and validate the list of proxy variables used to map the resources on the one hand (step 1) and high-risk communities on the other (step 2). The FGDs also facilitated the identification of local issues and challenges, as well as specific strategies to address them, based on the diversity of local resources, culture, and values. Key informants from the provincial health office, including immunization and surveillance officers, health service officers, data and information center officers, and family health officers, participated in the FGDs virtually.

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The spatial analysis training focused on equipping health workers with skills to create maps using various variables and apply relevant analytical techniques. The aim was to enable health workers to incorporate the skills into the preparation of micro planning in immunization. Health workers would not only learn how to use the maps but would also acquire the skills to create them independently. Additionally, this activity aimed to test or explore the integration of mapping results in the preparation of micro planning in immunization

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Results and Discussion

Quantitative Approach

The average village coverage of UCI was 24.18%, while the coverage of CBI was 55.85%. Overall immunization coverage, including BCG, polio (doses 1–4), IPV, hepatitis B less than 24 hours and 1–7 days, DPT-HB-HIB (doses 1–3), measles, and measles-rubella, remained very low. The dropout rate from DPT/HB-1 to DPT/HB-3 was 11.6%, and from DPT/HB-1 to measles immunization was 22.35%. The average ratios of doctors, nurses, and midwives per 100,000 population were 42.13, 187.7, and 208.93, respectively. The ratios of community health centers and hospitals per 100,000 population were 28.64 and 1.51, respectively. The ratio of integrated health service posts per 1,000 target infants was 63.19 (Table 1).

Substantial variation was observed across regencies for each variable. The two main outcomes (UCI village coverage and CBI) were overlaid with each explanatory variable separately to investigate any similar features. In general, regencies with low village coverage of UCI and CBI were often found to have low human resources, inadequate health facilities, and a high proportion of high-risk communities. Notably, Pidie, Pidie Jaya, Aceh Jaya, Aceh Besar, and Aceh Barat were identified as regencies with low village coverage of UCI and CBI (Appendix A).

UCI village coverage exhibited a pattern similar to that of human resources, with areas reporting low UCI village coverage also experiencing low human resources, as observed in Aceh Utara. Similarly, CBI coverage showed a similar pattern with health facilities and an inverse pattern with poverty levels. Specifically, low CBI values were associated with inadequate health facilities and high rates of poverty. This situation was evident in regencies such as Bireuen, Pidie Jaya, and Aceh Singkil. In Subulussalam City, low UCI village coverage was reported alongside a low HDI. Additionally, regencies such as Pidie and Pidie Jaya were noted for having low UCI village coverage and a high proportion of poor population (Appendix A).

In summary, uneven distributions of variables (immunization coverage, resources, and facilities) were still prevalent in 2019. Significant positive autocorrelation was identified for several variables at the regency level in Aceh Province (Table 2). Variables exhibiting clustered patterns in this study included CBI, unemployment rates, coverage of polio immunization (doses 1–4), coverage of DPT-HB-Hib immunization (doses 1–3), coverage of measles immunization, coverage of measles-rubella immunization, and the number of congenital rubella syndrome (CRS) cases.

The LISA analysis revealed cold spot regencies in Aceh Jaya, Pidie, and Pidie Jaya. The variables that indicated low-low districts included complete basic immunization, as well as coverage of DPT-HB-Hib immunization (doses 1–3), measles immunization, and polio immunization (doses 1–4). Hot spot regencies were identified in Pidie Jaya and Bireuen for the CRS variable. Additionally, no significant autocorrelation was observed for the unemployment rates across all regencies (Appendix B).

The first outcome of the UCI village analysis utilized a backward method to examine the relationship between UCI village coverage and explanatory variables (Table 3). The variables included in the model were the ratio of hospitals per 100,000 population, the percentage of the poor population, and average monthly expenditure (IDR). The adjusted R^2 for this model was 0.18, while the F-test yielded a value of 2.57. For the second outcome of

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10.20473/jaki.v13i1.2025.68-81

CBI coverage, the ratios of doctors, nurses, and midwives per 100,000 population, as well as unemployment rates, were included in the final model (Table 3). The adjusted R^2 for this model was 0.19, while the F-test yielded a value of 2.26. All VIF values for both models were below 7, indicating no multicollinearity among the selected variables.

Qualitative Approach

Based on FGDs with key informants, the list of proxy variables was finalized and validated to enable the mapping of resources. Local issues and challenges were identified based on the diversity of local resources, culture, and values.

The challenges with human resources included the frequent replacement and redeployment of staff or officers to other divisions or departments. Many staff members did not have sufficient communication skills for delivering the messages to the community. Missed opportunities to reach the targets were still common, often occurring because the officers did not bring a sufficient supply of vaccines to integrated health service posts. Meanwhile, health facilities lacked communication materials and tools that were crucial for educating the community, such as flip charts, in integrated health service posts.

In terms of high-risk communities, there were rising concerns about vaccines being considered haram (prohibited by Islamic law). Certain groups within the community rejected immunization, posing a challenge for immunization teams as they had to confront arguments from religious leaders and community figures. Moreover, there were no official data on high-risk communities at the provincial level. Information about subsequent immunization schedules was often poorly communicated, leading to missed follow-up visits by the targets for receiving the next immunization service.

The challenges with the recording and reporting system included the absence of proper documentation by midwives working villages. The existing system still relied on supporting books which complicated the transfer of data into the cohort book and added to the workload of health workers. In some community health centers, only a single laptop was available and had to be shared across multiple programs. Therefore, the immunization team used rented computers to input the data into the system.

In the spatial analysis training session, pre- and post-tests were conducted. The tests consisted of 15 questions covering microplanning in immunization programs, map utilization, and the creation of maps using the mapping application. The pre-test results showed an average participant score of 35 with, scores ranging from 20 to 66. After the training, the post-test results showed an improvement, with an average score of 69.75, scores ranging from 47 to 80. There increase in scores between the pre and post-tests was statistically significant ($p = 0.028$). This indicated a significant increase in knowledge after the spatial analysis training.

Based on the evaluation feedback from the training participants, participants strongly agreed that using mapping applications simplified microplanning activities compared to manual (hand-drawn) map creation. The participants expressed intentions to use the mapping application for microplanning, recommended that officers create area maps for microplanning, and emphasized that mapping immunization data is essential to support the preparation of microplanning in immunization.

In general, this study found that the average coverage of UCI in villages was 24.18%, while CBI coverage was 55.85%. Regencies with low coverage of UCI and CBI often had low human resources, inadequate health facilities, and a high proportion of high-risk communities. This study revealed the presence of hot spots and cold spots in the study area. The results of the OLS analysis indicated no association between the explanatory and outcome variables. Focus group discussions (FGDs) provided further information about the implementation of immunization programs as well as the influencing factors that were not documented in the official data sources. Additionally, the participants

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Table 1. Distribution of variables in Aceh Province

Variables	Mean	SD[a]
UCI village coverage (%)	24.18	17.74
CBI coverage (%)	55.86	23.69
Ratio of doctors per 100,000 population	42.13	18.31
Ratio of nurses to 100,000 population	187.7	92.63
Ratio of midwives per 100,000 population	208.93	93.36
Ratio of hospitals per 100,000 population	1.51	1.51
Ratio of community health centers per 100,000 population	28.64	20.94
Ratio of integrated health service posts per 1,000 target infants	63.19	21.21
Poor population (%)	15.71	3.49
Human development index (HDI)	71.09	4.64
Monthly spending/expenditure (IDR)	1,043,253	282,147.19
Unemployment rate	5.82	2.42
Drop out (DO) rates of DPT/HB1-DPT/HB3	11.66	7.89
DO rates of DPT/HB1-measles	22.35	23.75
BCG immunization coverage (%)	68.71	16.92
Polio 1 immunization coverage (%)	72.05	14.99
Polio 2 immunization coverage (%)	70.57	18.79
Polio 3 immunization coverage (%)	63.86	19.61
Polio 4 immunization coverage (%)	60.88	20.5
IPV immunization coverage (%)	30.03	25.81
HB<24 hours immunization coverage (%)	59.94	21.89
HB1-7 days immunization coverage (%)	18.67	20.58
Total HB0 immunization coverage (%)	78.61	10.58
DPT-HB-Hib1 immunization coverage (%)	65.4	20.46
DPT-HB-Hib2 immunization coverage (%)	61.14	21.45
DPT-HB-Hib3 immunization coverage (%)	58.78	21.59
Measles-rubella immunization coverage (%)	51.84	24.73
Total measles immunization coverage (%)	52.46	24.49
Booster immunization for DPT-HB-Hib (%)	32.22	41.66
Booster immunization for measles (%)	7.80	12.35
Booster immunization for measles-rubella (%)	17.79	20.58
Booster immunization for total measles (%)	20.42	21.00
Number of congenital rubella syndromes (CRS)	0.39	0.72
Number of diphtheria cases	5.61	6.83

[a]Standard deviation

Table 2. The results of cluster detection in Aceh province with global analysis of Moran I

Variables	Moran's Index	Z Score	p-value
UCI village coverage (%)	0.05	0.59	0.56
CBI coverage (%)	0.33	2.35	0.02
Ratio of doctors per 100000 population	-0.18	-0.94	0.34
Ratio of nurses per 100000 population	-0.07	-0.17	0.87
Ratio of midwives per 100000 population	0.03	0.51	0.61
Ratio of hospitals per 100000 population	-0.12	-0.53	0.60
Ratio of community health center per 100000 population	0.18	1.42	0.15
Ratio of integrated health service per 1000 target babies	0.13	1.12	0.26
Poor population (%)	0.04	0.51	0.61
Human Development Index	0.20	1.60	0.11

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Variables	Moran's Index	Z Score	p-value
Monthly spending/ expenditure (IDR)	-0.07	-0.14	0.89
Unemployment rate	0.23	1.71	0.09
DO rates of DPT/HB1-DPT/HB3	0.09	1.18	0.24
DO rates of DPT/HB1-Measles	0.17	1.44	0.15
BCG immunization coverage (%)	0.19	1.46	0.14
Polio 1 immunization coverage (%)	0.27	1.97	0.05
Polio 2 immunization coverage (%)	0.40	2.81	0.00
Polio 3 immunization coverage (%)	0.30	2.13	0.03
Polio 4 immunization coverage (%)	0.27	1.97	0.05
IPV immunization coverage (%)	0.01	0.34	0.74
HB<24 hours immunization coverage (%)	-0.25	-1.30	0.20
HB1-7 days immunization coverage (%)	-0.23	-1.25	0.21
Total HB0 immunization coverage (%)	0.05	0.61	0.54
DPT-HB-Hib1 immunization (%)	0.35	2.47	0.01
DPT-HB-Hib2 immunization coverage (%)	0.29	2.10	0.04
DPT-HB-Hib3 immunization coverage (%)	0.25	1.82	0.07
Measles- rubella immunization coverage (%)	0.24	1.79	0.07
Total measles immunization coverage (%)	0.25	1.84	0.07
Booster immunization for DPT-HB-Hib (%)	0.07	0.90	0.37
Booster immunization for measles (%)	-0.19	-1.12	0.26
Booster immunization for measles-rubella (%)	-0.03	0.13	0.89
Booster immunization for total measles (%)	0.13	1.17	0.24
Number of congenital rubella syndromes (CRS)	0.30	2.55	0.01
Number of diphtheria cases	-0.07	-0.13	0.89

Table 3. Linear regression analysis results regarding UCI and CBI

No	Explanatory variables	Estimate	SE[b]	t value	p-value	VIF[c]
1	Model for UCI					
	Intercept	38.37	26.89	1.43	0.170	
	Ratio of hospitals per 100,000 population	-9.094	3.62	-2.51	0.021	2.52
	Poor population (%)	-1.903	1.12	-1.71	0.104	1.29
	Monthly expenditure	2.827e-005	0	1.49	0.153	2.43
	R^2	0.29				
	Adjusted R^2	0.18				
	F-test	2.57			0.085	
2	Model for CBI					
	Intercept	107.89	23.96	4.50	<0.001	
	Ratio of doctors per 100,000 population	-0.69	0.37	-1.86	0.079	2.24
	Ratio of nurses per 100,000 population	0.27	0.10	2.69	0.015	4.02
	Ratio of midwives per 100,000 population	-0.21	0.08	-2.51	0.022	2.89
	Unemployment rate (%)	-0.499	2.21	-2.27	0.036	1.38
	R^2	0.33				
	Adjusted R^2	0.19				
	F-test	2.26			0.103	

[b]Standard error
[c]Variance inflation factor

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10.20473/jaki.v13i1.2025.68-81

reported that using mapping applications was more practical and necessary to support the preparation of microplanning in immunization programs.

The average village coverage of UCI and CBI across regencies varied but remained low. The results of the choropleth mapping showed that UCI village coverage in Aceh Province exhibited a pattern similar to that of CBI coverage. Regencies with low UCI village coverage also tended to have low CBI coverage, as observed in Aceh Jaya, Pidie, Pidie Jaya, Aceh Besar, and Aceh Barat regencies.

According to the 2019 strategic plan targets, the expected CBI coverage among infants aged 0-11 months was 93%, while the target for UCI village coverage was 92% (Indonesian Ministry of Health, 2020b). Thus, Aceh province had not yet achieved the targets in the National Medium-Term Development Plan (*Rencana Pembangunan Jangka Menengah Nasional*/RPJMN) for CBI and UCI village coverage. In addition, dropout rates between DPT/HB-1 and DPT HB-3, as well as between DPT/HB-1 and measles immunization were 11.6% and 22.35%, respectively. These rate exceed the threshold of 5% (Indonesian Ministry of Health, 2020b).

Polio immunization coverage in Aceh province was still very low, despite the national target for polio immunization being set at a minimum of 95% with equal distribution across all regions (Indonesian Ministry of Health, 2020a). Therefore, in 2022, Aceh Province experienced a polio outbreak (Indonesian Ministry of Health, 2022). Low immunization coverage can hinder the development of herd immunity (Rasmussen, 2020; Bullen, Heriot and Jamrozik, 2023). The large population at risk causes the chain of transmission to persist when a case occurs, increasing the likelihood of an outbreak (Schaller, Schulkind and Shapiro, 2019). In this study, several regencies, including Pidie, which reported a polio outbreak in 2022, were identified as having low UCI village coverage and CBI coverage.

The average ratio of doctors per 100,000 population in Aceh Province was also far below the standard set by the Directorate of Health Worker Planning in Indonesia, which is 1 doctor per 1,000 population (Directorate of Health Worker Planning, 2022). Health workers, such as doctors, play an important role as primary sources of health information (Abdisa *et al.*, 2022). The low ratio of doctors likely contributed to limited parental access to information about vaccines.

CBI coverage had a pattern similar to that of health facilities and had an inverse pattern with the proportion of the poor population. Regencies with low CBI coverage also had inadequate health facilities and a high proportion of the poor population. This condition was observed in Biruen, Pidie Jaya, and Aceh Singkil regencies. Aceh Province also recorded an unemployment rate (5.3% in 2019) and a percentage of the poor population (9.22%) above the national averages. Additionally, Aceh Province's HDI remained lower than the national average of 71.92, and its average monthly expenditure was lower than the Indonesian average of IDR 1,388,212 (BPS, 2020).

Despite the non-significant results of the OLS linear model, the findings provide crucial underlying information regarding immunization programs in Aceh Province. Identifying risk factors can assist in mapping high-risk areas that are vulnerable to potential outbreaks. This study also found that significant clustered patters for CBI coverage, types of vaccine/antigen coverage, and the number of CRS cases.

Incomplete immunization remains a significant problem in Indonesia, especially in Aceh Province. Various attempts had been made by the government to overcome this problem. Various studies have also revealed geographic variations in immunization rates. For instance, research in Ethiopia identified clustered patterns of incomplete immunization in high-risk areas across multiple study periods (Melaku, Nigatu and Mewosha, 2020), as well as a significant clustered pattern of measles-containing vaccine first-dose coverage in children (Tesfa *et al.*, 2022). Similarly, research in Nigeria revealed variations in immunization coverage at the regional, urban or rural, and district levels, with some states forming hot spot and cold spot

Indonesian Journal of Health Administration
(Jurnal Administrasi Kesehatan Indonesia)
p-ISSN 2303-3592, e-ISSN 2540-9301
10.20473/jaki.v13i1.2025.68-81

clusters (Akinyemi, 2020). Research conducted in Pakistan also showed a clustered pattern in districts with low vaccine coverage (Umer *et al.*, 2020). District-level variations in vaccination coverage might be due to strong environmental factors such as socioeconomic and demographic characteristics (Singh and Vishwakarma, 2021; Dimitrova *et al.*, 2023).

In Aceh province, the spatial variation in incomplete immunization was likely influenced by geographic and climatic differences, as well as differences in population distribution (Aceh, B.P., 2020). Population distribution poses complex challenges, as it contributes to more complex economic and social problems (Aceh, D.K., 2020). Moreover, differences in the number of health personnel and health services across regencies or cities in Aceh Province were identified as one of the factors affecting immunization coverage (Aceh, D.K., 2020). Substantial differences in health service utilization at the regency or city level persists in Indonesia, influencing access to health services (Mulyanto, Kunst and Kringos, 2019, 2020). This ultimately results in differences in immunization coverage in each region. Studies have also shown that the distance between households to health facilities affects immunization coverage (Johns *et al.*, 2022; Ogero *et al.*, 2022).

Socioeconomic inequalities in access to health services remains a persistent challenge in Indonesia. Prioritizing geographic and financial access is critical to overcome these problems (Akinyemi, 2020; Mulyanto, Kunst and Kringos, 2020). In addition, low immunization coverage in regions such as Aceh Province may also be attributed to the low ratio of health workers in Indonesia. The ratio of healthcare providers in Indonesia is notably lower than the average in other Southeast Asian countries, and their distribution across regencies or cities is uneven (Muharram *et al.*, 2024). Most healthcare services in Indonesia are concentrated in primary health centers. Populations living below the poverty line are frequently affected, as they tend to have limited health knowledge and restricted access to quality health services. Moreover, geographical disparities exacerbate this condition. People have difficulties in reaching health facilities because of their location, thereby increasing the cost of health services. Together, geographic and financial inequalities limit equitable access to health services.

The implementation of decentralization in Indonesia's health sector has influenced service delivery, health financing, and workforce distribution (Rakmawati, Hinchcliff and Pardosi, 2019). Immunization programs continue to face significant challenges on both the supply and demand sides, due to geographic barriers, topographical conditions, and limited availability of cold chain outreach and maintenance activities. In addition, negative perceptions of immunization, such as side effects, as well as suspicion of its dangerous and haram ingredients, remain common among communities (Alsuwaidi *et al.*, 2023; Jinarong *et al.*, 2023).

The low coverage of immunization in Aceh Province was supported by the results of the FGDs, which revealed several local issues and challenges in the immunization program, namely the diversity of local resources, culture, and values. The results of the training evaluation highlighted that the use of mapping technology and applications enabled the identification of high-risk communities and supported the development of more comprehensive microplanning in immunization programs, thereby addressing inequalities in immunization. Although maps have been utilized in the preparation of microplanning in immunization programs, the maps were produced by manual hand-drawing and the information provided was limited to the number of villages in the service area, the total population, and the distance from the villages to health facilities (WHO, 2009).

A limitation of this study lies in the dataset which only included 23 units of analysis. The non-significant findings in non-spatial and spatial model represent the challenges in incorporating the dependent and independent variables within a single analytical framework.

Indonesian Journal of Health Administration
(Jurnal Administrasi Kesehatan Indonesia)
p-ISSN 2303-3592, e-ISSN 2540-9301
10.20473/jaki.v13i1.2025.68-81

The novelty proposed by this study is the introduction of more practical analytical techniques to provide scientific evidence that could inform microplanning in subsequent years. Unlike traditional hand-drawn maps that only provide a descriptive configuration, this study presents a more robust approach by employing a rigorous statistical framework to facilitate the creation of maps.

Microplanning applications in immunization programs such as GIS-based can help map the population, health facilities, and coverage of health services, making it easier to identify areas with high risk. In addition, accurate microplanning could reach people in remote areas and/or prioritize areas with vulnerable populations. In addition, proper microplanning enables the distribution of health workers, logistics, and transportation. Therefore, the use of applications in microplanning represents a promising technological innovation that can help address the root causes of inequality in access to health services, especially immunization services.

Conclusion

The average village coverage of UCI and CBI in Aceh Province remains low. This study revealed the presence of hot spots and cold spots in the study area, classifying certain districts as high-risk areas. The findings highlight the importance of addressing immunization problems by considering geographic factors. The use of spatial analysis methods in identifying the distribution of immunization coverage, the capacity of immunization services, and the pattern of relevant resources provided robust evidence for further stages of the immunization program, such as microplanning and intervention. This technique can reduce inequalities in immunization service and uneven distribution of supporting resources during the implementation of the immunization program. Further studies could examine the extent to which the use of GIS by local policy makers can improve the effectiveness of planning and distribution of immunization services.

Abbreviations

CBI: Complete Basic Immunization; BPS: Central Bureau of Statistics; FGD: Focus Group Discussion; GIS: Geographic Information System; HDI: Human Development Index; LISA: Local Indicators of Spatial Association; OLS: Ordinary Least Squares; UCI: Universal Child Immunization; VIF: Variance Inflation Factor.

Declarations

Ethics Approval and Consent Participant

This study received ethical approval from the Health Research Ethics Committee of the Faculty of Public Health, Universitas Airlangga, Indonesia, with a reference number 71/EA/KEPK/2020.

Conflict of Interest

The authors declared that there is no conflict of interest.

Availability of Data and Materials

Data and materials of this study can be provided upon request.

Authors' Contribution

Conceptualization: EA, AH, KDA, ACH, ZH. Data curation: EA, AH, KDA, ACH, ZH. Formal analysis: EA, ZH, SSNS. Methodology: AH, KDA, ACH, ZH, MF. Project administration: SSNS, KDA, EA. Visualization: EA, AH, KDA, ACH, ZH. Writing–original draft: EA, AH, KDA, ACH, ZH. Writing–review and editing: EA, AH, KDA, ACH, ZH, MF, AS, RVS, RBH.

Funding Source

This study was supported by the Alliance for Health Policy and Systems Research (Alliance). The Alliance's work is made possible through the commitment and support of various funders, including Gavi, the Vaccine Alliance, which contributed designated funding and support for this project, alongside the Alliance's long-term core contributors from national governments and international institutions.

Acknowledgment
The authors would like to thank the Faculty of Public Health, Universitas Airlangga, for their technical support and all contributors who assisted in the implementation of this study.

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