

BAZNAS and the Transformation of the Zakat Sector Program for the Empowerment of Poor Asnaf in Indonesia

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ABSTRACT

This study identifies the status of poor asnaf in Indonesia using the K-Nearest Neighbors (KNN) model to optimize zakat distribution. Data from 8,655 respondents covering economic and social variables — such as micro businesses, agriculture, and livestock — were analyzed. The KNN model, with $k=1$, rectangular weighting, and Euclidean distance, achieved outstanding results (MSE: 0.003, R^2 : 0.974). Respondents were classified into four poverty status categories: high (e.g., East Java, 0.731), medium (0.3047–0.5080), low (0.107–0.285), and very low (0.010–0.088). Key factors influencing poverty status include micro enterprises (dropout loss 0.056), agriculture (0.054), and livestock (0.048). The National Amil Zakat Agency (BAZNAS) plays a crucial role in coordinating fair and effective zakat distribution through a data-driven approach. This research's practical implications include developing zakat-based economic empowerment programs, such as skills training, access to capital, and micro business development. The study's main contribution lies in integrating technology for targeted poverty alleviation, empowering communities, and enhancing welfare. By adopting this approach, BAZNAS can ensure zakat

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reaches those in greatest need, supporting sustainable poverty reduction and fostering long-term community resilience.

ملخص

تحدد هذه الدراسة أوضاع الفقراء من مصارف الزكاة في إندونيسيا باستخدام نموذج أقرب الجيران (K-Nearest Neighbors - KNN) بهدف تحسين توزيع الزكاة. وقد تم تحليل بيانات 8655 شخصا خاضعا للدراسة شملت متغيرات اقتصادية واجتماعية، مثل المشاريع الصغيرة والزراعة وتربية الماشية. حقق نموذج أقرب الجيران، باستخدام القيمة $k=1$ ، ووزن مستطيل (Rectangular Weighting)، ومسافة إقليدية (Euclidean Distance)، نتائج متميزة للغاية ($MSE: 0.003$, $R^2: 0.974$). صنف المشاركون في أربع فئات من حيث حالة الفقر: فقر مرتفع (على سبيل المثال: جاوة الشرقية، 0.731)، فقر متوسط (بين 0.3047 و 0.5080)، وفقر منخفض (بين 0.107 و 0.285)، وفقر منخفض جدا (بين 0.010 و 0.088). وتشمل العوامل الرئيسية المؤثرة في تحديد حالة الفقر كلا من المشاريع المتناهية الصغر (خسارة الاستيعاد 0.056)، الزراعة (0.054)، تربية الماشية (0.048). وتؤدي الهيئة الوطنية الإندونيسية للزكاة (BAZNAS) دورا محوريا في تنسيق توزيع الزكاة بصورة عادلة وفعالة من خلال نهج قائم على البيانات. وتتمثل النتائج التطبيقية لهذه الدراسة في تطوير برامج للتمكين الاقتصادي القائمة على الزكاة، مثل التدريب على المهارات، وتوفير فرص الحصول على رأس المال، وتنمية المشاريع المتناهية الصغر. وتكمن المساهمة الرئيسية للدراسة في دمج التكنولوجيا من أجل استهداف أكثر دقة لجهود الحد من الفقر، وتمكين المجتمعات المحلية، وتعزيز الرفاه الاجتماعي. ومن خلال اعتماد هذا النهج، يمكن للهيئة الوطنية الإندونيسية للزكاة ضمان وصول أموال الزكاة إلى الفئات الأكثر احتياجا، بما يدعم الحد المستدام من الفقر ويعزز قدرة المجتمعات على الصمود والتنمية على المدى الطويل.

RÉSUMÉ

Cette étude identifie la situation des asnaf démunis en Indonésie à l'aide du modèle des K plus proches voisins (KNN) afin d'optimiser la distribution de la zakat. Les données provenant de 8 655 répondants, couvrant des variables économiques et sociales — telles que les micro-entreprises, l'agriculture et l'élevage — ont été analysées. Le modèle KNN, avec $k=1$, une pondération rectangulaire et une distance euclidienne, a donné d'excellents résultats ($MSE : 0,003$, $R^2 : 0,974$). Les répondants ont été classés en quatre catégories de niveau de pauvreté : élevé (par exemple, Java oriental, 0,731), moyen (0,3047–0,5080), faible (0,107–0,285) et très faible (0,010–0,088). Les principaux facteurs influençant le niveau de pauvreté comprennent les micro-entreprises (coefficient de décrochage de 0,056), l'agriculture (0,054) et l'élevage (0,048). L'Agence nationale de gestion de la zakat (BAZNAS) joue un rôle crucial dans la

coordination d'une distribution équitable et efficace de la zakat grâce à une approche fondée sur les données. Les implications pratiques de cette recherche comprennent l'élaboration de programmes d'autonomisation économique basés sur la zakat, tels que la formation professionnelle, l'accès au capital et le développement des micro-entreprises. La principale contribution de cette étude réside dans l'intégration de la technologie pour lutter de manière ciblée contre la pauvreté, autonomiser les communautés et améliorer le bien-être. En adoptant cette approche, la BAZNAS peut garantir que la zakat parvienne à ceux qui en ont le plus besoin, soutenant ainsi une réduction durable de la pauvreté et favorisant la résilience à long terme des communautés.

Keywords: K-Nearest Neighbors, BAZNAS, zakat, poor asnaf, poverty prediction, data-based policies

JEL Classification: D64, E61, I32

1. Introduction

Zakat is an effective Islamic economic instrument to alleviate poverty and empower the community, especially the asnaf and mustahiq groups, by distributing wealth evenly and creating social safety nets and sustainable livelihoods. In Indonesia, the distribution of zakat worth Rp 3.52 trillion has succeeded in improving local economic welfare and empowerment (Syarifuddin & Trimulato, 2024), while in the agricultural sector, zakat helps reduce unemployment and income inequality (Mongkito & Samdin, 2025). In addition, an effective zakat management framework also advises community participation and institutional collaboration, thereby strengthening social cohesion (Mokodenseho et al., 2024; Sarib et al., 2024). In Nigeria, despite facing challenges such as weak governance, zakat is still considered a vital tool for wealth redistribution and poverty alleviation (Busari & Salaudeen, 2024). Therefore, to maximize the impact of zakat, it is necessary to improve management strategies and further research to overcome logistical and governance obstacles that are still obstacles (Mokodenseho et al., 2024).

The National Amil Zakat Agency (BAZNAS) in Indonesia faces challenges in identifying and distributing zakat to recipients who really need it, which has been developed with the categories of scholarships, santripreneur, ultra-micro enterprises, agriculture, animal husbandry, qardhul hasan, uninhabitable house, micro enterprises, and others. Conventional methods that are still widely used are often inaccurate due

to the limitations of adequate data and analysis, so that they have the potential to cause injustice in distribution (Pratama & Asrida, 2024). To overcome this, BAZNAS has implemented Standard Operating Procedures to improve the verification process and align the distribution of zakat with the Sustainable Development Goals to increase effectiveness and social justice (Ahyani et al., 2025). However, the issue of governance and transparency remains an important obstacle that needs to be overcome so that the impact of zakat distribution can be more optimal (Sandie & Abdillah, 2024). The target of scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, qardhul hasan, uninhabitable houses, micro businesses, and others predicatively to poor asnaf has not been known so far. Therefore, a more accurate predictive approach is needed to improve the efficiency of zakat distribution and ensure that help is provided to individuals and regions that need it most.

This study aims to predict the status of poor asnaf in various provinces in Indonesia using the K-Nearest Neighbors Regression (KNN) model. This model was developed to identify the main factors affecting poverty and categorize provinces based on the level of poor asnaf, so that it can be used to develop a more optimal zakat distribution strategy by BAZNAS. By using economic and social factors, such as micro enterprises, agriculture, livestock, and scholarships, this model is expected to be able to provide a more accurate data-based approach in determining zakat recipients. Several previous studies have discussed the distribution of zakat and poverty alleviation, but there is still a research gap in the aspect of using machine learning-based prediction models in determining poor asnaf. Most of the research still focuses on descriptive analysis or manual approaches in the distribution of zakat, without the use of models that can systematically classify and predict. In addition, there have not been many studies that examine the specific role of economic factors, such as micro enterprises and agriculture, in determining the status of poor asnaf. Based on this, this study seeks to answer the main question: How can the KNN model be used to predict the status of poor asnaf and increase the effectiveness of zakat distribution by BAZNAS? By answering this question, this research is expected to contribute to the development of data-based zakat policies, increase the effectiveness of zakat distribution, and support the role of BAZNAS in alleviating poverty in Indonesia in a more systematic and sustainable manner.

2. Literature Review

Zakat is one of the instruments of Islamic economics that functions as a mechanism for wealth redistribution to reduce social inequality and alleviate poverty. Various studies have shown that zakat has a positive impact on the welfare of the poor, especially if it is distributed on target (Ahmad & Haq, 2021; Hasan, 2020). BAZNAS, as an institution that manages zakat in Indonesia, is responsible for the distribution of zakat to asnaf, including poor asnaf groups. However, the main challenge in distributing zakat is ensuring that zakat is received by those who really need it. In distribution, BAZNAS categorizes in the field of programs, including scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, qardhul hasan, uninhabitable houses, micro businesses, and others. Several previous studies have discussed various methods in determining the right zakat recipients. Several studies used descriptive approaches and field surveys to identify the characteristics of zakat recipients (Nurfadillah et al., 2022; Yusuf Alaika Fawaid, 2022). Although this approach is useful in understanding the condition of the beneficiaries, this method tends to be subjective and has limitations in generalizing zakat recipients on a wider scale. Therefore, a data-based and predictive approach is important to ensure that zakat can be managed more efficiently and on target.

In recent years, machine learning-based approaches have been used in various socio-economic fields, including poverty prediction and social help distribution (Khan et al., 2021; Zahrunnisa et al., 2021). Machine learning models such as KNN, Random Forest, and Neural Networks have been shown to identify poverty patterns with high accuracy. KNN is one of the widely used methods because it can group individuals or regions based on similar economic and social characteristics (Gosiewska & Biecek, 2019; Luo et al., 2019). A study by (Sami & Shawkat Ali, 2023) shows that KNN can be used to predict poverty levels with high accuracy, especially when combined with economic variables such as income, business ownership, and access to education. However, although various studies have discussed the use of prediction models in poverty analysis, there is still a research gap in the use of predictive models to optimize the distribution of zakat by BAZNAS. Most of the existing research still focuses on determining poverty status in general, without examining especially how the predictive model can be applied in the context of zakat distribution based on poor asnaf. In addition, there are still limited studies

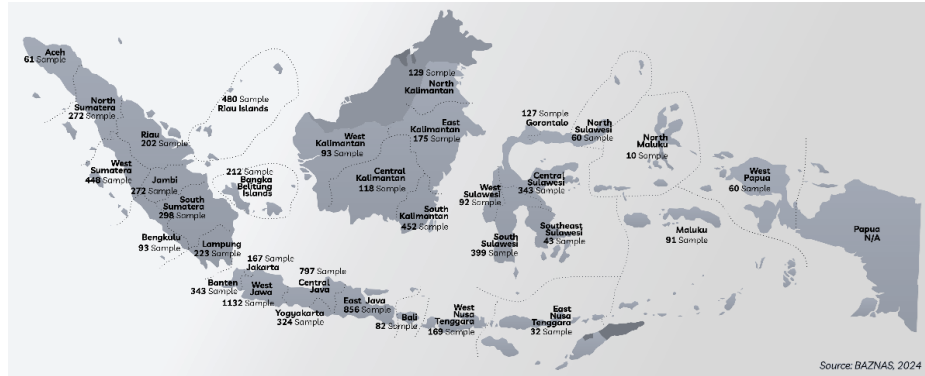
that identify specific economic factors that most affect the status of poor asnaf, such as scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, qardhul hasan, uninhabitable houses, micro businesses, and others. Based on this literature review, this study aims to fill this gap by applying the KNN model in predicting the status of poor asnaf and optimizing the distribution of zakat by BAZNAS. Thus, this study answers the main question: How can the KNN model be used to predict the status of poor asnaf and improve the effectiveness of zakat distribution by BAZNAS? By building a data-based approach in zakat management, this research is expected to contribute both in the development of machine learning-based poverty prediction theory, as well as in real practice through improving the accuracy of zakat distribution in Indonesia.

3. Data and Methodology

This study uses a quantitative approach with machine learning methods to predict the status of poor asnaf in Indonesia. The model used is KNN, which works by comparing the similarity of individual characteristics based on economic and social variables. Although individual characteristics are used as inputs, the empirical model is estimated at the provincial level. The main purpose of this study is to develop a prediction model that can help BAZNAS in optimizing the distribution of data-based zakat. Primary data in this study was obtained from BAZNAS, which included 8,655 respondents from 33 provinces in Indonesia in 2023. The primary unit of observation in this study is the individual zakat beneficiary, while the unit of analysis for model estimation is the province. Respondents consisted of individuals who had received zakat as well as those in the category of scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, Qardhul Hasan, uninhabitable houses, micro businesses, and others. The selection of the sample was carried out in a stratified manner, taking into account the proportion of the number of zakat recipients in each province, thus ensuring a balanced representation and reflecting the condition of poverty in each region. After data collection, individual-level observations were aggregated to the provincial level by calculating summary measures for each province, particularly proportions and averages of relevant variables. Data is collected directly through the BAZNAS data collection system, which includes scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, Qardhul Hasan, uninhabitable houses, micro businesses, and

others that affect the status of poor asnaf. The dependent variable, poor asnaf status, is initially constructed at the individual level based on BAZNAS eligibility criteria, where individuals classified as poor asnaf are coded as 1 and others as 0. This variable is then aggregated to the provincial level as the proportion of poor asnaf within each province, which serves as the outcome variable in the empirical model. The distribution of respondents in 33 provinces is visualized in figure 1.

Figure 1. Distribution of Research Respondents



The KNN model (Gosiewska & Biecek, 2019) works by calculating the distance among the sample to be predicted and the nearest neighbor k based on the Euclidean distance metric. The general equation for calculating the Euclidean distance among two data points X and Y in n -dimensional space is as follows:

$$d(X, Y) = \sqrt{\sum_{i=1}^n (x_i - y_i)^2} \quad (1)$$

After finding the nearest neighbors, the predicted value of the poor asnaf status is calculated as the average of the target value $\hat{y}_j$ in the nearest neighbors:

$$\hat{y} = \frac{1}{k} \sum_{j=1}^k y_j \quad (2)$$

Provided $d(X, Y)$ is the Euclidean distance among two individuals based on the predictor variable. $\hat{y}$ is the prediction value of the status of poor asnaf. $\hat{y}_k$ is the number of nearest neighbors selected. Y_j is the target value of the nearest neighbor.

The data is analyzed through several stages as follows: data pre-processing by cleaning the data, normalizing, and standardizing to ensure

data quality before being incorporated into the KNN model. The optimal parameter selection by determining the best number of neighbors (k) using the cross-validation approach. Model training, the data was divided into training data (80%) and test data (20%), then the KNN model was trained using training data to learn patterns from predictor variables. Model evaluation through model performance is measured using MSE, Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and R^2 to assess the accuracy of the model's predictions against the test data. Model accuracy is guaranteed through cross-validation and the use of standard evaluation metrics to assess model performance. Data reliability is also maintained by using primary data sources directly from BAZNAS, which have gone through a verification process in the zakat recipient data collection system. With this method, this research is expected to provide accurate data-based recommendations for BAZNAS in optimizing the distribution of zakat, so that it can be more effective in alleviating poverty and improving the welfare of poor asnaf in Indonesia.

4. Empirical Results

The distribution of zakat samples (figure 1) shows a striking inequality between regions in Indonesia. Java Island dominates with a contribution of more than 50% of the total sample collected. West Java itself contributed around 20.8% (1132 samples), followed by East Java with 15.7% (856 samples) and Central Java with 14.6% (797 samples). If combined, these three provinces cover almost 51.1% of the total national sample. Outside Java, the provinces with the highest contributions were West Sumatra (8.2%, 448 samples) and South Kalimantan (8.3%, 452 samples), which showed strong potential in the collection and management of zakat in the region. In contrast, eastern Indonesia, such as North Maluku (0.18%, 10 samples) and Papua for which no data is available, only contribute a very small or even nil portion. In Sulawesi, South Sulawesi was the most dominant with 7.4% (399 samples), while Southeast Sulawesi only contributed 0.8% (43 samples). This inequality indicates that the concentration of the population and more developed zakat infrastructure on the island of Java plays a major role in the capacity of data collection. However, this disparity also underscores the importance of strengthening the zakat ecosystem in regions with small contributions so that the potential of zakat can be optimized evenly throughout Indonesia.

Descriptive statistics from the allocation of zakat funds distributed by the BAZNAS for various community empowerment programs. This data covers 10 main program categories, such as help to poor asnaf, scholarships, santripreneurs, ultra-micro businesses, agriculture, livestock, Qardhul Hasan, uninhabitable houses, micro businesses, and others. The statistics presented include data validity values, median, mean, standard deviation, and minimum and maximum values of the proportion of fund allocation in each program.

Table 1. Descriptive Statistics on Zakat Fund Allocation for Poor Asnaf and Program Categories

	Poor	Scholarship	Other	Agriculture	Farm	Qardul Hasan	uninhabitable houses	Santripreneur	Micro	ultra-micro
Valid	33	33	33	33	33	33	33	33	33	33
Missing	0	0	0	0	0	0	0	0	0	0
Median	0.171	0.077	0.272	0	0.028	0	0	0	0.178	0.071
Mean	0.239	0.16	0.285	0.104	0.151	0.073	0.121	0.153	0.263	0.157
Std. Deviation	0.234	0.206	0.251	0.218	0.262	0.186	0.248	0.316	0.258	0.212
Minimum	0.01	0	0	0	0	0	0	0	0	0
Maximum	1	1	1	1	1	1	1	1	1	1

Source: Analysis Results, 2025

Table 1 shows that all data for 10 program categories are valid with no missing data (missing = 0). From the results of the analysis, it can be seen that the other program has the highest average allocation of 0.285, followed by micro enterprises with an average of 0.263. However, when viewed from the median value, the Poor and micro business asnaf show a more even distribution than other categories. The unique thing about this table is the large variation in standard deviation, which indicates instability or unevenness in the allocation of funds. For illustration, the Santripreneur program has the highest standard deviation (0.316), indicating significant fluctuations in the distribution of funds. On the other hand, the qardhul hasan and uninhabitable houses programs have a median of 0, which means that most regions or cases do not get the allocation of funds for the program, although on average there is still a small distribution. This data shows that although all programs have the potential to be allocated up to 100% of the overall analyzed (maximum = 1), their actual implementation is still very varied. This fact highlights the

importance of a more equitable and data-driven distribution strategy to ensure the effectiveness of zakat in achieving socio-economic goals.

Table 2. Model Summary KNN Regression

Nearest neighbors	Weights	Distance	n(Train)	n(Validation)	n(Test)	Validation MSE	Test MSE
1	rectangular	Euclidean	21	6	6	0.091	0.003

Note: The model is Optimized with Respect to the Validation Set MSE.
Source: Analysis Results, 2025.

The KNN (table 2) is used to predict poor asnaf with the parameter $k = 1$, using the rectangular weighting function and Euclidean distance. The dataset used consisted of 21 samples for training, six samples for validation, and six samples for testing. The model was optimized based on the MSE on the validation data, with the result of MSE Validation of 0.091 and Test MSE of 0.003. The choice of $k = 1$ prioritizes local similarity and minimizes bias; however, given the small effective sample size, this choice may increase model variance and the risk of overfitting. The much smaller MSE test value compared to the MSE Validation shows that the model has very high accuracy on the test data. At the same time, the large gap between validation and test MSE indicates that model performance should be interpreted with caution, as it may not fully reflect generalization to unseen data. The much smaller MSE test value compared to the MSE Validation shows that the model has very high accuracy on the test data. However, a considerable difference among MSE Validation and Test MSE can indicate the possibility of overfitting, especially due to the small size of the dataset. Therefore, the reported performance metrics are interpreted as indicative rather than definitive. To improve the generalization ability of the model to new data, the use of a larger number of neighbors (k) or an increase in the amount of training data can be considered to make the model more stable. In addition, alternative values of k were explored and yielded qualitatively similar patterns, although with slightly lower peak performance and improved stability. To improve the generalization ability of the model to new data, the use of a larger number of neighbors (k) or an increase in the amount of training data can be considered to make the model more stable. In addition, alternative values of k were explored and yielded qualitatively similar patterns, although with slightly lower peak performance and improved stability.

The KNN (table 3) used to predict poor asnaf shows excellent performance based on various evaluation metrics. A MSE value of 0.003 indicates that the average prediction error is very small, while an MSE (scaled) of 0.022 provides an overview of the normalized error against the data scale. A low RMSE and MAE indicate good in-sample predictive accuracy; however, these metrics should be interpreted carefully in light of the limited sample size and the non-parametric nature of the KNN model. A Root MSE (RMSE) value of 0.055 indicates that the average deviation of the prediction against the actual value is quite low. In addition, the MAE/MAD of 0.037 indicates the mean absolute difference among the prediction and the actual value, which is also relatively small. However, a MAPE value of 25.92% indicates that the error relative to the actual value is still quite high, which means that there is a possibility that the model is less accurate for individuals with smaller target values. This suggests heterogeneity in predictive accuracy across the distribution of the dependent variable. Nonetheless, an R^2 value of 0.974 indicates that the model can account for about 97.4% of the variation in the data. Given the small sample size, this high R^2 is not interpreted as evidence of strong generalizability, but rather as an indication of the model's ability to fit observed patterns in the available data. Overall, the model has a high performance in predicting poor asnaf, but there is still room for improvement in reducing the relative error of some predictions.

Table 3. Model Performance Metrics

	Value
MSE	0.003
MSE(scaled)	0.022
RMSE	0.055
MAE / MAD	0.037
Mean Absolute Percentage Error (MAPE)	25.92%
R^2	0.974

Source: Analysis Results, 2025

Feature Importance analysis (table 4) on the KNN to predict poor asnaf shows that the variable with the greatest influence on prediction is micro enterprises with a mean dropout loss of 0.056, followed by agriculture (0.054) and others (0.052). This shows that individuals involved in micro enterprises and the agricultural sector have a strong relationship with the status of poor asnaf. In addition, the Animal Husbandry (0.048) and Santripreneur (0.046) variables also had a significant contribution in the model.

Table 4. Feature Importance Metrics

	Mean dropout loss
Micro	0.056
Agriculture	0.054
Other	0.052
Farm	0.048
Santripreneur	0.046
Ultra-micro	0.032
Scholarship	0.031
Qardol Hasan	0.025
uninhabitable houses	0.014

Note: Mean dropout loss (defined as RMSE) is based on 50 permutations.

Source: Analysis Results, 2025

Meanwhile, variables such as Ultra-micro business (0.032), Scholarship (0.031), and qardhul hasan (0.025) had a lower influence than other variables, although they still contributed to determining predictions. The variable with the least influence is uninhabitable houses (0.014), which means that this factor is not very decisive in the classification of poor asnaf status. Overall, these results suggest that economic aspects such as micro enterprises, agriculture, and livestock have a large role in determining poverty status, while financial aid factors such as scholarships and qardhul hasan have a smaller influence in the model.

The analysis of Additive Explanations (table 5) for the prediction of the status of poor asnaf in five test cases shows how each feature contributes to the prediction results compared to the base value of 0.194. In Case 1, a prediction of 0.028 indicates that this individual has a low probability of being a poor asnaf, with the micro business (-0.043) and other (-0.033) factors making the largest negative contribution in lowering the prediction. Case 2, with a prediction of 0.792, shows a high probability of being a poor asnaf, mainly influenced by scholarships (0.195), agriculture (0.159), and micro enterprises (0.173) which significantly increased the prediction. In Case 3, a prediction of 0.440 indicates an intermediate category, with agriculture (0.203) being the dominant factor that increased the prediction, while Animal Husbandry (-0.017) and Santripreneur (-0.003) made a small contribution in decreasing it.

Table 5. Additive Explanations for Predictions of Test Set Cases

Case	Predicted	Base	Scholarship	Santripreneur	Ultra-micro	Agriculture	Farm	Qardul Hasan	uninhabitable houses	Micro	Other
1	0.028	0.194	-0.006	-0.009	-0.016	-0.007	-0.021	-0.023	-0.007	-0.043	-0.033
2	0.792	0.194	0.195	0	0	0.159	-0.02	0.07	0	0.173	0.022
3	0.44	0.194	0.011	-0.003	-0.004	0.203	-0.017	-0.004	0	-0.007	0.067
4	0.274	0.194	0	0.037	0.002	-0.008	0.022	0	0	0.044	-0.018
5	0.076	0.194	-0.024	-0.014	0.003	-0.011	-0.016	-0.021	0	-0.06	0.024

Note: Displayed values represent feature contributions to the predicted value without features (column 'Base') for the test set.

Source: Analysis Results, 2025

Case 4, with a prediction of 0.274, is also in the medium category, where Santripreneur (0.037) and micro enterprises (0.044) slightly increase the probability of being a poor asnaf, while others (-0.018) slightly reduce it. Finally, Case 5 has a low prediction of 0.076, with micro enterprises (-0.060) as the main factor that reduces the likelihood of individuals being included in poor asnaf, while scholarships (-0.024) and qardhul hasan (-0.021) also contribute negatively to the prediction. Economic factors such as micro enterprises, agriculture, and scholarships have a significant influence on increasing or decreasing the likelihood of individuals being categorized as poor asnaf. Those who have micro businesses or get certain forms of financial support tend to have a lower probability, while those who depend on agriculture and scholarships have a higher probability of being categorized as poor asnaf.

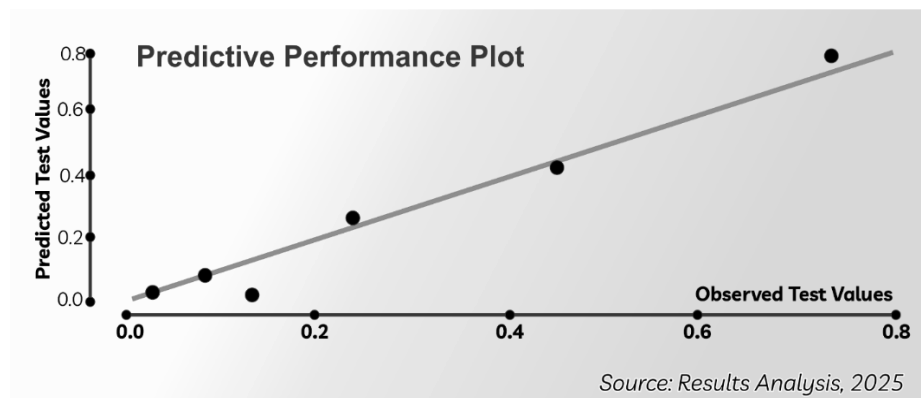
Figure 2. Predictive Performance Plot

Figure 2 plots among the predicted value and the actual value on the test data in the KNN Regression model used to predict the status of poor asnaf.

The dots in the plot represent the predicted value pair and the actual value, while the red line indicates the identity line ($y = x$), which indicates the perfect prediction. The distribution of points parallel to the identity line indicates that the model has high accuracy, with predictions very close to the actual value. There is only a slight deviation from the line, which indicates that the prediction error is relatively small. This is also consistent with the high R^2 value (0.974), which indicates that the model and to account for most of the variation in the data. Thus, this model can be said to have excellent performance in predicting the possibility of someone being classified as a poor asnaf.

5. Discussion

Based on the results of the prediction of K-Nearest Neighbors Regression (KNN), provinces in Indonesia are grouped into four categories of poor asnaf. This grouping is based on predicted similarities in economic and social characteristics and should be interpreted as a predictive classification rather than a causal determination of poverty. This categorization helps in designing a more targeted zakat distribution strategy. Accordingly, the proposed strategies are framed as decision-support insights to assist policy prioritization, not as prescriptive causal interventions. The following table presents the results of provincial classification based on KNN predictions along with recommended strategies (table 6). Research shows that unemployment and inflation have a significant positive relationship with poverty, increasing people's vulnerability to economic instability, especially in regions with a high dependence on the informal sector (Ghazi & Dhahir, 2024). In addition, non-standard or unstable jobs, despite creating jobs, often fail to reduce poverty effectively, especially in areas with limited social protection, while declining social transfers further magnify the risk of poverty (Gábos et al., 2024).

Table 6. Poor *Asnaf* Category based on KNN Predictions and Strategies

Poor Asnaf	Province	KNN Prediction	Strategy
High	East Java (Group A)	0.731	Increase micro and agricultural business help; productive zakat program for entrepreneurship; and access to capital and skills training.
Moderate	West Java, Central Java, South Kalimantan, West Sumatra, Yogyakarta, Central Sulawesi, South Sulawesi (Group B)	0.3047–0.5080	Educational scholarships to reduce long-term poverty; capital support for small businesses and farmers; skills training and entrepreneurship programs.
Low	Banten, Riau Islands, South Sumatra, Lampung, North Sumatra, Riau, Jambi, Bangka Belitung District, East Kalimantan, Jakarta, West Nusa Tenggara, Gorontalo, Central Kalimantan (Group C)	0.107–0.285	Consumptive zakat helps for vulnerable groups; community-based economic strengthening programs; monitoring the effectiveness of the zakat program.
Very Low	Bengkulu, North Kalimantan, West Sulawesi, Bali, North Sulawesi, West Kalimantan, East Nusa Tenggara, Southeast Sulawesi, Maluku, Aceh, North Maluku, West Papua (Group D)	0.010–0.088	Development of social investment-based zakat programs; improvement of social and economic infrastructure; Evaluation of the sustainability of zakat help.

Source: Analysis Results, 2025

Research shows that unemployment and inflation have a significant positive relationship with poverty, increasing people's vulnerability to economic instability, especially in regions with a high dependence on the informal sector (Ghazi & Dhahir, 2024). In addition, non-standard or unstable jobs, despite creating jobs, often fail to reduce poverty effectively, especially in areas with limited social protection, while declining social transfers further magnify the risk of poverty (Gábos et al., 2024). Group A is the only province that is included in the category of high poverty rate based on the results of the KNN analysis with a prediction value of 0.731, the highest among all other provinces (table 6). This is due to the similarity of the economic and social characteristics of

Group A with other provinces that have high poverty rates, based on the calculation of the Euclidean distance in the KNN model. From the feature importance analysis, the factors that most affect the status of poor asnaf are micro enterprises (0.056), agriculture (0.054), and livestock (0.048). Within the KNN framework, these variables should be interpreted as having stronger predictive associations with poor asnaf status, rather than being causal determinants of poverty. Group A has a high score in the micro and agricultural sectors, which in this model is associated with high poverty rates. This association reflects similarity patterns in the data rather than evidence that micro enterprises or agriculture directly cause higher poverty. Although micro enterprises can generally help the economy, in areas with high poverty rates such as Group A, many micro enterprises are still on a small scale and have not developed optimally to improve the economic welfare of the community. This interpretation is consistent with prior literature but remains inferential rather than causal within the scope of the current model. In addition, social factors such as scholarships (0.031) and qardhul hasan (0.025) have a lower influence on the status of poor asnaf, suggesting that despite educational and financial assistance programs, their contribution to poverty reduction is still limited compared to other economic factors. In the KNN model, Group A has a smaller Euclidean distance from high-poverty areas, such as Group B, but has a higher prediction value due to a stronger combination of economic variables in driving poor asnaf status. Meanwhile, other provinces with lower prediction scores have a more stable combination of economic factors, with support from more developed business and industry sectors. Therefore, the KNN model consistently classifies Group A as the only province in the high poverty category, indicating that the province needs a more aggressive and economic empowerment-based zakat distribution strategy to reduce high poverty rates. Low socioeconomic factors have a significant impact on welfare indicators, such as the fulfillment of basic needs, education, and the risk of stunting in children in developing countries (Fatsena et al., 2020). The informal sector, including micro-enterprises, plays an important role in reducing poverty, but without optimal development, the sector often fails to significantly improve welfare, especially in areas with high poverty (Tatipikalawan et al., 2022). Social assistance programs, such as scholarships and financial assistance, although positively impacted, are often not on target due to suboptimal distribution for the poor who need it most (Yunis et al., 2020). In addition, the agriculture and livestock sectors, which are the backbone of the rural economy, face challenges such as lack of technological support and

market access, so their contribution to poverty reduction is limited (Simanjuntak & Batu, 2022).

Group B is categorized as moderate poverty based on the results of the KNN prediction (table 6), with a prediction value range among 0.3047 to 0.5080. This shows that the economic and social characteristics in these provinces are similar to those of regions with moderate poverty levels, but not as bad as Group A which is categorized as high. From the feature importance analysis, the dominant factors associated with higher predicted poor asnaf status in this group are micro enterprises (0.056), agriculture (0.054), and livestock (0.048), but with a lower level of involvement than Group A. These variables exhibit stronger predictive associations within the KNN model rather than causal effects on poverty. In addition, provinces in this category have stronger social support, such as access to scholarships (0.031) and Qardhul Hasan (0.025) which are slightly more effective in reducing poverty than in Group A. Research shows that education, inflation, and unemployment have a significant relationship with poverty, where higher education and economic diversification play a role in reducing long-term poverty, while inflation and unemployment increase people's vulnerability, especially in areas with suboptimal micro enterprises (Zafar et al., 2021). Cultural factors and social structures that support dependence on traditional sectors, such as agriculture, point to the need for economic diversification through the services and trade sectors (Kliuchnyk, 2022), as well as infrastructure support and access to capital to develop small and medium-sized enterprises to reduce unemployment and increase economic stability (Tariel Kikvadze & Temur Shakiashvili, 2023). Technically in the KNN model, these provinces have a greater Euclidean distance than Group A to areas with high poverty, but are still quite close to provinces with vulnerable economic characteristics. For illustration, West Java and DI Yogyakarta have more developed service and creative industry sectors, while South Kalimantan and South Sulawesi have stronger trade and mining sectors to support their economies. Therefore, although there is still a significant poverty rate, the provinces in this category do not show a strong relationship with the region that has the highest level of poor asnaf in the KNN model. The KNN model classifies these provinces in the category of moderate poverty, which shows that the zakat distribution strategy by BAZNAS in this region needs to be focused on strengthening micro enterprises, increasing access to capital for farmers and ranchers, as well as supporting scholarships and financial help to ensure that the

poor can improve their living standards more independently. Micro enterprises play an important role in reducing poverty, especially with the support of innovative strategies such as marketing digitalization, packaging training, and product diversification, which increase people's competitiveness and income (Pribadi et al., 2023). Diversification in the agriculture and livestock sectors, such as processing crops into value-added products (fish nuggets or microalgae-based soy milk), is also effective in increasing income and reducing dependence on primary products (Fathurohman et al., 2020; Sari et al., 2022). Help in risk management, business diversification, and product processing training also strengthens the community's economic independence (Unsunidhal & Suryawati, 2020). Although social programs such as scholarships and financial help contribute to welfare, their impact is more limited than strengthening the direct economic sector, so improving the efficiency of the distribution of these programs can provide greater benefits to the poor (Roswiyani & Amanda, 2021).

Group C (table 6) is categorized in the low poverty level based on the results of the KNN prediction, with a prediction value range of 0.107 to 0.285. These results show that although there is still a poor asnaf population in these provinces, their poverty rate is lower than that of the province group with medium and high categories. From the feature importance analysis, economic factors such as micro enterprises (0.056), agriculture (0.054), and livestock (0.048) remain relevant predictors of poor asnaf status, but with a smaller influence than provinces in the high and medium poverty categories. This indicates weaker predictive associations within the KNN model rather than direct causal contributions. In addition, provinces in this category have a more diverse economic structure and better access to industrial, trade, and service sectors, which allows their population to have more economic opportunities than regions with higher poverty. In the KNN model, these provinces have a greater Euclidean distance to areas with high poverty, suggesting that their economic characteristics are closer to those with lower poverty levels. Another differentiating factor is the level of urbanization and the diversity of economic sectors in these regions. Jakarta, Riau Islands, and East Kalimantan, for illustration, have more advanced industrial, trade, and service sectors, so their populations are less dependent on micro enterprises and agriculture that have higher economic risks. Meanwhile, provinces such as South Sumatra, North Sumatra, and Lampung have more stable agricultural and plantation

sectors than areas in the medium and high poverty category. In addition, areas such as Jambi and Bangka Belitung have sufficient natural resources to support the economy, thereby reducing dependence on zakat help significantly. The KNN model classifies these provinces into low poverty categories, indicating that their observed characteristics are more similar to provinces with relatively lower predicted poverty levels. Accordingly, zakat distribution in these regions can be oriented toward strengthening the community-based economy, consumptive zakat helps for vulnerable groups, and monitoring the effectiveness of zakat programs to ensure that the help provided really has an impact on the beneficiaries. Urbanization and the development of the trade and services sectors contribute significantly to reducing poverty by creating wider economic opportunities, especially in regions with strong formal and informal economic activities (Yuniarman et al., 2020). Better education in urban areas increases labor productivity, such as in the agricultural and service sectors, where the use of modern technology becomes more efficient (Apriliani et al., 2023). Adequate infrastructure in urban areas supports access to markets and public services, while social support such as education and scholarships make an more contribution, although the impact is more limited than the strengthening of the direct economic sector (Munawaroh, 2020). Urbanization plays an important role in reducing poverty by creating job opportunities, improving access to infrastructure, and encouraging diversification of the local economy, as seen in Vietnam (Ha et al., 2021). The trade and services sectors are also reducing dependence on primary sectors, such as agriculture, with urbanization in China proving its positive impact on average incomes and urban employment (X. Wang et al., 2022). In addition, access to education and social infrastructure through planned urbanization further improves household welfare in urban and semi-urban areas (Z. Wang et al., 2023).

Group D is categorized as having very low poverty levels based on KNN predictions, with values ranging from 0.010 to 0.088 (Table 6). Although poor asnaf groups still exist in these areas, their poverty rates are lower compared to other provinces. Economic variables like micro-enterprises (0.056), agriculture (0.054), and livestock (0.048) have a smaller impact on poverty here compared to higher-category provinces. In the KNN model, these provinces show a large Euclidean distance from high-poverty areas, indicating economic and social characteristics closer to regions with better well-being. Key factors contributing to this classification include strong economic support from natural resources,

tourism, and stable service sectors. These factors characterize provinces with lower predicted poor asnaf status, rather than representing causal drivers of poverty reduction. For example, Bali and North Sulawesi benefit from thriving tourism industries, while West Papua, West Kalimantan, and Maluku leverage abundant natural resources. Aceh and North Maluku also exhibit better social investment programs and infrastructure. Social factors, such as improved access to education and effective social aid distribution, further reduce poverty. The KNN model indicates that these regions are characterized by relatively lower predicted poverty levels; therefore, zakat distribution in these regions may be directed toward long-term social investments, such as economic infrastructure, ultra-micro enterprise development, and skills training. Periodic evaluations are crucial to ensure zakat remains aligned with evolving community needs. Tourism is a major driver of the local economy, especially in areas with tourist attractions such as Bali and North Sulawesi, which not only increases people's income but also creates job opportunities and supports the growth of small and medium-sized enterprises (Dapang et al., 2023). Infrastructure development, such as road access and public facilities, strengthens tourist attraction and increases the number of visitors, thereby contributing to poverty reduction (Lolowang et al., 2024). Ecotourism programs in areas with natural environmental potential make a major contribution through increasing environmental awareness, creating local jobs, and more income from sustainable tourism activities (Lina et al., 2022). Across Groups B to D, the discussion emphasizes similarities in predicted patterns and relative vulnerability levels rather than causal explanations of poverty dynamics, consistent with the predictive nature of the KNN framework.

From a policy perspective, the KNN-based predictions provide a data-driven tool to support prioritization and targeting of zakat distribution rather than definitive prescriptions (Guan et al., 2020). By comparing predicted poor asnaf levels with realized zakat distribution, BAZNAS can conduct monitoring and evaluation to assess program alignment and effectiveness. Future research incorporating additional macroeconomic and institutional variables, as well as alternative modeling approaches, may further strengthen the robustness and policy relevance of the findings. The integration of household data with local policies allows the identification of the specific needs of target groups, thus creating more effective programs to address multidimensional poverty (Giest et al., 2021). Diversification of the local economy, supported by data analysis,

helps create jobs and increase household incomes, especially in low-income countries (Cyrille Mabiata Nzobo, 2021). In addition, the use of technologies such as AI and satellite data allows for high accuracy prediction of poverty rates, supporting more precise interventions in regions with traditional data limitations (Raghu Raman et al., 2023). BAZNAS and local governments to design data-based policies, so that the distribution of zakat is not only equitable but also effective in reducing poverty rates. By comparing the results of the KNN prediction with the realization of zakat distribution, monitoring and evaluation can be carried out to assess the effectiveness of the program that has been running and adjust the strategy if necessary. This prediction model can also be further developed by adding other economic and social variables to improve accuracy. Furthermore, the results of the KNN can help in determining the economic sectors that need the most intervention in each province. For illustration, in Central Java and West Sumatra, empowerment programs can be focused on supporting micro and agricultural enterprises, while in urban areas such as Jakarta, zakat programs can be directed to small business development and workforce skill improvement. With this data-based approach, the distribution of zakat can be more targeted, efficient, and have a long-term impact, supporting the main goal of zakat in poverty alleviation systematically. The distribution of zakat based on the principles of equity and justice, by prioritizing eight groups of zakat recipients proportionally according to the level of need and location, has proven to be effective in reducing poverty (Wiranda, 2023). This effectiveness is supported by targeted zakat distribution management through the Zakat Core Principles approach, which emphasizes transparency, accuracy, and timeliness (Yuliasih et al., 2021). The use of technology also plays an important role in optimizing the distribution of zakat, with technology-based applications helping to manage more accurate data and more efficient distribution processes (Fitriani, 2021).

6. Conclusion

This study applies a predictive machine learning approach to identify poverty levels in various provinces in Indonesia using the KNN model, which classifies provinces into four categories: high, medium, low, and very low. The classification reflects similarities in observed economic and social characteristics across provinces rather than causal determinations of poverty. The KNN results show that East Java is included in the high poverty category with a prediction value of 0.731, while provinces such

as Bali and West Papua are in the very low poverty category with prediction values ranging from 0.010 to 0.088.

Economic factors such as micro enterprises, agriculture, and livestock exhibit stronger predictive associations with poor asnaf status within the KNN framework, with micro enterprises being the dominant predictor (mean dropout loss 0.056). Meanwhile, social factors such as scholarships and qardhul hasan show relatively weaker but still relevant predictive contributions. These results should be interpreted as model-based patterns that enhance understanding of relative vulnerability rather than as evidence of causal drivers of poverty.

From a policy perspective, the findings provide decision-support insights for designing a more targeted zakat distribution strategy, particularly in provinces classified as having higher predicted poverty levels, where economic empowerment programs may be prioritized based on observed patterns in the data. The KNN-based approach is intended to support prioritization and monitoring rather than to prescribe definitive policy interventions.

However, this study has several limitations that should be acknowledged. These include the relatively small effective sample size at the provincial level, potential aggregation bias arising from the use of province-level data, and sensitivity of the KNN model to parameter choices, which may affect model stability and generalizability. In addition, macroeconomic variables such as inflation and unemployment, while discussed conceptually, are not incorporated empirically and therefore limit the scope of the predictions.

The theoretical implication of this study lies in demonstrating the potential role of data-driven and predictive approaches in supporting research on Islamic social finance and poverty alleviation. The practical implication is the use of machine learning as a complementary tool to enhance the efficiency, transparency, and targeting of zakat distribution. Future research may benefit from incorporating additional macroeconomic and institutional variables, conducting robustness checks using alternative models, and examining the longer-term outcomes of zakat programs on mustahik economic resilience and independence.

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