

Data-Driven Insights of the Ecotheology Implementation at Islamic Schools in Indonesia using Machine Learning

Dian Sa'adillah Maylawati^{a*}, Cepy Slamet^a, Muhammad Khalifa Umana^b, Akhmad Ridlo Rifai^a, Rohmat Mulyana^c, Muhammad Ali Ramdhani^a, Syafi'i Syafi'i^d

^aDepartment of Informatics, UIN Sunan Gunung Djati Bandung, Jl. A. H. Nasution Bandung 40614, Indonesia

^bFaculty of Tarbiyah and Teaching, UIN Sunan Gunung Djati Bandung, Jl. A. H. Nasution Bandung 40614, Indonesia

^cDepartment of Islamic Education, UIN Sunan Gunung Djati Bandung, Jl. A. H. Nasution Bandung 40614, Indonesia

^dDepartment of Islamic Education, UIN Syarif Hidayatullah, Jl. Ir H. Juanda No.95, Ciputat, Tangerang Selatan, Banten 15412, Indonesia

Abstract

Ecotheology is an integration of religious values towards awareness of environmental preservation. Indonesia's Ministry of Religious Affairs has identified ecotheology as a strategic program, including Islamic school students. Therefore, this study aims to reveal the understanding, implementation, challenges, and opportunities of ecotheology in Islamic schools. This research applies data science and machine learning algorithms to analyze a large student dataset, 22,933 data from 32 provinces, with a 41-question validated questionnaire (Cronbach's Alpha = 0.765, Kappa = 0.791). This research uses K-Means and PCA for clustering to group students by ecotheology awareness and implementation, Association Rules with Apriori algorithm to identify knowledge sources, obstacles, and program linkages, classification using ensemble learning with CatBoost as the best model with 98.71% accuracy, and sentiment analysis using RoBERTa-based Indonesian model on open responses. The research found that students' understanding of ecotheology is high, with most learning from teachers and others gaining knowledge from social media and books, while implementation remains moderate due to limited programs, policies, and subject integration. Clustering analysis identified three groups, including Cluster 0 with low awareness and impact, Cluster 1 with high scores in all categories, and Cluster 2 with moderate levels. The classification result can detect the level of students' implementation of ecotheology with four classes: low, moderate, high, and very high. Last, sentiment analysis revealed neutral tones in suggestions but mostly positive expectations, with students desiring more practical, Quran-linked, and community-based activities.

Keywords: data science; ecotheology; environmental awareness; Islamic schools; machine learning.

Received: 27 December 2025

Revised: 27 February 2026

Published: 30 April 2026

1. Introduction

Environmental preservation is one of the world's focuses to maintain the sustainability of a healthy and habitable environment for living things. The issue of environmental preservation is part of the Sustainable Development Goals (SDG) agenda number 7 (affordable and clean energy), 13 (climate action), 14 (life below water), 15 (life on land), and has an impact on SDG 3, namely good health and well-being (United Nations, 2026). Because a healthy environment will have an impact on a healthy and prosperous life. The balance of the environmental ecosystem needs to be maintained with human awareness of the importance of preserving the environment. All religions clearly command not to cause damage to the earth, more broadly to make the earth peaceful, including the environment of living creatures living in it. One form of environmental preservation is stated in the strategic program of the Ministry of Religion of the Republic of Indonesia for 2025-2029, namely ecotheology.

Ecotheology is an interdisciplinary field that integrates theological perspectives with ecological issues, emphasizing the relationship between faith and environmental stewardship (Andira et al., 2024; Dalihade, 2021; Worotikan et al., 2024). Ecotheology is a diverse field that encompasses various religious and cultural perspectives, each contributing to a more comprehensive understanding of the relationship between faith and the environment (Barnhill & Gottlieb,

* Corresponding author.

E-mail address: diansm@uinsgd.ac.id

2010; Gottlieb, 2003, 2006; Northcott, 2020). Ecotheology aims to address the ecological crisis we face by utilizing religious teachings and practices to promote sustainability and stewardship of nature (Hove, 2024; Kgatele & Chigorimbo, 2024). Diverse religious perspectives contribute unique insights to ecotheology. For example, Islamic ecotheology emphasizes principles such as stewardship and justice in environmental management (Ach. Syaiful Islam et al., 2024). Postcolonial approaches in ecotheology highlight the importance of local wisdom and cultural context, especially in regions such as Indonesia (Aruan, 2024). Practical applications of ecotheology encourage practical actions, such as environmental education, community engagement, and sustainable practices within religious communities (Ach. Syaiful Islam et al., 2024).

Environmental education is an essential part of the educational curriculum from elementary school to higher education, including Islamic schools. Islamic schools are educational institutions under the auspices of the Ministry of Religious Affairs, each with its own unique curriculum. Indonesia has 10,491,243 Islamic school students from all levels and classes (Raudhatul Athfal (RA)/ Kindergarten, Madrasah Ibtidaiyah (MI)/ Elementary School, Madrasah Tsanawiyah (MTs)/ Junior High School, and Madrasah Aliyah (MA)/Senior High School) spread across 87,576 institutions in the even semester of 2024/2025. (Direktorat Jendral Pendidikan Islam Kementerian Agama RI, 2025). Incorporating environmental education into Islamic school subjects is one step in supporting environmental conservation. As educational institutions with a distinctive Islamic religious content, Islamic schools are educational institutions that can put ecotheological concepts into practice.

Ecotheology in Islamic schools refers to efforts to integrate religious values with environmental awareness and preservation in Islamic education (Januardi, 2025). The role of teachers, particularly Islamic Religious Education (IRE) teachers, is crucial. They act as educators by teaching ecotheology through classroom learning, encompassing theory, values, and their application. IRE teachers also act as facilitators, emphasizing the importance of environmental awareness through conservation activities based on Islamic law. Furthermore, IRE teachers motivate and serve as role models for students to develop environmentally conscious behavior, in accordance with religious teachings, starting in the classroom and Islamic school.

The Minister of Religion asked to include ecotheology and nature conservation in the religious and religious education curriculum (Januardi, 2025). The concept of ecotheology is a new approach to integrating environmental awareness into religious education. It is hoped that ecotheology will become a holistic approach at all levels of education, especially religious education (Laksono, 2022). The implementation of an ecotheology-based curriculum in Islamic schools and religious colleges is expected to foster a generation that is environmentally responsible. Therefore, this research is crucial to determine the extent to which Islamic school students understand the concept of ecotheology and its implementation.

Ecotheology has become a unique concept for religious schools that integrate ecology and theology, where religious values are part of the understanding and implementation of environmental conservation. Research related to ecotheology has developed globally, including in Indonesia. The concept of ecotheology in Islamic school education emphasizes the integration of environmental awareness into Islamic teachings. This approach seeks to foster a sense of ecological responsibility among students through various educational strategies and leadership roles within the Islamic school system. For example, the integration of environmental values into education is based on ecotheology, which combines religion and promotes environmental management (Laksono, 2022).

The Islamic ecotheology movement is also growing rapidly in Indonesia, which is exposing the ecotheological crisis in Indonesia. (Asmanto et al., 2016; Mardhiah et al., 2014; Romdloni & Sukron Djazilan, 2019; Saputro & Gunadi, 2021; Widiarto & Wilaela, 2022). The ecological crisis in Indonesia is one of the factors driving the importance of the concept of ecotheology in Indonesia. Therefore, ecotheological spirituality needs to be developed to increase environmental understanding and preservation. Through Islamic schools, the concept of ecotheology can be introduced and instilled. Islamic school curricula can include ecological spirituality, with a focus on the environment from an Islamic perspective (Solichin, 2017). Likewise, effective learning models include contextual, thematic, and inquiry-based learning, which encourage active engagement with ecological issues.

Ecotheology requires sound and consistent leadership and management. The role of the Islamic school Principal is crucial, promoting effective leadership to implement ecotheological principles, enhance teacher professionalism, and foster a conducive learning environment. While focusing on ecotheology in Islamic school education is promising, challenges such as limited resources and resistance to change can hinder its full implementation. Addressing these issues is crucial for the sustainability of ecotheological practices in Islamic education. Therefore, an understanding of ecotheology as a foundation for Islamic school students needs to be developed. Furthermore, ecotheological concepts need to be implemented within the Islamic school environment, both through learning and other academic activities.

This implementation needs to be consistently evaluated and examined for factors, impacts, challenges, and opportunities for sustainable ecotheology.

Therefore, by leveraging the rapid development of data science and machine learning technologies (B R et al., 2024; Munde, 2024; Rezaei & Jabbari, 2022; Shahapur et al., 2022; Shook, 2023; Yan, 2022), this study aims to explore the extent to which Islamic school students understand the concept of ecology from an Islamic perspective and the extent to which ecotheology is implemented in the Islamic school curriculum and learning. Furthermore, this study identifies the challenges and opportunities that arise during the implementation of ecotheology in Islamic schools, and analyzes the educational impact of applying ecotheology on Islamic school students' environmental awareness and behavior.

2. Research Methodology

2.1. Research Activities

This research adapts data science development methodologies and machine learning processes as a framework for research activities. The adapted data science methodology is the Cross-Industry Standard Process for Data Mining (CRISP-DM), depicted in Figure 1. CRISP-DM is a widely adopted framework that guides the data mining process through a structured methodology. Activities in CRISP-DM include (Doede et al., 2024; Elkabalawy et al., 2024; Gill et al., 2024; Saputra et al., 2024):

- Business Understanding involves identifying and defining business objectives. This activity involves conducting a literature review and understanding the context of ecotheology and its implementation in education.
- Data Understanding involves collecting and exploring data relevant to the needs of solving problems. This activity prepares a questionnaire design, measures the validity and reliability of the questionnaire, and then collects the questionnaire data.
- Data Preparation prepares the dataset for the modeling process, which involves cleaning, completing, integrating, and transforming the data.
- Modeling involves building a solution model for the business problem being solved. This activity is adapted to apply various machine learning algorithms to perform in-depth data analysis.
- Evaluation, which assesses the model's performance against business objectives, ensuring it meets required standards. Evaluation is part of the model development process.
- Deployment involves implementing the model in the real world by facilitating continuous monitoring and adjustments. This research disseminates the model using Gradio.

2.2. Data Collection and Pre-processing

The population data of Islamic school institutions and students in this study refers to EMIS, which is an educational data gateway application at the Directorate General of Islamic Education, Ministry of Religion of the Republic of Indonesia (Direktorat Jendral Pendidikan Islam Kementerian Agama RI, 2025). The target respondents for this study were students in grades 5 and 6 of Islamic elementary schools (MI), grades 8 and 9 of Islamic junior high schools (MTs), and grades 10, 11, and 12 of Islamic senior high schools (MA). Table 1 shows the distribution of the population that was the target of the research and the number of respondents who were successfully collected.

Table 1. Population Distribution Data and Research Respondents

Level (Class)	Number of Students	Number of Students as Respondents
MI (5)	690,110	1,900
MI (6)	679,448	1,292
MTs (7)	1,090,621	5,059
MTs (8)	1,088,260	5,549
MTs (9)	1,085,130	3,043
MA (10)	549,659	2,541
MA (11)	538,631	2,047
MA (12)	534,286	1,512
Total	6,256,145	22,933

Students who participated as respondents filled out a questionnaire consisting of 41 questions spread across 7 categories, including: (1) Respondent Identity and Demographics (A); (2) Level of Understanding of Ecotheology (B); (3)

Implementation of Ecotheology in Learning in Islamic school (C); (4) The Role of Teachers in Instilling Ecotheological Awareness (D); (5) Challenges and Opportunities for Implementing Ecotheology in Islamic school (only for MTs and MA) (E); (6) Impact of Ecotheology-Based Education on Student Awareness (F); and (7) Suggestions and Expectations (only for MTs and MA) (G). The questionnaire format consists of options in the form of a Likert scale, free choice, and open questions. The details of the questions are available in the Appendix. The questionnaire has been tested for validity and reliability using Cronbach's Alpha (Bland & Altman, 1997; Edelsbrunner et al., 2025; Forero, 2023) and Kappa Statistics (M. Li et al., 2023) with results of 0.765 and 0.791, respectively. These results indicate that the questionnaire has good and substantial reliability. Next, the data cleaning and transformation process is carried out according to modeling needs, such as handling missing values, changing data types, tokenization, and changing text values to numeric as needed.

2.3. K-Means and Principal Component Analysis (PCA) Algorithm

K-Means is one of the widely used clustering algorithms that finds the minimum distance value in the same cluster (A. Hartigan & Wong, 1979; J. A. Hartigan & Wong, 2006; Slamet et al., 2016). K-Means is a simple, fast algorithm that produces optimal clusters. The K-Means algorithm is as follows:

- Determine the number of clusters to be formed
- Initialize the centroid value for each cluster ($\mu_1, \mu_2, \dots, \mu_K \in \mathbb{R}$) randomly.
- Repeat the calculations in formulas (1) and (2) until convergence:

For each i , calculate:

$$c^{(i)} := \arg \min_j \|x^{(i)} - \mu_j\|^2 \quad (1)$$

For each j , calculate:

$$\mu_j := \frac{\sum_{i=1}^m 1\{c^{(i)}=j\}x^{(i)}}{\sum_{i=1}^m 1\{c^{(i)}=j\}} \quad (2)$$

Meanwhile, the Principal Component Analysis (PCA) algorithm is used to analyze data with multiple variables, which applies the data projection method (Ben Salem & Ben Abdelaziz, 2021; Cameron & Bizo, 2019; Shlens, 2014). The principal components in PCA can be arranged using several criteria, such as an a priori criterion when the number of components to be arranged in the analyzed data is known, an eigenvalue criterion that forms the principal components by eliminating components with values less than one, and a variance percentage criterion determined by looking at the cumulative percentage, with the component with the greater variance percentage being taken as the principal component.

PCA has five main stages: standardization, calculating the covariance matrix, calculating the eigenvalues and eigenvectors of the covariance matrix, followed by the feature vector, and finally, the analysis of changes along the principal component axes. In this study, PCA was used to reduce the dimensionality of the data. Dimensionality reduction performed in PCA does not eliminate important information from the data. In this study, the PCA algorithm was used to reduce dimensionality after labeling the data using the K-Means algorithm.

2.4. An Apriori and Association Rules Algorithm

Association rule mining is an important data mining approach that detects associative patterns between objects in a transactional dataset (Agrawal et al., 1996; Fauzi et al., 2025). This technique develops implication-based rules that express links between frequently occurring objects or occurrences. Initially used in the retail industry, notably in market basket research to identify commodities frequently purchased together, it has now spread to a variety of analytical sectors as technology has advanced. Association rule mining aids in the construction of management information systems by helping to establish marketing strategies, manage inventories, and enable data-driven decisions. Product association patterns, for example, might help managers create promotional bundles and place goods strategically in retail displays.

Apriori is a basic association rules algorithms that produce frequent itemsets from large data transactions. Apriori produces the frequent individual items and frequent itemsets as candidate features. The frequent itemsets can be used to determine association rules. There are several terms in the Apriori algorithm (Agrawal, 1995), including Itemset, which is a set of items that are not empty, for example, itemset denoted by i , where $i = (i_j, i_{j+1}, i_{j+2}, \dots, i_n)$ and i_j are items. A itemsets $A = \{a_1, a_2, a_3, \dots, a_n\}$ is said to be sub itemsets of itemsets $B = \{b_1, b_2, b_3, \dots, b_n\}$ and B is super itemset of A , if integers $i_1 < i_2 < i_3 < \dots < i_n$ and $a_1 \subseteq b_{i_1}, a_2 \subseteq b_{i_2}, a_3 \subseteq b_{i_3}, \dots, a_n \subseteq b_{i_n}$. There are several metrics of Apriori,

including Support (Equation (3)) to measure how frequently an item appears in the dataset relative to the total number of transactions; Confidence (equation (4)) to assess the likelihood that an item Y is purchased when item X is purchased; and Lift (equation 5)) to evaluate how much more likely two items are to be appeared together compared to being purchased independently.

$$\text{Support (A)} = \frac{\text{Transaction containing A}}{\text{Total Transactions}} \quad (3)$$

$$\text{Confidence (A} \Rightarrow \text{B)} = \frac{\text{Support (A} \wedge \text{B)}}{\text{Support (A)}} \quad (4)$$

$$\text{Lift (A} \Rightarrow \text{B)} = \frac{\text{Confidence (A} \Rightarrow \text{B)}}{\text{Support (B)}} \quad (5)$$

2.5. Ensemble Learning Algorithms

This research uses several classification algorithms that adapt ensemble learning in the model-building process, including: Random Forest Classifier, CatBoost Classifier, Light Gradient Boosting Machine (LightGBM), Extreme Gradient Boosting (XGBoost), Gradient Boosting Classifier, and AdaBoost Classifier. Random Forest algorithm is a development of the decision tree that aggregates several classifications from trees (Charim et al., 2019; H. Lan & Pan, 2019). There are three important aspects to the Random Forest algorithm (H. Lan & Pan, 2019): (1) perform bootstrap sampling to build prediction trees; (2) each decision tree predicts with a random predictor; (3) then the random forest makes predictions by combining the results of each decision tree using majority voting for classification or regression.

Random forests have also evolved into various boosting algorithm variants. CatBoost (Categorical Boosting) Classifier is a classification algorithm that is part of the Gradient Boosted Decision Tree using ensembling techniques (Hancock & Khoshgoftaar, 2020). CatBoost modifies gradient computation to avoid prediction drift to improve model accuracy (Bentéjac et al., 2021). CatBoost implements an ordered boosting, a permutation-driven alternative to classical algorithms, and an innovative algorithm for processing categorical features (Prokhorenkova et al., 2018). CatBoost has been proven has perform well in several studies (Ibrahim et al., 2020; Y. Zhang et al., 2020)

Next, Light Gradient Boosting Machine (LightGBM) is a decision tree-based machine learning algorithm to improve model efficiency and reduce memory usage (Alzamzami et al., 2020; Candido et al., 2021). This study also uses Extreme Gradient Boosting (XGBoost) is an implementation of Gradient Boosted decision trees, and focuses laser on computational speed and model performance (Mateo et al., 2021; W. Zhang et al., 2021). The main model features of XGBoost include gradient boosting, stochastic gradient boosting, and regularized gradient boosting. Finally, the Adaptive Boosting (AdaBoost) algorithm is a technique in Machine Learning used as an ensemble method (Saini, 2021)(Sayeed, 2020) that creates a sequence of adaptive, simple weighted decision trees.

2.6. Sentiment Analysis using Bidirectional Encoder Representations from Transformers (BERT)

Sentiment analysis is a part of NLP that involves the automatic identification and categorization of opinions expressed in textual data (S. Chen, 2025; Ghatara et al., 2024; S. Li et al., 2015; Ngalawa & Mponela, 2024). Sentiment analysis is popular used in many fields, such as business, politics, and social media. This research uses transformers as a neural network-based method that uses an encoder-decoder structure connected to an attention layer (Vaswani et al., 2017). The Transformers method continues to evolve from the original Transformers (Vaswani et al., 2017), Bidirectional Encoder Representations from Transformers (BERT) (Devlin et al., 2018), Text-to-Text Transfer Transformer (T5)(Raffel et al., 2020; Yenduri et al., 2023), Generative Pre-trained Transformer (GPT)-1 (Yenduri et al., 2023), GPT-2, GPT-3 (Thoppilan et al., 2022) , Robustly Optimized Pretraining Approach (RoBERTa) (Liu et al., 2019), Language Models for Dialog Applications (LaMDA) (Thoppilan et al., 2022), and Transformer XL (Dai et al., 2019).

BERT is a transformer model that uses pre-trained language representation methods for various NLP tasks (Devlin et al., 2018). BERT trains a language understanding model using a large text corpus (such as Wikipedia), and then applies that model to NLP tasks. BERT has two stages: pre-training and fine-tuning. Over time, BERT has developed into various variants, including DistilBERT (Sanh et al., 2019), Robustly Optimized Pretraining Approach (RoBERTa) (Liu et al., 2019), ALBERT (Z. Lan et al., 2019), and others. This study uses the w1 l1wo/indonesian-roberta-base-sentiment-classifier model for sentiment analysis of questionnaire results with open-ended questions.

3. Result

3.1. Exploratory Data Analysis Result

Based on the descriptive statistical results of the 22,933 data collected, there were no missing data. However, there were fewer than 5% of inconsistent data values, which were replaced with average values. As shown in Figures 1 and 2, the data obtained consisted of 3,204 MI students, 6,062 MTs students, and 13,667 MA students. The distribution of students per class is according to Table 1, there are numbers that are not in line with the total level of Islamic Schools because there are students who do not fill the class. Respondents came from 32 different provinces in Indonesia, with the most respondents coming from Central Java Province.

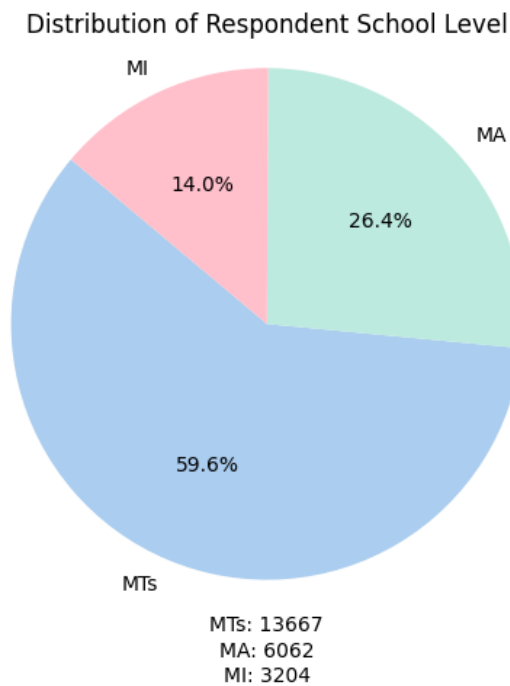


Fig. 1 Level of Islamic Schools

JAWA TENGAH	10986
BENGKULU	2515
JAWA TIMUR	2498
SUMATERA UTARA	1549
SUMATERA BARAT	1053
SULAWESI UTARA	631
LAMPUNG	485
KALIMANTAN TIMUR	442
KALIMANTAN BARAT	432
DAERAH ISTIMEWA YOGYAKARTA	398
DKI JAKARTA	371
JAWA BARAT	293
KALIMANTAN SELATAN	274
NUSA TENGGARA BARAT	241
KEPULAUAN BANGKA BELITUNG	197
RIAU	180
ACEH	175
JAMBI	54
SULAWESI TENGGARA	31
BANTEN	29
MALUKU	23
SUMATERA SELATAN	20
GORONTALO	16
PAPUA BARAT	13
NUSA TENGGARA TIMUR	5
KEPULAUAN RIAU	5
SULAWESI TENGAH	4
MALUKU UTARA	3
CENTRAL JAVA	3
BALI	2
P A P U A	2
SULAWESI SELATAN	2
KALIMANTAN TENGAH	1

Fig. 2 Distribution of Province

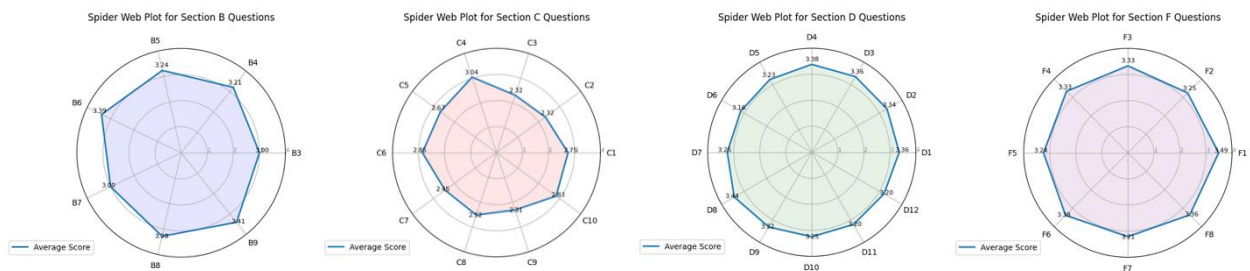


Fig. 3 Mean of Each Question Category

Question categories B, C, D, and F contain questions answered on a Likert scale ranging from 1 to 4, with 4 being the highest or best score. Figure 3 shows the average score for each question, showing the measurement results for each question category. Based on the average value, categories B, D, and F have good values for each question item, with all values above 3, while in category C, most of the questions have values below 3. Simply put, students have sufficient understanding and knowledge regarding what ecotheology is and its importance. According to students, the teacher's role is good in conveying information and reminding the importance of protecting the environment according to religious teachings in learning. This also has an impact on student awareness of the importance of environmental conservation through ecotheology education. However, the implementation of ecotheology still needs to be improved.

3.2. Clustering Result

The clustering model using K-Means and PCA produced 3 optimal clusters based on the Elbow (Hamka & Ramdhoni, 2022; Permadi et al., 2023; Sammouda & El-Zaart, 2021) and Silhouette (Aranganayagi & Thangavel, 2008) results in Figure 4. PCA optimizes in producing the 3 optimal clusters by simplifying and structuring the data so that K-Means can form clearer, more meaningful groups. PCA reduces the dimensionality of the dataset. In this research, there are many variables that are correlated based on 41 questions with 7 categories that can produce unstable or overlapping clusters. Therefore, PCA transforms these correlated variables into a smaller number of uncorrelated components (principal components) that retain most of the variance (information) in the data.

The sentiment in G1 contains the majority of responses, which were neutral (57.71% or 11,385 respondents), with positive at 32.22% (6,356 respondents), and negative at 10.08% (1,988 respondents), whereas in G2, positive sentiment becomes the majority (55.68% or 10,986 respondents) while neutral responses fall to 37.03% (10,986 respondents 7,306) and negative responses decline to 7.28% (1,437 respondents). Cluster 0 (a group of students who have low knowledge, implementation, teacher role, and perceived ecotheological impact) has 5,672 responses and shows the clear transition pattern from neutral-dominant G1 to positive-dominant G2 in the earlier summary. Cluster 1 (Cluster 1 a group of students with the highest ecotheological value) shows a clear shift from largely neutral responses in G1, 51.53% neutral, and in G2 positive responses is 46.95%. While Cluster 2 (a group of students with good or moderate ecotheological value follows the same pattern as Cluster 1, most of G1 is neutral (47.31% neutral), and G2 is positive, 48.76%.

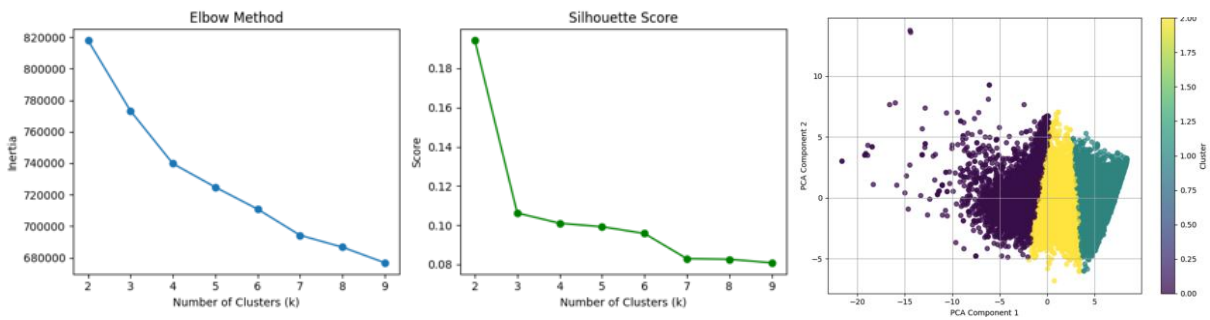


Fig. 4 Elbow, Silhouette, and Cluster Result

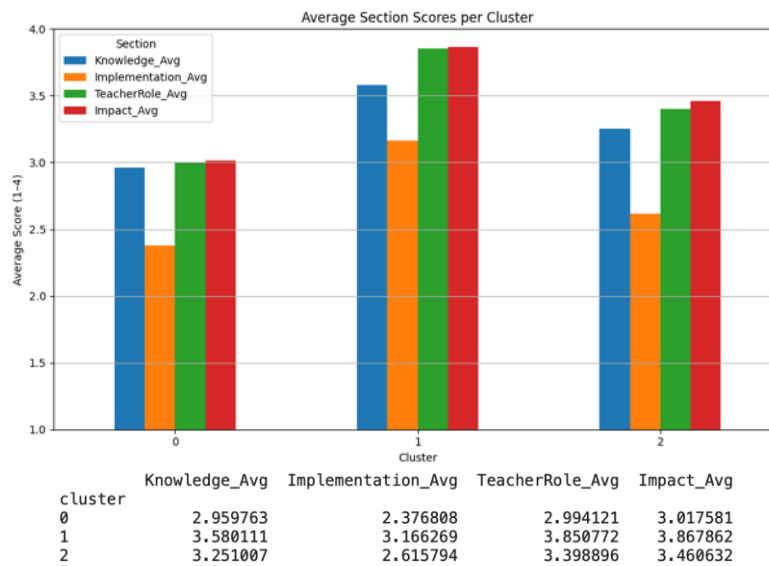


Fig. 5 Characteristics of Each Cluster

The cluster results in Figure 5 show different cluster characteristics. Cluster 0 is a group of students who have low knowledge (B), implementation (C), teacher role (D), and perceived ecotheological impact (F). Students in Clusters 0 have a moderate understanding of ecotheology, perceive moderate implementation of ecotheology in their school, believe their teachers moderately promote Ecotheology, and report a strong positive impact of Ecotheology education on their environmental awareness and behavior. Cluster 2 is a group of students in good conditions, while Cluster 1 is a group of students with the highest B, C, D, and F grades compared to Clusters 0 and 2. Generally, students have a good to very good understanding of ecotheology, perceive moderate implementation of ecotheology in their school, strongly believe their teachers actively promote Ecotheological awareness, and report a strong positive impact of Ecotheology education on their environmental awareness and behavior.

3.3. Association Rules Result

Questions B2 and category E (E1 and E2) were analyzed using association rules with the Apriori algorithm. This method was chosen to identify patterns in students' free choices regarding ecotheological knowledge sources, challenges, and opportunities (provided in Indonesian language). Figures 6, 7, and 8, respectively, show the distribution of patterns found in B2, E1, and E2. In question B2, most students learned about ecotheology from the teacher. However, if we look at the pattern that appears most often simultaneously, if students know the term ecotheology from social media or news, then students must also know it from religious textbooks.

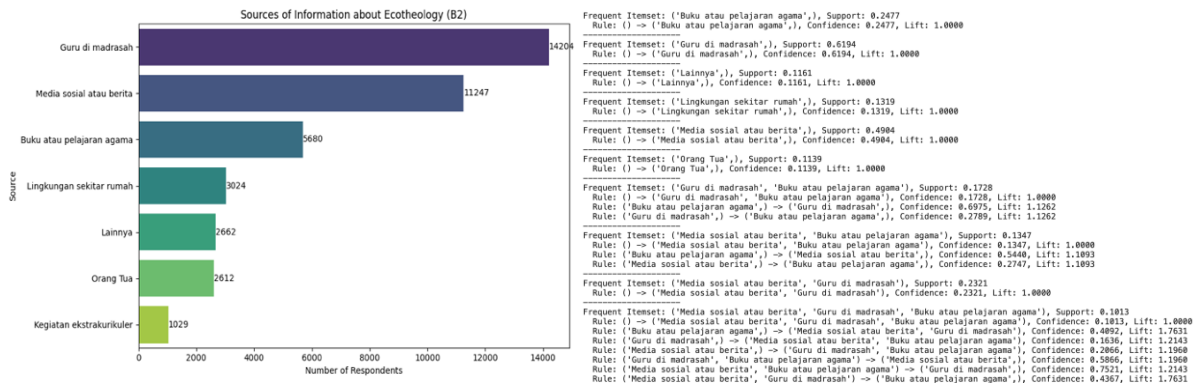


Fig. 6 Itemsets and Association Rules of B2

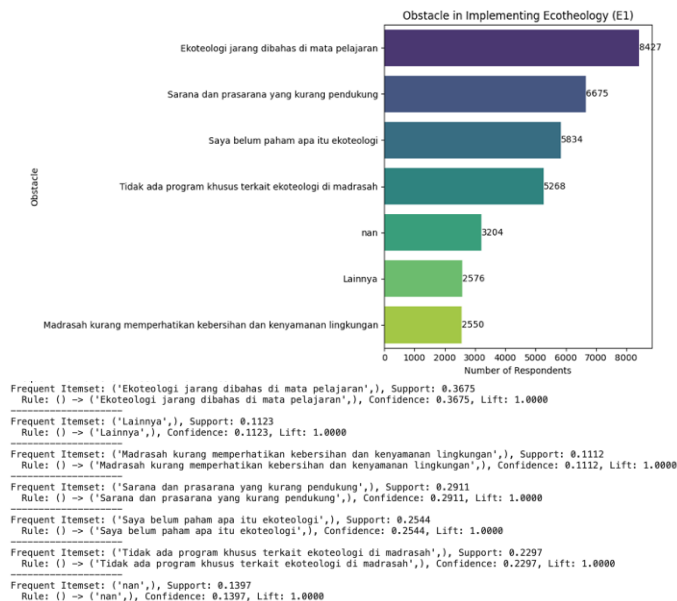


Fig. 7 Itemsets and Association Rules of E

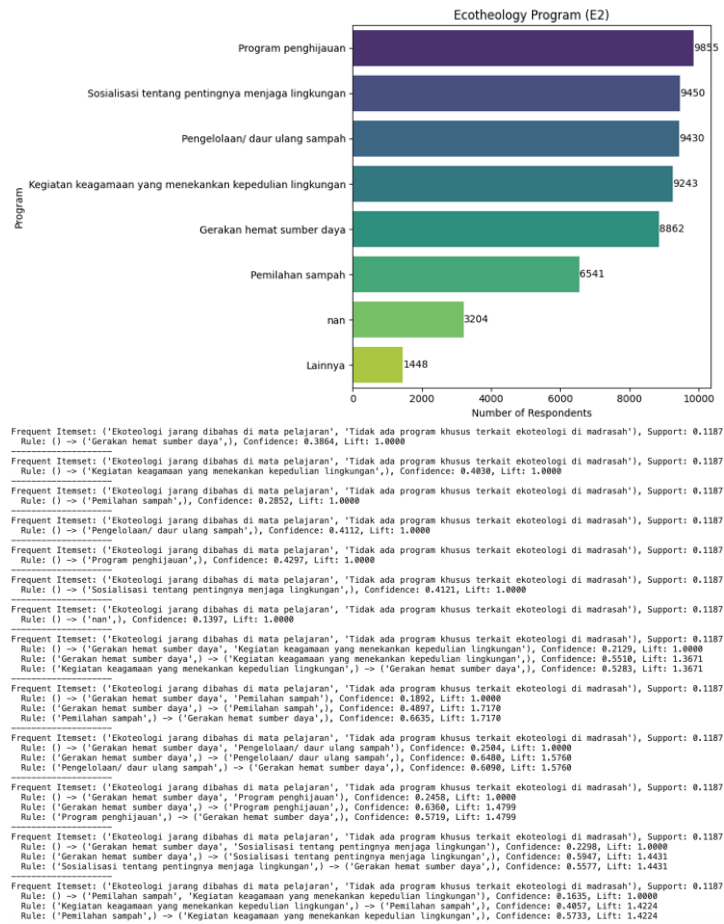


Fig. 8 Itemset and Association Rules of E2

This pattern has a confidence value of 0.4 with a lift of 1.5. Furthermore, in question E2, a pattern was found that the obstacle to implementing ecotheology is that it is rarely discussed in learning, with the largest support value of 0.45. It turns out that this obstacle has an impact on the absence of an ecotheology program in Islamic schools, with a confidence value of 0.6 and a lift of 1.2. The absence of this ecotheology program is also supported by inadequate facilities and infrastructure, with a support of 0.15. Then in question E2, the greening program was most often chosen by students with a support of 0.6. In addition, if a waste sorting program is carried out, it must be accompanied by a waste recycling program with a confidence value of 0.7 and a lift of 1.5.

3.4. Sentiment Analysis Result

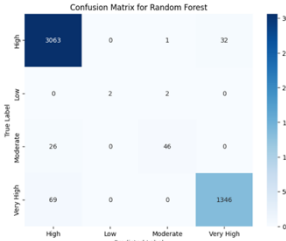
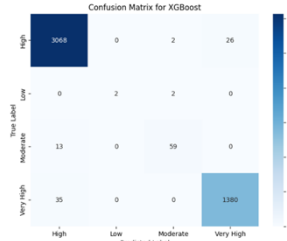
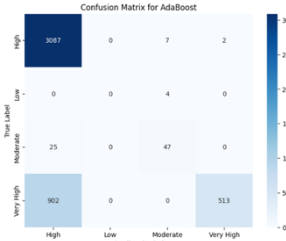
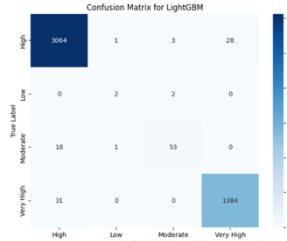
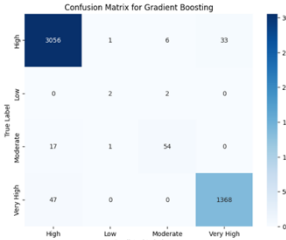
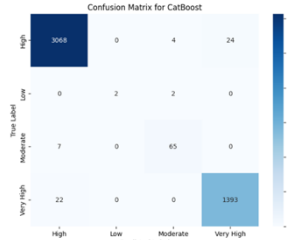
Sentiment analysis was applied to category G, which is an open-ended question about Suggestions (G1) and Expectations/Hopes (G2) regarding ecotheology programs in Islamic schools. This study used the pre-trained RoBERTa model for Indonesian. Figure 9 shows the distribution of sentiments formed from each cluster of PCA results. Overall, students have neutral sentiments towards ecotheology programs in Islamic schools, while they expect positive things from the implementation of ecotheology programs in Islamic schools.

The sentiment in G1 contains the majority of responses, which were neutral (57.71% or 11,385 respondents), with positive at 32.22% (6,356 respondents), and negative at 10.08% (1,988 respondents), whereas in G2, positive sentiment becomes the majority (55.68% or 10,986 respondents) while neutral responses fall to 37.03% (10,986 respondents 7,306) and negative responses decline to 7.28% (1,437 respondents). Cluster 0 (a group of students who have low knowledge, implementation, teacher role, and perceived ecotheological impact) has 5,672 responses and shows the clear transition pattern from neutral-dominant G1 to positive-dominant G2 in the earlier summary. Cluster 1 (Cluster 1 a group of students with the highest ecotheological value) shows a clear shift from largely neutral responses in G1

3.5. Classification Result

A classification model was built using the Random Forest, AdaBoost, Gradient Boosting, XGBoost, LightGBM, and CatBoost algorithms, which aimed to group the level of ecotheology implementation of Islamic school students into Low, Moderate, High, and Very High levels. This model can be used as a predictive model to measure the maturity level of understanding and implementation of ecotheology for students. Table 2 shows the evaluation results of each algorithm using a confusion matrix (Ting, 2017). The experimental results show that CatBoost is the best model that can be implemented as a prediction model for the level of ecotheology implementation for Islamic school students, with an accuracy level reaching 0.9871 or 98.71%. The CatBoost model’s performance is indeed extremely high, but the matrix does not show clear evidence of overfitting or leakage by itself. However, confirm that the reported 98.71% accuracy is plausible on this evaluation set. A confusion matrix result shows very few misclassifications across four classes. This performance is exceptionally high, but not proof of overfitting or data leakage. The confusion matrix actually supports the plausibility of the accuracy on that evaluation set, including reasonably good performance on the “Moderate” class.

Table 2. Classification Results

Algorithm	Confusion Matrix	Accuracy	Algorithm	Confusion Matrix	Accuracy
Random Forest		0.9717	XGBoost		0.9830
AdaBoost		0.7951	LightGBM		0.9817
Gradient Boosting		0.9767	CatBoost		0.9871

4. Discussion

4.1. Student Knowledge and Understanding of Ecotheology

Ecotheology is the concept of integrating religious values into environmental conservation. Islamic schools, as Islamic educational institutions, play a crucial role in educating and providing students with an understanding of the importance of ecotheology. This study found that 75.4% of Islamic school students at the elementary, middle, and high school levels had heard the term ecotheology, 24.3% had not, and the remaining 0.3% did not answer. This fact demonstrates that ecotheology is well-known to Islamic school students. Further analysis using association rules revealed that most students learned the term ecotheology from their teachers, followed by social media or news reports. Interestingly, students who learned the term from social media or news reports often received information from religious textbooks. This finding is in accordance with previous research that mentioned that social media is a 63% effective platform to promote ecotheology (Sabtina & Mahariah, 2025). This suggests that information about ecotheology is effectively

disseminated through social media or news portals, in addition to books. This study also demonstrated that students have a good understanding that ecotheology is a term that connects religion with environmental awareness, in accordance with Islamic teachings. Students also understand that environmental damage is prohibited in religious teachings and that preserving the environment is part of worship. The impact of natural disasters and health crises is also something that students understand if they do not protect the environment. These results are in line with previous research that ecotheology becomes a habit, awareness, lifestyle, value, and character in schools (Cholil & Parker, 2021; Rohman et al., 2024; Romdloni et al., 2024; Syafaruddin, 2025).

4.2. Implementation of Ecotheology in Learning

Ecotheology as part of learning in Islamic schools still needs improvement. This study shows that the average score for ecotheology implementation in Islamic school learning is 2.6, indicating a moderate level that needs further improvement. Most students learn that environmental conservation is in line with religion, but environmental conservation programs are still lacking. Discussion of environmental conservation material in subjects, activities, policies, and special programs related to environmental conservation in Islamic schools is still rare. In line with previous research, the implementation of ecotheology in learning and educational policy presents its own challenges, such as the persistence of knowledge gaps and misconceptions regarding ecotheology (Asare, 2022) and minimal student awareness of the global environmental crisis (Cholil & Parker, 2021). However, the implementation of ecotheology is certainly important to integrate into learning (Rohman et al., 2024). Furthermore, environmental conservation programs with a religious approach are very feasible (Widianto et al., 2023).

4.3. The Role of Teachers in Instilling Ecotheological Awareness

Teachers play a crucial role in the implementation of ecotheology in Islamic schools (Cholil & Parker, 2021; Pangihutan & Jura, 2023). Based on the results of pattern analysis using association rules, teachers are one of the primary sources of information about ecotheology for students. This study found that students have a positive assessment of the role of teachers in Islamic schools, who teach, guide, and provide concrete examples in preserving the environment in accordance with Islamic teachings. The teacher's role also provides motivation and awareness for students to preserve the environment, which is part of implementing religious teachings. The exploration of ecotheology emphasizes the importance of integrating social justice with environmental ethics. The religious teachings can address both ecological and social injustices, advocating for a more inclusive and equitable approach to environmentalism (Gottlieb, 2003).

4.4. Challenges and Opportunities for Implementing Ecotheology in Islamic Schools

This research used association rules with an Apriori algorithm to uncover the challenges and opportunities of implementing ecotheology programs in Islamic schools. The study found that the biggest challenge is that ecotheology is rarely presented in lessons, which undoubtedly impacts the concept and implementation of ecotheology. However, the infrequent discussion of ecotheology in class is due to the lack of specific programs related to ecotheology in Islamic schools, with the highest confidence score of 0.5169 and a lift of 1.4067. Inadequate facilities and infrastructure also pose a challenge to implementing ecotheology in Islamic schools. Limited understanding of ecotheology is indeed a major challenge in implementing ecotheology (Anabaraonye et al., 2024). The challenge of facilities that are supported by social invention and economic are fact, but the potential for religious engagement in ecological issues is still optimistic (Gottlieb et al., 2007).

This finding has major implications for educator training because it shows that teachers and religious texts remain the dominant epistemic authorities in Islamic schools. When students rely more on traditional teachers and the Al-Qur'an than on digital media for ecological knowledge, it means that environmental understanding is being filtered primarily through religious pedagogy rather than through scientific or digital literacy channels. Therefore, the quality, depth, and contextualization of ecotheology education depend heavily on how well teachers themselves understand and integrate ecological concepts into Islamic teachings. This does not necessarily indicate resistance to technology, but rather that religious authority still shapes trust and legitimacy in knowledge transmission. In educational contexts where the Qur'an and teachers are central, ecological issues must be framed theologically and pedagogically, not merely scientifically (Febrianingsih et al., 2025; Taufikin, 2025).

Therefore, educator training programs in Indonesia should not only provide environmental science knowledge but also equip teachers with theological-environmental integration skills. If educators are not systematically trained in integrating theology with environmental action, the entire program risks remaining symbolic (Febrianingsih et al., 2025;

Hermawansyah, 2025; Mustofa et al., 2025). Conversely, strengthening teacher training (through curriculum development workshops, interdisciplinary modules, and digital literacy enhancement) can transform ecotheology from a rarely discussed topic into an institutionalized educational practice.

Opportunities for ecotheology programs resulting from the implementation of other programs include waste sorting and recycling, with most rules having confidence scores above 0.9 and lift scores above 2. For example, greening programs, energy-saving movements, outreach on the importance of environmental protection, religious activities that emphasize environmental awareness, and waste sorting will impact the implementation of waste recycling programs. In line with previous research, religious activities that wish to integrate theological beliefs need to be supported by concrete ecological actions such as environmental preservation and reforestation (Runtuwene, 2025).

4.5. The Impact of Ecotheology-Based Education on Student Awareness

Through questions in category F, this study found that according to students, the impact of ecotheology learning will increase awareness of the importance of protecting the environment. Students will have a sense of responsibility and play an active role in preserving the environment. Of course, the level of student implementation will vary. Therefore, through a classification approach, this study found a model that can predict the level of student ecotheology implementation with 4 levels, namely Low, Low, Moderate, High, and Very High. Based on the experimental results, the best model that can be used for classification is CatBoost with the highest accuracy of 98.71%. In line with the experimental results that show a higher level of accuracy, XGBoost, LightGBM, and CatBoost are generally preferred, with LightGBM often being the fastest and CatBoost excelling with categorical features (Z. Chen, 2025; Florek & Zagdański, 2023; Hancock & Khoshgoftaar, 2020; Prokhorenkova et al., 2018).

4.6. Student Hopes in Ecotheology

This study used open-ended questions to uncover students' suggestions and expectations regarding the implementation of ecotheology in Islamic schools. The collected text data was processed using sentiment analysis using the RoBERTa model for Indonesian. Overall, students held neutral views regarding suggestions and positive views regarding expectations. The content of neutral sentiment generally followed the same pattern as positive sentiment. Sentiment analysis of student messages or suggestions included:

- Positive sentiments suggested that the ecotheology implementation program be implemented more effectively. This was demonstrated through the terms "*pembelajaran ekoteologi* (ecoteology learning)," "*lebih menarik* (more interesting)," and "*menarik efektif* (interesting and effective)." Examples of texts containing these terms include "*Menurut saya pembelajaran ekoteologi akan lebih menarik jika dilakukan secara langsung dan bersama sama* (I think ecotheology learning would be more interesting if it were done directly and collaboratively)"; "*Pembelajaran ekoteologi dapat lebih menarik dan efektif jika dihubungkan dengan kehidupan sehari-hari, menggunakan metode interaktif, melibatkan komunitas lokal, memanfaatkan teknologi* (Ecotheology learning can be more interesting and effective if it is connected to everyday life, uses interactive methods, involves the local community, and utilizes technology)," and "*Saran saya, pembelajaran ekoteologi bisa dikaitkan langsung dengan ayat-ayat al-qur'an yang membahas tentang alam, penciptaan, dan tanggung jawab manusia sebagai khalifah di bumi. kegiatan praktik seperti membuat kebun madrasah, daur ulang sampah, atau aksi bersih lingkungan juga bisa dilakukan agar siswa tidak hanya memahami secara teori, tapi juga mempraktikkannya dalam kehidupan sehari-hari. guru juga bisa menggunakan media visual seperti video pendek atau poster agar pembelajaran lebih menarik* (My suggestion is that ecotheology learning can be directly linked to verses from the Quran that discuss nature, creation, and human responsibility as caliphs on earth. Practical activities such as creating Islamic school gardens, recycling waste, or environmental clean-up activities can also be implemented so that students not only understand the theory but also practice it in their daily lives. Teachers can also use visual media such as short videos or posters to make learning more engaging.)"
- Neutral sentiment shows most participants answered with factual, practical, or tentative suggestions rather than clear approval or disapproval, like "*Penerapan program-program ekoteologi di madrasah diharapkan tidak hanya menjadi instrumen pelestarian lingkungan, tetapi juga sarana penanaman nilai spiritual dan sosial*. (The implementation of ecotheology programs in madrasas is expected to not only be an instrument for environmental conservation, but also a means of instilling spiritual and social values)" and "*dengan di selingin bermain agar tdk boring dan supaya efektif harus rutin/ada jadwal tertentu*" (by playing in between so that it is not boring and to be effective it must be routine/have a certain schedule). This predominance of neutral language indicates that when

asked for suggestions, participants tended to describe processes, constraints, or informational steps (for example, outlines of programs, schedules, or roles) instead of expressing strong evaluative judgments.

- In the negative sentiment, the term "*membuang sampah* (throwing away trash)" was found, which indicates a negative action, although the sentiment is not negative. The word "*kurang* (lack)" also appears, which apparently reveals a lack of understanding of ecotheology. The sentence "*Saya selalu mambersihkan toilet (karna kurang bersih)* (I always clean the toilet (because it's not clean enough))" suggests that the cleanliness of the toilets in the Islamic school needs attention.

Next, there are sentiments related to student expectations, including:

- Positive sentiments include the terms "*lebih baik* (better)," "*peduli lingkungan* (environmentally conscious)," "*menjaga lingkungan* (protecting the environment)," and "*program ekoteologi* (ecoteology program)," which represent hopeful phrases such as "*Dapat membentuk karakter siswa yang peduli lingkungan berbasis iman dan lahirnya generasi yg tidak hanya cerdas secara intelektual tetapi juga memiliki kepedulian lingkungan yang kuat dan berakar pada nilai keamanan mereka* (It can shape students' character and care for the environment based on faith, and produce a generation that is not only intellectually intelligent but also possesses a strong environmental concern rooted in their values of security)," and "*Harapan saya program ekoteologi dapat membantu meningkatkan partisipasi kami para siswa/i dalam kegiatan lingkungan, seperti kegiatan penghijauan, pengelolaan sampah dan yang lainnya yang terkait dengan lingkungan. Saya juga berharap program ekoteologi dapat membantu membangun komunitas Islamic school yang peduli lingkungan dan dapat menjadi contoh bagi masyarakat luas dan juga dapat membantu meningkatkan kualitas kualitas pendidikan di madrasah dengan mengintegrasikan nilai nilai agama dan kepedulian lingkungan dalam proses pembelajaran* (I hope the ecotheology program can help increase our students' participation in environmental activities, such as reforestation, waste management, and other environmentally related activities. I also hope the ecotheology program can help build an environmentally conscious Islamic school community and serve as an example for the wider community. It can also help improve the quality of education in Islamic schools by integrating religious values and environmental awareness into the learning process.)"
- In student expectation, many of these neutral stances shift toward positive affect as respondents move from describing what should be done to imagining desired outcomes. For example "*Dapat membentuk karakter siswa yang peduli lingkungan berbasis iman dan lahirnya generasi yg tidak hanya cerdas secara intelektual tetapi juga memiliki kepedulian lingkungan yang kuat dan berakar pada nilai keamanan mereka*" (It can shape the character of students who care about the environment based on faith and give birth to a generation that is not only intellectually intelligent but also has a strong environmental concern rooted in their security values). It reflects a problem-solving, procedural mindset across clusters where participants are thinking in terms of actions and logistics rather than advocating strongly for or against the topic.
- Negative terms such as "*sampah sembarangan* (litter)" and "*kotor* (dirty)" emerge within positive sentiments. Although these terms are negative, they do not carry a negative connotation. For example, the sentence "*Harapan saya madrasah lebih bersih dan tidak kotor* (I hope the Islamic school is cleaner and less dirty)."

4.7. Pedagogical Implications of Ecotheology Implementation for Islamic Education

The findings of this study show that most Islamic school students already recognize and understand the concept of ecotheology. With 75.4% of respondents familiar with the term, ecotheology has gained significant cognitive acceptance among students. Teachers are the primary source of this knowledge, followed by social media and religious textbooks. This indicates that Islamic schools already have a strong theological foundation for environmental education (Syafaruddin, 2025). Pedagogically, this research suggests that ecotheology should no longer be introduced as a new concept, but rather deepened and systematically integrated into the curriculum. Islamic education can explicitly connect Qur'anic teachings about leadership (*khalifah*), trust (*amanah*), and balance (*mizan*) with contemporary environmental challenges (Azhari et al., 2025; Taufikin, 2025), thereby transforming environmental awareness into a structured component of religious learning (Mafaza et al., 2025).

However, despite high levels of understanding, the implementation of ecotheology in learning remains moderate, with an average score of 2.6. Students acknowledge that environmental conservation aligns with religious teachings, yet structured programs, policies, and routine ecological activities are still limited in many schools. This gap between knowledge and practice has important pedagogical implications (Mustofa et al., 2025; Taufikin, 2025). Islamic schools need to move from conceptual teaching toward experiential and action-based learning, such as school gardening, waste

sorting programs, energy-saving campaigns, and community-based environmental service activities (Nagiya & Zebua, 2025). By embedding ecotheology into daily school routines and institutional policies, environmental awareness becomes part of school culture rather than an occasional topic of discussion (Mujahidin et al., 2025).

The role of teachers is particularly crucial in this transformation. Students view teachers as key agents in promoting ecotheological awareness and modeling environmentally responsible behavior. So, it is important to strengthen teacher capacity through professional development programs that equip educators with contextual teaching strategies, interdisciplinary materials, and practical environmental projects (Syafaruddin, 2025; Taufikin, 2025). Teachers should not only explain theological principles but also connect them to social and ecological justice, encouraging students to see environmental care as both a religious obligation and a moral responsibility (Rahman et al., 2025).

This research also highlights structural challenges, particularly the absence of specific ecotheology programs and limited facilities. Nevertheless, strong opportunities exist, especially in greening initiatives, recycling programs, and religious activities that emphasize environmental responsibility (Febrianingsih et al., 2025). These findings imply that institutional commitment is essential to allocate resources for eco-friendly infrastructure and integrate environmental indicators into school evaluation systems (Albar et al., 2024). When supported by clear policies and infrastructure, ecotheology can evolve from individual awareness into collective institutional practice (Hajar, 2024).

Finally, students' suggestions and expectations provide valuable pedagogical insight. Many students expressed a desire for more interactive, practical, and Qur'an-linked environmental learning. Neutral responses often reflected procedural thinking, such as the need for routine scheduling and structured programs, rather than indifference. Students hope that ecotheology education will shape an environmentally conscious character rooted in faith (Anwar et al., 2025; Nagiya & Zebua, 2025). This indicates that learners are ready for participatory and experiential approaches. Islamic schools should therefore adopt more engaging methods, including project-based learning, community involvement, and the use of digital media to enhance motivation and relevance (Mafaza et al., 2025).

Furthermore, the classification model demonstrates that ecotheology implementation levels can be predicted using machine learning approaches. This opens opportunities for data-driven educational monitoring and targeted interventions. Policymakers, particularly within the Ministry of Religious Affairs, can use such models to identify schools requiring additional support and to evaluate the effectiveness of ecotheology-based programs. Thus, ecotheology implementation can move beyond normative aspiration toward measurable and evidence-based policy development. Overall, the findings suggest that Islamic schools possess strong theological awareness and student readiness, but require more systematic curriculum integration, teacher empowerment, institutional support, and data-informed policy design (Mustofa et al., 2025). By bridging the gap between understanding and structured implementation, ecotheology can become a transformative pedagogical model that integrates faith, environmental responsibility, and sustainable character formation within Islamic education (Rohman et al., 2024).

5. Conclusion

This study uses various machine learning approaches to uncover and deeply analyze the implementation of ecotheology in Islamic schools. This study found that Islamic school students have a good level of knowledge and understanding of ecotheology, most of which information is obtained from teachers, although social media, news, and books have an important role in disseminating information related to ecotheology. However, the implementation of ecotheology programs still needs to be improved. Based on the results of association rules, the biggest obstacle in the implementation of ecotheology in Islamic schools is the absence of a specific program related to ecotheology due to inadequate facilities and infrastructure. It has an impact on the insertion of ecotheology in learning, which is still rarely implemented. Islamic school students also have a good belief that the role of teachers is very important to teach, instill, raise awareness, and model environmental conservation activities (such as sorting and recycling waste) as part of worship or religious teachings.

Based on several machine learning methods that are used to reveal the insightful information of data, this research recommends that the Ministry of Religious Affairs should provide actionable guidance for curriculum revitalization. First, ecotheology can be systematically integrated into Islamic Religious Education subjects through clearly defined learning outcomes that connect Qur'anic principles of stewardship, justice, and balance with environmental practice. Second, teacher professional development programs can prioritize ecotheological pedagogy, equipping educators with interdisciplinary strategies and project-based approaches. Third, institutional accreditation and evaluation systems can incorporate environmental responsibility indicators to ensure implementation moves beyond rhetoric. Finally,

predictive analytics can assist policymakers in identifying schools that require additional support, resources, or mentoring, thereby enabling more efficient and equitable program distribution.

It is recommended that further research focus on designing and evaluating targeted ecotheology programs, including teacher professional development, curriculum integration, and extracurricular environmental activities. The readiness of facilities and infrastructure in Islamic schools needs to be assessed in more detail. Studies could explore how resource limitations hinder program execution and identify policy measures to support the provision of eco-friendly infrastructure and learning materials. Expanding the scope of respondents to include teachers, school leaders, and parents could also offer a more comprehensive understanding of the ecosystem supporting ecotheology in education. From a methodological perspective, future work could employ advanced machine learning techniques, such as explainable artificial intelligence, to better interpret prediction models and identify the most influential factors affecting ecotheology implementation. Comparative studies between regions, countries, or different types of educational institutions could also highlight cultural and contextual differences in adoption and practice.

Acknowledgment

The authors would like to thank Religious Moderation and Human Resource Development, Ministry of Religious Affairs of the Republic of Indonesia, and all respondents who contributed to this research.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

- Ach. Syaiful Islam, Suhermanto Ja'far, & Ahmad Sunawari Long. (2024). Islam and Eco-Theology: Perspectives and Strategies of Muhammadiyah in Addressing the Environmental Crisis. *Fikri : Jurnal Kajian Agama, Sosial Dan Budaya*, 9(2), 170–181. <https://doi.org/10.25217/jf.v9i2.4821>
- Agrawal, R., Mannila, H., Srikant, R., Toivonen, H., & Verkamo, a I. (1996). Fast discovery of association rules. In *Advances in knowledge discovery and data mining* (Vol. 12, pp. 307–328). <http://www.cs.helsinki.fi/hannu.toivonen/pubs/advances.pdf>
- Albar, M. K., Hamami, T., Sukiman, S., & Roja Badrus Z, A. (2024). Ecological Pesantren as an Innovation in Islamic Religious Education Curriculum: Is It Feasible? *Edukasia Islamika*, 9(1), 17–40. <https://doi.org/10.28918/jei.v9i1.8324>
- Alzanzami, F., Hoda, M., & Saddik, A. El. (2020). Light Gradient Boosting Machine for General Sentiment Classification on Short Texts: A Comparative Evaluation. *IEEE Access*, 8, 101840–101858. <https://doi.org/10.1109/ACCESS.2020.2997330>
- Anabaraonye, B., Onnoghen, U. N., Orji, I. E., Ewa, B. O., & Olisah, N. C. (2024). Enhancing Eco-Theology for Climate Change Education and Sustainable Development in Nigeria. *TELEIOS: Jurnal Teologi Dan Pendidikan Agama Kristen*, 4(2), 172–184. <https://doi.org/10.53674/teleios.v4i2.146>
- Andira, M. A., Pallu, D., Sari, I., & Maria, H. (2024). Merajut Spiritualitas Dan Lingkungan: Tinjauan Teologis Terhadap Keselamatan Alam. *Jurnal Silih Asih*, 1(2), 10–18. <https://doi.org/10.54765/silihassih.v1i2.53>
- Anwar, S., Frida Maulani, Wina Lutfiah, Syadiah, S. I. H., & Azizah, A. S. N. (2025). Integrasi Nilai Ketauhidan dan Ekopedagogi dalam Kurikulum Madrasah Ibtidaiyah untuk Penguatan Karakter Peduli Lingkungan. *TSAQAFATUNA : Jurnal Ilmu Pendidikan Islam*, 7(1). <https://doi.org/10.54213/tsaqafatuna.v7i1.611>
- Aranganayagi, S., & Thangavel, K. (2008). Clustering categorical data using silhouette coefficient as a relocating measure. *Proceedings - International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007*. <https://doi.org/10.1109/ICCIMA.2007.127>
- Aruan, A. K. (2024). Postcolonial Typology: A Pedagogical Note on the Field of Ecotheology. *Religions*, 15(12), 1422. <https://doi.org/10.3390/rel15121422>
- Asare, J. (2022). *Eco-Theology: Content Analysis Of The Teaching Contents Employed For Environmental Education In The Religious Education Curricula From Basic Schools To High Schools In Ghana*. <https://doi.org/10.14293/S2199-1006.1.SOR-PP5DV64.v1>

- Asmanto, E., Miftakhurrohmat, A., & Asmarawati, D. (2016). *Dialektika Spiritualitas Ekologi (Eco-Spirituality) Perspektif Ekoteologi Islam pada Petani Tambak Udang Tradisional Kabupaten Sidoarjo*. Universitas Islam Negeri Sulthan Thaha Saifuddin Jambi.
- Azhari, H., Ropitasari, A., Mu'min, U. A., Khutomi, B. M., & Bakar, A. A. (2025). The Role of Green Islamic Education in Developing Eco-Theological Consciousness Among Emerging Muslim Generations. *EDUKASI: Jurnal Penelitian Pendidikan Agama Dan Keagamaan*, 23(3), 531–542. <https://doi.org/10.32729/edukasi.v23i3.2374>
- B R, A., Pulari, S. R., Muruges, T. S., & Vasudevan, S. K. (2024). *Machine Learning*. CRC Press. <https://doi.org/10.1201/9781032676685>
- Barnhill, D. L., & Gottlieb, R. S. (2010). *Deep ecology and world religions: New essays on sacred ground*. State University of New York Press.
- Ben Salem, K., & Ben Abdelaziz, A. (2021). Principal component analysis (PCA). *Tunisie Medicale*, 99(4), 383–389. <https://doi.org/10.1515/9783110629453-078>
- Bentéjac, C., Csörgő, A., & Martínez-Muñoz, G. (2021). A comparative analysis of gradient boosting algorithms. *Artificial Intelligence Review*, 54(3), 1937–1967. <https://doi.org/10.1007/s10462-020-09896-5>
- Bland, J. M., & Altman, D. G. (1997). Statistics notes: Cronbach's alpha. *BMJ*, 314(7080), 572–572. <https://doi.org/10.1136/bmj.314.7080.572>
- Cameron, K. E., & Bizo, L. A. (2019). Use of the game-based learning platform KAHOOT! to facilitate learner engagement in animal science students. *Research in Learning Technology*, 27. <https://doi.org/10.25304/rlt.v27.2225>
- Candido, C., Blanco, A. C., Medina, J., Gubatanga, E., Santos, A., Ana, R. S., & Reyes, R. B. (2021). Improving the consistency of multi-temporal land cover mapping of Laguna lake watershed using light gradient boosting machine (LightGBM) approach, change detection analysis, and Markov chain. *Remote Sensing Applications: Society and Environment*, 23. <https://doi.org/10.1016/j.rsase.2021.100565>
- Charim, A., Basuki, S., & Akbi, D. R. (2019). Detect Malware in Portable Document Format Files (PDF) Using Support Vector Machine and Random Decision Forest. *Jurnal Online Informatika*, 3(2), 99–102.
- Chen, S. (2025). Sentiment Analysis Techniques for Deep Learning Classification and Comparison. *Theoretical and Natural Science*, 86(1), 74–80. <https://doi.org/10.54254/2753-8818/2025.20342>
- Chen, Z. (2025). *Wine Quality Prediction with Ensemble Trees: A Unified, Leak-Free Comparative Study*.
- Cholil, S., & Parker, L. (2021). Environmental education and eco-theology: insights from Franciscan schools in Indonesia. *Environmental Education Research*, 27(12), 1759–1782. <https://doi.org/10.1080/13504622.2021.1968349>
- Dai, Z., Yang, Z., Yang, Y., Carbonell, J., Le, Q. V., & Salakhutdinov, R. (2019). *Transformer-XL: Attentive Language Models Beyond a Fixed-Length Context*.
- Dalihade, R. D. (2021). Eko-Spiritualitas Trinitaris: Sebuah Upaya Membangun Spiritualitas Lingkungan terhadap Krisis Lingkungan (Reklamasi Pantai) di Manado. *Aradha: Journal of Divinity, Peace and Conflict Studies*, 1(2), 199–216. <https://doi.org/10.21460/aradha.2021.12.625>
- Devlin, J., Chang, M.-W., Lee, K., & Toutanova, K. (2018). *BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding*.
- Direktorat Jendral Pendidikan Islam Kementerian Agama RI. (2025). *EMIS: Gerbang Data Pendidikan Kementerian Agama*. EMIS 4.0. <https://emis.kemenag.go.id/>
- Doede, N., Merkel, P., Kriwall, M., Stonis, M., & Behrens, B.-A. (2024). Implementation of an intelligent process monitoring system for screw presses using the CRISP-DM standard. *Production Engineering*. <https://doi.org/10.1007/s11740-024-01298-8>
- Edelsbrunner, P. A., Simonsmeier, B. A., & Schneider, M. (2025). The Cronbach's Alpha of Domain-Specific Knowledge Tests Before and After Learning: A Meta-Analysis of Published Studies. *Educational Psychology Review*, 37(1), 4. <https://doi.org/10.1007/s10648-024-09982-y>

- Elkabalawy, M., Al-Sakkaf, A., Mohammed Abdelkader, E., & Alfalah, G. (2024). CRISP-DM-Based Data-Driven Approach for Building Energy Prediction Utilizing Indoor and Environmental Factors. *Sustainability*, 16(17), 7249. <https://doi.org/10.3390/su16177249>
- Fauzi, R. S., Arianisa, S., & Vahira, V. A. (2025). Finding Important Patterns of Sadaqah and Waqf Transactions in the Eid Charity Global Donation using Frequent Pattern Growth. *Khazanah Journal of Religion and Technology*, 3(1), 1–8. <https://doi.org/https://doi.org/10.15575/kjrt.v3i1.1641>
- Febrianingsih, D., Arifi, A., & Sabarudin, S. (2025). Ecotheology as a New Direction in the Politics and Policy of Islamic Religious Education in Indonesia. *QALAMUNA: Jurnal Pendidikan, Sosial, Dan Agama*, 17(2), 1455–1468. <https://doi.org/10.37680/qalamuna.v17i2.7426>
- Florek, P., & Zagdański, A. (2023). *Benchmarking state-of-the-art gradient boosting algorithms for classification*.
- Forero, C. G. (2023). Cronbach's Alpha. In *Encyclopedia of Quality of Life and Well-Being Research* (pp. 1505–1507). Springer International Publishing. https://doi.org/10.1007/978-3-031-17299-1_622
- Ghatora, P. S., Hosseini, S. E., Pervez, S., Iqbal, M. J., & Shaukat, N. (2024). Sentiment Analysis of Product Reviews Using Machine Learning and Pre-Trained LLM. *Big Data and Cognitive Computing*, 8(12), 199. <https://doi.org/10.3390/bdcc8120199>
- Gill, M. S., Westermann, T., Steindl, G., Gehlhoff, F., & Fay, A. (2024). *Integrating Ontology Design with the CRISP-DM in the context of Cyber-Physical Systems Maintenance*.
- Gottlieb, R. S. (2003). *This sacred earth: Religion, nature, environment*. Routledge.
- Gottlieb, R. S. (2006). *The Oxford handbook of religion and ecology*. OUP USA.
- Gottlieb, R. S., Norlock, K. J., Gottlieb's, R., & Greener, A. (2007). Faith and Environment. *Capitalism Nature Socialism*, 18(1), 126–129. <https://doi.org/10.1080/10455750601164709>
- Hajar, A. (2024). Transforming Islamic Education for Environmental and Social Sustainability. *Sinergi International Journal of Islamic Studies*, 2(2), 82–95. <https://doi.org/10.61194/ijis.v2i2.601>
- Hamka, M., & Ramdhoni, N. (2022). *K-Means cluster optimization for potentiality student grouping using elbow method*. 060011. <https://doi.org/10.1063/5.0108926>
- Hancock, J. T., & Khoshgoftaar, T. M. (2020). CatBoost for big data: an interdisciplinary review. *Journal of Big Data*, 7(1), 94. <https://doi.org/10.1186/s40537-020-00369-8>
- Hartigan, A., & Wong, M. A. (1979). A K-Means Clustering Algorithm. *Journal of the Royal Statistical Society*. <https://doi.org/10.2307/2346830>
- Hartigan, J. A., & Wong, M. A. (2006). Algorithm AS 136: A K-Means Clustering Algorithm. *Applied Statistics*. <https://doi.org/10.2307/2346830>
- Hermawansyah, H. (2025). Eco-Pesantren-Based Islamic Education Management. *Fitrah: Jurnal Studi Pendidikan*, 16(1), 102–114. <https://doi.org/10.47625/fitrah.v16i1.982>
- Hove, R. (2024). Eco-theology: Reimagining the image of God in the context of creation and care in Africa. *Wawasan: Jurnal Ilmiah Agama Dan Sosial Budaya*, 9(1), 37–46. <https://doi.org/10.15575/jw.v9i1.34356>
- Ibrahim, A. A., Ridwan, R. L., Muhammed, M. M., Abdulaziz, R. O., & Saheed, G. A. (2020). Comparison of the CatBoost Classifier with other Machine Learning Methods. *International Journal of Advanced Computer Science and Applications*, 11(11), 738–748. <https://doi.org/10.14569/IJACSA.2020.0111190>
- Januardi. (2025, January 24). *Madrasah Jadi Pilar Pendidikan Keagamaan Berwawasan Lingkungan*. Radio Republik Indonesia. <https://www.rri.co.id/papua-barat/iptek/1277718/madrasah-jadi-pilar-pendidikan-keagamaan-berwawasan-lingkungan>
- Kgatle, M. S., & Chigorimbo, J. (2024). Towards Holistic Healing: A Pentecostal Ecotheological Perspective. *Religions*, 15(12), 1479. <https://doi.org/10.3390/rel15121479>
- Laksono, G. E. (2022). Mewujudkan Kesadaran Lingkungan melalui Pendidikan Agama Islam berbasis Ecotheology Islam. *Jurnal Kependidikan*, 10(2), 247–258. <https://doi.org/10.24090/jk.v10i2.8043>

- Lan, H., & Pan, Y. (2019). A crowdsourcing quality prediction model based on random forests. *Proceedings - 18th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2019*, 315–319. <https://doi.org/10.1109/ICIS46139.2019.8940306>
- Lan, Z., Chen, M., Goodman, S., Gimpel, K., Sharma, P., & Soricut, R. (2019). *ALBERT: A Lite BERT for Self-supervised Learning of Language Representations*.
- Li, M., Gao, Q., & Yu, T. (2023). Kappa statistic considerations in evaluating inter-rater reliability between two raters: which, when and context matters. *BMC Cancer*, 23(1), 799. <https://doi.org/10.1186/s12885-023-11325-z>
- Li, S., Da Xu, L., & Zhao, S. (2015). The internet of things: a survey. *Information Systems Frontiers*, 17(2), 243–259.
- Liu, Y., Ott, M., Goyal, N., Du, J., Joshi, M., Chen, D., Levy, O., Lewis, M., Zettlemoyer, L., & Stoyanov, V. (2019). *RoBERTa: A Robustly Optimized BERT Pretraining Approach*.
- Mafaza, V., Khobir, A., Zahra, F. D., & Firdaus, M. J. (2025). Peran Ekoteologi dalam Pendidikan Islam: Belajar Menjaga Alam sebagai Amanah Tuhan. *Hikmah : Jurnal Studi Pendidikan Agama Islam*, 2(4), 161–178. <https://doi.org/10.61132/hikmah.v2i4.1498>
- Mardhiah, I., Aulia, R. N., & Narulita, S. (2014). Konsep Gerakan Ekoteologi Islam Studi atas Ormas NU dan Muhammadiyah. *Jurnal Studi Al-Qur'an Membangun Tradisi Berfikir Qur'ani*, 10(1), 1–14.
- Mateo, J., Rius-Peris, J. M., Marañá-Pérez, A. I., Valiente-Armero, A., & Torres, A. M. (2021). Extreme gradient boosting machine learning method for predicting medical treatment in patients with acute bronchiolitis. *Biocybernetics and Biomedical Engineering*, 41(2), 792–801. <https://doi.org/10.1016/j.bbe.2021.04.015>
- Mujahidin, M. D., Imron, A., & Abdiliah, M. H. (2025). Internalizing Ecotheological Values: Strategies of Pesantren in Fostering Environmentally Conscious Character. *Santri: Journal of Pesantren and Fiqh Sosial*, 6(2), 155–170. <https://doi.org/10.35878/santri.v6i2.1908>
- Munde, A. (2024). The Machine Learning Pipeline. In *Deep Learning Concepts in Operations Research* (pp. 226–243). Auerbach Publications. <https://doi.org/10.1201/9781003433309-18>
- Mustofa, T., Nurhasan, N., Farida, N. A., Zahra, D. N., & Nursecha, A. (2025). Integrating Ecotheological Values in the Islamic Religious Education Curriculum: The Green Islamic Education Perspective in Karawang Secondary Schools. *Jurnal Iqra' : Kajian Ilmu Pendidikan*, 10(3), 51–65. <https://doi.org/10.25217/ji.v10i3.6589>
- Nagiya, N., & Zebua, A. M. (2025). Eco-Pedagogic Based on Eco-Theology: Strategies for Building Students' Spiritual, Social, and Cognitive Character. *Jurnal Cendekia Media Komunikasi Penelitian Dan Pengembangan Pendidikan Islam*, 17(02), 419–433. <https://doi.org/10.37850/cendekia.v17i02.1091>
- Ngalawa, C. M., & Mponela, U. (2024). Social Sentiment Analysis. *International Journal of Advanced Research in Science, Communication and Technology*, 669–674. <https://doi.org/10.48175/IJARST-22291>
- Northcott, M. S. (2020). Ecological hope. In *Historical and multidisciplinary perspectives on hope* (pp. 215–238). Springer.
- Pangihutan, P., & Jura, D. (2023). Ecotheology and Analysis of Christian Education in Overcoming Ecological Problems. *International Journal of Science and Society*, 5(1), 13–27. <https://doi.org/10.54783/ijssoc.v5i1.621>
- Permadi, V. A., Tahalea, S. P., & Agusdin, R. P. (2023). K-Means and Elbow Method for Cluster Analysis of Elementary School Data. *PROGRES PENDIDIKAN*, 4(1), 50–57. <https://doi.org/10.29303/prospek.v4i1.328>
- Prokhorenkova, L., Gusev, G., Vorobev, A., Dorogush, A. V., & Gulina, A. (2018). Catboost: Unbiased boosting with categorical features. *Advances in Neural Information Processing Systems, 2018-Decem*, 6638–6648.
- Raffel, C., Shazeer, N., Roberts, A., Lee, K., Narang, S., Matena, M., Zhou, Y., Li, W., & Liu, P. J. (2020). Exploring the limits of transfer learning with a unified text-to-text transformer. *The Journal of Machine Learning Research*, 21(1), 5485–5551.
- Rahman, R., Ismail, F., Nurhayati, N., & Abu Nazar, I. (2025). Ecological Ethics in Islamic Religious Education Textbooks: A Qualitative Representation Analysis. *Tafkir: Interdisciplinary Journal of Islamic Education*, 6(3), 844–861. <https://doi.org/10.31538/tijie.v6i3.1995>

- Rezaei, N., & Jabbari, P. (2022). Introduction to machine learning. In *Immunoinformatics of Cancers* (pp. 53–69). Elsevier. <https://doi.org/10.1016/B978-0-12-822400-7.00012-9>
- Rohman, A., Kurniawan, E., Syifauddin, M., Muhtamiroh, S., & Muthohar, A. (2024). Religious Education For The Environment: Integrating Eco-Theology In The Curriculum of Islamic Religious And Character Education To Enhance Environmental Education In Indonesia. *Nadwa: Jurnal Pendidikan Islam*, 18(2), 201–226. <https://doi.org/10.21580/nw.2024.18.2.21094>
- Romdloni, M. A., Fitriyah, F. K., Djazilan, M. S., & Taufiq, M. (2024). Eco-Theology; Habits and Lifestyle of Santri in Indonesian Islamic Boarding Schools. *E3S Web of Conferences*, 482, 04030. <https://doi.org/10.1051/e3sconf/202448204030>
- Romdloni, M. A., & Sukron Djazilan, M. (2019). Kiai dan Lingkungan Hidup; Revitalisasi Krisis Ekologis Berbasis Nilai Keagamaan di Indonesia. *Journal of Islamic Civilization*, 1(2), 119–129. <https://doi.org/10.33086/jic.v1i2.1322>
- Runtuwene, H. C. M. (2025). Ecotheology: Integrating Faith, Creation Care, and Contextual Practice in Indonesian Protestant Congregations. *Educatio Christi*, 6(1), 145–170. <https://doi.org/10.70796/educatio-christi.v6i1.215>
- Sabtina, D., & Mahariah, M. (2025). Internalizing Islamic Ecotheology through School Culture to Foster Eco-Character. *Halaqa: Islamic Education Journal*, 9(2), 21–41. <https://doi.org/https://doi.org/10.21070/halaqa.v9i2.1754>
- Saini, A. (2021). *AdaBoost Algorithm – A Complete Guide for Beginners*. Analytics Vidhya. <https://www.analyticsvidhya.com/blog/2021/09/adaboost-algorithm-a-complete-guide-for-beginners/>
- Sammouda, R., & El-Zaart, A. (2021). An Optimized Approach for Prostate Image Segmentation Using K-Means Clustering Algorithm with Elbow Method. *Computational Intelligence and Neuroscience*, 2021(1). <https://doi.org/10.1155/2021/4553832>
- Sanh, V., Debut, L., Chaumond, J., & Wolf, T. (2019). *DistilBERT, a distilled version of BERT: smaller, faster, cheaper and lighter*.
- Saputra, D. B., Atina, V., & Nastiti, F. E. (2024). Model CRISP-DM Pada Prediksi Nasabah Kredit Menggunakan Algoritma Random Forest. *IDEALIS: InDonEsiA Journal Information System*, 7(2), 240–247. <https://doi.org/10.36080/idealisis.v7i2.3244>
- Saputro, D. E., & Gunadi, D. (2021). Ekoteologi Komunitas Sedulur Sikep. *Jurnal Abdiel: Khazanah Pemikiran Teologi, Pendidikan Agama Kristen Dan Musik Gereja*, 5(1), 42–56. <https://doi.org/10.37368/ja.v5i1.243>
- Sayeed, M. A. (2020). Detecting Crows on Sowed Crop Fields using Simplistic Image processing Techniques by Open CV in comparison with TensorFlow Image Detection API. *International Journal for Research in Applied Science and Engineering Technology*, 8(3), 61–73. <https://doi.org/10.22214/ijraset.2020.3014>
- Shahapur, V., Shetty, A., Shetty, C. P., Gayathri, & Shetty, P. (2022). Data Science. *International Journal of Advanced Research in Science, Communication and Technology*, 487–495. <https://doi.org/10.48175/IJAR SCT-2904>
- Shlens, J. (2014). A tutorial on principal component analysis. *ArXiv Preprint ArXiv:1404.1100*.
- Shook, E. (2023). Data Science. In *International Encyclopedia of Geography* (pp. 1–5). Wiley. <https://doi.org/10.1002/9781118786352.wbieg2050>
- Slamet, C., Rahman, A., Ramdhani, M. A., & Dharmalaksana, W. (2016). Clustering the verses of the holy qur'an using K-means algorithm. *Asian Journal of Information Technology*. <https://doi.org/10.3923/ajit.2016.5159.5162>
- Solichin, M. M. (2017). Pendidikan Agama Islam Bewawasan Spiritualitas Ekologi: Telaah Materi dan Model Pembelajaran. *Al-Tahrir*, 17(2), 471–494.
- Syafaruddin, B. (2025). Ecotheology in the Perspective of Islamic Education: A Conceptual Review. *ETDC: Indonesian Journal of Research and Educational Review*, 4(3), 720–731. <https://doi.org/10.51574/ijrer.v4i3.3253>
- Taufikin, T. (2025). Integrating Eco-Theology In Islamic Education: A Case Study On Fostering Ecological Awareness Through Religious Pedagogy. *El-Tarbawi*, 18(1), 1–37. <https://doi.org/10.20885/tarbawi.vol18.iss1.art1>

- Thoppilan, R., De Freitas, D., Hall, J., Shazeer, N., Kulshreshtha, A., Cheng, H.-T., Jin, A., Bos, T., Baker, L., Du, Y., Li, Y., Lee, H., Zheng, H. S., Ghafouri, A., Menegali, M., Huang, Y., Krikun, M., Lepikhin, D., Qin, J., ... Le, Q. (2022). *LaMDA: Language Models for Dialog Applications*.
- Ting, K. M. (2017). Confusion Matrix. In *Encyclopedia of Machine Learning and Data Mining*. https://doi.org/10.1007/978-1-4899-7687-1_50
- United Nations. (2026, January). *Sustainable Development Goals (SDGs) 2030*. Sdgs.Un.Org. <https://sdgs.un.org>
- Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, L., & Polosukhin, I. (2017). Attention is all you need. *ArXiv Preprint ArXiv:1706.03762*.
- Widianto, A. A., Putra, A. K., Alam, M., Fatanti, M. N., Thoriquttyas, T., Yuanda, B., Afiah, A. N., & Sulistywati, E. (2023). *Practising Eco-Theology: Pesantren and Green Education in Narmada Lombok, Nusa Tenggara Barat (NTB), Indonesia* (pp. 118–125). https://doi.org/10.2991/978-2-38476-078-7_14
- Widiarto, W., & Wilaela, W. (2022). Ekoteologis Perspektif Agama-Agama. *TOLERANSI: Media Ilmiah Komunikasi Umat Beragama*, 13(2), 103–124.
- Worotikan, D. B., Baleona, Y., Katanggung, A. E., Dehoop, B. S., Pietersz, K. V., Samudra, A. M., Pangkerego, T. O., Pieter, L., Momongan, E. T., & Kapugu, J. (2024). Menyatukan spiritualitas dan ekologi: Peran vital penyuluhan agama dalam pelestarian lingkungan. *Merenda: Jurnal Penyuluh Agama*, 1(1), 5–9.
- Yan, Y. (2022). Machine Learning Fundamentals. In *Machine Learning in Chemical Safety and Health* (pp. 19–46). Wiley. <https://doi.org/10.1002/9781119817512.ch2>
- Yenduri, G., M, R., G, C. S., Y, S., Srivastava, G., Maddikunta, P. K. R., G, D. R., Jhaveri, R. H., B, P., Wang, W., Vasilakos, A. V., & Gadekallu, T. R. (2023). *Generative Pre-trained Transformer: A Comprehensive Review on Enabling Technologies, Potential Applications, Emerging Challenges, and Future Directions*.
- Zhang, W., Wu, C., Zhong, H., Li, Y., & Wang, L. (2021). Prediction of undrained shear strength using extreme gradient boosting and random forest based on Bayesian optimization. *Geoscience Frontiers*, 12(1), 469–477. <https://doi.org/10.1016/j.gsf.2020.03.007>
- Zhang, Y., Zhao, Z., & Zheng, J. (2020). CatBoost: A new approach for estimating daily reference crop evapotranspiration in arid and semi-arid regions of Northern China. *Journal of Hydrology*, 588. <https://doi.org/10.1016/j.jhydrol.2020.125087>