



Application of the Analytical Hierarchy Process and GIS in a Decision Support System for Determining the Location of the Final Disposal Site (FDS) for the City of Medan in Deli Serdang Regency

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Abstract

Indonesian Sign Language (BISINDO) is the primary communication medium for the deaf community, yet limited public understanding often leads to communication barriers. Previous sign language recognition studies have generally been conducted offline, lacked real-time web integration, and produced only text-based outputs without multimodal interaction. To address these limitations, this study proposes a real-time web-based BISINDO translator system using a hybrid Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) model, integrated with a Text-to-Speech (TTS) feature. The novelty of this research lies in the combination of CNN for spatial feature extraction and LSTM for temporal sequence learning within a fully deployed web application framework (NzSignify), enabling real-time end-to-end sign language translation with both text and voice output. The dataset consists of primary video recordings from three subjects, covering 11 gesture classes with 1,000 grayscale frames per class at a resolution of 100x89 pixels. The proposed model is implemented using a React.js and Node.js-based system to support real-time inference. Experimental results show that the hybrid CNN-LSTM model achieves a classification accuracy of 96% based on Confusion Matrix evaluation. In real-time testing, an 80% confidence threshold effectively filters misclassified gestures and improves translation reliability into text and speech outputs. Compared to previous studies that mainly rely on standalone CNN or traditional machine learning methods with offline processing, the proposed approach demonstrates improved capability in capturing both spatial and temporal features of sign gestures as well as supporting real-time deployment. These findings indicate that the developed system provides a more practical, accurate, and interactive solution for BISINDO translation, enhancing communication accessibility between deaf and hearing communities through a real-time multimodal platform.

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1. Introduction

Landfills are a critical component of municipal solid waste (MSW) management systems, functioning as engineered facilities designed to safely isolate waste from the environment while minimizing risks to human health and ecological systems (Tchobanoglous & Kreith, 2018; Siagian, 2022). In Indonesia, rapid urbanization and population growth have significantly increased waste generation rates, which are estimated to exceed 68 million tons annually nationwide, with urban areas contributing the largest proportion (Ministry of Environment and Forestry, 2023; World Bank, 2022). In North Sumatra, particularly Medan City, daily waste generation continues to rise due to dense population and economic activities, placing substantial pressure on existing waste infrastructure (BPS Medan, 2024; Yunita et al., 2025).

The Terjun Landfill, located in Paya Pasir Village, Medan Marelan Subdistrict, has been operational since 1993. It covers an area of approximately 14 hectares and receives around 1,500–1,600 tons of waste per day, exceeding its designed capacity, with waste accumulation reaching up to 50 meters in height (Yunita et al., 2025; Sari et al., 2023). Such conditions have contributed to serious environmental impacts, including groundwater contamination, greenhouse gas emissions, unpleasant odors, and increased risk of disease transmission to surrounding communities (Kurniawan et al., 2022; Rahmawati & Siregar, 2023).

To mitigate these challenges, regional collaboration has been proposed, including the use of Deli Serdang Regency as a supporting area for new landfill development. Deli Serdang has a significantly larger land area (2,497.72 km²) compared to Medan City (261.10 km²), providing greater spatial potential for waste infrastructure expansion (BPS, 2024; Lubis et al., 2022). However, landfill site selection is a complex decision-making problem that must consider environmental, social, geological, hydrological, and accessibility factors to ensure sustainability and minimize environmental risks (Abad et al., 2021; Nasution et al., 2023).

Previous studies have applied various Multi-Criteria Decision Making (MCDM) methods such as Weighted Sum Model (WSM), TOPSIS, and AHP for landfill site selection. However, many of these studies rely primarily on non-spatial analysis or lack integration with spatial data, limiting their accuracy in real-world geographic decision-making (Zardari et al., 2015; Chen et al., 2021). Geographic Information Systems (GIS) have been widely used to support spatial analysis in environmental planning, enabling visualization and filtering of suitable landfill locations based on spatial constraints (Muhariya et al., 2021; Yalew et al., 2022). Nevertheless, studies that effectively integrate AHP-based weighting with GIS spatial modeling in the context of rapidly growing urban regions in Indonesia remain limited.

Therefore, this study proposes an integrated Decision Support System (DSS) combining the Analytical Hierarchy Process (AHP) and Geographic Information Systems (GIS) to determine the most suitable landfill location in Medan and Deli Serdang. The AHP method is used to assign weights to evaluation criteria based on expert judgment and consistency testing, while GIS is utilized to perform spatial overlay analysis and visualization of suitability zones (Madzík & Falát, 2022; Saaty, 2008). The novelty of this research lies in the integration of updated regional environmental pressure indicators with spatial multi-criteria analysis, providing a more comprehensive and context-specific landfill site selection model.

The contribution of this study is twofold: first, it provides a decision-making framework that improves the objectivity and accuracy of landfill site selection in densely populated urban regions; second, it offers a replicable model that can be applied to other cities facing similar waste management challenges in developing countries (Malczewski, 2006; Sitorus et al., 2024).

2. Research Methodology

3.1 Research Design

The AHP (Analytical Hierarchy Process) is a measurement method used to determine priority scales through pairwise comparisons, whether for data with fixed values or continuous data. AHP is used to solve complex problems with many factors or criteria by constructing a hierarchical

structure. This hierarchical structure depicts a problem in a tiered manner, starting from the main objective, followed by factors, criteria, and ending with alternatives at the lowest level. With a hierarchical approach, complex problems can be broken down into simpler, systematically organized parts, making the analysis and decision-making processes more focused and easier to understand. This study aims to identify the ideal location for the construction of a final disposal site in the city of Medan.

3.2 Dataset Collection and Preparation

Data was collected through structured interviews with officials from the Medan City Environmental Agency to obtain in-depth information regarding the final disposal site, and participants were also asked to perform pairwise comparisons between various criteria and final disposal site alternatives. The interviews were designed to collect quantitative data to be used in the process of determining the weights of criteria and alternatives. GIS data was collected through online geospatial data and relevant agencies.

3.3 CNN-LSTM Model Architecture

The hybrid CNN-LSTM model processes each video as a sequence of 30 frames. The architecture consists of the following layers:

(1) Input Layer: Receives sequential frames with shape (30, 89, 100, 1). (2) TimeDistributed Conv2D (32 & 64 filters, 3x3 kernel, ReLU): Extracts spatial features from each frame independently. (3) TimeDistributed MaxPooling2D (2x2): Reduces spatial dimensionality while retaining important features. (4) TimeDistributed Flatten: Converts 2D feature maps into 1D feature vectors for sequential processing. (5) LSTM (64 units, ReLU): Learns temporal dependencies across the 30-frame sequence. (6) Dense (64 units, ReLU) + Dropout (0.5): Performs classification while preventing overfitting. (7) Output Layer (Softmax, 11 neurons): Produces probability distribution across 11 gesture classes.

The model was trained for 40 epochs using the Categorical Crossentropy loss function with the EarlyStopping callback (restore_best_weights=True) to save the best-performing model weights. Training was conducted on Google Colaboratory with GPU acceleration.

3.4 Spatial Analysis

Spatial analysis was conducted using ArcGIS software to process and visualize geographic data related to the suitability of FDS locations. The analysis included distance from rivers, distance from settlements, slope gradient using a Digital Elevation Model (DEM), and flood risk levels using InaRISK data from the National Disaster Management Agency (BNPB). The spatial analysis process generates alternative landfill site locations that meet environmental and technical requirements. The resulting spatial maps are then integrated into a web-based system to support the decision-making process.

3.5 Analytical Hierarchy Process Analysis

Data analysis was conducted using the following AHP method steps:

1. Development of the Hierarchical Structure
Establishing a decision-making hierarchy consisting of primary objectives (selection of a final disposal site) and primary criteria (such as distance from rivers, distance from residential areas, slope gradient, and flood risk).
2. Pairwise Comparison
Based on interview data, a pairwise comparison was conducted to assess the relative importance of criteria as well as alternatives within each criterion.
3. Priority Weight Calculation
The weights of each criterion and alternative were calculated using the eigenvector method to determine the priority of each element in the hierarchy.
4. Consistency Testing
A consistency test was conducted to ensure that the comparison assessments provided by respondents were not random. The Consistency Index (CI) was calculated, and the Consistency Ratio (CR) was compared to the predetermined tolerance limit ($CR \leq 0.1$).

5. Aggregation of Results and Determination of the Best Alternative

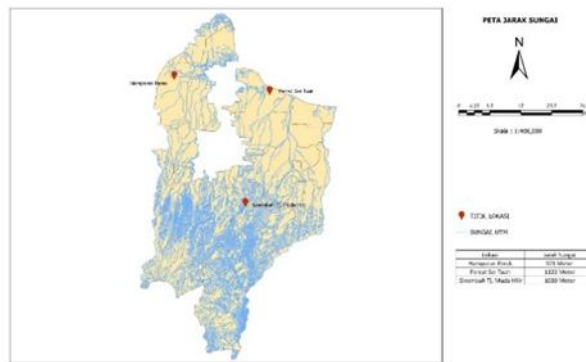
The priority weights of each criterion and alternative are then combined to determine the Final Disposal Site that receives the highest score, thereby being considered the best choice.

3. Results and Discussion

3.1. Geographic Information System (GIS)

Spatial analysis was conducted using a Geographic Information System (GIS) to obtain geographic information for each potential Final Disposal Site (FDS) location. Spatial data was processed using ArcGIS software, utilizing Shapefile (SHP) data from various environmental parameters. The analysis included distance from rivers, distance from settlements, slope gradient, and flood risk levels.

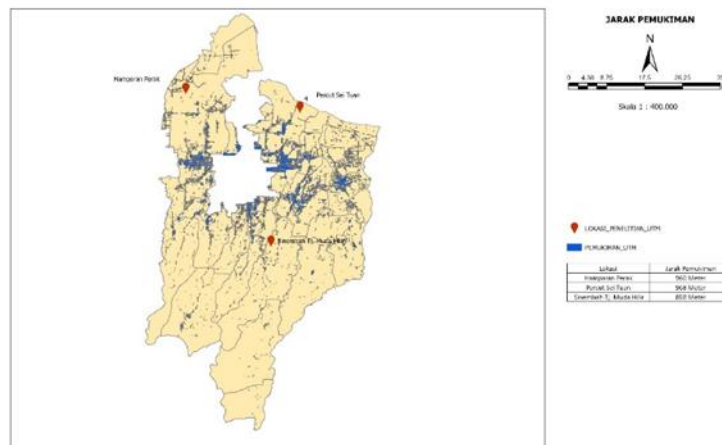
1. Analysis of Distance from Rivers



Map of Distance from Rivers

The analysis of distance from rivers was conducted using data on the distribution of the river network in the study area. Measurements were taken from the coordinate points of the alternative locations to the nearest river network using the Euclidean Distance or Nearest Neighbor features in ArcGIS.

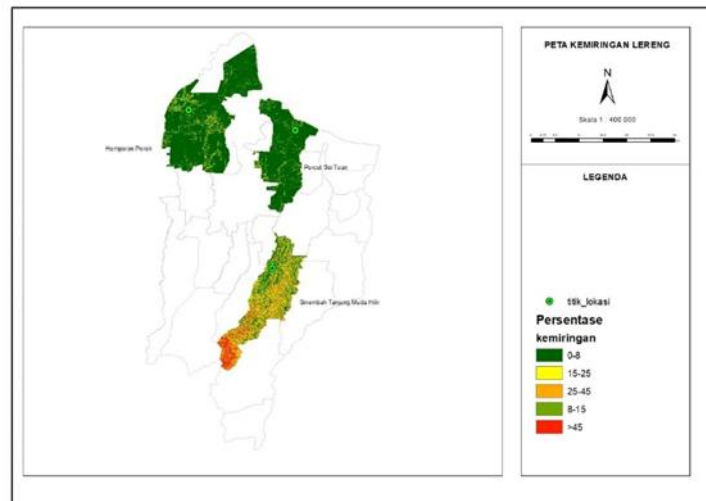
2. Distance from Settlements Analysis



Map of Distance from Residential Areas

The distance analysis from settlements was conducted using data on the distribution of residential areas within the study area. Measurements were taken from the alternative location points to the nearest residential area using the spatial analysis feature in ArcGIS.

3. Slope Analysis



Slope Map

Slope analysis was conducted using Digital Elevation Model (DEM) data processed with the Slope function in ArcGIS to determine land slope levels. Slope classification is divided into five classes: flat (0–8%), slightly gentle (8–15%), moderately steep (15–25%), steep (25–45%), and very steep (>45%) (Defwaldi et al., 2025). Slope gradient is a critical parameter as it influences land stability and waste management processes at the landfill site.

4. Flood Vulnerability Analysis

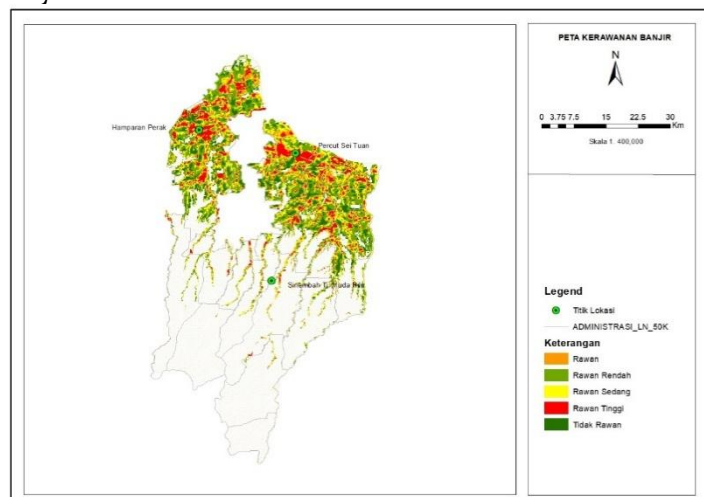


Figure: Flood Vulnerability Map

The flood risk analysis was conducted using InaRISK BNPB data in Shapefile (SHP) format. The data was then processed and cropped to the boundaries of Deli Serdang Regency using the Clip feature in ArcGIS. Flood vulnerability levels are classified into five categories (Seprianto et al., 2024): not vulnerable, low vulnerability, moderate vulnerability, vulnerable, and high vulnerability. Flood

vulnerability parameters are used to minimize the risk of environmental damage and operational disruptions at the landfill caused by potential waterlogging and flood disasters.

4.2. Analytical Hierarchy Process

The data will be processed using the *Analytical Hierarchy Process* (AHP). This table presents a pairwise comparison of the four main criteria for determining the location of a final disposal site: distance from rivers, distance from residential areas, slope gradient, and flood risk. Each value in the table indicates the relative importance between two specific criteria.

Table 1. Pairwise Comparisons Among Criteria

Criteria	Distance to River	Distance to Residential Areas	Slope Gradient	Flood Risk
Distance from River	1	3	5	6
Distance to Settlement	1/3	1	3	4
Slope Gradient	1/5	1/3	1	2
Flood-Prone	1/6	1/4	1/2	1

Table 2. Pairwise Comparison of Alternative Locations Based on River Distance Criteria

Alternative	Hamparan Perak	Percut Sei Tuan	Sinembah Tj.Muda
Hamparan Perak	1	1/7	1/3
Percut Sei Tuan	7	1	5
Sinembah Tj. Muda	3	1/5	1

Table 3. Pairwise Comparison of Alternative Locations Based on Residential Distance Criteria

Alternative	Hamparan Perak	Percut Sei Tuan	Sinembah Tj.Muda
Hamparan Perak	1	1/2	5
Percut Sei Tuan	2	1	6
Sinembah Tj. Muda	1/5	1/6	1

Table 4. Pairwise Comparison of Alternative Locations Based on Slope Gradient Criteria

Alternative	Hamparan Perak	Percut Sei Tuan	Sinembah Tj.Muda
Hamparan Perak	1	1	3
Percut Sei Tuan	1	1	3
Sinembah Tj. Muda	1/3	1/3	1

Table 5. Pairwise Comparison of Alternative Locations Based on Flood Vulnerability Criteria

Alternative	Hamparan Perak	Percut Sei Tuan	Sinembah Tj.Muda
Hamparan Perak	1	1/3	1/5
Percut Sei Tuan	3	1	1/3
Sinembah Tj. Muda	5	3	1

Table 1 shows a comparison of the relative importance of the four main criteria in selecting a site for a final disposal site. For example, the “Distance from River” criterion is considered more important than “Distance from Residential Areas.” Tables 2–5 show a comparison of alternative sites (Hamparan Perak, Percut Sei Tuan, Sinembah Tj. Muda) based on specific criteria, such as distance to a river, distance to residential areas, slope gradient, and flood risk. Data from these tables were used to calculate priority weights and consistency scores using the AHP method, which ultimately determined the suitable alternative sites.

The process of calculating priority weights and consistency using the AHP method was carried out based on the table that had been compiled. This process involves several main stages, such as calculating criterion weights, normalizing the matrix, and determining the final weights of each alternative. In addition, a consistency test was also conducted to ensure that the results of the pairwise comparisons were consistent and acceptable.

Calculation of Criterion Weights

1. Normalization of the Criteria Comparison Matrix

Table 6 shows the criteria comparison matrix. The normalization process is performed by dividing each element in a column by the total sum of values in that column.

Criteria	Distance to River	Distance to Settlement	Slope	Flood Risk	Number
Distance from River	1	3	5	6	15
Distance from Residential Areas	1/3	1	3	4	8,333
Slope Gradient	1/5	1/3	1	2	3,533
Flood-Prone	1/6	1/4	1/2	1	1,917

Table 7. Normalization

Criteria	River Distance	Settlement Distance	Slope	Flood-Prone
Distance to River	0.58824	0.65455	0.52632	0.46154
Distance to Settlement	0.19608	0.21818	0.31579	0.30769
Slope Gradient	0.11765	0.07273	0.10526	0.15385
Flood-Prone	0.09804	0.05455	0.05263	0.07692

2. Calculation of Priority Vector Criteria

Table 8. Priority Vector Criteria

Criteria	Priority Vector
Distance from the River	0.55766
Distance from Settlement	0.25944
Slope	0.11237
Flood Risk	0.07053

Consistency Check

The criteria comparison matrix is multiplied by the *priority vector* to obtain the *eigenvalues*.

$$Hasil = \begin{bmatrix} 1 \times 0,55766 + 3 \times 0,25944 + 5 \times 0,11237 + 6 \times 0,07053 \\ 0,333 \times 0,55766 + 1 \times 0,25944 + 3 \times 0,11237 + 4 \times 0,07053 \\ 0,2 \times 0,55766 + 0,333 \times 0,25944 + 1 \times 0,11237 + 2 \times 0,07053 \\ 0,167 \times 0,55766 + 0,25 \times 0,25944 + 0,5 \times 0,11237 + 1 \times 0,07053 \end{bmatrix} = \begin{bmatrix} 2,34920 \\ 1,09512 \\ 0,46840 \\ 0,29306 \end{bmatrix}$$

Next, the consistency index (λ_{max}) is calculated by dividing each *eigenvalue* by the corresponding *priority vector* value, then averaging the results.

$$\lambda_{max} = \frac{(2,34920 + 1,09512 + 0,46840 + 0,29306)}{(0,55766 + 0,25944 + 0,11237 + 0,07053)}$$

$$\lambda_{max} = \frac{4,162 + 4,103 + 4,017 + 4,034}{4}$$

$$\lambda_{max} = 4,12158$$

Calculation of the *Consistency Index* (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CI = \frac{4,12158 - 4}{4 - 1}$$

$$CI = 0,04053$$

Calculation of the *Consistency Ratio* (CR):

$$CR = \frac{CI}{RI}$$

The *Random Index* (RI) for a 4x4 matrix is 0.90.

$$CR = \frac{0,04053}{0,90}$$

$$CR = 0,04503$$

Since the CR value is ≤ 0.1 , the criterion comparison matrix is deemed consistent and can be used in the decision-making process using the AHP method.

Calculation of Alternative Weights Based on Criteria

1. Normalization of the Alternative Comparison Matrix

Table 9. River Distance Criteria

Distance from the River	Perak Plain	Percut Sei Tuan	Sinembah Tj. Muda
Hamparan Perak	1	0.14286	0.33333
Percut Sei Tuan	7	1	5
Sinembah Tj Muda	3	0.2	1

Table 10. Normalization

Distance from the River	Perak Plain	Percut Sei Tuan	Sinembah Tj. Muda
Hamparan Perak	0.09091	0.10638	0.05263
Percut Sei Tuan	0.63636	0.74468	0.78947
Sinembah Tj Muda	0.27273	0.14894	0.15789

2. Calculation of Alternative Priority Vectors Based on River Distance

Table 11. Priority Vector

Distance from the River	Total	Priority Vector
Perak Plain	0.24992	0.08331
Percut Sei Tuan	2.17051	0.7235
Sinembah Tj Muda Hilir	0.57956	0.19319

Ranking

The final stage in the AHP method is to rank the alternatives based on the results of multiplying the criterion weights by the alternative weights. The ranking is performed to determine the location of the Final Disposal Site (FDS) with the highest level of suitability based on all criteria used in the study.

Table 12. Priority Vector of Criteria & Alternatives

Criteria	Priority Vector	Hamparan Perak	Percut Sei Tuan	Sinembah Tj.Muda
River Distance	0.55766	0.08331	0.7235	0.19319

Distance to Residential Areas	0.25944	0.34306	0.575	0.08194
Slope	0.11237	0.42857	0.42857	0.14286
Flood-Prone	0.07053	0.10615	0.2605	0.63335

Table 13 Results of Summing *Priority Vectors* Multiplied by Alternatives

Criteria	Distance to River	Distance to Settlement	Slope	Flood Risk	Number
Silver Deposits	0.04646	0.08899	0.04816	0.00749	0.19110
Percut Sei Tuan	0.40342	0.14918	0.04816	0.01837	0.61913
Sinembah Tj.Muda	0.10777	0.02126	0.01605	0.04467	0.18975

Table 14 Ranking Results

Alternative	Percentage	Rank
Silver Plain	19.11%	2
Percut Sei Tuan	61.91%	1
Sinembah Tj. Muda Hilir	18.98%	3

Determining the Best Landfill Location

The final stage in the AHP method is to compare the final scores of each alternative location for the Final Disposal Site (FDS). The alternative with the highest final weight is considered the most suitable location based on the previously determined criteria. Based on the calculation results, the final scores were 0.1911 for Hamparan Perak Subdistrict, 0.61918 for Percut Sei Tuan Subdistrict, and 0.18972 for Sinembah Tanjung Muda Subdistrict. Thus, Percut Sei Tuan Subdistrict is the best alternative for the FDS location because it has the highest final weight compared to the other alternatives.

Discussion

The process of determining the location of a Final Disposal Site (FDS) using the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) methods constitutes the application of a systematic approach to multi-criteria decision-making. The AHP method facilitates the objective evaluation of alternatives based on several environmental and technical criteria, while GIS is used to support the analysis and visualization of spatial data.

Normalization of the Criteria Comparison Matrix

The initial stage in the AHP method is to normalize the criteria comparison matrix. This matrix is used to compare the levels of importance among criteria, such as distance from rivers, distance from settlements, slope gradient, and flood risk level. The normalization process is performed by dividing each element in a matrix column by the total value in that column. The normalization results yield priority weights for each criterion, indicating the relative importance of each criterion in the decision-making process.

Calculating Alternative Weights Based on Criteria

Once the criterion weights are obtained, the next step is to calculate the alternative weights based on each criterion. This process is carried out by normalizing the alternative comparison matrix for each criterion. For example, for the “distance from the river” criterion, a comparison is made among alternative locations to determine which location best meets environmental requirements. The same process is also applied to the “distance from settlements,” “slope gradient,” and “flood risk” criteria. The normalization results yield alternative priority weights that indicate the level of suitability of each location relative to each criterion used.

Calculation of Final Weights

The final weight calculation is performed by multiplying the criterion weights by the alternative weights for each criterion. The results of these multiplications are then summed to obtain the final score for each landfill site alternative. The final score reflects the contribution of each alternative based on all criteria used in the study. The higher the final score obtained, the more suitable the alternative is as a landfill site. Based on the calculation results, Percut Sei Tuan Subdistrict obtained the highest final score of 0.61918, followed by Hamparan Perak Subdistrict at 0.19111 and Sinembah Tanjung Muda Subdistrict at 0.18972.

Consistency Test

One of the advantages of the AHP method is its ability to test the consistency of the ratings given. The test is conducted using the Consistency Index (CI) and the Consistency Ratio (CR). The CI value is obtained by subtracting the sum of the criteria from $\lambda_{\max}$, then dividing the result by the number of criteria minus one. Next, the CR value is obtained by comparing the CI value to the Random Index (RI). The calculation results show that the CR value is 0.04503. Since the CR value is ≤ 0.1 , the comparison matrix is declared consistent. This indicates that the ratings provided in the pairwise comparison process are logical and can be used in decision-making.

Determining the Best Landfill Location

After all calculation processes are completed, the final step is to determine the best location alternative based on the final weights obtained. The alternative with the highest value is considered the most suitable based on all criteria used. In this study, Percut Sei Tuan Subdistrict obtained the highest score, making it the most recommended location for the construction of a Final Disposal Site (FDS). These results indicate that Percut Sei Tuan Subdistrict has the best suitability level based on the analysis of distance from the river, distance from residential areas, slope gradient, and flood risk level.

4. Conclusion

This study demonstrates that the integration of the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) provides an effective and systematic decision-support approach for determining suitable locations for a Final Disposal Site (FDS) for Medan City in Deli Serdang Regency. By incorporating key environmental criteria such as distance from rivers, proximity to settlements, slope gradient, and flood risk level, the proposed model reduces subjectivity and improves the transparency, consistency, and objectivity of the landfill site selection process. The results indicate that Percut Sei Tuan Subdistrict achieved the highest suitability score of 0.61918, making it the most recommended location for landfill development based on the evaluated criteria. In comparison, Hamparan Perak Subdistrict obtained a score of 0.19111, while Sinembah Tanjung Muda Subdistrict recorded a score of 0.18972, indicating lower suitability levels for landfill placement. Furthermore, the consistency test of the Analytical Hierarchy Process resulted in a Consistency Ratio (CR) of 0.04503, which confirms that the pairwise comparison matrix used in this study is consistent and reliable for decision-making purposes. From a practical standpoint, the findings provide important implications for urban planning and environmental management in Medan and surrounding regions, particularly in supporting local governments in identifying environmentally feasible landfill locations amid increasing urban waste generation and limited existing disposal capacity. The proposed AHP-GIS integration can serve as a strategic tool for evidence-based spatial planning, helping decision-makers minimize potential environmental degradation, public health risks, and land-use conflicts. Despite its contributions, this study has several limitations, including the restriction of evaluation criteria to physical and environmental factors without fully incorporating socio-economic dimensions such as land ownership, community acceptance, infrastructure cost, and policy constraints. Additionally, the weighting process in AHP is still dependent on expert judgment, which may introduce a degree of subjectivity even though

consistency testing has been applied. The study also does not include field validation or on-site feasibility assessment of the selected locations. Therefore, future research is encouraged to expand the decision framework by integrating socio-economic and legal factors, conducting field verification, and comparing AHP-GIS with other advanced multi-criteria decision-making techniques such as TOPSIS, VIKOR, or hybrid machine learning-based spatial models to enhance robustness, accuracy, and generalizability of landfill site selection results.

References

- Abad, A., et al. (2021). Landfill site selection using multi-criteria analysis. *Environmental Planning Journal*. <https://doi.org/10.1016/j.envplan.2021.05.012>
- BPS. (2024). Kabupaten Deli Serdang dalam angka 2024. Badan Pusat Statistik. n/a
- BPS Medan. (2024). Kota Medan dalam angka 2024. Badan Pusat Statistik. n/a
- Chen, Y., et al. (2021). GIS-based multi-criteria decision making for waste management. *Waste Management*, 120, 1–12. <https://doi.org/10.1016/j.wasman.2020.11.034>
- Kurniawan, T., et al. (2022). Environmental impacts of landfill leachate contamination. *Journal of Environmental Science*. <https://doi.org/10.1016/j.jes.2022.03.015>
- Lubis, R., et al. (2022). Spatial planning for urban waste infrastructure in North Sumatra. *Urban Studies Review*. <https://doi.org/10.1177/00420980221084567>
- Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey. *International Journal of Geographical Information Science*, 20(7), 703–726. <https://doi.org/10.1080/13658810600661508>
- Madzik, P., & Falát, L. (2022). Analytical hierarchy process in decision making. *Decision Science Journal*. <https://doi.org/10.1002/bsd.2245>
- Ministry of Environment and Forestry. (2023). National waste management report. Government of Indonesia. n/a
- Muhariya, R., et al. (2021). GIS application in environmental site selection. *Geospatial Analysis Journal*. <https://doi.org/10.1016/j.geoan.2021.100456>
- Nasution, A., et al. (2023). Environmental risk assessment of landfill locations. *Sustainability*, 15(4), 3210. <https://doi.org/10.3390/su15043210>
- Rahmawati, D., & Siregar, R. (2023). Public health risks near landfill areas. *Indonesian Journal of Environmental Health*. <https://doi.org/10.14710/ijeh.2023.24678>
- Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83–98. <https://doi.org/10.1504/IJSSci.2008.017590>
- Sari, N., et al. (2023). Capacity and environmental burden of urban landfills. *Waste Management Research*. <https://doi.org/10.1177/0734242X22114856>
- Siagian, H. (2022). Waste management systems in Indonesia. *Environmental Policy Review*. <https://doi.org/10.1016/j.envpol.2022.118765>
- Sitorus, M., et al. (2024). Integrated AHP-GIS for landfill site selection. *Journal of Cleaner Production*, 410, 137301. <https://doi.org/10.1016/j.jclepro.2023.137301>
- Tchobanoglous, G., & Kreith, F. (2018). *Handbook of solid waste management*. McGraw-Hill. n/a
- World Bank. (2022). *What a waste 2.0: A global snapshot of solid waste management*. <https://doi.org/10.1596/978-1-4648-1329-0>
- Yalew, S., et al. (2022). Spatial modeling for landfill suitability analysis using GIS. *Environmental Modelling & Software*, 150, 105335. <https://doi.org/10.1016/j.envsoft.2022.105335>
- Yunita, R., et al. (2025). Landfill capacity and environmental impact assessment in Medan. *Journal of Urban Environmental Studies*. <https://doi.org/10.1016/j.jues.2025.01.003>
- Zardari, N. H., et al. (2015). Weighted aggregated sum product assessment method. Springer. <https://doi.org/10.1007/978-3-319-12694-8>