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Decision Support System for Determining Priorities for Disaster Relief in North Sumatra Using the Analytical Hierarchy Process (AHP) Method Based on Geographic Information System (GIS)

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Abstract *:Disaster relief distribution requires precise prioritization so that aid can be distributed effectively to affected areas. This study aims to design and build a Geographic Information System (GIS)-based Decision Support System (DSS) using the Analytical Hierarchy Process (AHP) method to determine the priority of disaster relief distribution in North Sumatra Province. This study uses a system development approach with a population of districts and cities in North Sumatra and a sample of three regions, namely Sibolga City, Central Tapanuli Regency, and South Tapanuli Regency. The research instruments include paired comparison questionnaires, spatial data, and documentation. Data analysis was carried out using AHP through criteria weighting calculations, consistency testing, and alternative rankings, while system functional testing used Blackbox Testing. The results showed that the number of affected victims had the highest weight of 0.5011, with a Consistency Ratio (CR) value of 0.0746. Central Tapanuli Regency received the first priority with a score of 0.3862, followed by Sibolga City with 0.3097 and South Tapanuli Regency with 0.3040. All tested features functioned according to the test scenarios. In conclusion, the integration of AHP and GIS produces a system that can support structured aid prioritization through multi-criteria calculations and digital map visualization.*

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Introduction

Indonesia is a region with a high potential and frequency of disasters, including natural disasters, non-natural disasters, and social disasters. Among these various types of disasters, natural disasters are one of the most frequent occurrences every year and can cause major environmental damage, such as tsunamis, volcanic eruptions, major floods, tornadoes, earthquakes, and landslides. North Sumatra Province, located in the Pacific Ring of Fire, is at risk of various types of disasters, such as earthquakes, floods, landslides, and volcanic eruptions. These events not only cause physical losses but also have social, economic, and psychological impacts on affected communities (ARISTA, 2025). This condition indicates that disaster management requires a planned effort, especially in determining the priority of aid distribution to areas in need.

In a disaster emergency, aid distribution is a critical priority to meet basic needs and alleviate the burden on affected communities. However, the aid distribution process still faces various obstacles, such as inaccurate targeting, delays in distribution, and imbalances in the amount of aid received by each region. These problems can arise from the manual and subjective decision-making process, which does not fully consider data and the urgency of needs on the ground (Damanik et al., 2020). Prioritization without a structured system also has the potential to lead to a backlog of aid in certain areas, while other areas in greater need experience shortages. This situation can hinder the effectiveness and fairness of disaster management (Alfa Puryono et al., 2024). Therefore, an approach is needed that can assist the decision-making process in determining priority locations for aid distribution in a more measured manner.

A Decision Support System (DSS) is a subset of information systems that can improve the effectiveness of decision-making through data presentation, predictions, and analytical support to generate optimal decisions (Arif et al., 2023). This system can be used to prioritize aid distribution areas based on several criteria, such as the number of affected victims, infrastructure damage, the level of regional accessibility, and local response capacity. According to Lubis (2025), a Decision Support System functions to help solve problems based on data collected and analyzed through a decision-making model. In its application, the Analytical Hierarchy Process (AHP) method can be used to determine the importance weight of each criterion through pairwise comparisons, resulting in more structured and measurable priorities. Several studies have shown that the AHP method is effective in determining disaster relief priorities because it can produce consistent and objective decisions (Sari et al., 2025). However, determining location priorities also requires the presentation of geographic information so that the analysis results can be understood based on the distribution of affected areas.

The integration of DSS using the AHP method with a Geographic Information System (GIS) can support priority setting while presenting analysis results in the form of spatial visualization. The AHP method is used to determine the weighting of criteria in a structured manner based on respondent assessments, while GIS helps identify and display priorities based on location so that the decision results are more relevant and can be applied at the regional operational level (Audy A. Kenap, 2026). In the context of North Sumatra Province, the implementation of this integration is important because this region has diverse disaster risks and a wide scope of affected areas (ARISTA, 2025). However, this study was limited to three regions as alternative priority setting. Thus, a system is needed that can process assessment criteria systematically and present priority results through digital maps so that the resulting information is more easily understood by relevant parties.

Based on the description, this study aims to design and build a Decision Support System in determining priority locations for natural disaster aid distribution in North Sumatra Province, applying the Analytical Hierarchy Process (AHP) method to determine the weight of criteria and location priorities objectively, and integrating the system with a Geographic Information System (GIS) to present decision results through informative digital maps. This research is important to support the process of determining aid distribution priorities to be more structured, transparent, and targeted. The novelty of this research lies in the application of the AHP method integrated with GIS in a decision support system to determine priority locations for natural disaster aid distribution in North Sumatra Province, with the decision results displayed in the form of digital map visualizations. The developed system is expected to be a tool for related parties in determining priority locations more effectively and reducing subjectivity in the decision-making process.

Method

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This study uses a system development approach to design and build a Decision Support System (DSS) for determining priority locations for natural disaster relief distribution in North Sumatra Province using the Analytical Hierarchy Process (AHP) method based on a Geographic Information System (GIS). The AHP method is used to determine the priority weights of criteria and rank alternatives based on pairwise comparisons, while GIS is used to present the results of the priority determination in the form of a digital map. The use of AHP enables structured decision-making on multi-criteria problems through an assessment of the importance of each criterion (Ardyani Fitria Endah, 2022; Puryono et al., 2017). GIS integration supports the analysis and visualization of information based on geographic location, thus helping to determine priority areas for natural disaster relief distribution (Oksaping et al., 2015; Fadhilla et al., 2026).

The research instruments used included a paired comparison questionnaire, regional spatial data, and documentation of literature study results. The questionnaire was used to obtain respondents' assessments of the relative importance of each criterion in determining priority locations for natural disaster relief distribution. These assessments were compiled into a paired comparison matrix using the Saaty scale of 1 to 9 to obtain criterion priority weights (Maulana et al., 2025). Spatial data was used to support regional mapping and visualization of analysis results using ArcGIS software. Meanwhile, a literature study was conducted by collecting references from scientific journals, laws and regulations, and previous research related to decision support systems, the AHP method, GIS, and natural disaster relief distribution.

The data analysis technique was carried out using the AHP method through several stages, namely the preparation of a hierarchical structure, the creation of a pairwise comparison matrix, matrix normalization, calculation of priority weights (eigenvectors), calculation of the maximum eigenvalue ($\lambda_{\max}$), and testing the Consistency Index (CI) and Consistency Ratio (CR). The hierarchical structure consists of the objective of determining priority locations, four assessment criteria, and three alternative areas. The criteria used include the number of affected victims, the level of infrastructure damage, regional accessibility, and local handling capacity. The selection of these criteria refers to previous research on determining priorities for natural disaster relief (Sari et al., 2025; Alfa Puryono et al., 2024) as well as the development of criteria by the researcher. The stages of the AHP analysis were carried out based on the procedures for compiling a comparison matrix, normalization, calculating weights, and consistency testing (Handoko, 2022). The assessment is declared consistent if the CR value is less than 0.10. Next, the criteria weights are multiplied by the weights of each alternative to obtain the final value and order of regional priorities. The ranking results are then integrated with GIS to display the distribution of priority locations for aid distribution in the form of a digital map.

The population in this study includes districts or cities in North Sumatra Province that serve as priority alternative locations for natural disaster relief distribution. The research sample was determined as three regions: Sibolga City, Central Tapanuli Regency, and South Tapanuli Regency. These three regions were used as alternatives in the decision-making process using the AHP method. Each alternative was assessed based on four criteria: the number of affected victims, the level of infrastructure damage, regional accessibility, and local response capacity. Criteria assessment data were obtained through a paired comparison questionnaire aimed at respondents with knowledge of disasters, such as the Regional Disaster Management Agency (BPBD) or related agencies. The assessment results were used as the basis for calculating the criteria weights and determining the priority of each alternative region.

The research procedure was carried out systematically through the stages of data collection, data analysis using the AHP method, system design and development, and presentation of results through GIS. The data collection stage was carried out through paired comparison questionnaires, spatial data collection, and literature studies. Next, the obtained data were processed using the AHP method by constructing a hierarchical structure, forming a pairwise comparison matrix, performing matrix normalization, calculating priority weights, and testing the consistency of the assessment. After the criteria weights were obtained and declared consistent, alternative comparisons were conducted based on each criterion to calculate the final score and determine the priority order of aid distribution locations.

The next stage is the design and development of the system using the Unified Modeling Language

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(UML) approach, which includes use case diagrams, activity diagrams, sequence diagrams, and class diagrams to describe the functions, activity flows, interactions, and structure of the system (Elis & Voutama, 2023). The system was developed using Visual Studio Code as the code editor, PHP as the programming language, and XAMPP as the local server environment. The results of the AHP calculations were then integrated with ArcGIS to display regional priority information in the form of a digital map (Rukmana et al., 2025). The system developed provides alternative data management features, the AHP calculation process, ranking results, and GIS map visualization. The final stage of the research was carried out by presenting the results of the priority calculations and a digital map showing the order of regions based on the priority level for distributing natural disaster relief in North Sumatra Province.

Results and Discussion

AHP Logic Implementation

At this stage, the Analytical Hierarchy Process method is applied to a PHP-based program. This process allows the system to process the comparison values provided against four predetermined criteria. These comparison values are then processed into a pairwise comparison matrix and normalized to obtain priority weights. In addition to generating weights, the system also calculates the consistency level to ensure that the entered comparison values can be used in the decision-making process.

1. Formation of comparison matrix

```php
$matriks = [];

for($i=0;$i<$jumlah;$i++){

    for($j=0;$j<$jumlah;$j++){

        if($i==$j){

            $matriks[$i][$j]=1;

        }else{

            $matriks[$i][$j]=0;

        }

    }

}
```

Figure 1. Formation of Comparison Matrix

This section is used to create an initial matrix based on a predetermined number of criteria. The $i loop is used to determine the rows, while the $j loop is used to determine the columns of the matrix. If the position and column are the same, the system assigns a value of 1 because a criterion, when compared to the same criterion, has the same level of importance. Other positions are assigned a value of 0 as the initial value, which will later be filled in based on the comparison between the criteria.

2. Comparative Value Filling

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```
if($d['arah']=="kiri"){
    $matriks[$baris][$kolom]=$d['nilai'];
    $matriks[$kolom][$baris]=1/$d['nilai'];
}
elseif($d['arah']=="kanan"){
    $matriks[$baris][$kolom]=1/$d['nilai'];
    $matriks[$kolom][$baris]=$d['nilai'];
}
else{
    $matriks[$baris][$kolom]=1;
    $matriks[$kolom][$baris]=1;
}
```

Figure 2. Comparative Value Filling

This code is used to determine the position of the comparison value in the matrix based on the user's chosen direction. If the direction is left or right, the system automatically fills in the inverse value using the formula 1/value. This way, the matrix can be completely filled in from a single user-supplied comparison value.

3. Calculation of the number of columns

```
$jumlahKolom=[];
for($j=0;$j<$jumlah;$j++){
    $jumlahKolom[$j]=0;
    for($i=0;$i<$jumlah;$i++){
        $jumlahKolom[$j]+=$matriks[$i][$j];
    }
}
```

Figure 3. Calculation of the Number of Columns

This code is used to calculate the sum of the values in each column of the comparison matrix. The loop $j is used to move from one column to another, while $i is used to add up all the values in that column. The sum of each column is stored in the variable $jumlahkolom. This value is then used as a divisor in the matrix normalization process. This step is necessary so that the values in each column can be converted to the same scale.

4. Matrix normalization and priority weights

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```php
for($i=0;$i<$jumlah;$i++){

    echo "<tr>";

    echo "<th class='table-light'>".$kriteria[$i]['kode_kriteria']."</th>";

    $totalBaris=0;

    for($j=0;$j<$jumlah;$j++){

        $normalisasi[$i][$j]=$matriks[$i][$j]/$jumlahKolom[$j];

        $totalBaris += $normalisasi[$i][$j];

        echo "<td>".number_format($normalisasi[$i][$j],4)."</td>";

    }

    $bobot[$i]=$totalBaris/$jumlah;

    echo "<td class='fw-bold text-primary'>".number_format($bobot[$i],4)."</td>";

    echo "</tr>";

}
```

Figure 4. Matrix Normalization and Priority Weights

This code is used to normalize the comparison matrix. Each matrix value is divided by the corresponding number of columns to produce a normalized value. The normalized values for each row are then summed and stored in $totalrows. This result is then divided by the number of criteria to obtain a $weight value. The resulting weights indicate the importance of each criterion and serve as the basis for subsequent AHP calculations.

5. Calculating lambda max

```php
$hasilKali = [];
$lambda = [];

for($i=0;$i<$jumlah;$i++){

    $hasilKali[$i]=0;

    for($j=0;$j<$jumlah;$j++){

        $hasilKali[$i]+=($matriks[$i][$j]*$bobot[$j]);

    }
}
```

Figure 5. Calculating Lambda Max

```php
for($i=0;$i<$jumlah;$i++){

    if($bobot[$i]!=0){

        $lambda[$i]=$hasilKali[$i]/$bobot[$i];

    }else{

        $lambda[$i]=0;

    }

}

$lambdaMax=array_sum($lambda)/$jumlah;
```

Figure 6. Calculating Lambda Max

This code is used to calculate the maximum lambda. The system multiplies the comparison matrix by the priority weight of each criterion, then divides the result by the weight of each criterion. These values are averaged to obtain a value that is then used in the consistency test.

6. Implementation of consistency testing

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```
$CI=($lambdaMax-$jumlah)/($jumlah-1);
```

Figure 7. Implementation of Consistency Test

```
if($nilaiRI==0){
    $CR=0;
}else{
    $CR=$CI/$nilaiRI;
}
```

Figure 8. Implementation of Consistency Test

This section is used to evaluate the level of consistency of the specified comparative assessment. The system performs testing and calculates the consistency index (CI) and consistency ratio (CR) values. The results are then compared with the consistency limit. If the CR value is <10, the assessment is considered consistent and can be used. However, if it is not considered consistent, improvements need to be made to the comparison provided.

Implementation of digital map interface

```
<script src="https://unpkg.com/leaflet@1.9.4/dist/leaflet.js"></script>

<script src="https://cdnjs.cloudflare.com/ajax/libs/dom-to-image-more/3.3.0/dom-to-ima
<script>

var map = L.map('map',{
```

Figure 9. Implementation of Digital Interface

The system uses the leaflet.js library to display an interactive digital map as a visualization medium for alternative locations based on AHP calculations. The map uses OpenStreet Map as a base map and GeoJSON data to display district/city boundaries in North Sumatra. The system also determines the center coordinates and zoom level so that the map automatically displays the research area with an appropriate display.

Web code structure

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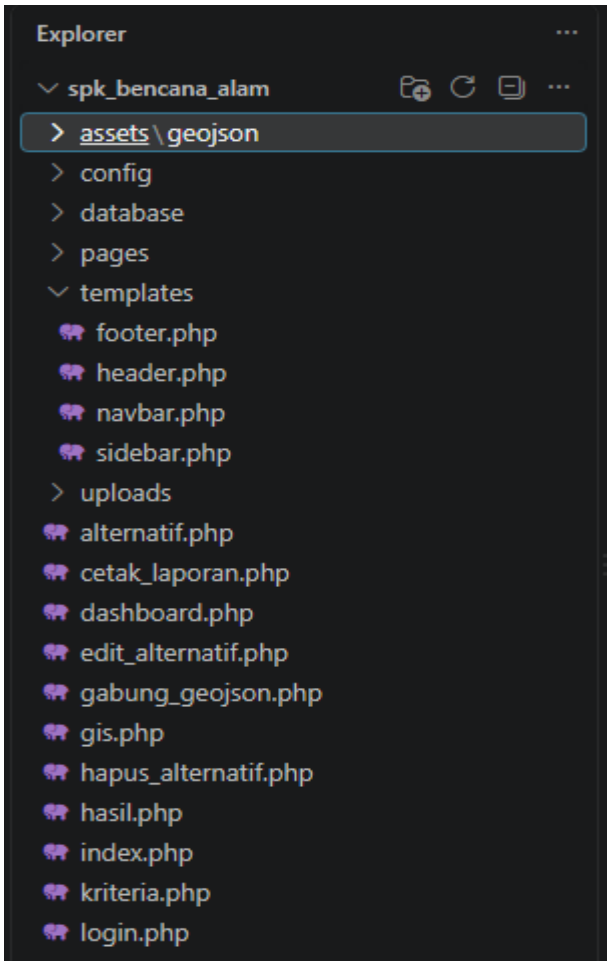


Figure 10. Web Code structure

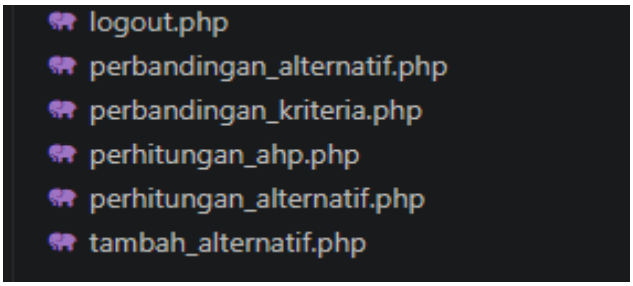


Figure 11. Web Code Structure

This system is built by dividing the program code into several files based on their respective uses. This division is done so that each part of the system, from the display to the calculation process, has a clear and neat storage location.

Interface Display

1. Login Page

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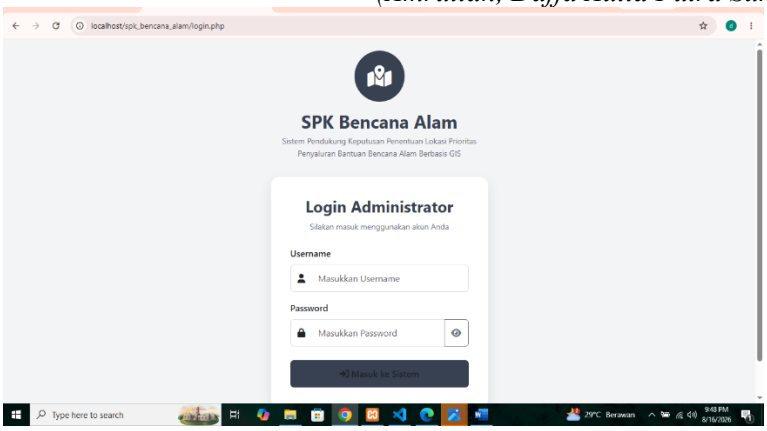


Figure 4.12. Login Page

The login page serves as the initial entry point for the system. This page serves to restrict system access so that only authorized users can access and manage available features. The login page makes system usage more organized and the data security within the system is enhanced.

2. Dashboard Page

Next is the dashboard page, which is the main system page that is displayed after the user has successfully logged in.

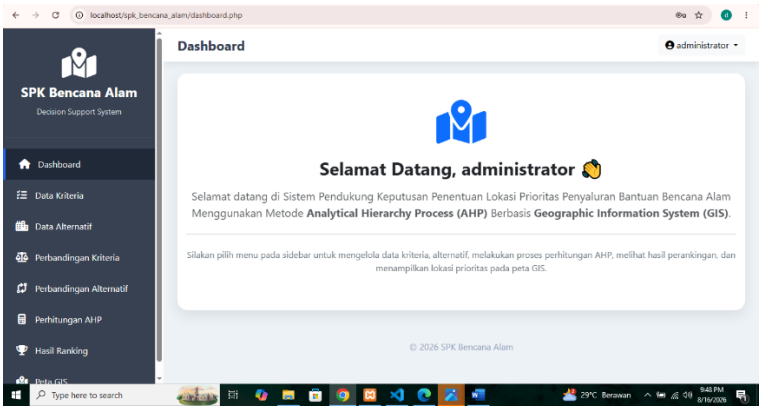


Figure 13. Dashboard page

The dashboard page is used to make it easier for users to access various available features and the dashboard display is also made simple so that users can understand the available features and continue the required processes more easily.

3. Criteria Page

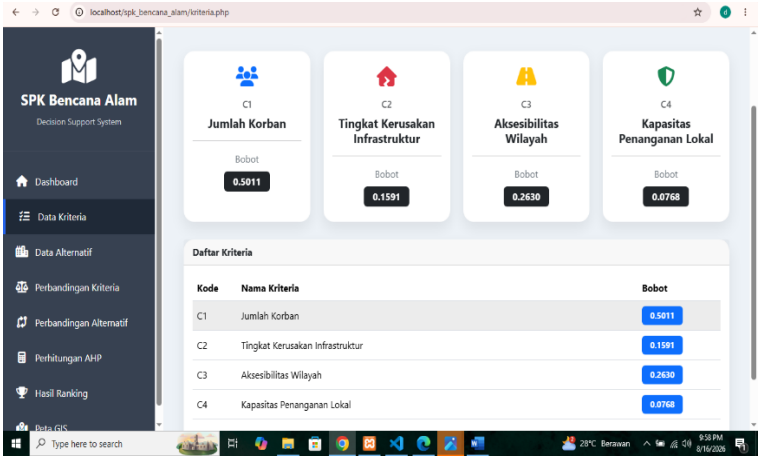


Figure 14. Criteria Data Page

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The criteria data page displays the criteria used to determine priority locations for disaster relief distribution. This page displays the code, criterion name, and weight of each criterion used in the system. These weights indicate the importance of each criterion and are used as the basis for the AHP calculation process.

4. Alternative Pages

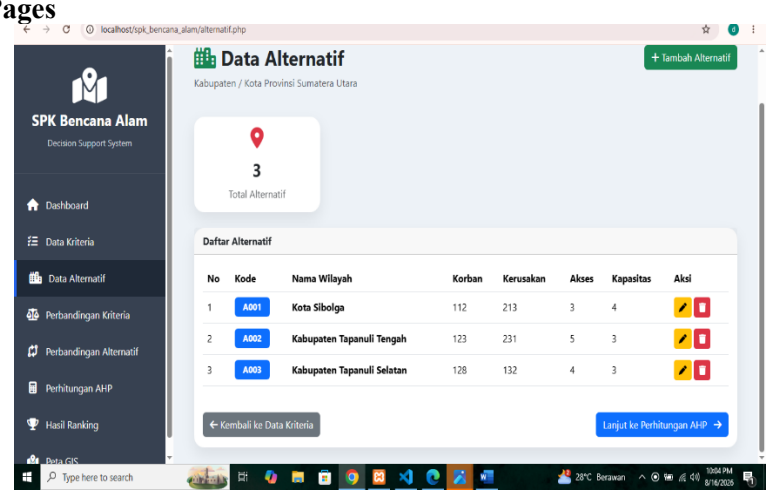


Figure 15. Alternative Data Page

The alternative page is used to manage data on alternative areas used in the process of determining priority locations for natural disaster relief distribution. On this page, users can view a list of areas and their scores for each criterion. Alternative data can also be added, modified, or deleted as needed before being used in the calculation and ranking process.

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5. Criteria comparison page

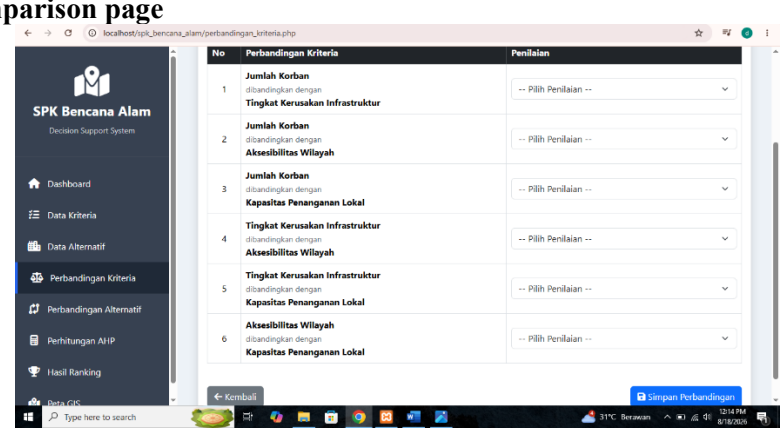


Figure 16. Criteria Comparison Page

The criteria comparison page is used to assess the level of importance between one criterion and another. The assessment results are then used in the AHP calculation process to generate priority weights for each criterion.

6. Alternative comparison page for the number of victims

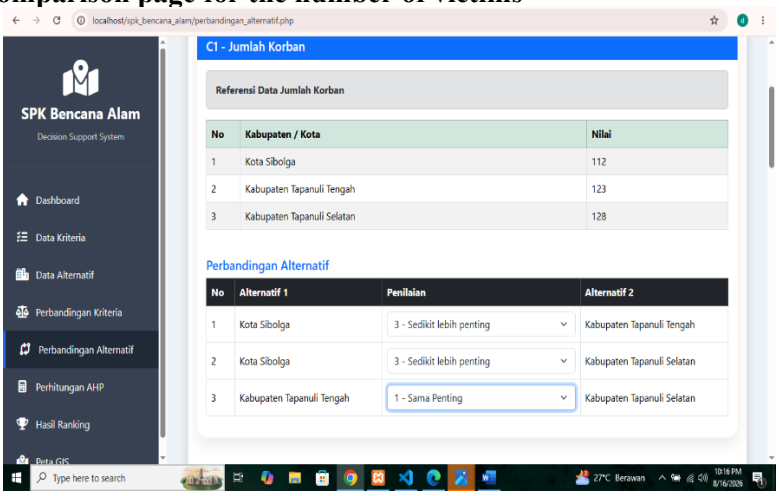


Figure 17. Alternative Comparison Page of Number of Victims

This page is used to compare regions based on the number of victims. The number of victims is displayed as a reference, and each alternative is then compared to determine its level of importance based on the number of victims criterion.

7. Infrastructure Damage Level Alternative Comparison Page

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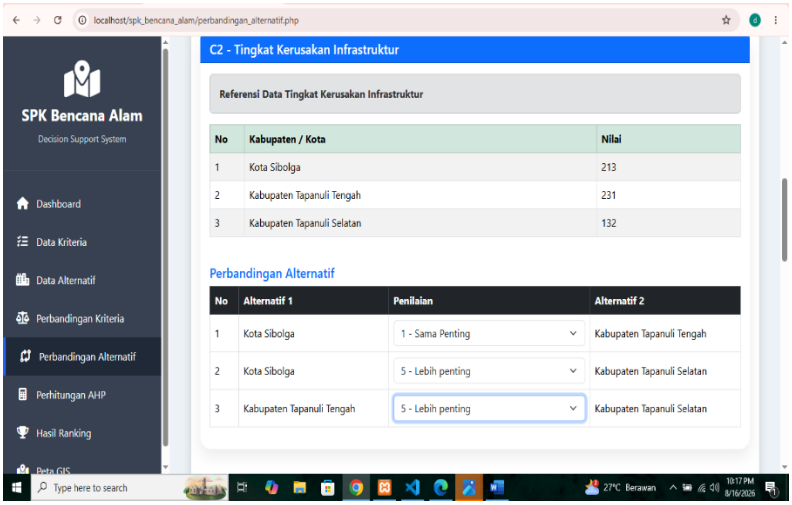


Figure 18. Comparison Page of Alternative Infrastructure Damage Levels

This page is used to compare regions based on the level of infrastructure damage. Damage data for each region is displayed as a reference, and alternatives are then compared to determine their level of importance based on the existing damage conditions.

8. Regional Accessibility Alternative Comparison Page

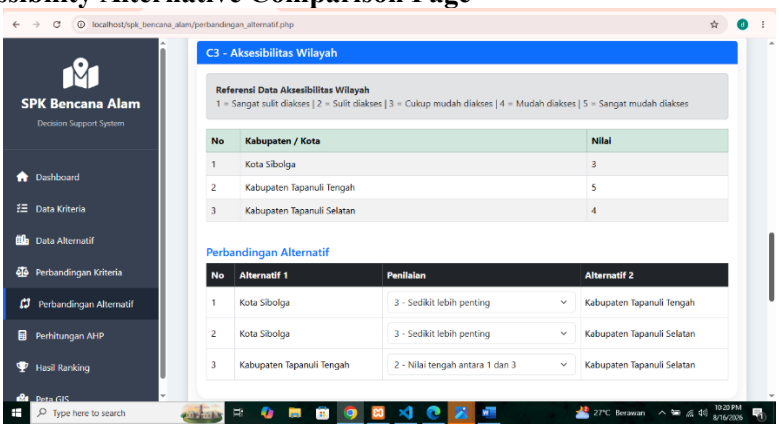


Figure 19 Regional Accessibility Alternative Comparison Page

This page is used to compare regions based on their accessibility. The accessibility value of each alternative is displayed as a reference, and then a comparison is made between the alternatives to provide an assessment based on their level of importance.

9. Local Handling Capacity Alternative Comparison Page

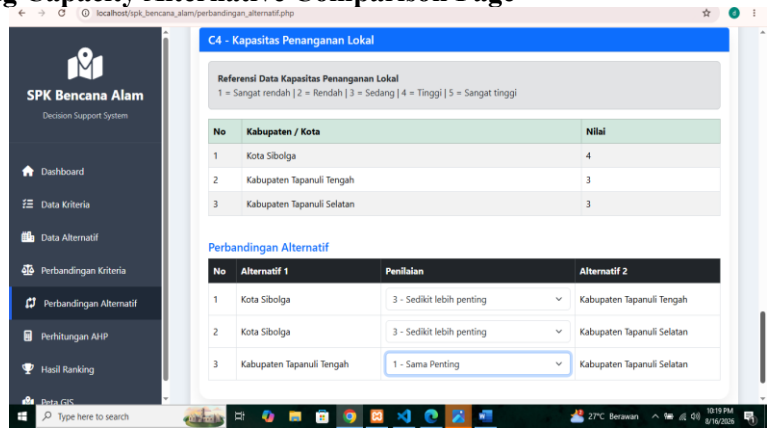


Figure 20. Local Handling Capacity Alternative Comparison Page

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This page is used to compare regions based on local handling capacity. Each region's handling capacity data is displayed as a reference, and each alternative is then compared to determine its level of importance based on these criteria.

10. AHP Calculation Page

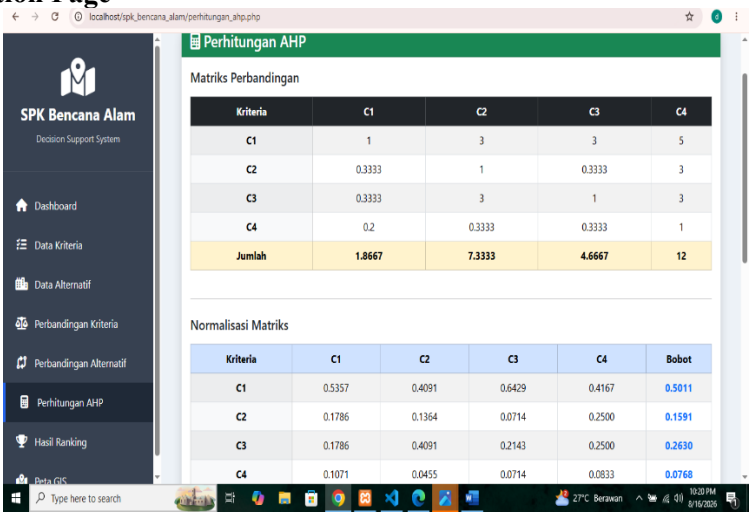


Figure 21. AHP Calculation Page

This page is used to process the criteria comparison results into priority weights for each criterion. This page displays the criteria comparison matrix and the results of the matrix normalization. The values in the weight column indicate the level of importance of each criterion, which will later be used in the assessment process and prioritization of alternatives.

11. Alternative Comparison Results Page Number of Victims

This page displays the alternative comparison calculation process based on the number of victims criteria.

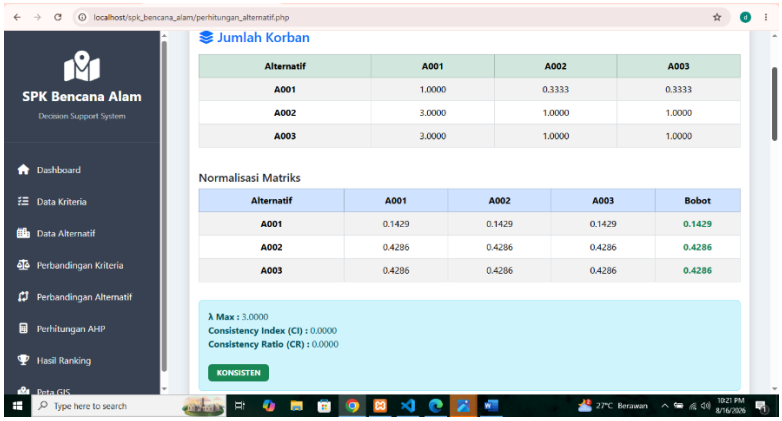


Figure 22. Alternative Results Page for Number of Victims

Initial data, including the number of victims in each district or city, is used as the basis for determining the level of importance between alternatives. The comparison results are then compiled into a comparison matrix and normalized to obtain the priority weight for each alternative based on the number of victims.

12. Alternative comparison results page of Infrastructure Damage Level

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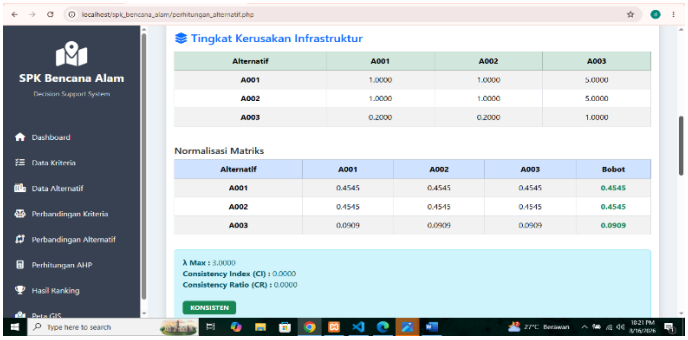


Figure 23. Comparison Results Page of Alternative Infrastructure Damage Levels

This page displays alternative calculations based on the Infrastructure Damage Level criteria. Each alternative used is compared based on the damage value. The comparison results compile a matrix which is then normalized to obtain the weight of each alternative at that level of criteria.

13. Regional Accessibility alternative comparison results page

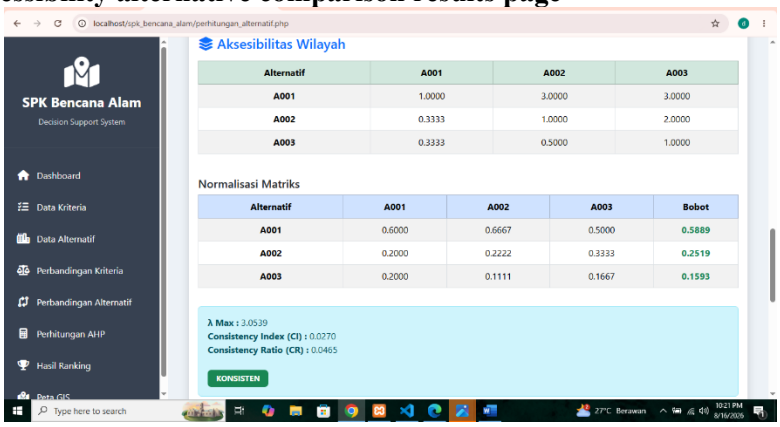


Figure 24. Regional Accessibility Alternative Comparison Results Page

This page displays alternative calculations based on regional accessibility. The accessibility value of each alternative is used as a reference for comparing alternatives. The comparison matrices are then normalized to generate priority weights for alternatives based on the level of difficulty in reaching a region.

14. Local Handling Capacity Alternative Comparison Results Page

This page is used to determine the priority weights of alternatives based on Local Handling Capacity. Each alternative is compared based on its handling capacity value. The comparison results are then normalized to obtain the priority weights for each alternative based on that criterion.

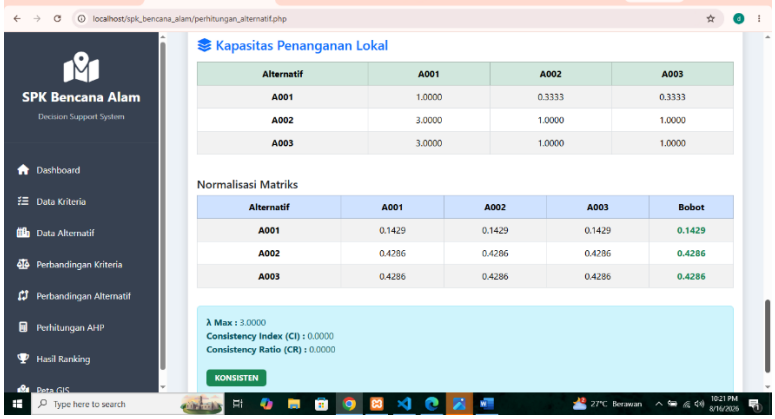


Figure 25. Local Handling Capacity Alternative Comparison Results Page

15. Ranking Results Page

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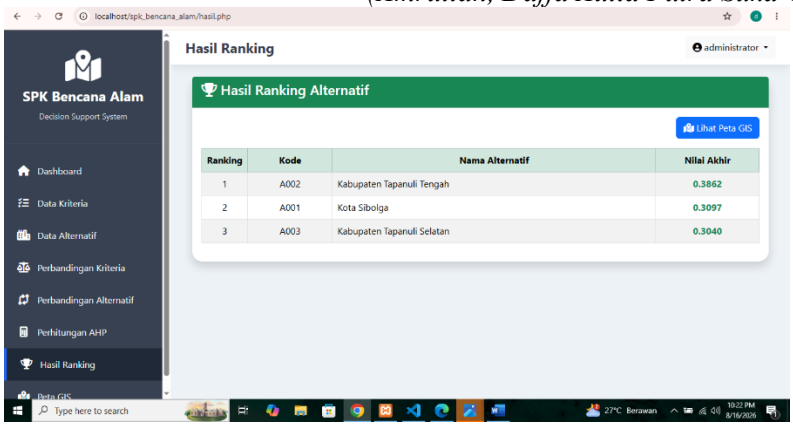


Figure 26. Ranking Results Page

The ranking results page displays the final results of the AHP calculation in the form of a priority order for each alternative. The alternative with the highest final score becomes the region with the highest priority for disaster relief distribution.

16. Map Page

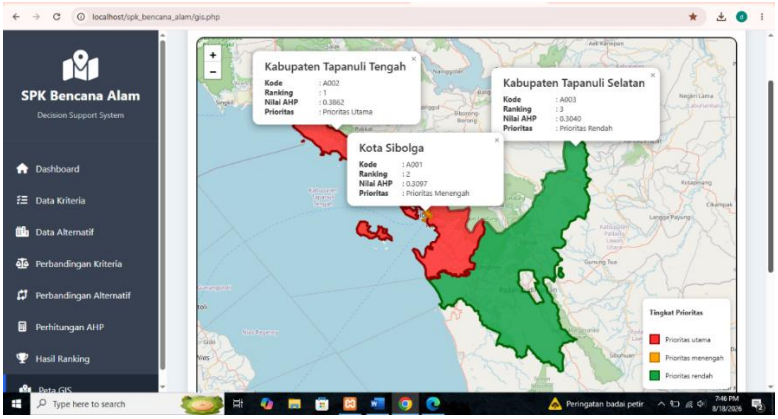


Figure 27. Digital Map Page

This page is used to visually display ranking results by district or city. Each region is displayed with a color that indicates its priority level: high, medium, and low. The map also provides information in the form of codes, AHP rankings, and priority levels when selecting a region, allowing for clearer results based on geographic location.

Interface Testing

Interface testing is conducted to ensure that the system being built functions according to user needs. Blackbox testing is used, which focuses on system functionality by providing input and observing the resulting output without considering the system's internal processes.

Black Box Testing

Black Box testing is carried out to ensure that every function in the system can run properly and produce output that matches the input provided by the user, without considering the structure or program code in the system.

Table 1. Blackbox Testing

No	Pages / features	Test scenario	Desired results	results
1.	System Login	Username / password, correct, incorrect	The system successfully verifies the user and displays the dashboard page.	Succeed

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No	Pages / features	Test scenario	Desired results	results
2	Criteria Data	Displays 4 criteria, and the results of the criteria weighting	Display all data	Succeed
3	Alternative Data	Users add, change, and delete data	The system saves data changes and displays data according to input.	Succeed
4	Comparison of criteria	Users provide comparative values between criteria.	The system stores the values and displays the comparison matrix and criteria weights.	Succeed
5	Alternative Comparison	Users provide ratings between alternatives on each criterion.	The system stores the assessments and generates a matrix and alternative weights.	Succeed
6	Ranking Results	User opens ranking page	The system displays the final value and priority order of each alternative.	Succeed
7	GIS Map	User opens GIS page	The system displays alternative locations on the map based on ranking results and priority levels.	Succeed

Test Results

After testing the system, it was found that the application of the Analytical Hierarchy Process (AHP) method, starting from the login process, inputting criteria and alternative data until obtaining the final results, was able to provide recommendations in determining priority locations for distributing natural disaster aid.

Conclusion

This research successfully designed and built a Decision Support System (DSS) to determine the priority of natural disaster aid distribution in North Sumatra Province by integrating the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) methods. The system uses four criteria, namely the number of affected victims, the level of infrastructure damage, regional accessibility, and local handling capacity. The results of the AHP calculation show that the number of affected victims has the highest importance weight of 0.5011, followed by regional accessibility of 0.2630, the level of infrastructure damage of 0.1591, and local handling capacity of 0.0768. The Consistency Ratio (CR) value of 0.0746 indicates that the pairwise comparison assessment meets the established consistency limits. Based on the final ranking value, Central Tapanuli Regency occupies the first priority with a score of 0.3862, followed by Sibolga City with a score of 0.3097 and South Tapanuli Regency with a score of 0.3040. Testing using Blackbox Testing shows that the main features of the system function according to the test scenario. GIS integration also allows ranking results to be displayed visually via digital maps so that regional priority information is easier to understand and use as a consideration in decision-making.

This study has limitations because the priority setting only involved three alternative areas in North Sumatra and used four criteria. Therefore, the results cannot be generalized to all areas or different disaster conditions. The assessment results also depend on the alternative data and the respondents' judgments, while the testing conducted focused on the system's functionality and did not directly evaluate its impact on the effectiveness of aid distribution. Therefore, further research is recommended to expand the coverage area, add relevant criteria, use more up-to-date disaster data, and involve more stakeholders to improve the accuracy of the results. Evaluation through direct implementation in the field is also needed to measure the system's operational benefits. Practically, this system can be a tool for the Regional Disaster Management Agency (BPBD) and related agencies in setting aid distribution priorities in a more structured, transparent, and data-driven manner, without replacing the judgment of officers in dealing with dynamic emergency situations.

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