"Analysis of School Infrastructure Potential as Temporary Evacuation Centers During Emergency Disaster Conditions in Palu and Surrounding Areas"

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Abstract. The earthquake that occurred in Central Sulawesi province on September 28, 2018, devastated parts of Palu City, Sigi Regency, and Donggala Regency. The earthquake and tsunami caused damage to various facilities and infrastructure, resulting in a significant number of casualties. To minimize the risk of casualties during disasters, a rescue strategy is needed, one of which is providing evacuation centers in disaster-prone areas. Therefore, it is necessary to identify which areas can be proposed as temporary evacuation sites during disasters. This research aims to assess the benefits of school infrastructure by examining the suitability of school infrastructure when utilized as temporary evacuation centers. The recommended locations consider the availability of toilets, classrooms, schoolyard area, and service radius. The weighting criteria use Spatial Multi-Criteria Decision Analysis (SMCDA) with the Weighted Overlay method. The analysis is carried out using ArcGIS Pro software, and the weighting of each criterion/layer uses the Analytical Hierarchy Process (AHP) method, considering the criteria of classroom availability, schoolyard area, and service radius. The results of this study indicate that of the 72 schools reviewed, there are 24 schools with a high level of conformity, 19 schools with a moderate level of conformity and 29 schools with a low level of conformity.

Keywords: suitability level, school infrastructure, temporary evacuation site, Spatial Multi-Criteria Decision Analysis

INTRODUCTION

Following the natural disaster of the earthquake, tsunami, and liquefaction that occurred on September 28, 2018, the Ministry of National Development Planning (Bappenas), Ministry of Agrarian and Spatial Planning/National Land Agency (ATR/BPN), Ministry of Energy and Mineral Resources (ESDM), Meteorology, Climatology, and Geophysics Agency (BMKG), and Ministry of Public Works and Housing (PUPR) have established and collectively approved the Disaster Prone Zone Map of Palu and Surroundings.

Schools, as one of the public facilities, have been chosen to serve as Temporary Evacuation Sites (TES) due to their infrastructure. Schools typically consist of multiple classrooms, practical rooms, administrative offices, teacher rooms, libraries, multipurpose or indoor sports halls, cafeterias, student council rooms, prayer rooms, restrooms, and storage rooms. School buildings usually have open outdoor spaces utilized for ceremonies and sports activities. These school buildings are considered safe and comfortable because they are often constructed following high building standards, possess good visibility and familiarity, and are accessible to everyone.

Based on these issues, a research study was conducted to determine the availability of school infrastructure in Central Sulawesi to be used as temporary evacuation sites during emergency disaster conditions. The research aimed to identify the suitability level of schools for this purpose and determine which schools are appropriate for temporary evacuation sites during emergencies in Central Sulawesi. The research location encompasses schools within Zone 3 (Limited Zone) of the Disaster Prone Zone Map of Palu and Surroundings (Figure 1).

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Figure 1. Map of Disaster-Prone Zones in Palu and Surrounding Areas
The objective of this study is to analyze the suitability of school infrastructure for use as evacuation buildings and to identify alternative school locations that are suitable for use as evacuation buildings during disasters. The suitability determination employs the Spatial Multi Criteria Decision Analysis (SMCDA) method, with the Analytical Hierarchy Process (AHP) being the MCDA method used in this research. AHP is utilized to establish the weights for each criterion.

**LITERATURE REVIEW**

**Geographic Information System (GIS)**

GIS is a computer-based information system used for processing and storing geographic data. It possesses four capabilities in handling geographically referenced data: input, data management (storage and retrieval), analysis and manipulation methods, and output (Aronoff, 1989). GIS is an effective tool not only for analyzing and displaying geospatial information but also for creating databases used as starting points to support decision support systems (Dominguez & Amador, 2007).

The data managed in GIS is spatial data, which is geographically oriented data (having a coordinate system). Spatial data consists of two essential components: location information (spatial) and descriptive information (attributes). Spatial data is represented in two formats: raster data and vector data. Raster data consists of a grid of cells, such as scanned maps or images. On the other hand, vector data comprises positional information of points, lines, and areas/polygons stored in the form of x, y coordinates.

**Multi Criteria Decision Analysis (MCDA)**

MCDA is a procedure used to find the best alternative from various feasible alternatives (Wu & Geng, 2014). MCDA is a technique for selecting the best alternative based on multiple criteria, allowing conflicting and conflicting criteria (Watson & Hudson, 2015).

**Analytic Hierarchy Process (AHP)**

AHP is a comprehensive Decision Support System (DSS) model that considers both qualitative and quantitative aspects. AHP enables the formation of a system's structure and environment as interacting components, and then combines them by measuring and managing the impact of component system errors (Saaty, 1980).

A hierarchy of problems is designed to aid the decision-making process by considering all the decision elements involved in the system. At the highest level of the hierarchy, goals and objectives of the system seeking a problem solution are stated. The next level elaborates on these objectives. It is expected that each level has homogeneous elements. An element becomes a criterion and a reference for the elements beneath it.

**RESEARCH METHODOLOGY**

The research methodology is systematically structured as the research framework, which consists of the following steps:

1. Defining criteria
2. Determining scores and weighting for each criterion using the AHP method
3. Spatial data analysis

**Defining Criteria**

Criteria are measurable aspects of a decision that characterize and measure alternatives in determining a decision (Carrion, Estrella, Dols, Toro, Rodriguez, & Ridao, 2008). The selection of evaluation criteria is based on the objectives to be achieved. In this study, there are four criteria: availability of toilets, service radius, availability of classrooms, and school yard area. The chosen criteria form the structure of the AHP criteria.

**Scoring Each Criterion**

A scoring or value assignment method is applied to each parameter value to determine its level of capability. The classification method in this study involves both quantitative and qualitative analyses. The quantitative method is used to determine scoring/grading for each suitability parameter in the research area. The resulting scores and weights are then classified into three ranges: high, medium, and low, using qualitative methods. The scoring results are obtained from the total calculation of scores for each parameter. The formula used is:
\[ K_i = \frac{x_t - x_r}{k} \]  
(Source: Pratomo, 2008)

The interval values are determined relatively by considering the maximum and minimum values of each mapping unit. Interval class values are obtained by finding the difference between the highest and lowest data and dividing it by the desired number of classes (Pratomo, 2008). The classification for each criterion is shown in Table 1.

<table>
<thead>
<tr>
<th>Suitability Level</th>
<th>Score</th>
<th>Color Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>1</td>
<td>red</td>
</tr>
<tr>
<td>moderate</td>
<td>2</td>
<td>yellow</td>
</tr>
<tr>
<td>high</td>
<td>3</td>
<td>green</td>
</tr>
</tbody>
</table>

Table 1. Suitability Level Classification

Determining the Weighting for Each Criterion Using the AHP Method

Next, these criteria will be assigned weight values to facilitate AHP calculations. This weighting assessment involves 5 respondents, consisting of experts from the academic field and community leaders in the research area. This is done by having them fill out a questionnaire for pairwise comparisons between criteria, as illustrated in Example Figure 1. The first step in assessing the weight between criteria involves comparing the level of importance intensity between two criteria. The fundamental assessment method used is Saaty's fundamental scale (2008), which divides the scale into nine levels, as explained in Table 2.

<table>
<thead>
<tr>
<th>Importance Intensity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Same importance</td>
</tr>
<tr>
<td>2</td>
<td>Less important</td>
</tr>
<tr>
<td>3</td>
<td>Fairly important</td>
</tr>
<tr>
<td>4</td>
<td>More than moderately important</td>
</tr>
<tr>
<td>5</td>
<td>Highly important</td>
</tr>
<tr>
<td>6</td>
<td>More highly important</td>
</tr>
<tr>
<td>7</td>
<td>Very important</td>
</tr>
<tr>
<td>8</td>
<td>Extremely important</td>
</tr>
<tr>
<td>9</td>
<td>Absolutely important</td>
</tr>
</tbody>
</table>

Table 2. Scale for Inter-Criteria Assessment

![Figure 2. Questionnaire for Criteria Comparison](https://example.com/figure2.png)

The scale values for the criteria comparisons you have determined are organized into a matrix table. The subsequent steps involve AHP calculations, as summarized from Gumusay (Gumusay et al., 2016). First, the normalization values are determined by dividing the values of each criterion by the total values of each column. Then, the normalized values of each row are summed up to obtain the priority vector values, as shown in Table 4. Next, the criteria weights (W) are calculated by dividing the values per priority vector by the total sum of priority vectors, as indicated in Table 3. Finally, an AHP consistency test is conducted. The steps of the consistency test are as follows: calculating the matrix multiplication between weights (W) and criterion scores (A), dividing the matrix multiplication result by the weights (W) of that criterion, calculating the value of \( \lambda_{\text{max}} \) using Equation (2), determining the random consistency index (RI) based on Table 5, calculating the consistency index (CI), and finally calculating the consistency ratio (CR)

\[ \lambda_{\text{max}} = \frac{\sum_{i=1}^{n} (AxW)_i \cdot t}{n} \]  
(2)

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  
(3)
Spatial Data Analysis

Spatial data processing is carried out to integrate spatial data and tabular data into geographically referenced information. Spatial data processing is performed for each criterion. The criteria used are toilet availability, service radius, availability of classrooms, and school yard area. The spatial data analysis process in this study utilizes the Geoprocessing facilities within ArcGIS Pro software.

RESULTS AND DISCUSSION

Criterion Weighting

AHP is employed to determine the weight of each criterion. To establish priorities, pairwise comparison matrices are created by comparing all elements for each hierarchy. This comparison assessment utilizes the 9-scale values predetermined by Saaty. In this operational subsystem, there are 4 operational elements. The comparison results of operational elements from the questionnaires answered by five respondents are summed up for each column of the matrix based on the criteria. This forms a 4x4 matrix as shown in Table 3.

Based on the pairwise comparison matrix, normalization is carried out by adding up the weights in each column. Then, the values in each column are divided by the total column value. Subsequently, the relative priority vector for each criterion is calculated by averaging the normalized weights. To calculate the weights (eigenvector), the average values are divided by the number of criteria (4). The final result of the priority weighting calculation (eigenvector value) is a decimal value below one, with the total priority for criteria in a group being equal to one (1). The normalized matrix result is shown in Table 4.

Table 3 Pairwise Comparison Matrix Column Sum based on Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Toilet Availability</th>
<th>Service Radius</th>
<th>Classroom Availability</th>
<th>School Yard Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet Availability</td>
<td>1.000</td>
<td>7.560</td>
<td>3.201</td>
<td>0.839</td>
</tr>
<tr>
<td>Service Radius</td>
<td>0.132</td>
<td>1.000</td>
<td>0.762</td>
<td>0.478</td>
</tr>
<tr>
<td>Classroom Availability</td>
<td>0.312</td>
<td>1.312</td>
<td>1.000</td>
<td>0.360</td>
</tr>
<tr>
<td>School Yard Area</td>
<td>1.191</td>
<td>2.091</td>
<td>2.775</td>
<td>1.000</td>
</tr>
<tr>
<td>Total</td>
<td>2.636</td>
<td>11.963</td>
<td>7.738</td>
<td>2.678</td>
</tr>
</tbody>
</table>

Table 4 Normalized Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Toilet Availability</th>
<th>Service Radius</th>
<th>Classroom Availability</th>
<th>School Yard Area</th>
<th>Poverty vector</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet Availability</td>
<td>0.379</td>
<td>0.632</td>
<td>0.414</td>
<td>0.313</td>
<td>1.738</td>
<td>0.43</td>
</tr>
<tr>
<td>Service Radius</td>
<td>0.050</td>
<td>0.084</td>
<td>0.098</td>
<td>0.179</td>
<td>0.411</td>
<td>0.10</td>
</tr>
<tr>
<td>Classroom Availability</td>
<td>0.119</td>
<td>0.110</td>
<td>0.129</td>
<td>0.135</td>
<td>0.492</td>
<td>0.12</td>
</tr>
<tr>
<td>School Yard Area</td>
<td>0.452</td>
<td>0.175</td>
<td>0.359</td>
<td>0.373</td>
<td>1.359</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Eigen Factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

To calculate the consistency of a matrix with a size of n based on the maximum eigenvalue ($\lambda_{max}$) and determine the Consistency Index (CI), the inconsistency index is converted into the form of the inconsistency ratio (CR) by dividing it by a random index (RI). The random index represents the average consistency of comparison matrices, as shown in Table 4. A comparison matrix is considered consistent if the CR value is not more than 10% or CR ≤ 0.1.
\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]  

(5)

\[ CR = \frac{CI}{RI} < 0.1 \]  

(6)

Table 5 Magnitude of Random Index (RI) Values (Saaty, 1980)

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.9</td>
<td>1.12</td>
<td>1.245</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

With a calculated CI value of 0.063 and a CR value of 0.070, the preference weighting is consistent.

**Spatial Data Analysis**

Spatial data processing involves utilizing the Geoprocessing facilities within ArcGIS Pro software, enabling the analysis and combination of layers based on different spatial relationships between features. The available spatial analysis tools in ArcGIS Pro can be accessed through the ArcToolbox window. Geoprocessing Tools include Interpolation, IDW, Clip, Reclassify, and Weighted Sum.

The classifications that have been conducted are then integrated with GIS. The classifications are divided into three levels as shown in Table 1. The results of these classifications are represented in maps for each criterion, as illustrated in Figure 3.

Figure 3. Map of Classification Results for Each Criterion: (a) Toilet Availability, (b) Service Radius, (c) Classroom Availability, (d) School Yard Area

From the classification results of schools based on toilet availability in Figure 3(a), there are 32 schools classified as having a low suitability level, 26 schools with a moderate suitability level, and 14 schools with a high suitability level. For the classification of schools based on the service radius criterion in Figure 3(b), there are 6 schools with a low suitability level, 18 schools with a moderate suitability level, and 48 schools with a high suitability level. The
classification of schools based on classroom availability in Figure 3(c) results in 55 schools with a low suitability level, 14 schools with a moderate suitability level, and 3 schools with a high suitability level. Lastly, the classification of schools based on school yard area in Figure 3(d) yields 60 schools with a low suitability level, 11 schools with a moderate suitability level, and 1 school with a high suitability level.

Results of Combining All Classification Maps

The classification maps for the criteria mentioned above are then overlaid using a weighted sum approach, where each criterion is multiplied by the weight obtained from the AHP calculation, and the results are summed up. The suitability map generated from the AHP scores can be seen in Figure 4.

Figure 4. Map of School Location Suitability as Temporary Evacuation Centers (TES) in Zone 3 of the Disaster-Prone Zone Map of Palu and Surrounding Areas

The results of the analysis from the suitability map indicate that there are 24 schools with a high suitability level, 19 schools with a moderate suitability level, and 29 schools with a low suitability level.
CONCLUSION

Based on the results and analysis conducted in this study, several conclusions can be drawn:
1. The suitability level of school infrastructure is categorized into 3 classes: low suitability level with a score of 1, moderate suitability level with a score of 2, and high suitability level with a score of 3.
2. The SMDCDA analysis results for the 72 schools reviewed to be utilized as temporary evacuation centers during emergency disaster conditions indicate that there are 24 schools with a high suitability level, 19 schools with a moderate suitability level, and 29 schools with a low suitability level.

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REFERENCES

Kimura, S., Complete the next sentence:


