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Development of Walkability Indicators for the Feasibility Parameters of Pedestrian Evacuation Routes in Tsunami-Prone Areas Based on User Needs

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Abstract

The readiness of pedestrian evacuation infrastructure is a key aspect in tsunami disaster mitigation management, especially for communities living in coastal areas with high levels of vulnerability. The lack of availability and adequacy of pedestrian facilities during tsunami evacuations is often a major obstacle that hinders the evacuation process. This study has found a solution to this problem, which aims to deeply examine the issue of evacuation infrastructure readiness and formulate optimal pedestrian path feasibility parameters for walkability. Based on the theoretical framework of disaster mitigation and transportation infrastructure, this quantitative study applies a survey method to collect data in the field involving 350 respondents residing in various disaster-prone areas. The collected data are then processed comprehensively using statistical analysis, which includes validity tests, reliability tests, and Respondent Achievement Level Analysis (TCR). The results of the analysis reveal that the feasibility of pedestrian paths for evacuation is largely determined by the fulfillment of feasibility parameters for walkability that are specifically tailored to user needs in the intended emergency conditions. As the main output, this study successfully formulated feasibility parameters for walkability parameters for the feasibility of evacuation-based pedestrian paths, namely walking path mode conflict, availability of walking paths, amenities, obstruction, motorist behavior, and security from crime, which can be practically used to assess whether an area is walkable or not. In conclusion, this study provides comprehensive strategic guidance for city planners to design urban areas that are resilient, adaptive, sustainable, and responsive to the threat of tsunami disasters in the future.

Keywords: Infrastructure, Tsunami Evacuation, Walkability, Pedestrian Path, Sustainable.

1. Introduction

In the past 10 years, research on walking accessibility has undergone a fundamental shift, moving from simply assessing the physical attributes of infrastructure to an approach that integrates human dimensions and behaviors. The concept of walkability has always focused on how pedestrians have their own space within a transportation network. Previous research has reconceptualized the theory of pedestrian accessibility through the development of an open-source index capable of dynamically mapping mobility opportunities for this mode [1]. In developing countries, such as Indonesia, several studies have demonstrated that pedestrian satisfaction is determined by the synergy of facility integration within functional areas [2]. This reinforces findings regarding crucial factors, such as safety and comfort, as key elements of user perceptions of pedestrian-specific urban spaces [3]. At a macro level, evaluating a walkable or pedestrian-friendly environment is a theoretical framework that is no longer limited to mobility issues alone but has become a crucial pillar for a city's sustainability and livability index [4]. In an effort to precisely implement this theoretical framework,

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the proposed use of Geographic Information Systems (GIS) as an instrument produces measurable accessibility indicators that are essential for data-driven policymaking in pedestrian-inclusive urban space planning [5].

Urban space planning for pedestrians is currently in a state of readiness to serve pedestrians in various conditions, both under normal conditions and in emergency conditions such as evacuation processes. The priority of pedestrian space has now reached the stage of urgency for disaster mitigation during evacuation. This encourages the standardization of the tsunami evacuation behavior research framework to minimize uncertainty when a crisis occurs [6]. In pedestrian-based evacuation scenarios, rescue effectiveness is largely determined by the dynamics between individual movement speed and available evacuation onset time [1], [7]. The complexity of urban environments related to pedestrian evacuation has been studied by previous researchers using multi-criteria decision analysis (MCDA) to optimize the selection of the most efficient evacuation routes and design parameters and indicators based on the walkability index. Furthermore, the development of a walkability index specific to the disaster context is needed to evaluate the quality of the route, considering that high pedestrian density can significantly reduce the speed of evacuation flows and increase the risk of fatalities [2], [8]–[10]. The integration of physical environmental variables and density simulations is the main foundation in designing the physical infrastructure of tsunami-prone cities.

The quality of physical infrastructure in question is highly dependent on effectiveness and active mobility, where these spaces are facilities that can respond to user needs inclusively. Recent research indicates that facility availability and user satisfaction must be aligned with walkability index assessments [1]. This aligns with the findings of a study that emphasized that sidewalk inclusiveness is not merely a technical issue but a crucial parameter in determining universal pedestrian accessibility [2].

From a macro perspective, this summary of dimensions must be incorporated into the urban DMA (density, mix, access) framework, which emphasizes that a dense and connected urban structure is a prerequisite for functional walking activities [3], [4]. To efficiently validate these conditions, the use of software-based tools has become a current methodological trend for systematically conducting environmental audits [5]. Ultimately, infrastructure readiness in high-risk zones, such as coastal cities and tsunami-prone areas, and security and comfort aspects are key determinants in ensuring pedestrian safety during the situation [6], [7].

The significant threat of a tsunami in coastal cities near seismic fault lines in Indonesia, such as Padang City, is one reason why it's crucial to improve the city's infrastructure design for future evacuations. Geographically, Padang City, with its 68.126 km of coastline, has eight sub-districts directly impacted by a tsunami [8]–[10]. The risk distribution within these eight sub-districts is as follows: West Padang, North Padang, Nanggalo, and parts of Koto Tangah are in the high-risk zone. Meanwhile, East Padang, South Padang, Kuranji, and Bungus Teluk Kabung are in the medium-risk zone [10].

Statistical data from 2025 indicates that 950.512people lived in these eight sub-districts. The population of these eight sub-districts is 242,750, all of whom are affected by or vulnerable to the tsunami. [11].

The pattern of activities and people living in a region or area is closely related to the arrangement and management of its infrastructure [12]. If the area, such as Padang City, is vulnerable to tsunamis, the development of its infrastructure must be evacuation-based [9]. This effort is a form of disaster management and prevention in the event of a disaster, which takes the form of an evacuation process [13]. Evacuation movements are categorized as movements in an emergency, including people walking [14]. Emergency conditions often cause people walking to panic, which affects their movement [15].

The choice of walking during evacuation is influenced by both the internal factors described previously and external factors. Several previous studies have recommended that evacuation processes are more effective on foot [10], [12], [16]. Additionally, improving pedestrian evacuation can be achieved by facilitating routes and shelters (safe temporary refugee camps) [17]. Effective use of these pedestrian evacuation routes can be achieved by connecting them to shelters. This effectiveness depends on feasibility, immediacy, and timeliness [18], [19].

These three measures of effectiveness are issues that need to be addressed in Padang City. One of the densely populated areas of Padang City with a high tsunami potential, such as the Padang State

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University (UNP) campus, is still striving to maximize existing resources in the form of facilities to support pedestrian evacuation. Efforts to utilize these facilities, such as sidewalks (pedestrian paths) and multifunctional shelters, are underway. However, these ongoing efforts must be supported by guidelines. These guidelines are still missing and need to be assessed using indicators. Previous studies on tsunami evacuation only provide information that can serve as a basis for further research on evacuation infrastructure design. However, evacuation infrastructure has not been discussed as a continuation of these studies. Therefore, efforts to develop indicators in the form of an approach to designing such infrastructure are necessary. This research has attempted to address this issue by obtaining parameters for assessing the feasibility of evacuation infrastructure.

2. Method

This study employed a quantitative descriptive approach, involving expert assessments (urban planning and disaster management) and user preferences, specifically those of residents in tsunami-prone areas, to determine walkability indicators for evacuation-based pedestrian path design. This approach is highly appropriate because it represents statistical data and perspectives based on the findings, specifically the indicators.

The research began with the issue of the lack of preparedness of pedestrian infrastructure in emergencies. This study used the theoretical foundations of tsunami disaster mitigation and transportation to collect primary data from 350 respondents in tsunami-prone areas in Padang City. The field data was then statistically processed, including validity and reliability tests and respondent achievement level (TCR) analysis. This was done to produce measurable walkability parameters based on the actual needs of the community undergoing evacuation. The concrete output obtained was the feasibility parameters for recommended evacuation-based pedestrian paths.

2.1 Walkability Instruments

The research instrument was developed based on the Global Walkability Index (GWI) indicators adapted to the context of tsunami evacuation. Eight indicators were used: walking path mode conflict, availability of path, amenities, obstruction, disability infrastructure, availability and grade crossing safety, motorist behavior, and security from crime [9]. All of these indicators were tested for validity and reliability by six experts (in the fields of transportation, urban planning, and policy making). This expert judgment technique used the Likert scale to assist experts in filling out the validity form. Its scale of 1-5 is used as a reference in the assessments completed by experts. Each expert provides a score for each indicator test, testing its validity and reliability.

2.2 Validity and Reliability Test of Walkability Indicators

Validity and reliability tests are conducted in this section based on the experts' responses to each walkability indicator described previously. The results are tested using the following equation, and their validity values are compared with the Right Tile Probabilities (P) Table for Selected Values of the Validity Coefficient (V) [20], [21].

$$V = \frac{\sum S}{[n(c-1)]} \quad (1)$$

where,
S = r – lo If the highest rating scale is 5
S = lo - r If the highest rating scale is 1
R = The number given by the assessor
Lo = The lowest validity rating number, in this analysis, is 1
n = The number of assessors in this analysis = 6
c = The highest validity rating number, in this analysis, is 5

Meanwhile, the reliability test uses the ICC (Interclass Correlation) technique. This test is used to determine the agreement of all experts on the values (1-5) given for each walkability indicator. The equation used is as follows [22].

$$ICC = \frac{MS_R + MS_E}{MS_R + (k-1)\, MS_E} \quad (2)$$

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where, ICC = Reliability values are compared with Table 2
MSR = Mean Square Indicator Values in the ANOVA test results table
MSE = Mean square residual values in the ANOVA test results table
k = The number of experts who completed the assessments

This ICC value will be matched with the ICC value interpretation table. The intended interpretation is explained in Table 1 below [23], [24].

Table 1. Interpretation of ICC Values

Interpretation	Value	
	(Koo dan Li, 2016)	(Cicchetti dan Sparrow, 1981)
Poor	<0.50	<0.40
Fair	0.50-0.75	0.40-0.60
Good	0.75-0.90	0.60-0.75
Excellent	0.90-1	0.75-1

2.3 Population and Sample

The research location is in Padang City, specifically in the tsunami-prone zone with a radius of 2 km from the coastline [25]. This area is divided into six sectors based on the official evacuation map. The research population includes all residents domiciled in the vulnerable sector, spread across 65 sub-districts with a total of 318,677 people. Based on Isaac and Michael's sampling technique with a 5% probability level, the number of samples determined was 350 respondents.

2.4 Questionnaire Instrument Development

The questionnaire was developed from six valid and reliable walkability indicators. A total of 15 statements were developed, all distributed across each indicator.

2.5 Data Collection

Data collection at the research site went through several stages, starting with the initial trial and ending with the main survey. These stages are explained below.

- Instrument Trial: Before being widely distributed, the research instrument, in the form of a questionnaire developed into 16 statements, was distributed for trial testing to 100 samples or trial respondents outside the main research sample.
- Main Survey: The questionnaire that had been validated based on the previous trial was distributed to 350 respondents at the research location, spread across the 65 sub-districts described previously.

2.6 Data Analysis

The data analysis used in this study uses a structured technique to address the research objectives through several concrete and systematic steps. The sequence of analysis performed in this study is as follows.

- First, a validity test was conducted on the questionnaire administered to the trial sample. The results of the questionnaire were processed using the Statistical Package for the Social Sciences (SPSS Version 26) software. The values observed in the processed results were the calculated R values for each statement, compared with the Karl Pearson R Table value (N=100, R=0.1966, and p-value=5%).
- Second, a reliability test was conducted using 15 valid statements from the 16 questionnaire items. All statements were distributed to 350 respondents, the research sample. Questionnaire responses were processed using SPSS version 26 to obtain Cronbach's alpha values.
- Third, after being declared reliable, descriptive analysis was carried out: mean and standard deviation.
- Finally, 320 of the 350 data points that did not deviate or passed the standard deviation were analyzed from a perspective to obtain the level of achievement of the respondent's degree of

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walkability indicator, which was the final objective of the study. Equation 3, along with Table 2, is used in this section.

$$TCR = \frac{\sum x}{N\ x\ \sum item\ x\ Highest\ Scale} \tag{3}$$

where,
TCR = Total Percentage of Respondents' Answers in Table 3
Σ x = Total score of answers given by 320 respondents perindicator
N = Number of respondents in the sample = 320
Σ item = Number of statements per indicator
Highest Scale = Highest scale answer = 5

Table 2. Respondent TCR Criteria (TCR)

Percentage Interval	Category
81-100	Very Important
61-80	Important
41-60	Somewhat Important
21-40	Not Important
0-20	Very Unimportant

3. Result and Discussion

3.1 Result

The results of the walkability indicator validity test using expert judgment can be seen in Table 3 below. This table explains and illustrates the input from each expert for each walkability indicator.

Table 3. Walkability Indicator Validity Test Results for Tsunami Evacuation Parameters

Val.	Indicators															
	A	S	B	S	C	S	D	S	E	S	F	S	G	S	H	S
FA	5	4	5	4	4	3	4	3	4	3	4	3	5	4	3	2
EE	4	3	4	3	4	3	5	4	3	2	4	3	5	4	5	4
ET	4	3	5	4	4	3	5	4	3	2	4	3	5	4	5	4
OO	5	4	5	4	4	3	5	4	3	2	4	3	5	4	4	3
RB	4	3	4	3	4	3	4	3	3	2	4	3	5	4	4	3
MG	4	3	3	2	5	4	3	2	3	2	4	3	5	4	4	3
Σ S		20		20		19		20		13		18		24		19
V		0.83		0.83		0.79		0.83		0.54		0.75		1		0.79

Information

A = Walking Path Moda Conflict
B = Availability of Walking Paths
C = Amenities
D = Obstruction
E = Disability Infrastructure
F = Availability and Grade Crossing Safety
G = Motorist Behavior
H = Security from Crime
FA, EE, ET, OO,RB, MG = Validator Initials

S = r – lo
r = The number given by the assessor
o = The lowest validity rating number, in this analysis, is 1
Σ S = Number of S
n = The number of assessors in this analysis = 6
c = The highest validity rating number, in this analysis, is 5
V = Validation Value

Table 3 explains that the V value obtained from each indicator, 6 indicators whose V ≥ 0.79, and 2 indicators whose V value is less than the V table value, with a probability (p-value) of 5% [20], [21]. Meanwhile, the results of the ICC test obtained are explained in Table 4 below.

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Table 4. Cronbach's Alpha Analysis Results

Test	Value	P-Value
Cronbach's Alpha	0.800	
Anova Sig. Value	0.382	0.05
ICC	0.800	

Table 4 explains that the Cronbach's Alpha value obtained is 0.8, and this explains the consistency of the assessment of each indicator by the rater or validator because the value is > 0.6 [8]. Then, the ANOVA value obtained is 0.382, which is greater than the 5% probability value (0.05). This indicates that there is no significant difference between the 6 experts in their assessments per indicator. Furthermore, the ICC figure is in the good category with a value of 0.800, as shown in Table 1 [23], [24]. This indicates that the agreement between raters or experts in assessing the indicators in question is acceptable or said to be reliable. The analysis in this section produces a discussion of valid and reliable indicators. This is explained in the following Table 5.

Table 5. Valid and Reliable Walkability Indicators

Indicators	Valid	Reliable
Walking Path Moda Conflict	Ok	Ok
Availability of Walking Paths	Ok	Ok
Amenities	Ok	Ok
Obstruction	Ok	Ok
Disability Infrastructure	Not valid	Ok
Availability and Grade Crossing Safety	Not valid	Ok
Motorist Behavior	Ok	Ok
Security from Crime	Ok	Ok

Based on Table 5, six valid and reliable indicators were obtained, which were then developed into a research instrument with 15 statements in the form of a questionnaire. This questionnaire was piloted on 100 test samples, with the results of the trial in the form of a validity test by comparing the calculated R with the tabular R. Table 6 below explains this.

Table 6. Results of Instrument Validity Test on 100 Trial Samples

Statement	Counted R	R in Table	Description
No. 1	0.505	0.1966	Valid
No. 2	0.615	0.1966	Valid
No. 3	0.455	0.1966	Valid
No. 4	0.379	0.1966	Valid
No. 5	0.392	0.1966	Valid
No. 6	0.318	0.1966	Valid
No. 7	0.340	0.1966	Valid
No. 8	0.373	0.1966	Valid
No. 9	0.324	0.1966	Valid
No. 10	0.328	0.1966	Valid
No. 11	0.514	0.1966	Valid
No. 12	0.495	0.1966	Valid
No. 13	0.517	0.1966	Valid
No. 14	0.463	0.1966	Valid
No. 15	0.395	0.1966	Valid

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The validity test results in Table 6 indicate that the calculated r of 15 questionnaire statements is greater than Karl Pearson's r table (N=100, R=0.1966, and p-value=5%) and is declared valid. These 15 statements were then distributed to 350 research samples, and the reliability test results can be seen in Table 7 below.

Table 7. Results of Questionnaire Reliability Test on 350 Research Samples

Description	Value
Cronbach's Alpha	0.652
Number of items	15
Status	Valid and Reliable

Table 7 shows that 15 statements in the questionnaire had a Cronbach's α value of 0.652. This value is in the satisfactory category [26]. After the questionnaire was deemed reliable, descriptive analysis was conducted by calculating the mean (13.56) and standard deviation (1.50). Based on these values, 30 out of 350 deviant data were obtained.

The 320 deviant data were analyzed from their perspective using Equation 3 to obtain tsunami evacuation parameters from the walkability indicators described previously. The results were obtained by using the respondents' achievement levels from the deviant data. Table 8 below displays the results.

Table 8. Category of TCR Results of Achievement of Indicators

Parameter	A	B	C	D	E	F
TCR	94.90	91.25	94.27	81.25	94.84	96.25
Category	Very Important	Very Important	Very Important	Important	Very Important	Very Important

Information : A = Walking Path Moda Conflict, B = Availability of Walking Paths, C = Amenities, D = Obstruction, E = Motorist Behavior, F = Security from Crime

In Table 8 above, there are two categories of TCR achievement obtained, referring to Table 2: very important and important. The very important category falls under the walking path mode conflict, availability of walking paths, amenities, motorist behavior, and security from crime indicators. Meanwhile, the important category falls under the obstruction indicator.

3.2 Discussion

This study has explained that the concept of walkability, which has so far focused on normal conditions, can be designed for emergency conditions, especially for tsunami evacuation. Based on the results of validity tests by experts of eight Global Walkability Index (GWI) indicators, there are six indicators that are declared valid for the suitability of a pedestrian path for tsunami evacuation. Meanwhile, two other indicators (disability infrastructure and the availability and safety of crossings) were declared invalid. The failure of these two indicators is likely due to the characteristics of tsunami evacuations, which require rapid (immediate and timely) movement in conditions of mass panic. Persons with disabilities should be given priority in evacuation management, such as priority movement by ambulance or similar means. This means they are not involved in conflicts on evacuation routes that could endanger their safety. [1], [7], [18]. In panic situations, pedestrians tend to ignore the provided crossing points and other specific infrastructure, such as signs and pedestrian paths provided to find the shortest route to the shelter or safe zone [7].

In the analysis of TCR, public perception of the 6 valid indicators shows very important findings for infrastructure planning in Padang City. The Security from Crime indicator occupies the highest position, with the value of 96.25% (very high). It indicates that a sense of psychological security is very necessary for the community when carrying out evacuation movements, considering that disaster situations often trigger panic and social vulnerability. Furthermore, the walking path mode conflict and motorist behavior indicators also occupy the very high category with values of 94.90% and 94.84%, respectively. The high urgency of these two parameters is in line with previous

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research, which states that density and conflict between pedestrians and motorized vehicles can significantly reduce the speed of evacuation flow [16], [27]. In high-risk areas such as Padang City, highways often experience total congestion (gridlock) when an early tsunami warning sounds. Therefore, providing a special space for pedestrians that is free from motorized vehicle intervention is an absolute prerequisite to ensure the effectiveness of evacuation. The indicators of amenities and availability of walking paths were also highly rated by respondents (94.27% and 91.25%). This proves that evacuation by foot requires a direct and feasible route to the nearest shelter. Meanwhile, obstruction had a TCR score of 81.25% (high). Physical obstacles on sidewalks, such as electricity poles, street vendors, or damaged road materials, must be minimized, considering that the complexity of the urban environment significantly affects the efficiency of available evacuation onset time.

Overall, these findings complement the evaluation framework for pedestrian-friendly environments, which is no longer merely a mobility issue but has become an integral part of urban spatial planning, disaster resilience, and mitigation strategies. Therefore, this framework can serve as a foundation for policymakers to create more adaptive and inclusive infrastructure. This spatial transformation is expected to not only reduce the risk of loss of life during tsunami evacuations but also improve the quality of life and health of urban communities sustainably.

4. Conclusion

This study successfully formulated and validated walkability indicators specifically for design to meet the needs of tsunami evacuation for pedestrians. Of the 8 initial global walkability index indicators, six parameters were proven valid and reliable based on expert assessment and field trials. Based on community preferences in high-risk zones, these six parameters have a very crucial degree of achievement in supporting smooth evacuation, namely: security from crime (96.25%), walking path moda conflict (94.90%), motorist behavior (94.84%), amenities (94.27%), availability of walikng paths (91.25%), and obstruction (81.25%). These six indicators should be used as the main guideline for local governments and urban spatial planners in designing evacuation infrastructure that is inclusive, feasible, and integrated with shelters. Future research is recommended to integrate these six walkability parameters into spatial simulation modeling to map route capacity in real-time during a disaster, and the form of pedestrian path design specifically to serve the evacuation process.

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