Optimization of Tsunami and Earthquake Awareness Through Digital Mapping Using a Decision Support System with Simple Additive Weighting (SAW) in Padang City

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Abstract. Padang is a city that is prone to earthquakes and tsunamis due to its location between the India and Asia plates on the west coast and being crossed by the Great Sumatran fault. The Padang coastal region is a strong source of earthquakes and tsunamis. Despite having experienced earthquakes in 2006, 2007, and 2009, Padang still faces difficulties in managing tsunami evacuation because of the lack of infrastructure and straight roads from the coast to higher ground. The presence of rivers in Padang causes the tsunami waves to be concentrated within a 200-meter radius and the evacuation routes are hindered by the presence of bridges that are not durable against tsunamis and earthquakes. Additionally, traffic congestion after an earthquake exacerbates the evacuation problems. This study aims to map the risk and potential of earthquakes and tsunamis in Padang 3 KM from the coast by comparing population and building data with the availability of shelters. The Simple Additive Weighting (SAW) method, as part of Geographic Information System, is used to analyze demographic data and shelter locations. The results show that Koto Tangah is the area with the highest risk level for earthquakes and tsunamis.

Keywords: Shelter, Geographic Information System (GIS), Simple Additive Weighting (SAW), Digital Mapping

INTRODUCTION

Padang is a city vulnerable to earthquakes and tsunamis due to its location between two tectonic plates, India and Asia, along the west coast and intersected by the major Sumatran fault. The coastal region and sea in Padang are known to be a significant source of earthquakes and tsunamis as a result of the megathrust [1][2]. The high demographic density in the area, particularly close to the coastal region at an elevation of 5 meters above sea level, puts many residents at risk in the event of an earthquake or tsunami. Evacuation routes must reach a height of over ten meters above sea level to provide adequate safety [3][4][5].

Additionally, the lack of infrastructure has further hampered the ability of the residents of Padang to evacuate safely during a tsunami [6]. A monitoring system for infrastructure stability is necessary to guarantee the safety of individuals affected by disasters [7]. The concentration of the tsunami waves due to multiple rivers in the area only adds to the danger [8]. Furthermore, the bridges along the evacuation route pose a significant threat, as they may not be able to withstand the impact of a tsunami or earthquake [9]. The aftermath of an earthquake can also lead to a traffic jam, making it even more difficult for residents to evacuate in a timely manner [10][11].

Previous studies have served as the basis for this research, such as the model for determining the priority of shelter [12] [13]; for locations in Padang during critical situations using the AHP-TOPSIS method. The outcome of this previous study was the development of a priority model for temporary shelters during tsunamis and earthquakes to minimize the number of casualties.

This study aims to develop an application to assist earthquake and tsunami victims in finding their shelter locations. The title of this research is: "An Application for Identifying the Closest Tsunami Shelter in Padang using the Best-First Search Method [4]. Another title of the research shared a similar topic: "Deter-mining Vertical Shelter Location Based on The Height of Tsunami" [14]. The third study evaluates the shelter's height if the Tsunami wave reaches more than 10 meters height using the ELECTRE method [14].

Previous studies have been conducted in Padang, but there is still room for further research to identify the locations of existing shelters and help the local government build new shelters in other areas. This study focuses on creating a digital map of the shelters throughout Padang using Geographic Information System (GIS); and using analyze for complete this research with Simple Additive Weighting (SAW) method [15]. GIS involves spatial data and software for collecting, managing, and analysing these data [16][17]. The GIS is capable of addressing multiple problems related to spatial aspects by combining databased operations and statistical analysis with a unique visualization feature, which offers digital map-ping-based spatial analysis [18][19][20]. This system is particularly interesting as it provides more accessible routes. It has a distinctive capability compared to other information systems, as it provides more accurate information that is closer to reality, predicts results, and supports the development of strategic plans [21][22].

Perceiving the distribution of shelter locations in Padang using GIS will result in a final map displaying the distribution of shelters in the city. The data analysis technique used in this study is the SAW method, which is based on rated weighting. The decision-maker directly assigns weights to each attribute according to their relative importance [23]. The total value of each alternative is calculated by multiplying the weight of each attribute and summing the results [24]. Finally, the total score of all alternatives is calculated and the alternative with the highest score will be selected [25].

METHODS

The method employed in this research is the SAW method. According to Fishburn, the fundamental idea behind the SAW method is to calculate the weighted sum from the rating of each alternative. The SAW method involves the normalization of the decision matrix (X) to a common scale for comparison across all alternatives [25].

The situation where multiple conflicting objectives exist is referred to as a multi objective system. In such scenarios, one aspect of the system may be improved, but at the same time, another aspect may be negatively impacted. Dimensional analysis can assist decision makers in making better decisions in these situations. Spatial multi criteria decision analysis involves combining and transforming both spatial and nonspatial data inputs into a resultant decision (output). The relationship between inputs and outputs is defined by the principles of multi criteria decision making [26][27].

The SAW method is designed to address selection in a multi objective decision-making process [28][29]. This method is also utilized to handle Multi Attribute Decision Making (MADM) situations. It requires decision-makers to establish the weight of each attribute. The total score for each alternative is obtained by summing the products of the rate (comparable attribute rates) and the weight of each attribute.

The ranking of each attribute must be dimensionless, meaning it has under gone the process of normalization. Essentially, this method relies on rated weighting. The decision makers directly determine the weight of relative importance in each thematic map. The total value of each alternative is calculated by multiplying the weight of each attribute and summing the results. The evaluation of the decision rule for each alternative, Ai, is defined by the following formula:

$$Ai = Wj\ Xij \qquad [25]$$

Where Xij is the alternative to I on the attribute j, Wj is the weight normalization (Wj = 1). These weights show the significance of the attributes relatively. The alternative is selected by identifying the maximum value of Ai.

$$Ai\ (i= 1, 2, ..., n) \qquad [25]$$

The application of the GIS-based SAW method utilizes the GIS based on the overlaying technique. This method evaluates the attributes in the input criteria map and adds them to determine the attribute of the output combined map [6]. The demographic and shelter data in Padang can be seen in Tables 1 and 2.

TABLE 1. Padang City Demographics From 2018 & 2020

Subdistrict	Total Population	
	2018	**2020**
Bungus Teluk Kabung	25.174	25.867
Lubuk Kilangan	56.214	58.580
Lubuk Begalung	123.167	128.571
Padang Selatan	59.962	60.546
Padang Timur	79.610	79.992
Padang Barat	46.055	46.170
Padang Utara	70.951	71.380
Nanggalo	61.559	62.815
Kuranji	149.307	156.724
Pauh	73.686	78.665
Koto Tangah	19.3427	20.3842

Source: Padang City Central Bureau of Statistics

TABLE 2. Padang City Shelter Distribution Data

No	Shelter	Location	Floors	Capacity
1	Bank Indonesia	Jendral Sudirman Rd.	4 (roof concrete)	
2	Bank Nagari	Pemuda St.	6 (roof concrete)	1000
3	Badan Pemeriksa Keuangan (BPK)	Khatib Sulaiman Rd.	3 & 4	800
4	Bappeda Prov. Sumbar	Khatib Sulaiman Rd.	4	
5	Dinas Peternakan Prov. Sumbar	Rasuna Said Rd.	3	
6	Dinas PU dan Pemukiman Prov. Sumbar	Taman Siswa No.1 St.	3	
7	PSDA Prov. Sumbar	S. Parman Ulak Karang St.	3	200
8	DPRD Sumatera Barat	S. Parman Ulak Karang St.	4	100
9	Escape Building Kantor Gubernur	Jend. Sudirman No. 51, Padang Barat Rd.		
10	Pustaka Daerah	Khairil Anwar St.	5 (roof concrete)	
11	Polda Sumbar	Sudirman, Padang Pasir Rd.	8 (roof concrete)	1500
12	Telkom	Bagindo Azis Chan Rd.	7 (roof concrete)	300
13	PT. Sutan Kasim	Veteran St.	4 (roof concrete)	800
14	PT. AMP	Hamka Parupuk Tabing Rd.	4 (roof concrete)	1000
15	Daihatsu & ACC Finance	Khatib Sulaiman Rd.	3 (roof concrete)	30
16	Rumah Sakit M. Jamil	Perintis Kemerdekaan St.	6 (roof concrete)	
17	Rumah Sakit Yos Sudarso	Situjuh St.	5 (roof concrete)	300
18	Pasar Inpres	Sandang Pangan (Pasar Raya) St.	4 (roof concrete)	4000
19	Damar Plaza	Damar Kp. Olo St.	5	1000
20	Shelter Air Tawar Timur	Air Tawar Timur St.	4 (roof concrete)	200
21	Shelter Darussalam	Bungo Pasang District	6 (roof concrete)	1000
22	Shelter Nurul Haq	Jondul Complex 4 Parupuk Tabing Koto Tangah	6 (roof concrete)	1000

23	Shelter Wisma Indah Warta Bunda	Sumatera, Ulak Karang Utara St.	4 (roof concrete)	
24	Villa Hadis	Khatib Sulaiman Rd.	Rangka Baja	
25	Sekolah Al Azhar 32	Khatib Sulaiman Rd.	3	1000
26	SD 03, 04, 21 Purus	Veteran St.	4 (roof concrete)	
27	SD Agnes	Bandar Gereja St.	3 (roof concrete)	
28	SD Percobaan	Ujung Gurun St.	3 (roof concrete)	
29	SDN 23 dan 24 Ujung Gurun	Veteran No. 82 Padang St.	4 (roof concrete)	
30	SMP Frater	Khairil Anwar St.	4 (roof concrete)	
31	SMP Maria	Bandar Gereja St.	3 (roof concrete)	
32	SMPN 7 Padang	S. Parman Lolong Padang Rd.	3-4 (roof concrete)	2000
33	SMPN 25 Padang	Beringin Belanti Timur St.	3 (roof concrete)	
34	SMAN 1 Padang	Belanti Raya No. 11 Padang St.	4 (roof concrete)	2000
35	SMKN 5 Padang	Beringin No. 4 Padang St.	4 (roof concrete)	2000
36	Fakultas Ilmu Pendidikan UNP	Hamka, Air Tawar, Padang Rd.	5 (roof concrete)	1500
37	Pasca Sarjana UNP	Hamka, Air Tawar, Padang Rd.	6 (roof concrete)	1000
38	Perpustakaan UNP	Hamka, Air Tawar, Padang	6 (roof concrete)	1000
39	Universitas Muhammadiyah Sumbar	Pasie Kandang Parupuk Tabing St.	3	1500
40	STMIK Indonesia Padang	Khatib Sulaiman Rd.	4 (roof concrete)	
41	Universitas Bung Hatta	Bunda Raya, Ulak Karang St.	4 (roof concrete)	600
42	Universitas Ekasakti	Veteran Dalam, Banda Purus St.	6 (roof concrete)	800
43	STBA Prayoga	Veteran St.	5 (roof concrete)	
44	SPR Plaza	M. Yamin St.		
45	Plaza Andalas	Pemuda St.		
46	Hotel Pangeran Beach	Juanda St.	7 (roof concrete)	
47	Basko Hotel & Plaza	Hamka, Air Tawar, Padang Rd.	8 (roof concrete)	
48	Hotel Ibis	Taman Siswa St.	12 (roof concrete)	
49	Hotel Daima	Jend. Sudirman Rd.	6 (roof concrete)	
50	Hotel Grand Zuri	MH. Thamrin St.	8 (roof concrete)	
51	Hotel Rocky	Permindo St.		
52	Axana Hotel	Bundo Kanduang St.		
53	Bumi Minang Hotel	Gereja St.	8	
54	Hotel HW	Hayam Wuruk St.		
55	Hotel Inna Muara	Gereja St.	6 (roof concrete)	
56	Hotel Mercure	Purus IV St.		
57	Budha Tzu Chi	HOS Cokroaminoto St.	4	
58	Rusunawa	Purus IV St.	5	
59	Masjid Al Wustha	Veteran St.	4 (roof concrete)	

60	Masjid Muhajirin	Pasir Putih Complex RT. 3 RW 5 Bungo Pasang Koto Tangah	3 (roof concrete)	600
61	Masjid Raya Sumbar	Khatib Sulaiman Rd.	2	15000
62	Masjid Taqwa Muhammadiyah	M. Yamin (Pasar Raya) St.	4 (roof concrete)	2500
63	Transmart	Khatib Sulaiman Rd.	4 (roof concrete)	
64	Wiz Prime Hotel	Khatib Sulaiman Rd.	8 (roof concrete)	
65	Pengadilan Negeri Kota Padang	Khatib Sulaiman Rd.	2 (roof concrete)	
66	Rumah Sakit Hermina	Khatib Sulaiman Rd.	4 (roof concrete)	

RESULTS AND DISCUSSION

The Results of Finding the Distribution of Shelters Using the SAW Method

In the SAW method, the weight and ranking values for each attribute and alternative are determined based on the degree of relative importance of each criteria/ attribute in shelter distribution. The criteria evaluation, reversed weight, and rank attributes are used to calculate the weight and ranking values. The weight values are calculated with a minimum value of 1 and a maximum value of 10, while the ranking values are determined with a minimum alternative value of 1 and a maximum value of 5, as shown in Table 3.

TABLE 3. The Weight Value of The Shelter Location Attribute Ranking And Demographics

Attribute	Weight	Alternative	Ranking
Shelter location	1	0-5	1
		5-10	2
		10-15	3
		15-20	4
		>20	5
Demography	1	0-50000	1
		50000-100000	2
		100000-150000	3
		150000-200000	4
		>200000	5

The calculation of weight value and at-tribute ranking is explained in Table 3. Each attribute is identified with similar significance between the criteria of shelter location data in each prefecture and demographic data.

To determine the alternatives in this study, an objective approach to data adjustment is applied, dividing similarities into five ranks. Each attribute has a similar weight value in determining the weight value as there is no established standard for calculating the significance of attributes in shelter distribution. A weight value of 1 indicates that this at-tribute holds a similar significance to other attributes.

Moreover, the alternative rank value is standardized by dividing the rank alternative value; the maximum value can be seen in Table 4. The formula is as follows:

$$X'ij = Xij / Xjmaks \qquad [6]$$

Where:

X'ij is the standardized rank value for alternative to-i, and alternative to-i attributes to-j

Xij is the initial rank value

Xjmaks is the maximum ranking value of attribute to-j

TABLE 4. Normalization of weight and ranking values

Attribute	Weight	Alternative	Ranking
Shelter location			
	0.2	0-5	0.2
		5-10	0.4
		10-15	0.6
		15-20	0.8
		>20	1
Demography			
	0.2	0-50000	0.2
		50000-100000	0.4
		100000-150000	0.6
		150000-200000	0.8
		>200000	1

Digital Mapping of Padang Demography

The data obtained from Padang City Central Bureau of Statistics show that the highest density of people population in Padang is located in Koto Tangah Prefecture; check out figure 1.

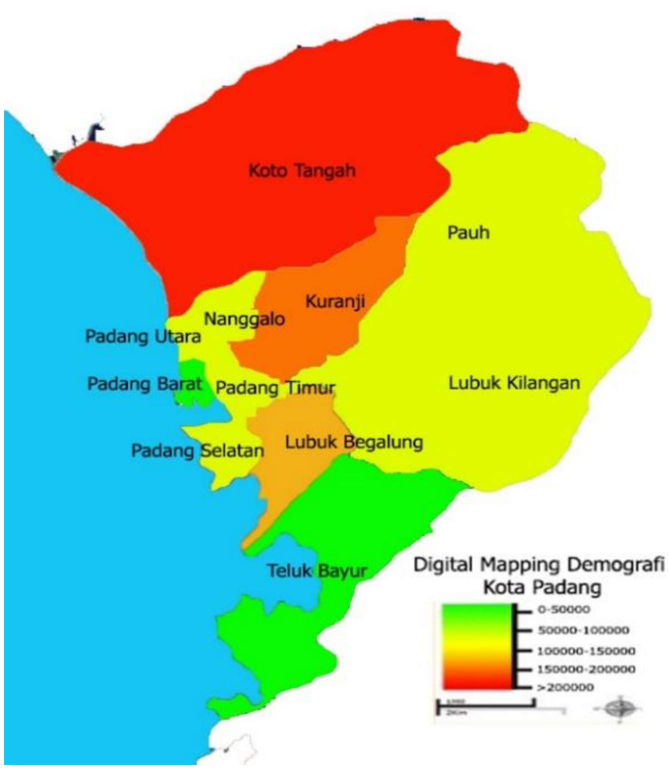

FIGURE 1. Digital Mapping of City Population Distribution (Demography) field

Picture 1 shows the high-density population prefecture indicated in red and the low-density population in green. Check out Table 5.

TABLE 5. Distribution of the Demographics of the City of Padang

Total Population	District
0-50000	- Bungus Teluk Kabung - Padang Barat
50000-100000	- Pauh - Nanggalo - Padang Utara - Padang Timur - Padang Selatan - Lubuk Kilangan
100000-150000	- Lubuk Begalung
150000-200000	- Kuranji
>200000	- Koto Tangah

Digital Mapping of Shelter Distribution in Padang

The data obtained from the local Biro of Disaster Mitigation The Padang City Disaster Management Agency show the distribution of shelters is mostly located in North and West Pa-dang Prefecture; check out Figure 2.

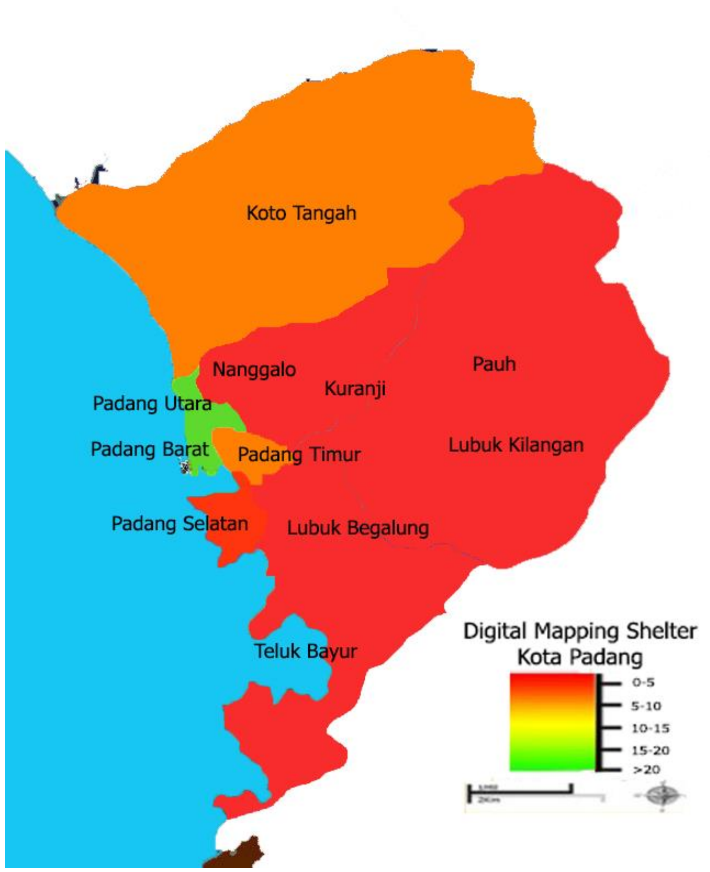

FIGURE 2. Digital Mapping of Padang City Shelter Distribution

Based on Figure 2, the green color indicates a high shelter distribution location, whereas the red color shows low shelter distribution; check out Table 6.

TABLE 6. Distribution of Padang City Shelters

Number of Shelter	District
0-5	- Bungus Teluk Kabung - Pauh - Nanggalo - Kuranji - Lubuk Begalung - Lubuk Kilangan - Padang Selatan
5-10	- Padang Timur - Koto Tangah
10-15	-
15-20	-
>20	- Padang Barat - Padang Utara

Digital Mapping of Earthquake and Tsunami Hazards Based on Shelter Distribution and Demographics

The result of combining the demographic mapping and the number of shelters in Padang is the final output of the multi-criteria decision-making process to address the risk of earthquakes and tsunamis using the Simple Additive Weighting (SAW) method. The output is represented in different colors based on the total score calculated by summing up each attribute or criteria. The total score ranges from 1.0 to 5.0 and is divided into five categories of risk degrees. Prefectures with a very low risk are shown in green, while the increasing risk is indicated by a stronger brown color, as depicted in Figure 3.

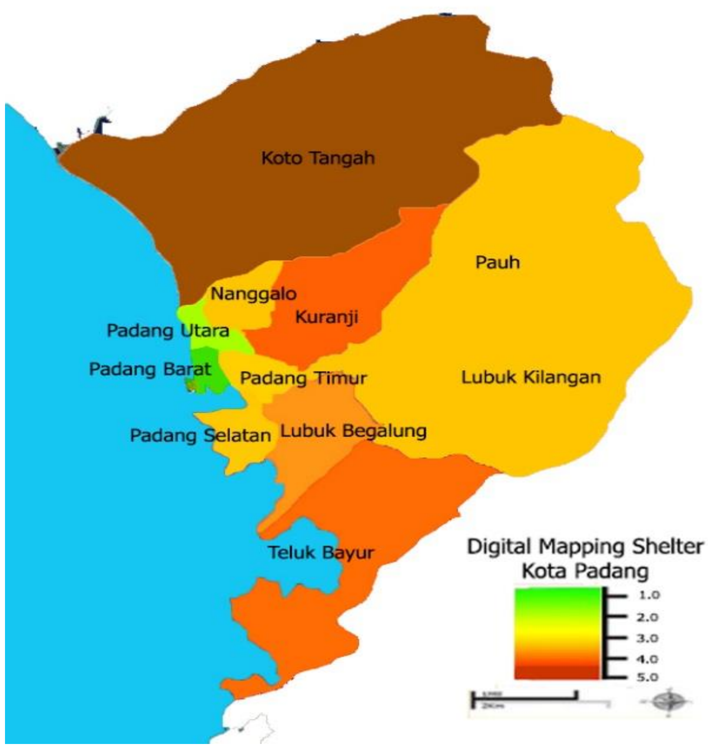

FIGURE 3. Digital Mapping of Earthquake and Tsunami Hazards Based on Shelter Distribution and Demographics

The classification of earthquake and tsunami risk based on the distribution of the shelter and total score-based demography resulting from applying the SAW method is as follows:
1. 0-1.0 Risk-free to very low risk, scored from 0-1.0
2. Low risk, scored from 1.0-2.0
3. Moderate risk scored from 2.0-3.0
4. High risk, scored from 3.0-4.0
   Very high risk scored from 4.0-5.0

Discussion

Based on the result of this study, the digital mapping of earthquake and tsunami risk degree designed for the functional need is expected to have no errors shown in Table 7.

TABLE 7. Distribution of Padang City Shelters

No	Description	
	Before Research	**After Research**
1	To obtain information about shelters in Padang City, the community must seek information from the Padang City BPBD without being aware of the distribution of each existing shelter location.	The public now has access to information on the distribution of shelters through digital mapping.
2	The community is still unaware of disaster hazard information based on the distribution of shelters and demographics in Padang City.	The public can obtain information on areas in Padang City that are susceptible to earthquakes and tsunamis through the calculation of the decision support system utilizing the Simple Additive Weighting (SAW) method.

CONCLUSIONS

The findings of this study demonstrate the effectiveness of the Simple Additive Weighting (SAW) method in mapping the distribution of shelters, demographics, and the risk degree of earthquakes and tsunamis in Padang. The digital mapping of the risk of earthquakes and tsunamis based on the distribution of demographics and shelters is represented by varying colors, with green signifying the lowest risk locations and stronger browns indicating higher risk locations. As a result, the prefecture with the highest risk has been identified. This study can serve as a valuable reference for the local government in building additional shelters to mitigate the impacts of earthquakes and tsunamis in Padang.

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