

Mapping Evacuation Routes During a Tsunami Using the A* Algorithm

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Abstract: As an archipelagic region located at the convergence of three major tectonic plates, West Sumatera Province has a high level of vulnerability to tsunami disasters. One of the areas at significant risk is Padang City, particularly Lubuk Buaya District, which is geographically adjacent to the coastline and close to active tectonic and underwater volcanic zones. These conditions highlight the importance of effective disaster mitigation efforts, especially in planning optimal evacuation routes. This study aims to determine the shortest evacuation route from tsunami prone areas to safe zones by applying the A* algorithm. The data used in this research are secondary data in the form of coordinate points and distances between locations obtained from Google Earth. These data are modeled as a weighted graph, where nodes represent paths connecting the nodes with distances as weights. The A* algorithm is utilized because it combines shortest path searching with a heuristic approach, making it more efficient compared to conventional methods. The result of this study indicates that the A* algorithm successfully identifies the shortest evacuation route from the starting point at Pasir Jambak to the nearest safe zone, with a total distance of 2.751 meters (2,7 km). The resulting route is expected to serve as a recommendation for local communities and government authorities in improving disaster preparedness and minimizing casualties during a tsunami event.

Keywords: A* Algorithm; Disaster Mitigation; Evacuation Route; Shortest Route

1. Introduction

Indonesia is an archipelagic country consisting of more than 17,000 islands and is located at the convergence of the Indo-Australian, Eurasian, and Pacific tectonic plates. This geotectonic setting makes Indonesia highly vulnerable to earthquakes and tsunamis (Syahputra & Asriyanik, 2023). According to the National Coordinating Agency for Surveys and Mapping, nearly all coastal areas in Indonesia are exposed to tsunami hazards, although the level of vulnerability varies by location (Rusli & Rudyanto, 2010). Tsunamis are primarily triggered by undersea earthquakes, which account for approximately 90% of tsunami events (Rumondor et al., 2019). West Sumatra Province, particularly Padang City, lies within an active megathrust subduction zone and the Sumatra fault system, making it prone to high-magnitude earthquakes that may generate tsunami waves (Zulfikar, 2025). One of the high-risk areas is Lubuk Buaya Subdistrict, which is directly adjacent to the

coastline. In emergency situations, determining the shortest and fastest evacuation route becomes crucial. Mathematically, this issue can be formulated as a shortest path problem in graph theory, where intersections are represented as vertices and roads as weighted edges.

Several algorithms have been developed to solve shortest path problems in weighted graphs. Dijkstra's algorithm determines the minimum cumulative weight between vertices and has been successfully applied in route optimization studies (Bunaen *et al.*, 2022). However, its computational complexity becomes less efficient for large-scale graphs. Best First Search utilizes heuristic functions to guide node exploration, but it does not always guarantee optimal solutions (Afero, 2022). The A* algorithm improves upon Dijkstra's approach by incorporating heuristic estimation into the path cost evaluation, thereby reducing the number of explored nodes while maintaining optimality under admissible heuristics (Pratama, 2024). Previous studies have demonstrated the effectiveness of A* in determining optimal routes in various contexts, such as locating healthcare facilities (Arsyad, 2019), identifying building navigation paths (Irsyad & Rasila, 2015), and optimizing regional transportation routes (Susilawati, 2020). Nevertheless, limited research has applied the A* algorithm specifically to tsunami evacuation route planning in high-risk coastal regions such as Lubuk Buaya, Padang City.

Addressing this mathematical problem is significant because evacuation efficiency directly influences disaster mitigation outcomes and potential casualty reduction. A scientifically computed shortest evacuation route can support local government preparedness and community safety planning. Therefore, this study aims to implement the A* algorithm to determine the shortest tsunami evacuation route from Pasir Jambak to the designated green zone (bypass) in Lubuk Buaya Subdistrict.

2. Methods

The type of research used in this study is applied research using the A* algorithm approach. This research was conducted from December 2024 to August 11th, 2025. The research location was in Lubuk Buaya Subdistrict. The data used as the object of this study was secondary data obtained from Google Earth. The data consisted of coordinate nodes and distances between nodes in meters. From these coordinate nodes, source and destination nodes were selected that were safe from tsunami disasters.

This study employed applied research using a graph-based computational approach with the A* algorithm to determine the shortest evacuation route in tsunami disaster mitigation. The research integrates concepts of disaster mitigation, evacuation route planning, graph theory, and shortest path algorithms.

Disaster mitigation refers to efforts aimed at reducing disaster risk and its impacts before a disaster occurs. According to Undang-Undang Nomor 24 Tahun 2007, disasters are events that threaten and disrupt community life due to natural or non-natural factors. Mitigation efforts aim to reduce casualties and losses (Wekke, 2021; Maulana & Andriansyah, 2024). In the context of tsunami

mitigation, evacuation route planning plays a crucial role in minimizing casualties (Rumondor et al., 2019; Banowati et al., 2024).

The shortest path problem in evacuation modeling can be solved using graph theory. A graph is defined as $G = (V, E)$, where V represents vertices (nodes) and E represents edges connecting the vertices (Munir, 2012; Marsudi, 2016). In this study, a weighted graph was used, where edge weights represent distances between nodes.

The A* evaluation function is defined as (Mutiaa et al., 2013) :

$$f(n) = g(n) + h(n) \quad (1)$$

where :

$f(n)$ = total estimated cost

$g(n)$ = actual cost from start node to node n

$h(n)$ = heuristic estimate from node n to the goal.

The heuristic function used in this study is the Euclidean Distance :

$$h(n) = \sqrt{(x_{goal} - x_n)^2 + (y_{goal} - y_n)^2} \quad (2)$$

where :

x_n : longitude value of node n

x_{goal} : longitude value of the destination node

y_n : latitude value of node n

y_{goal} : latitude value of the destination node

The A* algorithm has been widely implemented in shortest path and evacuation studies. The steps taken using the A* algorithm are as follows (Nugraeni et al., 2015) :

1. Create an open list and close list table.
 - a. The open list (contains nodes that have been generated), already have a heuristic function but have not been tested.
 - b. The close list (contains nodes that have been tested)
 - c. The first node is immediately entered into the close list table.
2. Enter the neighbors of the first node into the Open List column.
 - a. Select the node (n) with the smallest $f(n)$ value from the Open List and set it as the current node
 - b. Move the current node from the Open List and move it to the Close List
 - c. Do the following steps for each neighbor of the current node :
 1. Ignore neighboring nodes that cannot be traversed or are already in the Close List

2. If a neighboring is already in the Open List, set the current node as its parent and store its f , g , and h values.
3. If a neighboring node is already in the Open List, check whether its g value is better. If so, change the parent of the neighboring node to the current node, then recalculate its g and f values.
- d. Stop if the destination node has been entered into the Close List, indicating that the path has been found.

3. Results and Discussion

The A* algorithm was applied to determine the shortest evacuation route from Lubuk Buaya Subdistrict to two alternative safe zones. The following is a list of the location nodes used in this study:

Table 1 Sample Node Data for Lubuk Buaya Subdistrict

Node	<i>Lattitude</i>	<i>Longitude</i>	Node	<i>Lattitude</i>	<i>Longitude</i>
B_1	-0,8334536	0,315277	B_{14}	-0,823602	0,318272
B_2	-0,831499	0,318897	B_{15}	-0,822815	0,319042
B_3	-0,832195	0,319484	B_{16}	-0,829607	0,324928
B_4	-0,829981	0,322289	B_{17}	-0,827998	0,325500
B_5	-0,829098	0,323657	B_{18}	-0,829010	0,326042
B_6	-0,827899	0,320428	B_{19}	-0,830106	0,327198
B_7	-0,826817	0,321669	B_{20}	-0,828867	0,327405
B_8	-0,830873	0,324872	B_{21}	-0,827693	0,328083
B_9	-0,828659	0,324200	B_{22}	-0,823622	0,326289
B_{10}	-0,826675	0,319717	B_{23}	-0,820105	0,324424
B_{11}	-0,825879	0,326091	B_{24}	-0,817952	0,323197
B_{12}	-0,825004	0,318711	B_{25}	-0,824094	0,335427
B_{13}	-0,824339	0,319869	B_{26}	-0,815883	0,330578

The following is a complete list of various starting points, evacuation routes and destination points in Lubuk Buaya Subdistrict.

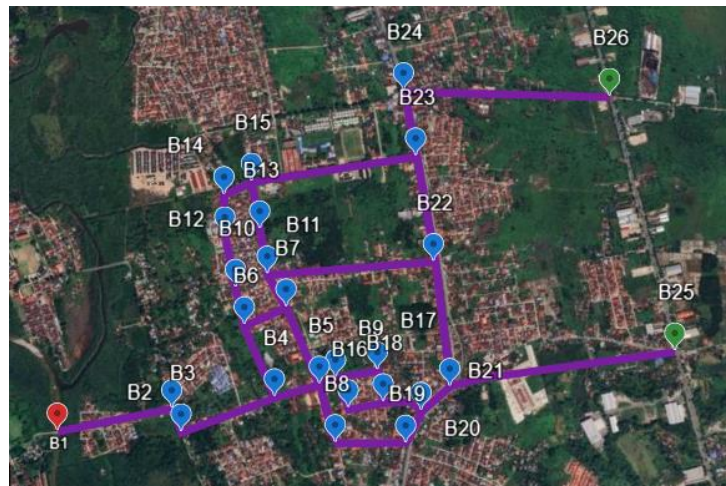


Figure 1. Node and Evacuation Route (Source : Google Earth)

Based on Figure 1, the red node represents the starting node located in the red zone, while the blue node represents the evacuation node paths, and the green node is the destination node located in the green zone. Table 2 shows the distance between the two coordinate nodes, where the distance is assumed to be $g(n)$.

Table 2. Weight of Edges Connecting Nodes

Side	Location Node	Distance ($g(n)$) (m)	Side	Location Node	Distance ($g(n)$) (m)
z_1	$B_1 - B_2$	460	z_{18}	$B_{11} - B_{22}$	615
z_2	$B_2 - B_3$	101	z_{19}	$B_{12} - B_{13}$	141
z_3	$B_3 - B_4$	391	z_{20}	$B_{12} - B_{14}$	167
z_4	$B_4 - B_5$	183	z_{21}	$B_{13} - B_{15}$	198
z_5	$B_4 - B_6$	308	z_{22}	$B_{14} - B_{15}$	118
z_6	$B_5 - B_7$	337	z_{23}	$B_{15} - B_{23}$	678
z_7	$B_5 - B_8$	236	z_{24}	$B_{16} - B_{18}$	141
z_8	$B_5 - B_9$	75	z_{25}	$B_{17} - B_{18}$	130
z_9	$B_6 - B_7$	183	z_{26}	$B_{18} - B_{20}$	158
z_{10}	$B_6 - B_{10}$	156	z_{27}	$B_{19} - B_{20}$	140
z_{11}	$B_7 - B_{11}$	154	z_{28}	$B_{20} - B_{21}$	147
z_{12}	$B_8 - B_{19}$	272	z_{29}	$B_{21} - B_{22}$	503
z_{13}	$B_9 - B_{16}$	132	z_{30}	$B_{21} - B_{25}$	963
z_{14}	$B_9 - B_{17}$	162	z_{31}	$B_{22} - B_{23}$	436
z_{15}	$B_{10} - B_{11}$	138	z_{32}	$B_{23} - B_{24}$	272
z_{16}	$B_{10} - B_{12}$	217	z_{33}	$B_{24} - B_{26}$	849
z_{17}	$B_{11} - B_{13}$	187			

Next, a graph is formed based on the location points in Lubuk Buaya Subdistrict as follows:

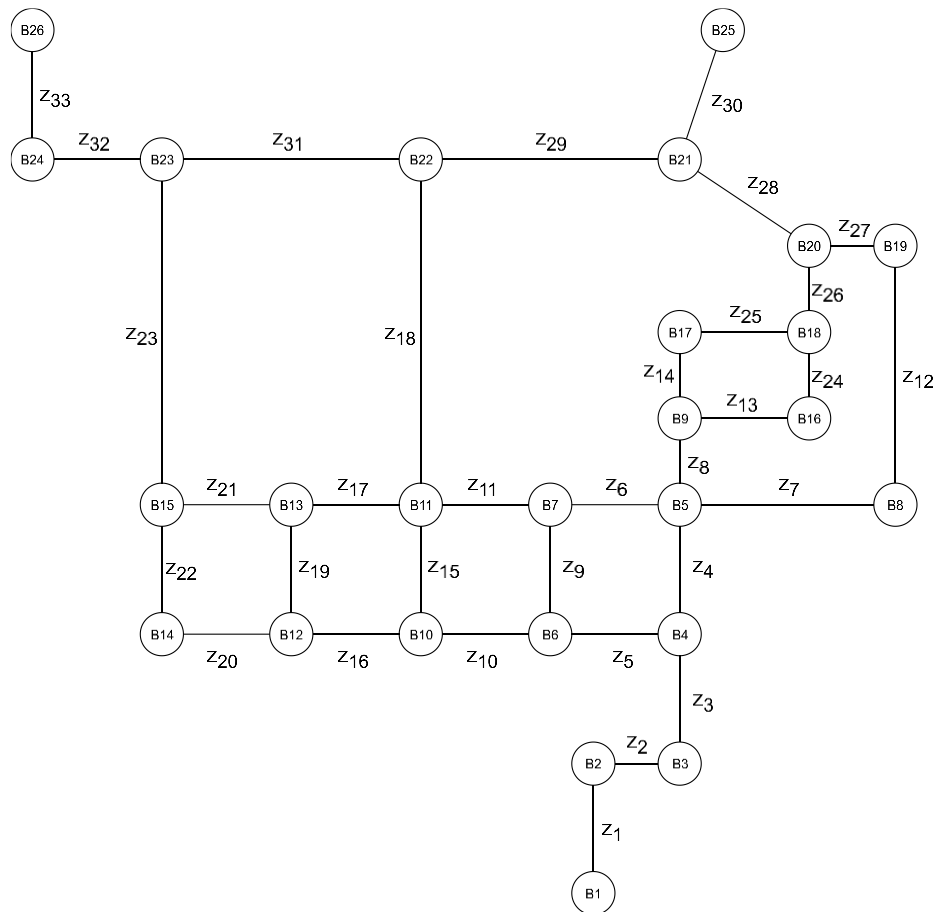


Figure 2. Nodes and Evacuation Paths in Graph Form

Heuristic value of each node to node B_{25} which can be seen in the following table :

Table 3. Heuristic Value for Destination Node (B_{25})

Starting Node	Destination Node	$h(n)$	Starting Node	Destination Node	$h(n)$
B_1	B_{25}	0,485917	B_{13}	B_{25}	0,482816
B_2	B_{25}	0,483515	B_{14}	B_{25}	0,48387
B_3	B_{25}	1,007253	B_{15}	B_{25}	0,483364
B_4	B_{25}	0,48124	B_{16}	B_{25}	0,479457
B_5	B_{25}	0,480311	B_{17}	B_{25}	0,479053
B_6	B_{25}	0,48246	B_{18}	B_{25}	0,478694
B_7	B_{25}	0,481626	B_{19}	B_{25}	0,477917
B_8	B_{25}	0,479511	B_{20}	B_{25}	0,477761
B_9	B_{25}	0,47994	B_{21}	B_{25}	0,477286
B_{10}	B_{25}	0,482923	B_{22}	B_{25}	0,4785
B_{11}	B_{25}	0,478639	B_{23}	B_{25}	0,479783
B_{12}	B_{25}	0,483582	B_{24}	B_{25}	0,480633

In the same way, the heuristic value of each node to node B_{26} is obtained, which can be seen in the following table :

Table 4. Heuristic Value for Destination Node (B_{26})

Starting Node	Destination Node	$h(n)$	Starting Node	Destination Node	$h(n)$
B_1	B_{26}	0,481131	B_{13}	B_{26}	0,477842
B_2	B_{26}	0,478672	B_{14}	B_{26}	0,478895
B_3	B_{26}	0,99812	B_{15}	B_{26}	0,47837
B_4	B_{26}	0,476347	B_{16}	B_{26}	0,47454
B_5	B_{26}	0,475393	B_{17}	B_{26}	0,474104
B_6	B_{26}	0,477544	B_{18}	B_{26}	0,473758
B_7	B_{26}	0,476683	B_{19}	B_{26}	0,472992
B_8	B_{26}	0,474617	B_{20}	B_{26}	0,472813
B_9	B_{26}	0,475011	B_{21}	B_{26}	0,472312
B_{10}	B_{26}	0,477991	B_{22}	B_{26}	0,47347
B_{11}	B_{26}	0,473648	B_{23}	B_{26}	0,474705
B_{12}	B_{26}	0,478628	B_{24}	B_{26}	0,475527

Next, from Table 2 and Table 3, create a weighted graph with the destination node B_{25} in the following graph image :

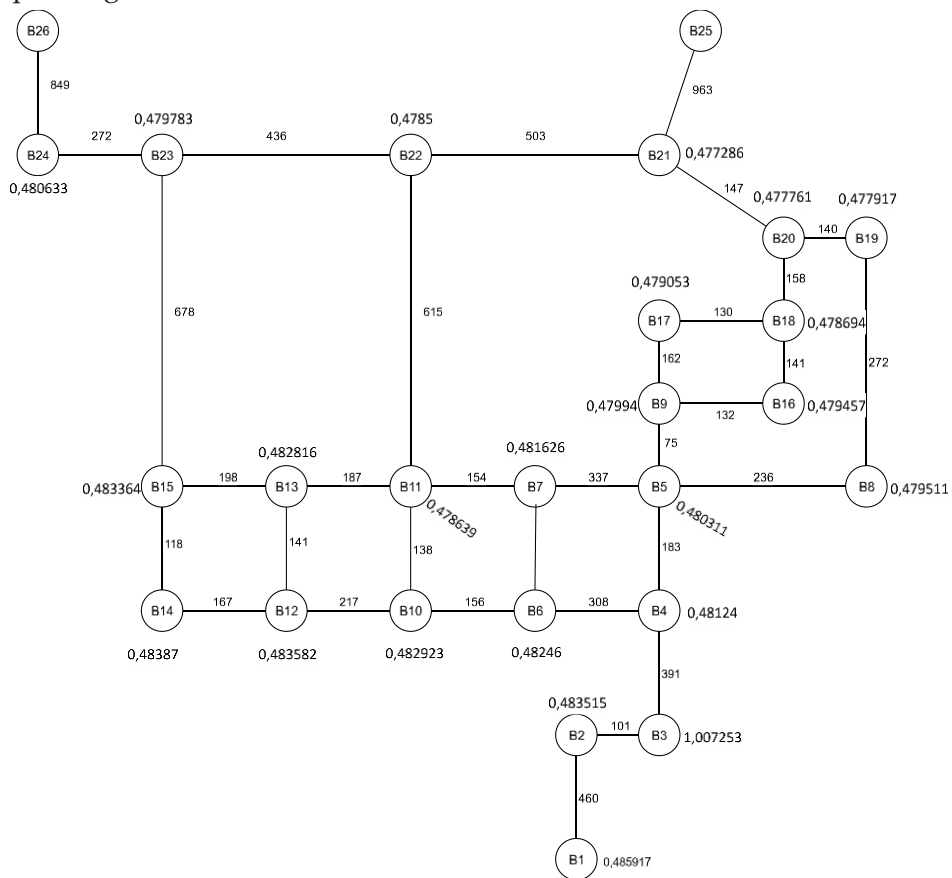


Figure 3. Graph for B_{25}

From the 10 iterations carried out, the shortest path from B_1 to B_{25} was obtained $B_1 - B_2 - B_3 - B_4 - B_5 - B_9 - B_{16} - B_{18} - B_{20} - B_{21} - B_{25}$ with a path length of 2.751 m (2,7 km).

Next, create a weighted graph with the destination node B_{26} . From Table 2 and Table 4 we get in the following graph image :

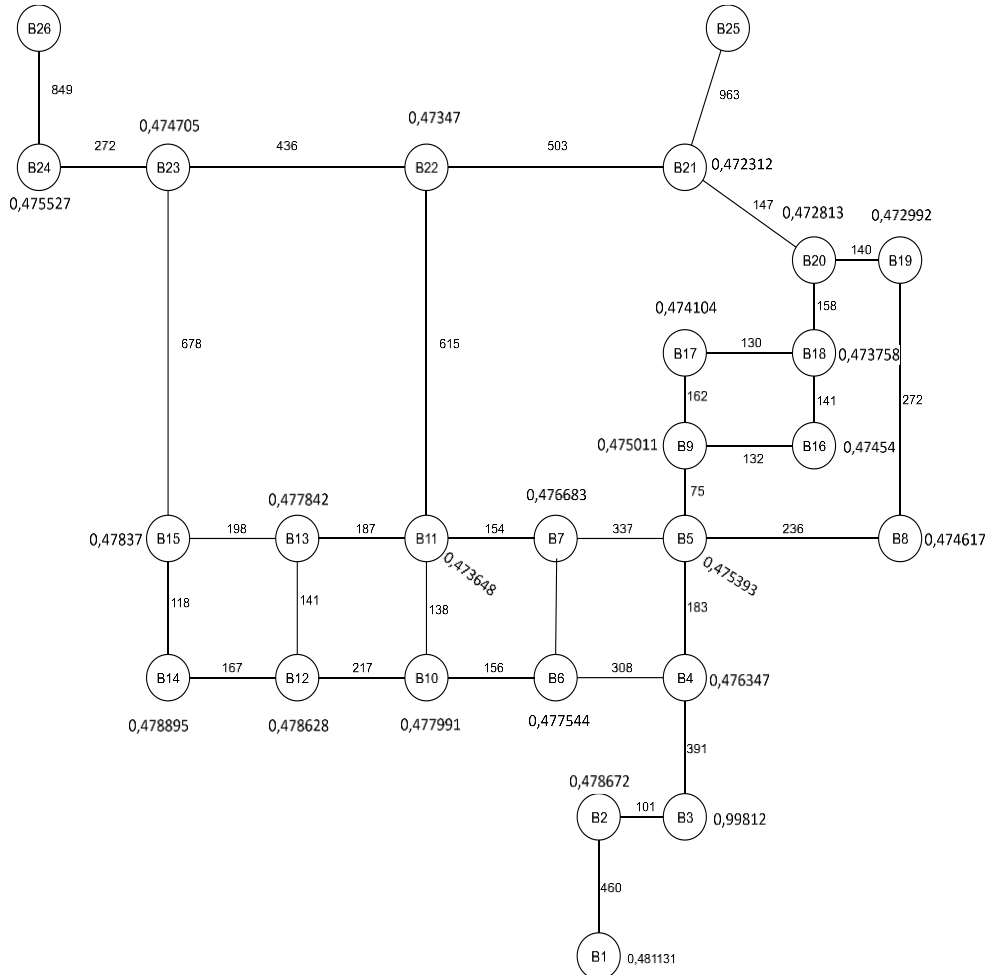


Figure 4. Graph for B_{26}

From the 13 iterations carried out, the shortest path from B_{21} to B_{26} was obtained $B_1 - B_2 - B_3 - B_4 - B_5 - B_9 - B_{16} - B_{18} - B_{20} - B_{21} - B_{22} - B_{23} - B_{24} - B_{26}$ with a path length of 3.848 m (3,8 km).

4. Conclusion

Based on the results of the research conducted, it can be concluded that the resulting graph is a weighted graph that has 26 vertices, 33 edges, heuristic values, and two goal vertices, namely B_{25} and B_{26} . The shortest route to destination B_{25} and B_{26} has a distance of 2,7 km and 3,8 km respectively.

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