Tsunami Evacuation Routes Optimization using Genetic Algorithms: A Case Study in Palu

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Abstract. Palu area and its surroundings, besides being very prone to earthquakes, are also prone to tsunamis. A devastating earthquake occurred On September 28, 2018, followed by a destructive and deadly tsunami that struck Palu Bay. This makes the need for proper planning in overcoming the tsunami disaster. One of them is by showing the evacuation route for people in tsunami-prone areas. This study aims to show the best route to the safe point of the tsunami using Genetic Algorithm. The results of the studies show that the best route for tsunami evacuations can be provided best depend on the available of the safe points. Some clusters, namely 9, 10, and 12 have few safe points, limiting people to access a safe location from the tsunami.

1 Introduction

There are a lot of faults that have the potential to generate earthquake disasters were found in Sulawesi region [1]. The potential disaster caused by active faults on land is more severe than earthquakes that originate in oceans in the same magnitude. Palu Koro fault is one of the active faults in Sulawesi that extends approximately 240 km from the north (Palu City) to the south (Malili) to Bone Bay [2]. One of the causes of the high seismic activity is the presence of active faults in this area, i.e. Palu Koro fault that moves 26-30 mm/year with the active sinistral movement direction [3]. With fault length approximately 240 km, Palu-Koro fault is existing in Central Sulawesi fault system which consists of complex left-lateral strike-slip fault zones located within the triple junction area between the Pacific, IndoAustralian and Eurasian plates [4].

Palu area and its surroundings, besides being very prone to earthquakes, are also prone to tsunamis. The vulnerability of earthquakes and tsunamis in this area has been proven by several historical records of earthquakes and tsunamis that took place since 1927, such as the Palu Earthquake and Tsunami in 1927, the Parigi Earthquake and Tsunami in 1988 and the Tambu Earthquake and Tsunami in 1968 [5], [6].

Tsunamis have become the biggest killer spectre for communities in coastal tsunami-prone areas in the last decade. The large scale of this natural disaster hazard potency is accompanied by vulnerability of social condition, infrastructures, economics, policies, and the local state of bureaucracies as the effect of complexity and its fast growth. This results in most coastal districts in tsunami-prone areas often neglecting natural disaster mitigation aspects in their development [7].

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The State of Indonesia has issued Law no. 24 of 2007 on Disaster Management and is downgraded in the General Guidelines for disaster risk assessment (BNPB) and technically translated into Indonesian National Standard document SNI 7766: 2012 on tsunami evacuation routes.

In the SNI 7766: 2012 document written some practical guidance in designing the tsunami evacuation route and one of the requirements is the existence of a temporary safe area of high or artificial hill as a place of vertical evacuation. In the determination of tsunami evacuation routes it is necessary to consider some parameters of evacuation routes such as away from shoreline, river mouth and river bodies, and as far as possible not passing bridges, especially bridges close to coastal areas due to the condition of post-earthquake bridge eligibility [8].

In practical implementation, some requirements of tsunami evacuation routes can be stated into computational methods so that the best routes and evacuation routes are expected to ultimately aim to minimize the risk of tsunami disaster. Various search algorithms have been developed and used find optimal solution for many problems including to determine the route of tsunami evacuation. Previous works has been done with Haversine Formula and Best First Search Method had been used to find Tsunami Evacuation Route in Padang city [9], Maulida et al[10] used Dijkstra Algorithm to find tsunami evacuation routes. Genetic Algorithm is an algorithm used for finding the optimal solution can be evolved and adapt in facing various problems [11], this method is expected to be a reliable method to find the best and optimal evacuation routes.

This study aims at building geographic information systems using genetic algorithms to get the best route for evacuation routes. With the objective of reducing the number of fatalities in this village, the shortest route algorithm is applied to analyse the direction of movement, and the travel time communities need to get to a safe area of the tsunami.

2 Palu Tsunami History

Data from global seismic networks, as well as Indonesian local networks and historical data on Sulawesi SeismiCity shows there is low depth activity in Central Sulawesi. Evidence of damage due to earthquakes in the past is observed through tectonic features such as faults, faults scraps, shear zones, or from historical of eyewitness reports documentation, etc. There are many traces of the history of the earthquake that are known, not only because of its enormous magnitude but also the many casualties it caused. Historical data on recent earthquakes show that depressed areas of Palu are very vulnerable to earthquake disasters [12]. This makes Sulawesi also has a long history of earthquake-triggered tsunamis. fourteen tsunamis have been reported around Sulawesi Island based on records in the period between 1820 and 1982 [13], [14]. Six of them, recorded by the Makassar Strait around the Sulawesi region. All tsunamis experienced in the Makassar Strait related to earthquakes involved the Palu-Koro fault zone, the North Sulawesi subduction zone system, and the Pasternoster fault zone [12].

The tsunami hazard area of the City of Palu is 3558.56 ha or ± 9.63% of the total area of the City (the area of Palu City is 36,946 ha). All sub-districts in Palu City have the potential of being hit by a tsunami hazard, both from low hazard levels to very high hazard levels, except South Palu District and Tatanga District which do not have very high tsunami hazards. Districts that have the largest area of tsunami hazard are North Palu District, which is 842.84 Ha. The area of North Palu Subdistrict is 3171 Ha, so that the total of sub-districts predicted to be flooded is 26.58% of the total area. The district with the smallest tsunami hazard area is the South Palu District [15].

On September 28, 2018, a devastating earthquake occurred (Mw 7.5) hit Sulawesi Island in Indonesia. Earthquake followed by a destructive and deadly tsunami that struck Palu Bay [13]. Figures 1, 2, and 3 show tsunami prone areas on the shore of the Palu Bay. There are three colors in the picture that indicate the state of the building in the shaded area, where the red color indicates the building in the area is destroyed, for the orange colored the condition of the building is damaged, and for those shaded in green the building in the area is possibly damaged.

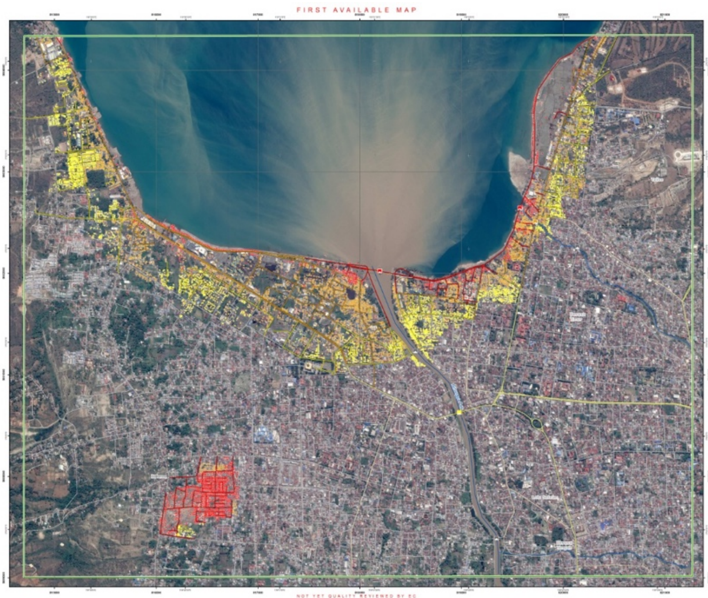

Fig. 1 Tsunami prone areas on the Talise Beach (Source : LAPAN, 2018)[16]

Fig. 2 Tsunami prone areas on the Eastern side of Palu Bay (Source : LAPAN, 2018)

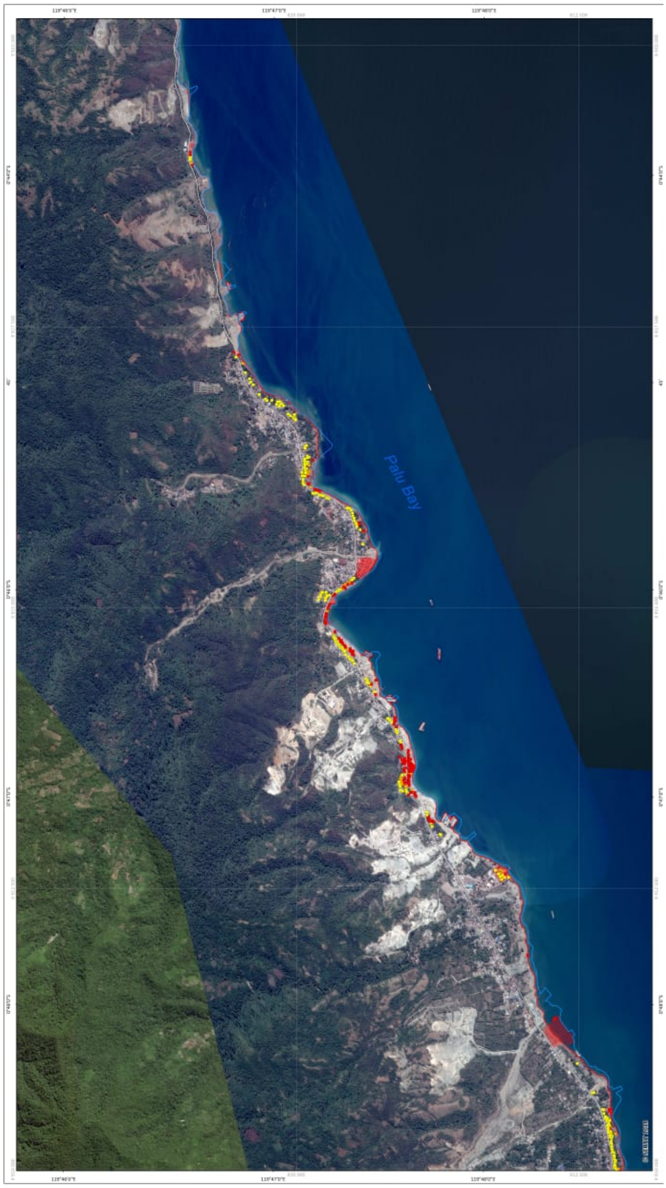

Fig. 3 Tsunami prone areas on the Western side of Palu Bay (Source: LAPAN, 2018)

3 Genetic Algorithm

In this section, we discuss Genetic Algorithm to find the optimal solution route for tsunami evacuation. Genetic Algorithm [17] is a probabilistic heuristics search process, based on the concept of genetics in living things that can be use to solve search optimization problems in the real world. This algorithm is formed based on the natural evolution process and the survival of fittest from Darwin's theory [17].

GA is a population-based search that takes a set of solutions from generation of chromosomes. GA combines information so that new chromosome combinations are formed in the search space with better expected results. The merging process goes through three stages, selection, crossover and mutation. As the population develops, the more the best solutions produced can replace the less suitable solution, which is expected to approach the optimal solution [18].

3.1 Chromosome Representation

In GA the first step that must be taken is to determine the representation of genes and chromosomes from the population. There are several types of representations, namely string bits consisting of binary numbers, real number arrays, permutation elements, list of rules, and other represents. In this study the representation used is permutation coding where each gene on a chromosome represents a sequence [19].

3.2 Fitness Evaluation

The chromosome fitness function interprets the physical representation and evaluates fitness based on the desired characteristics showing how well the appropriate solution [18]. But, the fitness function must accurately measure the chromosome quality in the population. The definition of a fitness function, is very important, therefore, the fitness function is expected to have computational efficiency and accuracy. In this research the fitness function is defined in (1).

$$f_i = \frac{1}{\sum_{j=1}^{l_i-1} C_{g_i(j),g_i(j+1)}} \tag{1}$$

where f_i denote the fitness value of the ith chromosome, l_i represent the length of the ith chromosome, $g_i(j)$ is the gene of the jth locus in the th chromosome, and C is define as the link cost between nodes. In GA, the fitness function is generally an objective function that will be optimized. In a certain sense, the fitness function can be fully considered as a reflection of the objective function. If the value of the fitness function produced is higher, the chromosome fitness characteristics are better than others. In addition, the fitness function introduces the criteria for chromosome selection [20].

3.3 Selection

This process is done by selecting the chromosome candidate with the selection operation. The selection operation method of the genetic algorithm consists of several methods, namely the selection of the roulette wheel, universal stochastic selection, ranking selection methods, etc [21]. The selection process will produce a parent population that will be used in the crossover process.

In this study the selection process used was Linear Fitness Ranking (LFR) or ranking selection. This process can be done after the fitness value of each chromosome has been calculated and then the cumulative probability calculation process will be carried out as a basis for selecting prospective parents [19].

3.4 Crossover

Crossover is one of the most important processes in GA Crossover examines the current solutions in order to find better ones. Crossover plays the role of exchanging each partial combination of two chosen parents gen in such a manner that the offspring produced by the crossover expected to have superior genes from both parents. The crossover between two dominant parents chosen by the selection gives higher probability of producing offspring having dominant traits [20].

3.5 Mutation

Mutation is a process in GA that is carried out to maintain uniqueness in a population [19]. Populations mutate by actual changes or reverse one of the genes of the candidate chromosome, thus distancing from local optima [17], [20], [22]. Mutations are applied to each chromosome individually after a crossover. this process is done by scrambling or changing each gene with a small probability, usually around 0,1 %. Based on the traditional view, to explore the search space rapidly, crossover is a technique that plays an important role than the mutation process. Mutations provide a small number of random searches, and help ensure that there are no points in the search space that have zero probability of being checked [23].

4 Results and Discussion

The condition of the Palu City that does not yet have a high-rise earthquake resistant building has to be carried out based on the distance from the coast and the height from the mainland. Based on the tsunami that occurred in 2018 the area worst hit by the tsunami was the coastline, where the run up height of the tsunami was 0.2 to 9.1 meters [13].

In this study several safe points will be determined on several clusters. The safe point is determined based on the height of the location from the sea level, and road access to the shelter or higher ground. The safe point is only a place for residents to be able to secure themselves from the tsunami first. After that residents can go to the location of the shelter. Seventy-two (72) safe points are determined based on the height of the location of the sea level, and two (2) safe points based on the distance from the beach. The safe points are divided into 24 clusters, each cluster can access one or more safe points and potential shelters. The safe points coordinate and altitude can be seen in Table 1, Table 2 and Table 3.

The best route is searched using the GA algorithm. The solution used is a route with a chromosome combination that have the best fitness value which have a minimum total cost. Routes with a minimum total cost will have smaller distances that are considered the best global optimum solution.

The computational process is done by applying the GA algorithm on an android device. The map used in this application is Google Map. Use of an android smartphone is to make it easier for users to be able to access information about tsunami evacuation routes at any time. This application can help users to be able to show the best route to the closest safe point.

The computational result shows that most clusters can show the best route to the closest safe point. This is because these Clusters have many safe points which make many alternative routes that can be passed for evacuation. Some clusters have problems in showing the best route to the safe point because of the location of the safe point that is far away and must pass through tsunami-prone areas. The problematic cluster is clusters 4, 9, 10 and 12 which only have one safe point. The four clusters are problematic because road access is limited and the main road is very close to the beach. The fewer safe points, the less public access to get to the safe location of the tsunami.

Table 1. Safe points coordinate and altitude from cluster 1 to 13

Cluster	Coordinate	Altitude (ft)
Cluster 1	-0.69876, 119.85525	86

	-0.70367, 119.85930	82
Cluster 2	-0.71297, 119.96504	33
	-0.71696, 119.86882	56
Cluster 3	-0.73123, 119.86688	121
	-0.73304, 119.86709	115
Cluster 4	-0.74015, 119.86681	98
Cluster 5	-0.74520, 119.86745	98
	-0.74884, 119.86648	72
Cluster 6	-0.75229, 119.86641	56
	-0.75442, 119.86641	66
	-0.75919, 119.86636	82
Cluster 7	-0.76401, 119.86764	105
	-0.77976 , 119.87492	148
Cluster 8	-0.78789 , 119.87611	92
	-0.79114 , 119.87617	82
	-0.79237 , 119.87631	69
	-0.79360 , 119.87656	61
	-0.79505 , 119.87654	47
Cluster 9	-0.80060, 119.88160	66
Cluster 10	-0.80571 , 119.88297	91
Cluster 11	-0.81078 , 119.88237	78
	-0.81531 , 119.88322	74
	-0.81795 , 119.88611	85
Cluster 12	-0.82779 , 119.88530	92
Cluster 13	-0.83087 , 119.88571	94
	-0.83322 , 119.88574	102
	-0.83613 , 119.88571	110
	-0.83832 , 119.88567	101
	-0.84175 , 119.88587	107

Table 2. Safe points coordinate and altitude from cluster 14 to 21

Cluster	Coordinate	Altitude (ft)
Cluster 14	-0.84870 , 119.88584	103
	-0.85095 , 119.88590	102
	-0.85687 , 119.88373	72
	-0.85866 , 119.88313	79
	-0.85970 , 119.88195	59
Cluster 15	-0.86756 , 119.87921	59

	-0.87071 , 119.87771	66
	-0.87277 , 119.87748	39
	-0.87579, 119.87703	33
	-0.87669 , 119.87690	36
Cluster 16	-0.87896 , 119.87658	52
	-0.88168 , 119.87653	52
	-0.88320, 119.87190	38
	-0.88692, 119.87112	49
Cluster 17	-0.89224, 119.86656	43
	-0.89217, 119.86419	30
Cluster 18	-0.89352, 119.85992	36
	-0.89356, 119.85814	30
	-0.89226, 119.85519	26
	-0.89305, 119.85174	43
	-0.89214, 119.85017	33
Cluster 19	-0.89070, 119.84637	33
	-0.89089, 119.84317	55
	-0.89060, 119.84043	69
	-0.88805, 119.83485	85
Cluster 20	-0.88034, 119.83007	118
	-0.87482, 119.82999	115
	-0.87115, 119.82933	108
	-0.86706, 119.82893	75
	-0.86163, 119.82674	85
Cluster 21	-0.86055, 119.82531	75
	-0.85615, 119.82260	131
	-0.85081, 119.82092	112
	-0.85036, 119.81796	141

Table 3. Safe points coordinate and altitude from cluster 22 to 24

Cluster	Coordinate	Altitude (ft)
Cluster 22	-0.84781, 119.81750	123
	-0.84226, 119.81574	69
Cluster 23	-0.82513, 119.80965	79
	-0.82342, 119.80937	79
	-0.82149, 119.80936	58
	-0.81878, 119.80812	131
	-0.81336, 119.80653	128

Cluster 24	-0.80932, 119.80670	108
	-0.80908, 119.80647	102
	-0.80690, 119.80569	99

5 Conclusions

Palu is one of the cities in Indonesia that has a long history of tsunamis. This makes the need for proper planning in overcoming the tsunami disaster. One of them is by showing the evacuation route for people in tsunami-prone areas. So that people can anticipate the steps that must be taken if the tsunami occurs again and which routes are safe for them to pass to the safe point of the tsunami.

This study aims to show the best route to the safe point of the tsunami using GA. The results indicate that the best route can provide according to the available of the safe points. Some clusters, namely 4, 9, 10, and 12 have few safe points, limiting people in that area to find and access safe location from the tsunami because there is only one safe point that had been provided for these clusters.

In the future, it is hoped that there will be more solutions for residents living in several clusters to avoid more victims. The following are some good solutions that is used, namely the use of earthquake-resistant high-rise buildings as shelters, the transfer of community residential locations far from the shore, or creating new evacuation routes to increase residents access to safety points.

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