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RESEARCH ARTICLE

A GIS – BASED OPTIMIZATION FOR THE FUEL LOCATION-ALLOCATION TO FACE THE PROBABLE TSUNAMI: CASE OF PADANG CITY

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ABSTRACT

The Mentawai Megathrust is predicted to cause a tsunami with the tremendous effects to societies and environments. As the coastal area located across the epicenter, Padang City is expected to have a high vulnerability to be surged by this future hazard. This issue has gradually grown in importance to provide an effective disaster countermeasure for minimizing losses and suffering. As the fuel is one of the most critical items required in the aftermath of disaster, this study seeks to propose the disaster relief planning in Padang City, particularly in the fuel location-allocation decisions to cope with the effects caused by the probable tsunami. In this research the Geographic Information System (GIS)-based optimization is utilized to generate the appropriate number of facilities as well as its allocated capacity to serve several demand points (e.g. hospitals and refugee camps) during the emergency periods. This paper initially considers the potential inundation area based on the worst-case scenario developed by the disaster countermeasure agency to identify the likelihood of the impassable paths and the candidate facilities in the safe zone. By using P-Median analysis, this work recommends 9 strategic facilities to handle 18 demand points during the critical periods. This study provides an exciting opportunity to comprehensively obtain the suitable facilities in order to fulfill the fuel needs in the disaster aftermath. Due to practical constraints, this paper may be further improved to be Decisions Support Systems (DSS) with the consideration to the real time conditions during emergency periods.

KEYWORDS

Disaster Relief Planning, Tsunami, Location-Allocation, GIS

1. INTRODUCTION

The West Sumatra has a high level of vulnerability to earthquake and tsunami. This is because of the prediction on the occurrence of the natural hazard, Mentawai Megathrust which is located just across the west coast of Sumatra island. The study conducted by EOS Nanyang Technological University Singapore and LIPI declared that the rupture in the subduction zones along megathrust faults will trigger an earthquake followed by tsunami with height of 10 meters or more (BPBD Kota Padang, 2017). These future calamities may lead to tremendous effects to societies and environments.

Padang City, the coastal region located at 150 km away across the epicenter, is expected to be the most affected area caused by this future hazard. As depicted in Figure 1, Padang City has the most considerable numbers on the people potentially exposed by tsunami due to its flat topography and the numbers of human settlements as well as economic activities concentrated along the shoreline (Latief, 2012). This is becoming the major challenge faced by the relief stakeholders in order to provide effective relief efforts regarding to the number of people requesting assistance.

The potential severities which may be resulted from Mentawai Megathrust are demanding conscious deliberations for conducting an emergency response preparedness (Sieh, 2006). The level of preparedness will essentially affect to the successfulness of delivering immediate assistance during emergency period. In this phase, the logistical activities are considered as the most significant elements (Inca and Nikorn, 2019). The strategic decisions are aimed at the selection of the relief facilities in order to enhance the logistics capabilities to adequately deliver the relief aids (Balcik and Beamon, 2008). These preparatory activities are fundamental to assist an effective and efficient logistical operation.

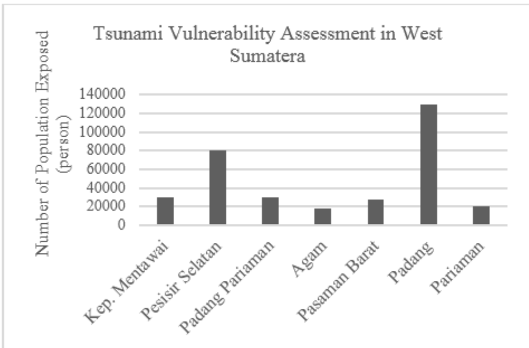

Figure 1: Potential Population Exposed to Tsunami in West Sumatra (Latief, 2012)

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This study seeks to determine the strategic facility location-allocation decisions to face the probable tsunami, particularly in the fuel fulfillment during the emergency periods. Referring the tsunami contingency plan developed by the local government, fuel is one of the most critical items required in the aftermath of disaster to support the operational activities in the emergency facilities (e.g. hospitals and refugee camps) (BPBD Kota Padang, 2017). However, the scarcity related to the insufficient supplies of fuel would be another problem due to the potential damages on the fuel infrastructures. This work presents a Geographic Information Systems (GIS) – based methodology to spatially generate the appropriate number of facilities as well as its allocated capacities to serve several demand points during emergency periods. Initially, the desired facility candidates as well as the likelihood of the impassable paths are spatially analyzed based on the worst-case inundation scenario by using ArcGIS. Afterwards, the P-Median method using Network Analyst feature is utilized to obtain the suitable facilities to adequately fulfill the accumulated fuel demands during 72 hours of critical periods. The remainder of this paper structured as follows. Section 2 defines several previous studies. Section 3 provides a comprehensive description of the research methodology. Section 4 shows the results and discussion of data processing. Section 5 presents the conclusion and the further research.

2. Literature Review

Several researches in the GIS-based facility location problems for the disaster management have been studied in the literature. In 2015, published a paper in which they studied a GIS – based methodology for the location-allocation of emergency facilities (Ping et al., 2015). The authors applied the P-center location-allocation model to select the suitable emergency shelters for the post-earthquake event. In their paper, the geographic network model based on Dijsktra algorithm and Euclidean distance were compared. Three criterias including effectiveness, accessibility, and safety are utilized to determine the most appropriate location-allocation decision. A study presented raster GIS as the decision-support tools to analyze the potential flooding areas to be later utilized for identifying the risky facilities during flood (Rodríguez- et al., 2016).

The real cases of floods in Mexico were used in order to prove the effectiveness of using GIS for disaster management. Another investigation from Saeidian et al. conveyed the selection of the adequate sites as well as the allocation problems by combining GIS and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to define the initial facilities to be chosen (Saeidian et al., 2018). Subsequently, the two meta-heuristic optimization algorithms of Particle Swam Optimization (PSO) and Ant Colony Optimization (ACO) were employed to sufficiently obtain the corresponding facilities and its allocated capacities. Their research was implemented for the establishment of the temporary relief centers to face an earthquake in Tehran, Iran.

The recent work of Liperda and Sirivongpaisal has attempted to determine the strategic location of the Local Distribution Centers (LDCs) by considering the incremental demand during 72 hours of emergency periods (Inca and Nikorn, 2019). The GIS with Maximum Coverage Location Problems (MCLP) was applied in order to determine the set of alternative LDCs to be established per day. The effectiveness of each alternatives was measured by calculating the total cost components in order to select the adequate facilities. The study case of Padang City was used to design the disaster relief planning for the basic fulfillment. Their research has inspired this study to conduct the facility location analysis by focusing on the fuel fulfillment in the aftermath of disaster.

3. Research Methodology

This section describes the solution methodology contained in this study to generate the facility location decisions for fulfilling the fuel needs in the aftermath of the probable tsunami. The ArcGIS software is employed regarding to its capability to spatially store, retrieve, analyse and visualize the data (Milenković and Kekic, 2016). Firstly, in this paper the location of the demand points as well as the available fuel facilities is recognized. Secondly, based on the worst-case inundation scenario developed by the local government, the identification of the potential candidate facilities located in the safe zone is predetermined (Inca and Nikorn, 2019). Thirdly, the accumulation of the total fuel requirements of each demand points during 72 hours of the critical periods is considered as the demands to be fulfilled. Subsequently, the P-Median location-allocation analysis by utilizing the network-based analyst tools in ArcGIS is applied to determine the assigned facilities along with its allocated fuel demands. In this final step, the consideration on the possible impassable paths to be avoided is taken into the deliberation in order to represent the accurate location-allocation decisions.

4. Finding and Discussion

The design of the location-allocation in this study assumes the gas stations as the leading supplier for the fuel fulfillment in the disaster aftermath. The supply of fuel in all candidate gas stations is assumed to be able to fulfill the post-disaster fuel requests based on standard disaster emergency management resource needs in the Padang City. Table 1 shows the location of the available gas stations in Padang City.

Table 1: The Location of Gas Stations

Gas Stations	Locations	Longitude	Latitude
SPBU 1	Pertamina 14.251.510 Tabing	-0.88867	100.35158
SPBU 2	Pertamina 13.251.503 By-Pass Padang	-0.9307	100.3981
SPBU 3	Pertamina Wowo Veteran	-0.93665	100.35437
SPBU 4	Pertamina Perintis Kemerdekaan	-0.94131	100.36593
SPBU 5	Pertamina Ranah	-0.95571	100.36807
SPBU 6	Pertamina 13.251501 PITAMEH	-0.9554	100.40752
SPBU 7	Pertamina S.Parman	-0.90546	100.35057
SPBU 8	Pertamina 14.251.523 Khatib	-0.91452	100.35872
SPBU 9	Pertamina Bungus	-1.03161	100.41527
SPBU 10	Pertamina KKSP Indarung	-0.9568	100.46477
SPBU 11	Pertamina Adinegoro	-0.81595	100.32056
SPBU 12	Pertamina KFC Khatib	-0.91006	100.35421
SPBU 13	Pertamina 13.251.510 AMPANG	-0.92394	100.37286
SPBU 14	Pertamina Pisang	-0.94356	100.40042
SPBU 15	Pertamina Marapalam	-0.95039	100.38639
SPBU 16	Pertamina By Pass	-0.91285	100.39698
SPBU 17	Pertamina 14.251.507	-0.90618	100.36349
SPBU 18	Pertamina 14.251.503	-0.92544	100.35136
SPBU 19	Pertamina 14.251.519	-0.94488	100.37049
SPBU 20	Pertamina14.252.514	-0.96494	100.35777
SPBU 21	Pertamina 14.251.525 Air Pacah	-0.87226	100.38265

In this paper we consider the refugee camps and hospitals to be the objects of the demand points since the fuel is crucially required in order to support its operational activities. The refugee camps are the locations where the victims gather and the refugees receive assistance during the disaster management process (Fijra, 2018). Meanwhile, the hospitals play a significant role to provide the medical care to the wounded people after the disaster occurrence. Table 2 describes the demand locations as well as its accumulated fuel requirements during 72 hours calculated from the tsunami contingency plan of Padang City (BPBD Kota Padang, 2017). Since in this work the decisions of the fuel location-allocation are focused on the land transportation modes for distributing the relief items, this work use the recommended shipping loading point by Liperda and Sirivongpaisal as the subsidiary demand location for TEA H1 which is predicted to be inaccessible by the road transportation (Inca and Nikorn, 2019).

Table 2: The Location of Demand Points and Its Accumulated Demands Modified From Tsunami Contingency Plan of Padang City (BPBD Kota Padang, 2017)

Hospitals	Locations	Longitude	Latitude	Fuel Demand for 72 Hours (Liters)
RS 1	RS Umum Daerah dr. Rasidin	-0.9307	100.39455	468
RS 2	RS Islam Siti Rahmah	-0.9554	100.38337	468
RS 3	Semen Padang Hospital	-0.9568	100.39912	468
RS 4	RS Universitas Andalas	-0.92394	100.45711	468
RS 6	RS Ibnu Sina Padang	-0.94356	100.36703	468
RS 9	RSUP Dr. M. Djamil Padang	-0.95039	100.36664	468
Refugee Camp	**Location**	**Longitude**	**Latitude**	
TEA A1	Batipuh Panjang	-0.823355	100.336297	13,407.429
TEA A2	Bukit Anak Aia	-0.803366	100.334917	468
TEA B1	Koto Pulai	-0.847455	100.345096	14,691.429
TEA B2	Balai Gadang	-0.827630	100.356143	468
TEA C1	Koto Panjang Ikua Koto	-0.854561	100.355754	13,407.429
TEA D1	Municipality Office, By-Pass	-0.875473	100.387617	468
TEA D2	TVRI Office, By Pass	-0.855786	100.369230	468
TEA E1	Gunung Pangilun	-0.912712	100.369611	38,221.715
TEA F1	Sungai Sapih	-0.903095	100.396620	468
TEA G1	Kubu Marapalam	-0.950539	100.38375	25,410.858
TEA I1	Banuaran nan XX	-0.968366	100.384343	37,414.286
Ship Loading Point		-0.961526	100.395324	7,028.286

The spatial visualization of the demand points and the fuel facilities is compiled by using ArcGIS 10.5. In this phase, the worst-case inundation scenario is included in order to identify the candidate facilites location as well as the possible impassable paths to be avoided during the distribution of the relief items. From Figure 1, there are 11 facilities which are expected to be damaged regarding to its hazardous location in the tsunami inundation area. Hence, the rest facilities in the safe zone are considered as the selected facilitiy candidates to fulfill the fuel requirements during the critical periods.

The proposed solution of the location-allocation decisions is obtained by utilizing P-Median analysis in the Network Analyst extension on ArcGIS 10.5. Network Analyst basically uses metaheuristic algorithm based on Tabu search (Bozkaya et al., 2010). The Network Analyst feature allows the users to specify the inclusive parameters such as network impedances, weighting coefficients, and network restrictions to obtain the suitable facilities to serve its assigned demand points. Figure 2 shows several examples of the Network Analyst P-Median analysis.

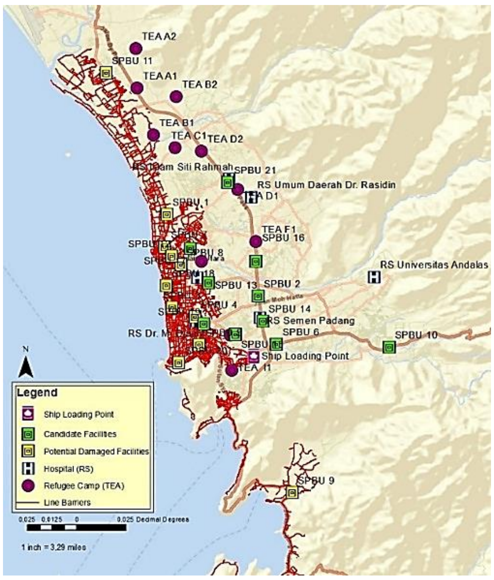

Figure 2: The Supply and Demand Locations of Post-Disaster Fuel Fulfillment

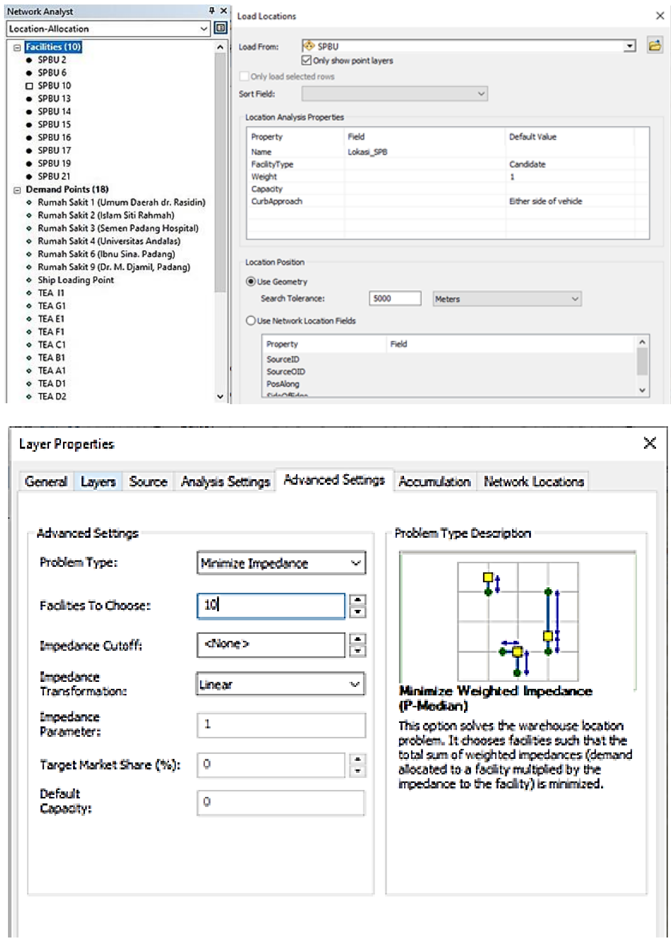

Figure 3: Network Analyst Interface

Table 3 represents the location-allocation results with P-Median analysis for the selected facilities to serve 18 demand points. The total accumulated fuel demands for 72 hours are assumed to be delivered by using 20 liters jerry-can. In addition, this work assumes that the candidate facilities have sufficient capacities to meet the requirement of fuel demands. From 10 candidate facilities there are 9 assigned facilities selected to serve the total 187,660 liters of fuel demands. The spatial visualization of the fuel location-allocation decisions is presented in Figure 3.

Table 3: The Location-Allocation of Fuel Fulfillment

Facility Locations	Assignment Points	Fuel Delivery for 72 Hours (Liters)	Allocated Fuel (Liters)
SPBU 2	RS 4	480	480
SPBU 6	TEA I1	41,800	55,960
	Ship Loading Point	14,160	
SPBU 13	RS 6	480	480
SPBU 14	RS 3	480	480
SPBU 15	TEA G1	36,920	36,920
SPBU 16	TEA F1	480	480
SPBU 17	TEA E1	47,960	47,960
SPBU 19	RS 9	480	480
SPBU 21	RS 1	480	44,420
	RS 2	480	
	TEA C1	13,420	
	TEA B1	14,700	
	TEA A1	13,420	
	TEA D1	480	
	TEA D2	480	
	TEA B2	480	
	TEA A2	480	
Total Allocated Fuel Demands (Liters)			187,660

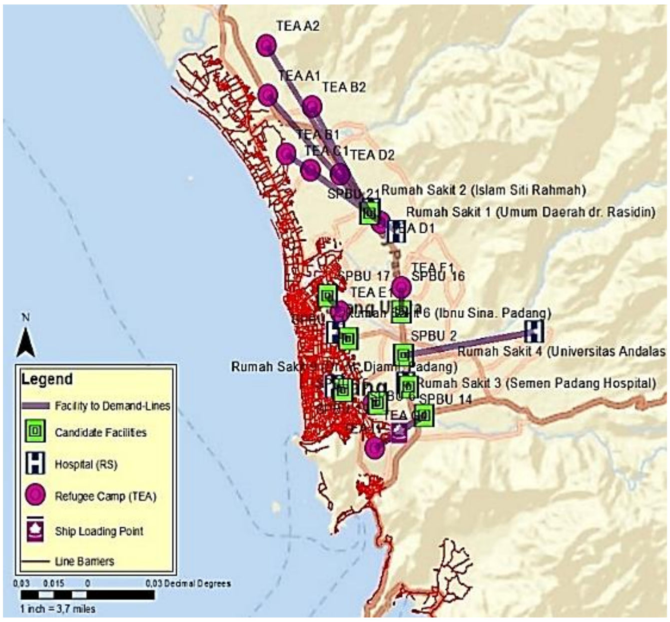

Figure 4: The Fuel Location-Allocation Decisions

5. Conclusion

This study set out with the aim of determining the suitable facilities to supply the fuel needs in the aftermath of the probable tsunami in Padang City. The relief fuel fulfilment is prioritized to support the operational activities for the emergency facilities. The refugee camps and hospitals are selected as the objects of demand points due to its vital role as the locations where the victims gather and to provide medical care to the wounded people. In this study, Geographic Information Systems (GIS) was implemented to analyse and visualize the spatial information of the respected facilities-demand points. The worst-case inundation scenario was used to identify the candidate facilities located in the safe areas. This work used the P-Median analysis in the Network Analyst tools on ArcGIS 10.5 to generate the proposed solution of the selected facilities as well as its allocated capacity to serve its assigned demand points. The accumulated fuel requirements during 72 hours of critical periods were used as the demanded relief items to be fulfilled. In addition, the expected impassable paths were considered to be avoided in the calculation of the location-allocation solutions. This work recommends 9 strategic facilities to handle 18 demand points with total fuel demands 187,660 liters. This finding has important implications for assisting the relief stakeholders to adequately arrange the disaster relief planning. Due to practical constraints, this paper may be further improved to be Decisions Support Systems (DSS) with the consideration to the real time conditions during emergency periods.

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