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Article

Bi-objective allocation model for flood relief centre

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Abstract: Floods have always been an unavoidable natural disaster globally. Due to that, many efforts have been taken in order to alleviate the effect, especially in protecting the victims from losing their lives as well as their belongings. This study focuses on ensuring a smooth allocation process for flood victims to the relief centres considering the nature of their location, near the river, inland, and coastal. The finding indicated that a few implications have been highlighted for disaster management, such as changes in flood victim allocation patterns, classification of prone areas based on three areas, identification of most disaster areas, and others. Thus, to enhance the efficiency of allocation and to avoid any bad incidents happening during the flood occurrence, the allocation of flood victims is proposed to be started at a more critical area like the river area and followed by other areas. The finding also indicated that the proposed allocation procedure yielded a slightly lower average travel distance than the existing practice. These findings could also provide valuable information for disaster management in implementing a more efficient allocation procedure during a disaster.

Keywords: location allocation model; flood victims; relief centre; prone area; bi-objective

1. Introduction

Locational analysis is a technique used for discovering, assessing, and specifying the optimal placement of an organization, information, activities, and materials. In this study, locational analysis is the process of analyzing variables such as topography or terrain, elevation, rainfall amount and distribution, population density, and locations of prone areas to arrange the placement of relief centres during flood events. This is a crucial concern for the preparation of an evacuation process in order to determine the necessary number of relief centres that should be set up for flood victims. Hence, in this study, the use of models that can reflect the real-world scenario in managing the evacuation process during the flood event is evaluated. A relief centre is vital as a shelter for flood victims and provides them with proper daily accommodations. Unfortunately, in the flood events at Kuala Kuantan, Malaysia, in 2013, several relief centres experienced an issue where the flood victims were relocated to other relief centres after the existing shelters were affected by the flood. This situation occurred because relief centres are located nearest to the river area and also in low-lying areas. This situation induced congestion at relief centres due to many flood evacuees over the expected capacity. As reported by the Department of Social Welfare (DSW), Malaysia, the total number of flood victims at Kuala Kuantan in 2013 was 27,088, with the total capacity of relief centres available is 25,410. This scenario indicates a lack of capacity available at relief centres to solve the flood victims. At the same time, there was no other procedure to identify which areas were the most critical in terms of safety. Therefore, based on the problem encountered from the flood events, a proper quantitative model is needed to cater to the problem.

A lot of relevant studies have been done in the past. Mostajabdaveh et al. (2019) conducted their study in choosing the sites of shelters to be built as a preparation step for possible natural disasters. In the other study, Nappi et al. (2019) conducted their study on a multi-objective decision model for the selection and special location of community or collective temporary shelters. Safety of the facility, cultural and location accessibility are the most valuable criteria based on their conclusion (Geng et al., 2020; Praneetpholkrang and Hyunh, 2020). Based on the previous research, identifying flood-prone areas enormously impacts decision-making and watershed management for suitable flood management and sustainable development. Papaioannou et al. (2015) stated that examining flood-prone areas for comprehensive flood management strategies was critical. According to Chang et al. (2021), the residential areas near rivers were the most vulnerable to flooding because of the large population density, economic resources, and transportation.

Additionally, Maryati et al. (2018) identified flood-prone areas for natural disaster mitigation using the geospatial approach in Bone Bolango Regency, Gorontalo Province, Indonesia. They highlighted indicators including rainfall, distance to the river, elevation, and land cover. In this study, the distance between the flood-prone areas and relief centres was also considered to determine the nearest optimal shelter to transfer the flood victims (Dhiwar et al., 2022). Identifying the shortest path (Nordin et al., 2017) helps the evacuation process efficiently by minimizing time and preventing worsening incidents. Flood victims are evacuated to relief centres based on the available capacity. Therefore, the capacity of relief centres is also of important concern and needs to be observed to avoid congestion at relief centres. At the same time, the other equally important variable is the elevation of relief centres from sea level.

Based on the real scenario, some relief centres are located at lower levels, which has resulted in the reallocation of evacuees because the relief centres are also affected by the flood. Thus, elevation is one of the most crucial factors for this study (Tehrany et al., 2019). Similarly, the distance of relief centres from the river affects the flood evacuation process. According to Lun et al. (2011), extreme rainfall may cause the overflowing of rivers, which leads to the inundation of nearby lowland areas. In this study, the adapted models that considered all the factors are analyzed for suitability.

2. Study areas

Figure 1 illustrates a map of Kuantan, which covers a total area of 2453 km^2 and is situated 250 km east of Kuala Lumpur. Kuantan district is divided into six mukims: Beserah, Kuala Kuantan, Penor, Sungai Karang, Ulu Kuantan, and Ulu Lepar. Kuantan is affected by the northeast monsoon from December to January annually. According to Yusmah et al. (2020), the monsoon that induces heavy rainfall from November to December each year is 2.3 times higher than the normal average rainfall. The Kuantan River Basin (KRB) is an important watershed of Kuantan City. The basin starts from Sungai Lembing, passes through Kuantan, and finally drains into the South China Sea. Note that heavy rainfall causes the spillover of rivers and flooding of lowland areas that encompass human activities, both social and economic. The recent flood occurrence in 2013 was suspected to cause prolonged heavy rainfall, high tides, and rapid urbanization. More development was undertaken in the low-lying areas that are easily flooded.

Among other districts, Kuala Kuantan has been identified as the most affected district in the flood (Nurul et al., 2021). On the other hand, Yusmah et al. (2020) also concluded that the severe flood in Kuala Kuantan had resulted in major damage to electricity, road structure, buildings, and personal belongings. Meanwhile, based on the flood inundation map for the year 2013, the maximum and minimum flood level ranges were of 3.276 m to 3.636 m and 0 m to 0.364 m, respectively (Ng et al., 2018).

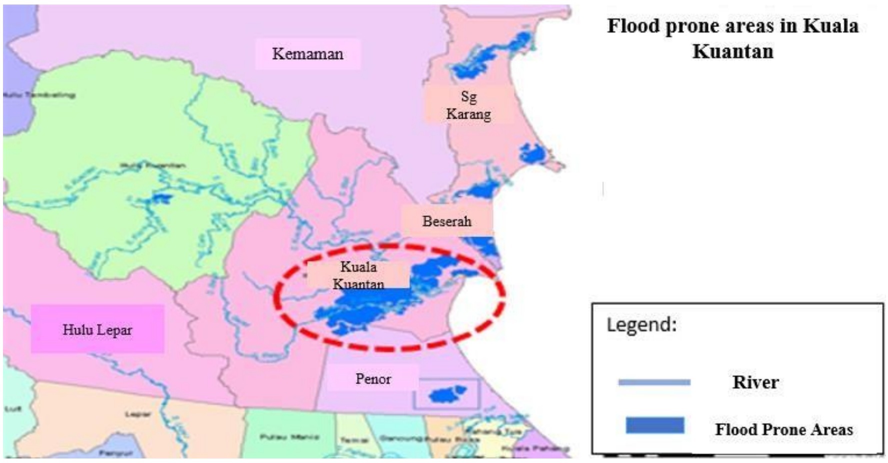

Figure 1. Map of flood-prone areas in Kuantan.

3. Materials and methods

The study considers combining the two basic location-allocation models of P-median and Location Set Covering Problem (LSCP). These two models were selected as the problem statement in this study is related to humanitarian issues, where all flood victims need to be allocated to the nearest safe relief centres in a short period to avoid any worse incidents from happening (Alizadeh and Nishi, 2019; Baharmand et al., 2019; Hashim et al., 2017; Hashim et al., 2021). Moreover, once the allocation process is conducted, the number of relief centres involved needs to be identified to guarantee the safe allocation of all flood victims to relief centres. Due to budget constraints and other factors, a minimum number of relief centres was considered, yet they could still serve all flood victims.

In order to apply the Bi-objective model, the weightage priorities for the objectives were considered as α and β. Since the objective of this model is to minimize the average travel time and the number of facilities, a sensitivity analysis was also conducted. In the sensitivity analysis, the two objectives of the study, the average travel distance and the total number of available relief centres, were considered. In this study, a study area called Kuala Kuantan, Malaysia, is selected. There were 29 existing relief centres available in Kuala Kuantan to cater to 27,088 people from 24 prone areas. The overall capacity of the existing relief centres was 25,410 people at a time, which was lower than the number of evacuees. The application of the Bi-objective model on the flood data for two years, 2013 and 2018, was done and solved using two procedures:

Procedure I (randomly assigned) and II (based on more prone areas or river areas).

Bi-objective model

In this study, the P-median and LSCP models were formulated as Bi-objective. The first objective, which is the original P-median model, is written as in Equation (1).

$$\text{Minimize } Z_1 = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij}\, z_{ij} \tag{1}$$

where,

i represents the prone areas,

j represents the relief centres,

z_{ij} represents the number of flood victims at prone areas, *i* assigned to relief centres, *j*,

d_{ij} represents the distance between prone areas, *i* and relief centres, *j*.

Subject to:

$$\sum_{j=1}^{J} z_{ij} = h_{i,} i = 1, \ldots, I \tag{2}$$

$$z_{ij} \le c_j x_j, i = 1, \ldots, I, j = 1, \ldots, J \tag{3}$$

$$z_{ij} \ge 0, i = 1, \ldots, I, j = 1, \ldots, J \tag{4}$$

$$x_j \in \{0,1\}, j = 1, \ldots, J \tag{5}$$

$$y_i \in \{0,1\}, i = 1, \ldots, I \tag{6}$$

Equation (2), ensure that people in all zones are assigned to a relief centre. Equation (3) a relief center can provide service up to its maximum capacity. Equations (4)–(6) enforce integrality restriction.

Meanwhile, the second objective, the LSCP model, is represented as in Equation (7).

$$\text{Minimize } Z_2 = \sum_{j=1}^{J} Y_j \tag{7}$$

where,

Y_j represents the number of relief centres,

h_i represents the number of flood victims at prone areas, i.

The (LSCP) model aims at minimizing the number of facilities required to cover all demand within specific distance. The LSCP is formulated as an integer programming model to locate the minimum number of facilities required to "cover" all of the demand nodes within some specific distance, which are 3 km, 5 km and 10 km travel distance.

$$a_{ij} = \begin{cases} 1 \text{ if site j can cover demand } i \\ 0 \text{ if not} \end{cases}$$

$$y_j = \begin{cases} 1 \text{ if site } j \text{ is selected for a relief centre to open} \\ 0 \text{ if not} \end{cases}$$

Denoting *Z* as the objective function Equation (7), it is to locate the minimum number of facilities (relief centres) required to cover all of the demand (affected population) node. The formulation for LSCP constraints is as follows.

Subject to

$$\sum_{j \in J} a_{ij} Y_j \geq 1 \qquad \forall \in I, \tag{8}$$

$$Y_j = \{0,1\} \qquad \forall \qquad j \in J, \tag{9}$$

Constraint set Equation (8) ensure that each demand node is covered by at least one facility. Constraint set Equation (9) enforces the yes or no nature of the sitting decision.

In this study, a Bi-objective mixed-integer linear programming model was developed to preparation the planning phase for disaster management. The two objectives were considered simultaneously and related to minimization problems. Hence, the model with the final Bi-objective function Equation (10) is re-written as follows:

$$\text{Minimize } Z = \alpha(Z_1) + \beta(Z_2) \tag{10}$$

α and β represent the priority weightage for the two objectives, Z_1 and Z_2 respectively. In order to solve the Bi-objective model, the Pareto and sensitivity analysis was considered the solution algorithm. A general Pareto analysis is as summarized in **Figure 2**.

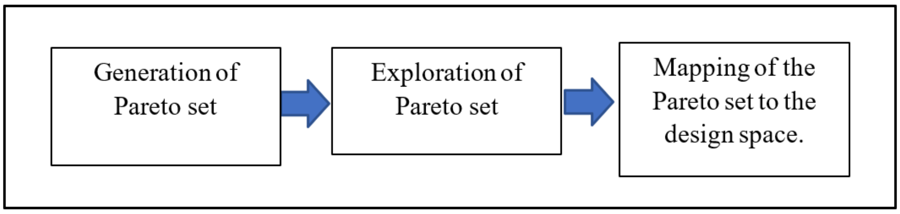

Figure 2. The procedure of pareto analysis to determine the values of α and β.

Procedure I: Randomly Assigned:

In order to find the optimal solution for the Bi-objective model, Visual Basic Programming was applied to run 100 times. In Step 1, the random number has been generated to create 10 sets of prone areas. Next, the distance between prone areas and relief centres has been identified. In Step 3, the allocation of the flood victims based on the nearest distance of relief centres has been conducted. In Step 4, before the flood victims are assigned to the relief centre, the capacity of each relief centre has been identified. In Step 5, if the capacity of the relief centre is available, the flood victims will be allocated to that selected relief centre. Meanwhile, if the capacity of the relief centre is already occupied, thus the next nearest relief centres should be identified, and Step 3 will be repeated. In Step 6, after the allocation is completed (all the capacity of the relief centre is already occupied), the total average travel distance has been calculated. In the final stage, this process will be repeated, as shown on the flow chart below, for the rest of the sequences of the prone area with the different positions.

In this random assignment, the average travel distance recorded differs depending on each allocation. Meanwhile, the total number of relief centres involved in this allocation also differs for each allocation. Some of the allocations have been fully utilizing all 29 relief centres, and some of the allocations only used 27, 28, and 25 relief centres capable of allocating all the flood victims. The procedure that was conducted is detailed in **Figure 3**.

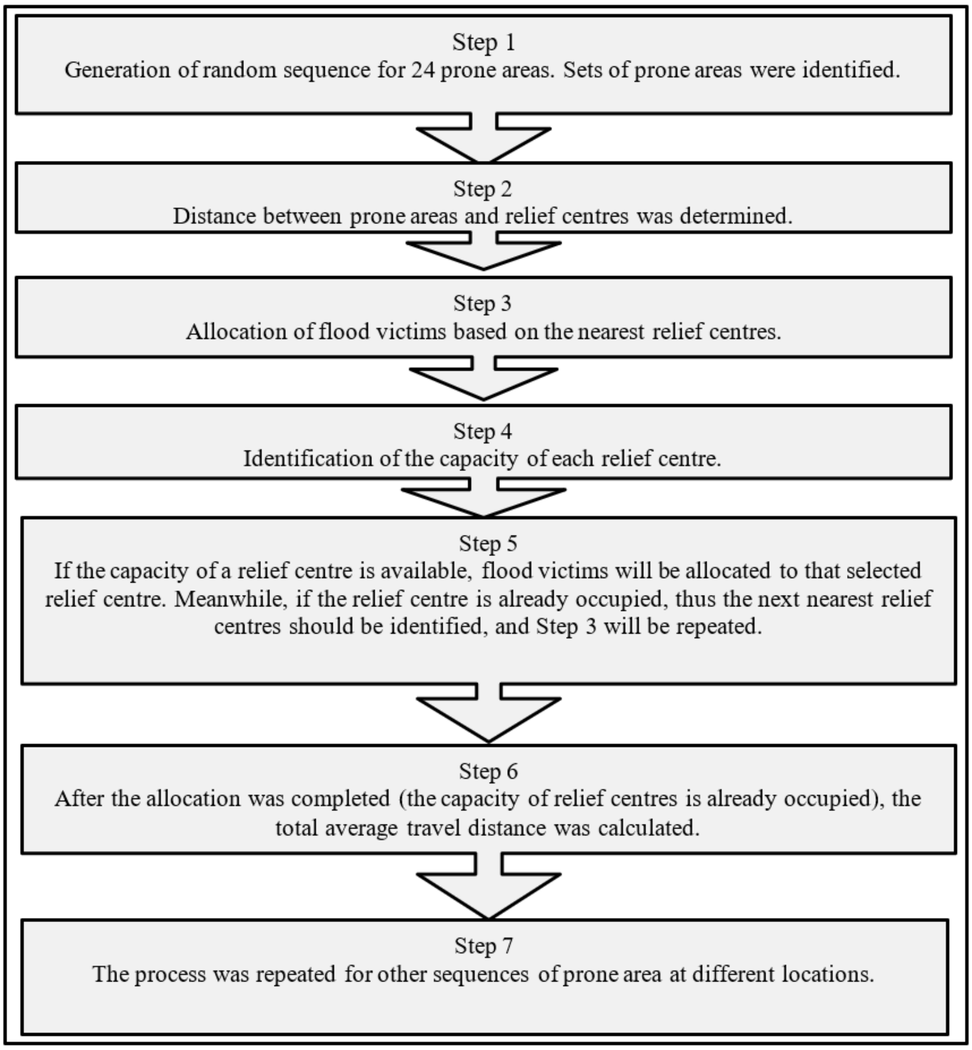

Figure 3. Procedure I of randomly assigned.

Procedure II: Allocation based on more prone areas (river areas):

Procedure II refers to the allocation of flood victims based on the areas most affected by floods during a disaster. In this second procedure, the flood victims from this area were primarily allocated to the nearest relief centres followed by other areas. In Step 1, find the distance between the prone area and the river. In Step 2, based on the distance from the river, categorize the prone area into three areas which are (Inland, River, and Costal). In Step 3, find the distance between the prone area and the relief centre. In Step 4, the flood victims from the river area will be assigned first, followed by those from the inland area. Next, in Step 5, allocate the flood victims based on the nearest distance to the relief centre. For Step 6, in order to allocate the flood victims, the availability of capacity for each relief centre has been identified. In the next step, if the capacity of the relief centre is available, the flood victims will be allocated to that selected relief centre. Meanwhile, if the capacity of the relief centre is already occupied, thus the next nearest relief centre should be identified, and Step 3 will be repeated. Finally, after the allocation has been completed (all the capacity of the relief centre is already occupied), the total average travel distance has been calculated. Detailed Procedure II is illustrated in **Figure 4**.

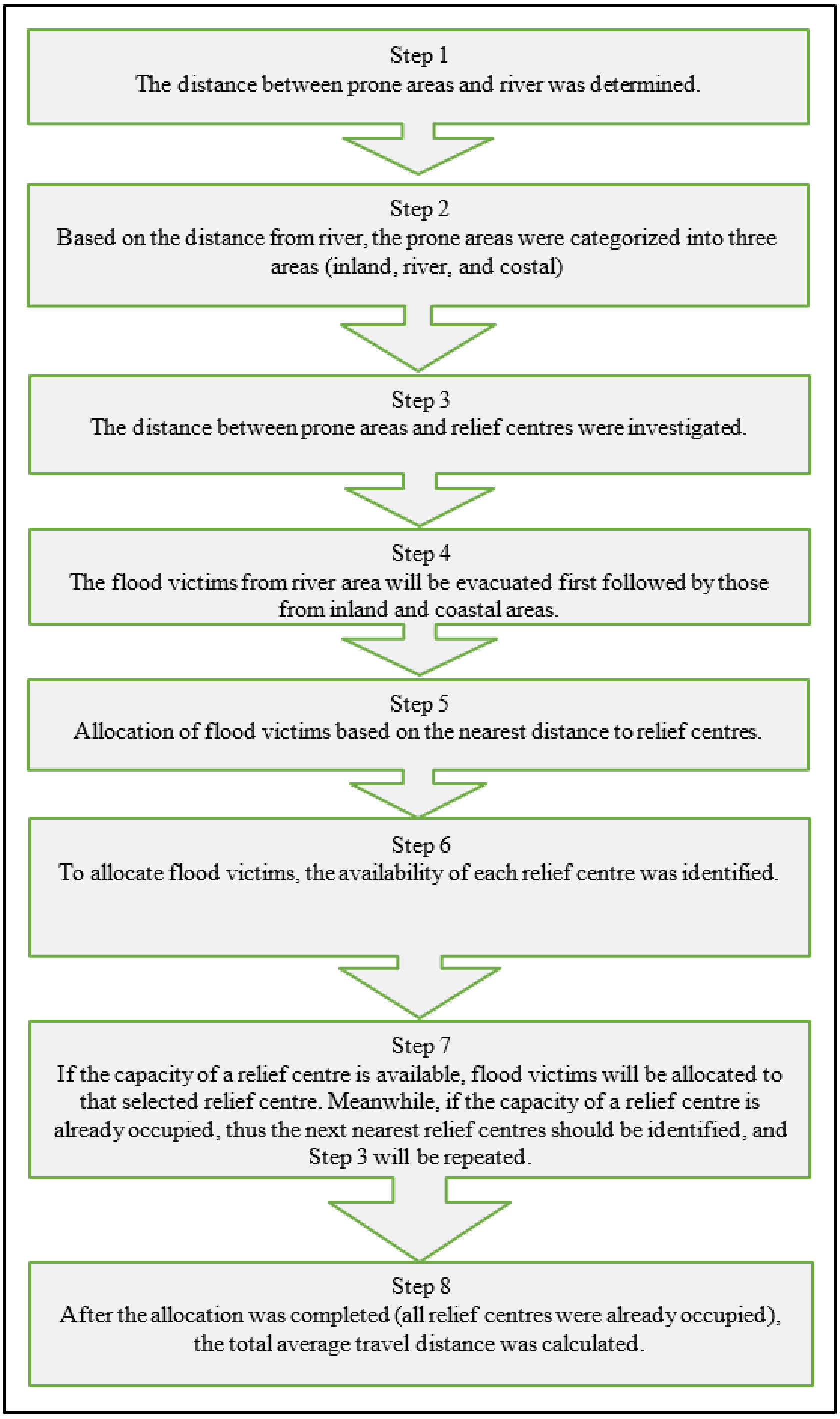

Figure 4. Allocation procedure of assign based on river area.

Procedure for determining the variations of α and β values.

This study proposed 10 combinations of average travel distance and the total number of available relief centres. (Z_1) refers to the average travel distance (from the P-median model) while $(Z_2$ refers to the total number of available relief centres (from LSCP model). Subsequently, Z indicates the score of sensitivity analysis. The Equation for Z is $Z = \alpha(Z_1) + \beta(Z_2)$ (Kim and de Weck, 2006; He et al., 2020; Ryu et al., 2021; Sunil and Venkaiah, 2024) where these combinations were tested to identify the smallest Z score. For α = 0.390 and β = 0.610, the calculation of Z is as follows: 0.390 (3) + 0.610 (22) = 14.59. The smallest Z score was 14.59 recorded at 3 km of average travel distance and 22 available relief centres. The calculation was applied to other combinations, highlighting the smallest Z score.

Figure 5 illustrates the proposed variation of α and β values. In this study, the considered value ranges for α and β were 0.390 to 0.600 and 0.610 to 0.400, respectively. These ranges of values were decided to avoid bias in determining the priority of the model. Moreover, the result indicates that at $\alpha = 0.60$ and $\beta = 0.40$, the smallest Z score was 10.60. Thus, these values were considered for the best combination of objectives. Based on the findings, it indicates that the P-median model was prioritized more than the LSCP model. In another words, the finding indicates that the average travel distance for flood victims is given more priority in the allocation process than the number of available relief centres.

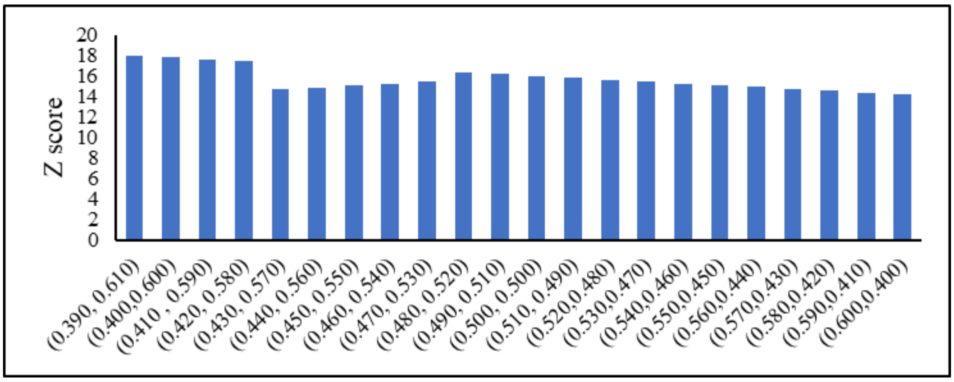

Figure 5. Variations of α and β values.

4. Results

The results indicated that using a randomly assigned procedure, the average travel distance range was recorded to be between 5.332 km and 6.6871 km. Meanwhile, the total number of relief centres involved in this allocation was between 13 and 16 relief centres. In addition, the results using more prone areas or river areas showed that the average travel distance recorded was between 4.96 km and 6.33 km. On the other hand, the total number of relief centres involved in this allocation was between 12 and 15 relief centres.

Procedure I: Randomly Assigned:

Table 1 presents the findings for 100 times iteration of allocation using the randomly assigned procedure. The results indicated that the average travel distance was recorded between 5.33 km and 6.68 km. Meanwhile, the total number of relief centres involved in this allocation was between 13 and 16 relief centres. Using Procedure 1, the optimal solution was found for loop number 20, with an average travel distance of 5.33 km, and the total number of relief centres involved was 13. The recorded average travel distance and the total number of relief centres involved in this allocation using the 2018 flood data were slightly lower compared to the allocation using the flood data of 2013.

Procedure II: Allocation Based on River Areas:

Table 1 also shows the finding for 100 times iteration of allocation based on river areas. The finding revealed that the range of average travel distance recorded for this allocation was between 4.96 km and 6.33 km. On the other hand, the total number of relief centres involved in this allocation was between 12 and 15 relief centres. Based on Procedure II, the optimal solution was found for loop number 60 with the recorded average travel distance of 4.96 km and a total number of relief centres involved of 12.

The recorded average travel distance and the total number of relief centres involved in this allocation were slightly lower compared to the allocation using the randomly assigned procedure for the year 2018. This scenario is due to the more concentrated location of relief centres in river areas. Thus, this has contributed to the shortest time for flood victims to travel to the nearest relief centres.

Table 1. Number of enforcements taken in the year 2020.

Weightage	***α* = 0.60**	***β* = 0.40**
Loops	Average Travel Distance (km)	Total Number of Relief Centres (Unit)
Procedure I		
100	5.8234	14
20	5.3322	13
Procedure II		
100	5.8002	14
60	4.9631	12

5. Discussion

The finding indicates that a few implications have been highlighted for disaster management, such as changes in flood victim allocation patterns, classification of prone areas based on three areas, identification of most disaster areas, and others. Thus, to enhance the efficiency of allocation and to avoid any bad incidents happening during the flood occurrence, the allocation of flood victims is proposed to be started at a more critical area like the river area and followed by other areas. This special arrangement can provide valuable information for disaster management to better organize other related sources such as medicine and sanitation, sufficient food and water, transportation, and secure accessibility. **Figure 6** illustrates the allocation process from prone areas to relief centres. Based on **Figure 6**, all of the flood victims from Kg. Belukar was transferred to SRJC Chung Ching without splitting it into other relief centres. At the same time, for Kg. Bukit Rangin, the flood victims are transferred to SRJC Chung Ching, and due to the limited capacity, some victims are transferred to Sk Bunut Rendang. The set of allocations will provide valuable information to Disaster Management in order to provide a better plan for the allocation process.

The application of the Bi-objective model in this study has also provided new findings on the allocation process. This study combined the two allocation models, P-median and LSCP, to solve the Kuala Kuantan flood allocation problem. This means that, on top of ensuring that the victims are transferred to safer places fast enough or within minimal distance, the objective of ensuring that all victims are transferred was also considered.

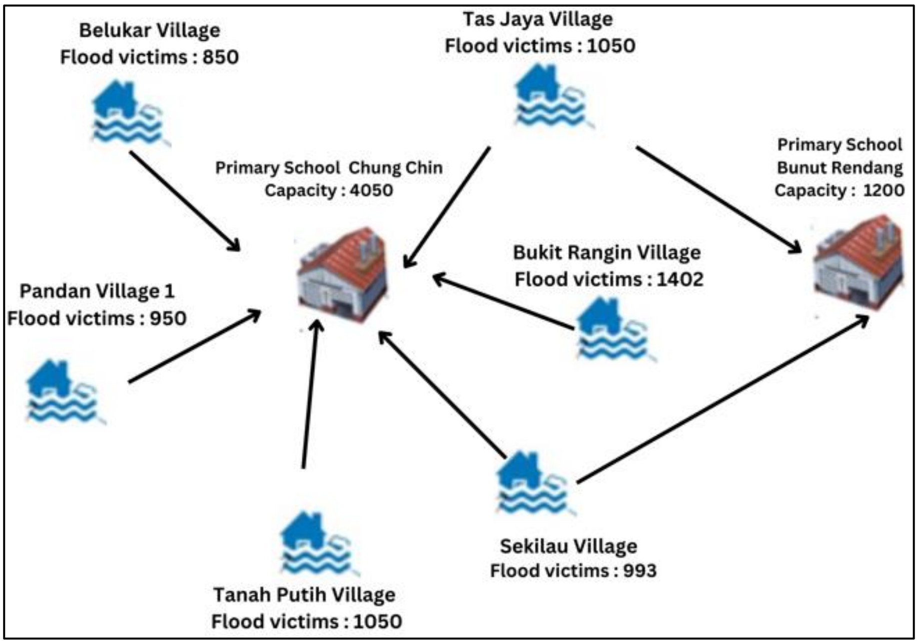

Figure 6. An example of the allocation process from prone areas to relief centres.

6. Conclusion

The results indicated that 100 percent allocation can be achieved based on the Bi-Objective. In order to implement the Bi-objective model, a sensitivity analysis was conducted to evaluate the best combination of α and β to be substituted in the model. Two procedures were considered in this analysis. For the first procedure, which was randomly assigned, the results indicated that the average travel distance was higher than the allocation made by the DSW, Malaysia.

Moreover, this allocation achieved 100 percent allocation of flood victims to the nearest relief centres. Based on the findings, river areas were identified as the most severe places hit by floods due to the huge rainfall distribution. Therefore, in this study, in order to improve the allocation, the second procedure (assigned based on river areas) was performed. The finding indicated that this second allocation procedure yielded a slightly lower average travel distance than the previous procedure. These findings could also provide valuable information for disaster management in implementing a more efficient allocation procedure during a disaster.

The finding indicates that a few implications have been highlighted for disaster management, such as changes in flood victims' allocation patterns, classification of prone areas based on three areas, identification of most disaster areas, and others. Thus, to enhance the efficiency of allocation and to avoid any bad incidents happening during the flood occurrence, the allocation of flood victims is proposed to be started at a more critical area like the river area and followed by other areas. This special arrangement can provide valuable information for disaster management to better organize other related sources such as medicine and sanitation, sufficient food and water sources, transportation, and secure accessibility. Meanwhile, the results of this study demonstrate that congestion at relief centers can be avoided during the allocation process.

The application of the Bi-objective model in this study has also provided new findings on the allocation process. It indicates that the location-allocation model is capable of solving the real-life problem. In the model, the two allocation models, the P-median model and the LSCP model, have been combined to solve the flood allocation problem at Kuala Kuantan. This means on top ensuring the victims are transferred into safer places fast enough or within minimal distance, as suggested by the results in which the higher weightage of 0.6 was discovered for the first objective compared to the second one (on the number of relief centres), the objective that ensures all victims are transferred is also applied. The use of weightage Alpha and Beta as in Pareto analysis has contributed to accurate findings in determining the priority of each model.

Meanwhile, the Bi-objective model was applied to solve the location-allocation problem in Kuala Kuantan. However, before the model was generated, the allocation conducted by DSW was primarily viewed. According to DSW, the smallest average travel distance was recorded at 3.73 km. However, the condition does not allow all flood victims to be allocated to the nearest relief centres due to capacity constraints. Thus, based on this scenario, the capacity of relief centres has to be upgraded based on certain criteria. The results indicated that 100 percent allocation could be achieved based on the Bi-objective. In order to implement the Bi-objective model, a sensitivity analysis was conducted to evaluate the best combination of α and β to be substituted in the model. Two procedures were considered in this analysis. For the first procedure, which was randomly assigned, the results indicated that the average travel distance was higher than the allocation done by DSW. Moreover, this allocation achieved 100 percent allocation of flood victims to the nearest relief centres. Based on the findings in Chapter Five, river areas were identified as the most severe places hit by floods due to the huge amount of rainfall distribution. Therefore, in this study, in order to improve the allocation, the second procedure (assigned based on river areas) was performed. The finding indicated that this second allocation procedure yielded a slightly lower average travel distance than the previous procedure. These findings could also provide valuable information for disaster management in implementing a more efficient allocation procedure during a disaster.

Authors contributions: Conceptualization, NMH and SSRS; methodology, NMH and SSRS; software, NMH; validation, NMH, SSRS and SMD; formal analysis, NMH; investigation, NMH; resources, NMH; data curation, NMH; writing—original draft preparation, NMH; writing—review and editing, NMH and SSRS; visualization, NMH, SSRS and SMD; supervision, SSRS and SMD; project administration, NMH; funding acquisition, NMH. All authors have read and agreed to the published version of the manuscript.

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