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Distribution Centre Location Selection for Disaster Logistics with Integrated Goal Programming-AHP based TOPSIS Method at the City Level

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Abstract

The importance of disaster logistics and its share in the logistics sector are increasing significantly. Most disasters are difficult to predict; therefore, a set of measures seems to be necessary to reduce the risks. Thus, disaster logistics needs to be designed with the pre-disaster and post-disaster measures. These disasters are experienced intensely in Turkey and the importance of these measures becomes more evidential. Therefore, accurate models are required to develop an effective disaster preparedness system. One of the most important decisions to increase the preparedness is to locate the centres for handling material inventory. In this context, this paper analyses the response phase designing the disaster distribution centres in Turkey at the provincial level. AHP (Analytical Hierarchy Process) based TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method and goal programming model integration is used to decide alternative locations of distribution centres. TOPSIS method is employed for ranking the locations, which is based on hazard scores, total area, population, and distance to centre. Two conflicting objectives are first proposed in the goal programming formulation, in which maximization of the TOPSIS scores and minimization of the number of distribution centres covering all demands named set covering model are included. Although Gecimli has the highest priority with 0.8 p score in the TOPSIS ranking, Altincevre (0.77) and Buzlupınar (0.75) ensure both the TOPSIS score and coverage of the demand nodes. The results from this paper confirm that the computational results ensure disaster prevention insights especially in regions with limited data.

Keywords: Disaster Management, AHP Based TOPSIS, Goal Programming, Location Problem

1. INTRODUCTION

Turkey is considered as a country vulnerable to natural disasters that bring about large number of victims and affected people. Tunceli province, located in the Eastern Anatolia Region of Turkey, is prone to many natural disasters like earthquake, flood, landslides, rockfall, fire, etc. (Özkan et al., 2019). Most earthquakes are measured with magnitude 5 or higher due to the tectonically active situation (Onat & Yön, 2018). Climate crisis, increasing population and natural disasters in the world lead to a redefinition of the concept of disaster logistics. These disasters threaten human lives and bring about critical damages. Disasters are events that occur

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unexpectedly and can bring about physical and moral damages. Although prediction of disasters is quite difficult, the preparedness phase can be ensured to prevent the undesired events. Different disasters such as fire, earthquake, flood, storm, landslides can cause different effects and dangers. The effects of each natural disaster are not similar for each area. However, general preparations can be deployed before facing any disaster. It is possible to categorize these preparations as before the disaster, during the disaster, and after the disaster. Disaster management focuses on preparedness in pre-disaster and post-disaster processes. First step consists of conducting and risk measurement and the second step is reacting to situations of the disaster (Ivanov et al., 2014). Pre-disaster preparations include precautionary activities before disasters occur and about what should be done when the disaster occurs. Post-disaster preparations, on the other hand, include the practices after the disaster event occurs. In the post-disaster phase, some of relief materials are required for the affected regions. Thus, prepositioning inventory is important to respond these demands (Stienen et al., 2021). These demands for materials should be distributed to disaster affected regions in defined times. To meet these demands, an engineering perspective based on efficiency and effectiveness should be developed. Creating effective methods to distribute relief in post-disaster situations is of increasing importance (Widener & Horner, 2011). As the intensity and number of disasters increase from year to year, establishing an appropriate balance between disasters and disaster victims becomes more and more difficult. In this context, it is important to decide the location of the most suitable disaster distribution centres. The location problem of disaster distribution centres is at the core of effective methods to handle and transfer disaster relief. Determining the locations of the distribution centres is conducted covering the closest and largest number of settlements.

These preparedness phases can be handled within the scope of disaster logistics to minimize the damage caused by disasters. Disaster logistics includes many activities such as optimal planning at the beginning, optimal location, optimal storage, control, and distribution. One of the most important of these activities for disaster management is the selection of proper distribution location. Preliminary papers focus on problems related to supplier selection, inventory optimization models, warehouse location problems, routing and scheduling problems, and relief centre operations. The choice of distribution centre location is very important to quickly deliver the aid materials needed to the required areas after the disasters. Choosing the optimal centre location can help reduce actual or future damage. The timely supply of materials affects the survival rate in the affected regions (Yi & Kumar, 2007). Thus, the main research objective of this study is to decide the optimal distribution centres to organize the post-disaster phase effectively. In this study, Tunceli, which has been popular in natural disasters in recent years, is discussed. It can be easily understood from the previous data that both different and effective disasters occurred in Tunceli. In this study, the provinces of Altınçevre, Balkaynar, Beşelma, Buzlupınar, Çağlarca, Dalören, Dervişcemal, Geçimli which are in Tunceli, are considered as alternative distribution areas. To evaluate these alternatives, the population in the provinces, the hazard score in the provinces, the distance to centres, and the total area for natural disasters such as earthquake and landslide are considered. An optimal centre location is selected with 8 different alternative regions and 4 different evaluation criteria. Location selection of disaster distribution centres has tended to integrate both mathematical modelling and decision-making approach. Thus, AHP based TOPSIS method is used for distribution location selection. The AHP method is used to find the weights of the criteria, and the TOPSIS method is applied to rank the alternative areas discussed. The AHP method is used to determine the effect level/weight of 4 different criteria on each other. Then, the TOPSIS method is applied by considering the weights and evaluation criteria information determined to evaluate the alternatives. Finally, goal programming approach is conducted to solve the locations selection based on the demand coverage. The motivation for this study is to examine and improve the post disaster preparations in Tunceli as a city vulnerable to natural disasters. The presented paper is important providing a framework with both quantitative and qualitative approaches to select the locations of distribution centres. The main challenge is to demonstrate the effectiveness of both approaches for a real case study.

Main contributions of this paper are summarized in the following.

(i) Determining the criteria weights of the candidate locations on each other and evaluating these locations using Multi-Criteria Decision Making (MCDM).

(ii) Presenting a mathematical model to evaluate the locations based on demand coverage in post-disaster phase.

(iii) Two conflicting objectives are included in the goal programming formulation consists of maximization of the TOPSIS scores and minimization of the number of distribution centres covering all demands.

(iv) Implementing a real-case study to validate the presented approach.

The organization of the paper is as follows. In Section 2, the preliminary works are examined. Then, material-method is explained in Section 3. Results and discussion are handled to present the findings and interpretation of the results in Section 4. Finally, the results are concluded, and future directions are given in Section 5.

2. LITERATURE REVIEW

Disaster management needs solving some problems such as location, routing, and inventory decisions to meet the demands of the affected people (Gocmen & Kuvvetli, 2020). Yilmaz & Kabak (2016) address a location problem of disaster response distribution problem. They aim to minimize the distances between demand points, local and main distribution centres using multi-objective decision model. Balcik & Beamon (2008) determine the disaster distribution centre and stock decisions using maximal covering location model. Campbell et al., (2011) address a supply problem of materials in the disaster preparedness phase. They determine the optimal supply location from a set of discrete options using a cost model. Duran et al., (2011) determine the optimal number, location and stock capacity of disaster warehouses using a mathematical model considering of two different disaster types. Schempp et al., (2019) decide the optimal location of rescue centres utilizing heuristics and mathematical modelling. This paper reveals the gaps in disaster management regarding societal benefits. Most studies mainly utilize the MCDM to select the disaster distribution centres (Ağdaş et al., 2014; Peker et al., 2016; Roh et al., 2013; Yılmaz & Kabak, 2020; Degener et al., 2013; Derse, 2021; Ergün et al., 2020). These papers address the decision problems regarding several decision criteria. In addition, some studies focus on the combined GIS (Geographic Information System) and MCDM to select the distribution centres (Timperio et al., 2017; Ahmadi Choukolaei et al., 2021; Saeidian et al., 2018). Table 1 also summaries the problem types and methods used in the literature. Heuristics algorithms are used to decide the disaster relief location in the studies (Zhong et al.,2020; Shavarani, 2019). Mathematical modeling and MCDM methods are mainly utilized by the researchers.

To the best of our knowledge, there is no paper integrating the AHP based TOPSIS and goal programming method. The outputs of the AHP based TOPSIS method are used as input to the goal programming model formulation. However, two stage selection based on both the various criteria consisting of hazard scores, total area, population, distance to centre and set covering approach is first employed in this paper.

Table 1. Preliminary Works About the Location of Distribution Centres

Author (s)	**Problem**	**Methodology**
Izadi & Samouei, 2021	Disaster relief location-routing problem	Two-stage programming
Zhong et al., 2020	Disaster relief location-routing problem	A hybrid genetic algorithm
Mohammadi et al., 2020	Facility location and routing decisions for disaster relief	An uncertain approach based on neutrosophic fuzzy and robust optimization
Gutjahr & Dzubur, 2016	Location of distribution centres	Adaptive epsilon-constraint method
Turğut et al., 2021	A disaster logistics centre location selection decision support system	Analytic hierarchy/fuzzy analytic hierarchy process methods
Garduno et al., 2021	Selection of Humanitarian Response Distribution Centre	P-median model
Shavarani, 2019	Location-allocation problem for post-disaster humanitarian relief distribution	A hybrid genetic algorithm
Ai & Wigati, 2017	Determining logistic distribution centre	Mathematical model
Alı et al., 2020	Operational site selection for disaster management	MCDM and spatial analysis

3. MATERIAL AND METHOD

In the first stage of the study, the weighing of the criteria for the most suitable distribution centre is conducted with AHP. Comparison scoring of the criteria is assigned by the average of three experts in Tunceli. These obtained weights are used in the TOPSIS method. In TOPSIS, the scores for each alternative place are obtained and included as parameters to the goal programming model. In the second stage, the optimal distribution centre location is selected according to the TOPSIS outputs and set covering model. The method is first to integrate both AHP based TOPSIS outputs and set covering model in a goal programming model formulation. The presented integrated method has some advantages as follows: (1) While AHP based TOPSIS method is an excellent method that ensures a hierarchy to calculate the criteria weights and ranking the alternatives, goal programming method ensures the best combination of set of objectives; (2) The weights of criteria are assigned with pair wise comparisons and the evaluation is conducted by the experts with high experience; (3) Goal programming handles multiple and conflicting goals and provides the best solution based on priorities of the objectives; (4) The integrated method reflects subjective judgments and objective information, and various criteria.

2.1. Problem Definition

Disaster management requires to transfer the disaster relief by distribution centres to the affected area. These centres are permanent or temporary, installed in a large area. The affected people take their relief demand in these centres or distribution vehicles deliver these items. After a disaster, multiple centres are installed to meet these demands (Ozen & Krishnamurthy, 2021). Figure 1 represents the examined problem in this paper. This network includes three phases of supplier, distribution centres and affected area. The lines represent the flows of relief materials between the supplier and distribution centre, distribution centre and affected area.

Turkey is one of the disaster-prone countries in the world. Tunceli, Eastern Anatolia Region of Turkey, has been affected by a lot of disasters. Tunceli is one of the leading provinces in terms of disasters. Thus, a comprehensive disaster study is important in this region. Table 2 shows the number of disaster types in Tunceli. It is seen that disasters such as earthquakes and avalanches are intense in Tunceli. Hozat, which is one of the districts of Tunceli, is selected because all disaster types are observed. Multi-disaster types are available in this district. Therefore, the priority of the management approach is assigned to this district. In addition, micro scale local disaster studies are suggested for the preparedness for the disasters (Yanilmaz et al., 2021). The presented district will be a guide for the other districts.

The presented work provides the modelling the distribution centre location problem in a disaster affected district. The distances between the alternative locations based on Tunceli province are shown in Table 3. These distances are used in the goal programming model which aims to establish the minimum number of distribution centres to cover the largest number of settlements.

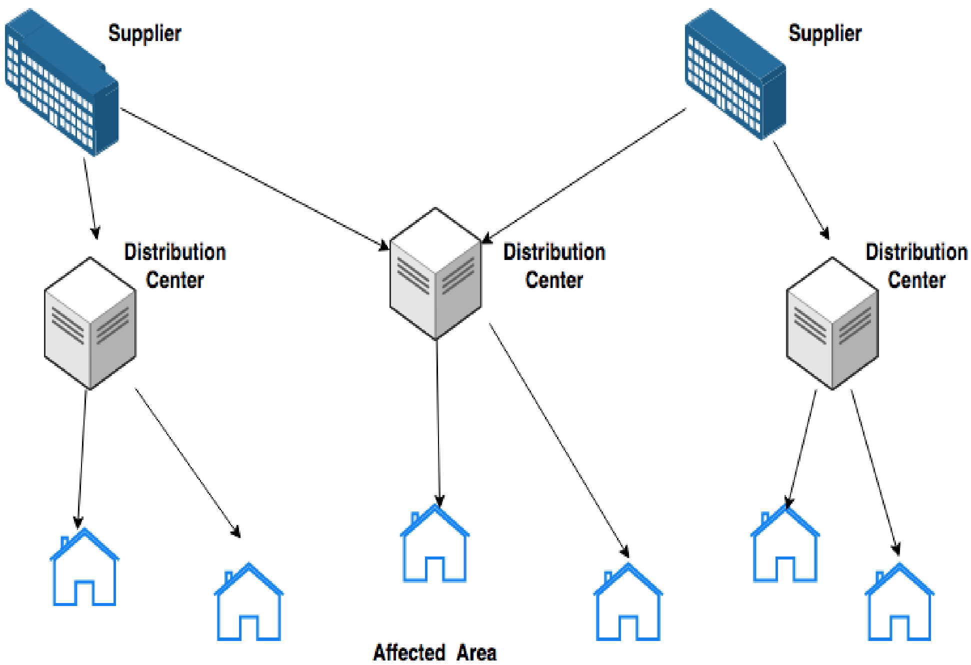

Figure 1. A Schematic Graph of the Presented Problem

Table 2. Number of Natural Disaster Types in Tunceli Between 1958 and 2011 (Dal et al.,2017)

District	Landslide	Avalanche fall	Rockfall	Flood	Fire	Total
Çemişgezek	4	1	2		2	9
Hozat	11	6	4	3	1	25
Mazgirt	18		2	1	1	22
Merkez	18	14	13	2	1	48
Nazmiye	17	12	3			32
Ovacık	11	8			1	20
Pertek	16		3		1	20
Pülümür	17	13	4			34

Table 3. Distances Between the Alternative Locations

Distances	Altınçevre	Balkaynar	Beşelma	Buzlupınar	Çağlarca	Dalören	Dervişcemal	Geçimli
Altınçevre	0	16	21.8	21.6	19.6	24.8	19.1	5.3
Balkaynar	16	0	9.3	8	29.4	12.3	5.5	14.8
Beşelma	21.8	9.3	0	14.9	35.2	3.6	12.4	20.7
Buzlupınar	21.6	8	14.9	0	35	17.9	4.1	20.5
Çağlarca	19.6	29.4	35.2	35	0	38.2	32.5	32.6
Dalören	24.8	12.3	3.6	17.9	38.1	0	15.4	23.6
Dervişcemal	19.1	5.5	12.4	4.1	32.5	15.4	0	17.9
Geçimli	5.3	14.8	20.7	20.5	32.6	23.6	17.9	0

To decide on the most appropriate distribution centre, criteria such as distance to centres, hazard scores, total area and population are considered for the MCDM. A suitable distribution centre location is selected with 8 different alternative locations and 4 different evaluation criteria. The AHP method is discussed to determine the importance of 4 different criteria relative to each other. In Table 4, the importance of each criterion was scored between 1-5 by the expert decision maker. A single value is entered by taking the average of each decision maker's evaluation.

The TOPSIS method is applied by considering the weights and evaluation criteria information determined to evaluate the alternatives. Figure 2 demonstrates the algorithm steps (Ren et al., 2007).

Table 4. Decision Matrix for AHP

	Distance to centre	**Hazard scores**	**Total area**	**Population**
Distance to centre	1.0	0.3	0.3	0.5
Hazard scores	4.0	1.0	2.0	3.0
Total area	3.0	0.5	1.0	3.0
Population	2.0	0.3	0.3	1.0

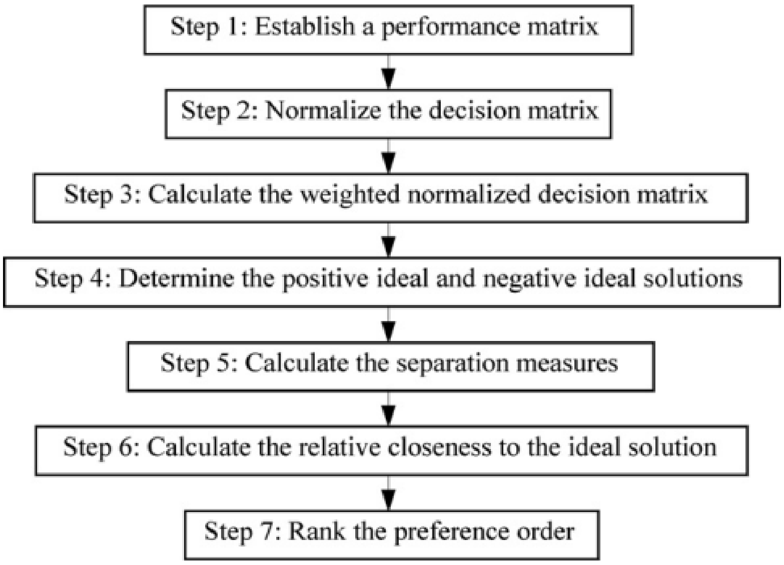

Figure 2. TOPSIS Method Algorithm (Sánchez-Lozano et al., 2013)

In the first step, a decision matrix is established.

Step 1: A matrix including M alternatives and N criteria.

$$A' = [A'ij]nxm, i = 1, \ldots, n; j = 1, 2, \ldots, m \quad (1)$$

Then, the normalization of the decision matrix and weighted normalized matrix are obtained.

Step 2: Normalization of decision matrix:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \quad (2)$$

Step 3: Weighted normalized decision matrix. normalized decision matrix (rij) is multiplied by the weight of the relevant criterion (wj) and the Vij matrix is formed

$$Vij = [wj. rij], i = 1, \ldots, n; j = 1, 2, \ldots, m \quad (3)$$

Positive ideal and negative ideal solutions are decided and the relative closeness to the ideal solution is calculated. Finally, the alternatives are ranked based on the scores.

Step 4: Best and worst alternatives for each criterion.

$$A^- = \{(min_i\, v_{ij}\, |j \in J), (max_i\, v_{ij}\, |j \in J')\} \quad (4)$$

$$A^+ = \{(max_i\, v_{ij}\, |j \in J), (min_i\, v_{ij}\, |j \in J')\}$$

Step 5: Euclidean distance between the target alternative and the best/worst alternative, calculate the ratio Ci:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^+\right)^2} \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}$$

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}$$

Step 6: Ranking alternatives by TOPSIS score.

The decision matrix of the problem is presented in Table 5. Values for each criterion represent the real data.

Table 5. Decision Matrix for TOPSIS

Alternative /Criteria	Distance to centre	Hazard scores	Total area	Population
Altınçevre	27	4	2,535.19	108
Balkaynar	11	2	3.12	47
Beşelma	17	2	306.97	20
Buzlupınar	18	4	2,628.21	80
Çağlarca	33	3	1,714.57	175
Dalören	22	2	2,065.85	65
Dervişcemal	14	3	13.49	80
Geçimli	20	4	3,104.61	85

2.2. Proposed Mathematical Model

In this section, the goal programming model integrating TOPSIS and set covering model is addressed. Most papers suggest consisting of the performance metrics in the mathematical modelling (Derse & Göçmen, 2019).

Demands are covered by each facility, which is set covering constraint (Derse et al., 2020). Goal programming is grouped as nonpreemptive in which all goals have equal priority and pre-emptive regarding priority of goals. Two objectives have equal priority in this model.
The sets, indices, parameters, and variables are presented in the following:

Mathematical model
Sets:
$A = Set of relief demand nodes$
$B = Set of alternative distribution centres$
Indices
$i \in A$
$j \in B$
Positive variables
d_j^+ *positive value of deviating from target for target i*
d_j^- *negative value of deviating from target for target i*
Parameters
y_{ij}: distance between location i and alternative centre j
$topsis_j$: topsis scores for the alternative centre j
Decision variables
x_j: $if alternative centre j is installed 1, otherwise 0$.
<u>Objective Function</u>
z objective function value

$$Z = d_1^+ + d_1^- + d_2^+ + d_2^- \tag{6}$$

<u>Constraints</u>
<u>Goal1</u>

$$\sum_j^B topsis_j * x_j + d_1^+ - d_1^- = 0 \tag{7}$$

<u>Goal2</u>

$$\sum_j^B x_j + d_2^+ - d_2^- = 0 \tag{8}$$

$$\textstyle\sum_{i/y_{ij}} x_j \geq 1 \tag{9}$$

$$dj^-, dj^+ \geq 0 \tag{10}$$

$$x_j = (0,1) \tag{11}$$

Constraint (6) represents the objective function that aims to obtain the optimal result with positive and negative deviating values. The negative and positive sling values related to d1 provide maximization while the sling value related to d2 aims to provide minimization. Constraint (7) ensures to maximize the TOPSIS scores, while minimization of the distribution centre covering all areas is aimed in Constraint (8). Constraint (9) ensures the distribution centres regarding the defined maximum distances. Constraint (10) defines that positive and negative sling values are positive. Constraint (11) defines that the variables x_j are binary.

4. RESULTS AND DISCUSSION

Choosing the most appropriate distribution centre location is important to minimize the number of centres covering all demands and maximize TOPSIS scores. Decision on the selected alternatives with the most appropriate criteria can greatly increase the efficiency of disaster management. The criteria weights obtained by the AHP method are hazard scores, total area, population, and distance to centre, respectively. Table 6 presents the results of the AHP method. Based on the results, the most important criteria are obtained as hazard scores assigned by the experts in this field.

Table 7 provides the consistency of AHP results. Consistency index is obtained as 0.030281389 that means the results are reliable (This index < 0.10).

Table 6. Criteria Weights by AHP

Criteria	Criteria weights
Distance to centre	0.09439
Hazard scores	0.45636
Total area	0.30318
Population	0.14606

Table 7. Criteria Weights and Consistency Index

Criteria	Total	Criteria weights	Total weight
Distance to centre	0.382575758	0.094393939	4.052969502
Hazard scores	1.878484848	0.456363636	4.116201859
Total area	1.252727273	0.303181818	4.131934033
Population	0.588030303	0.146060606	4.02593361
mean	**lamda max**	**consistency index**	
4.081759751	4.081759751	0.030281389	

Table 8 presents the normalization results of the decision matrix.

As a result of the TOPSIS method, p scores are obtained and shown in Table 9. These values are used as inputs in the goal programming model. Altınçevre and Geçimli are selected as most optimal location for the centres using MCDM.

Finally, based on the goal programming results, Altincevre and Buzlupinar are selected as two optimal distribution centres (Table 10). Although Gecimli has the highest p score in the TOPSIS ranking, its distance to demand nodes is effective on the model solution. Buzlupınar gives more optimal results ensuring both the TOPSIS score and coverage of the demand nodes.

Table 8. Normalized Matrix

	Distance to centre	Hazard scores	Total area	Population
Altınçevre	0.448013	0.452911	0.460752	0.410709
Balkaynar	0.182524	0.226455	0.000568	0.178734
Beşelma	0.282082	0.226455	0.055790	0.076057
Buzlupınar	0.298675	0.452911	0.477658	0.304229
Çağlarca	0.547572	0.339683	0.311610	0.665500
Dalören	0.365048	0.226455	0.375453	0.247186
Dervişcemal	0.232303	0.339683	0.002452	0.304229
Geçimli	0.331862	0.452911	0.564240	0.323243

Table 9. P Score Values for Each Candidate Centre

	Si +	Si-	p score
Altınçevre	0.052983091	0.178099	0.7707173
Balkaynar	0.208863599	0.035861	0.1465376
Buzlupınar	0.057810872	0.179978	0.7568817
Çağlarca	0.097054129	0.134586	0.5810128
Dalören	0.131498498	0.116156	0.4690254
Dervişcemal	0.183245402	0.066498	0.2662654
Geçimli	0.049765341	0.201381	0.8018475

Table 10. Results of the Distribution Centres

	LOWER	LEVEL	UPPER
Altınçevre	-	1.000	1.000
Balkaynar	-	-	1.000
Beşelma	-	-	1.000
Buzlupınar	-	1.000	1.000
Çağlarca	-	-	1.000
Dalören	-	-	1.000
Dervişcemal	-	-	1.000
Geçimli	-	-	1.000

All results are satisfactory ensuring the decision-making method and mathematical modelling approach. Thus, they are evaluated based on the various criteria by the field experts and, mathematical modelling provides the quantitative view to solve the problem. In line with the preliminary works, differences are provided as follows: (1) The paper has revealed the gap within this topic based on the literature through a new hybrid method, which reflects subjective judgments and objective information, and various criteria. This method includes MCDM and mathematical modelling to decide the optimal locations for distribution centres of a real-case study of Turkey; (2) The paper put forwards a new goal programming formulation handling maximization of the TOPSIS outputs and minimization of the number of distribution centres; (3) Set covering problem is first handled to minimize the distribution centers needed to cover all demands in the goal programming formulation.

5. CONCLUSION

Improper disaster planning brings about devastating effects on people, buildings, and environment. Most cities are mainly vulnerable to disasters and their effects. With the growth of cities, disasters and the devasting effects have become increasing problems for regional and national governments. Accurate disaster models are needed to prevent these impacts. Preliminary works for distribution relief focuses on mainly location and vehicle routing problems. To provide the relief materials effectively, an integrated decision-making approach is conducted. Therefore, an integrated method including MCDM, and mathematical modelling is provided to solve an aspect of the disaster management. The main aim of this paper is to decide the optimal locations for distribution centres of a real-case study of Turkey at the city level. To solve the problem at the city level can provide an exemplary guide for other areas in the province. The positive and negative differences between the demands of the people in the districts and the material supply is an important argument. By these district-based distribution centres, the response to the demands can be maximized and material shortage problem can be resolved. The obtained results reveal that proposed method ensures an effective framework to select the optimal disaster distribution centres. Two districts of the city are obtained with ensuring both the TOPSIS score and coverage of the demand nodes. Optimal planning provides an important perspective for priority management in disaster events, especially for locations with limited data sources. A detailed examination of the previous studies demonstrates that evaluation of various criteria such as hazard scores, total area, population, distance to centre and meeting all demand in the disaster-affected area is critical. Thus, the contribution of this research paper is provide a framework to handle the disaster effects on people using an integrated method based on the criteria. In addition, assessment of the problem is conducted using both subjective decisions by the experts with high experience and real-case data. Limitations of the study are presented as follows: (1) Linguistic evaluations are conducted by three experts due to the experience requirement and the selected area due to multi-disaster types available in this district. (2) The study could be expanded with other districts. In this paper, one district is selected due to all disaster types are observed here. (3) The model presented in this paper only considers the set covering constraints. Other metrics such as and environmental factors, risk in the target region etc., could be incorporated into the model. Set covering model in risk-prone situations should be surveyed. (4) In addition, different indicators apart from the four criteria mentioned above could be added to weighting phase. This paper provides a road map highlighting the use of integrated methods in the disaster management. For future works, potential point is attention to stochastic factors and system dynamics that affect the location problems. In addition, more comprehensive disaster management planning should be conducted including location-allocation-routing phases. Geographic Information Systems (GIS) can be integrated into the MCDM and mathematical models.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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