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# Prioritization of Districts in terms of Disaster Preparedness Planning: A Case Study for the Expected Istanbul Earthquake

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**Abstract**
Preparedness is the second among the four phases of disaster management after mitigation. In big cities with crowded populations like İstanbul, development of a single holistic disaster preparedness plan would be too complex. At this point, the prioritization of districts is needed because of the existence of a limited amount of available resources (time, staff, money, etc.) plan development stage. This decision can be affected by several factors, so this decision can be defined as a multiple criteria decision-making problem. The main aim in this paper is to develop an analytic approach to obtain the priority rank of districts of the city for disaster preparedness plan development. To do so, a hybrid multiple criteria decision-making model based on SWARA (Stepwise Weight Assessment Ratio Analysis) and WASPAS (Weight Aggregated Sum Product Assessment) is proposed. A case study on earthquake preparedness planning in districts of İstanbul is presented to demonstrate the applicability of the proposed model. Obtained results of the model would be helpful for policy making in volunteer organizations, municipality, and government level.

## 1. Introduction

Dangerous events that disrupt operations in an area or community are defined as disasters [1]. Disasters can be classified into natural (floods, earthquakes, etc.), technological (cyber-attacks, nuclear attacks, etc.), environmental (air pollution, etc.), and daily hazards (accidents, etc.) classes [2]. Disasters may have economic, material, environmental and social effects and dealing with these effects is in the field of disaster management [3]. It consists a process with four phases as it shown in Figure 1, as follows [4]:

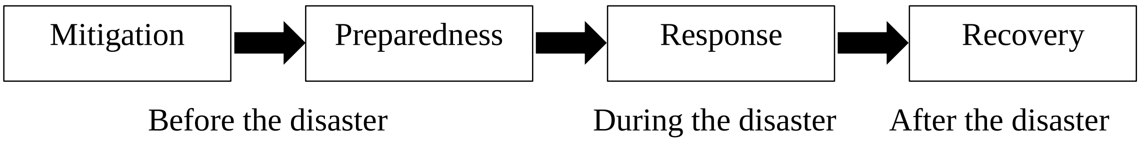


**Figure 1.** Phases of disaster management

Mitigation means the preventive activities before the disaster like regulation on building standards, education of the community about mitigation strategies and barrier construction. When a disaster is likely to happen, preparedness activities are performed. Preparedness activities consist of preparatory activities such as placing disaster supplies kits, preparing shelters and backup facilities, and planning rescue operations. When the disaster occurs, the response phase is put into action. Search and rescue operations, evacuation of people, and firefighting are some activities related to this phase.

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Finally, the recovery phase corresponds to the repair and reconstruction operations after the disaster to return to normal life in the area.

Istanbul is one of the major cities in Turkey, with a population of more than 15 million people and most of the economic activities in the country occur in this city. According to several research including Parsons et al. [5], an earthquake greater than 7.0 magnitude is expected with a significant probability in Istanbul in the near future. Since the earthquake is likely to happen, preparedness plans for the disaster must be made. However, preparedness plans require an important amount of resources to be allocated and there are 39 districts in İstanbul. So, prioritization of the districts for preparedness planning is needed.

Preparedness planning for a disaster contains various strategic decision problems that require consideration of a number of criteria simultaneously. This kind of problems may have a complex structure and obtaining a solution to them may be difficult because of the conflicts between alternative values on different criteria. Multiple criteria decision making (MCDM) approaches are useful for modelling and solution of decision problems with a finite number of alternatives and criteria [6]. Therefore, MCDM approaches could help in the determination of strategic decisions related to disaster management concept.

Strategic decisions within the context of disaster management have commonly taken interest of researchers. Some of the recent studies can be summarized as follows:

Mitigation scenarios from the cascading effects of a disaster, which can occur by reactivation of a volcano in Italy were analyzed by using a knowledge-based decision support system [7]. ELECTRE-TRI method was used within the system as the decision-making method. Tella and Balogun [8] observed that flood susceptibility model performances vary according to the disaster area, and they focused on developing a spatial flood susceptibility model to mitigate the effects of floods in Ibadan, Nigeria. Obtained results from the integrated model based on FAHP and GIS, they demonstrated that the model provides more accurate results. A spatial decision-making model based on GIS, AHP and TOPSIS was proposed as a tool to be used in the mitigation processes of disasters [9]. The proposed model was presented with a case study on the development of an earthquake risk map in Yalova, Turkey.

Ghavami [10] indicated that the identification of strategic roads in case of a disaster is an important aspect of preparedness plans and modeled the identification process as a spatial decision-making problem. A case study in Mazandaran, Iran, was analyzed using the integrated model he proposed based on GIS and AHP and 220 road sections are classified into very high, high, low and very low strategic classes. Rezaei-Malek et al. [11] proposed a prioritization model to determine the disaster-prone areas in Tehran. By using the Fuzzy PROMETHEE-II-based approach in the study, 22 sub-divisions of the study were analyzed.

The earthquake occurrence risk in İstanbul was considered by Yılmaz and Kabak [12] within the perspective of a need for humanitarian logistic centers. To provide efficient humanitarian relief service in case of a disaster, possible locations for humanitarian logistic centers in the city were evaluated by an Interval Type-2 Fuzzy Set-based AHP – TOPSIS model. Another study on the expected İstanbul earthquake focused on the debris demolition and transfer planning [13]. Numerical analysis of a number of scenarios by using a stochastic MILP model seems as an indicator of the importance of utilization of analytical models for preparedness planning. Barutcu and Ic [14] focused on the need of a field hospital in case of a possible earthquake in Ankara and they handled the site selection decision for the field hospital. A multi-criteria analysis based on the VIKOR method to evaluate three main parks in the city center, which were considered as alternative locations, was conducted by taking eight criteria into account.

As it can be understood from the aforementioned literature findings, different problems related to disaster management decisions have been analyzed by researchers by using various MCDM techniques. However, no studies have taken the prioritization of the districts of a big city for preparedness planning for an expected earthquake so far. Therefore, the main aim of this study is to develop an analytical approach to this strategic decision. To do so, a hybrid MCDM model based on SWARA [15] (Stepwise Weight Assessment Ratio Analysis) and WASPAS [16] (Weight Aggregated Sum Product Assessment) techniques was proposed. Districts of Istanbul, which is a big city with a great expectation of an earthquake occurrence, were prioritized in terms of preparedness planning for the expected great Istanbul Earthquake by using the proposed approach. The main contributions of the study can be listed as follows:

- A multi-criteria analysis model based on SWARA and WASPAS was proposed to determine preparedness planning decisions for an expected earthquake.

- A case study of district prioritization for preparedness planning in a big city is presented.
- 39 districts of Istanbul were evaluated by considering five criteria.

The remainder of the study is organized as follows: 2nd section presents the proposed decision model with basic definitions related to the methodology and decision elements of the model. In the 3rd section, obtained results of the study are given with discussion. The study was concluded in the 4th part by presentation of managerial implications and suggestions for further studies.

## 2. Proposed Model

In this study, a multi-criteria ranking model based on the SWARA and WASPAS methods was proposed. Within the proposed model, SWARA was used to obtain the importance degree of criteria and WASPAS was used to rank alternatives. This part contains an explanation of the SWARA and WASPAS methods along with a flowchart of the proposed model.

### 2.1. SWARA

SWARA is a multi-criteria decision-making method, which was introduced by Kersuliene et al. in 2010 [15], makes it possible for decision-makers to state their feelings without using fixed scales or measures. SWARA provides a rational decision according to the aggregated opinions of decision-makers by weighting of decision elements. There are several publications consisting of the SWARA method on decision problems in a wide application area, such as the third part logistics service provider evaluation [17] and country evaluation [18]. Steps of the method are as follows:

Step 1. Ranking of criteria and determination of relative importance scores ($s_j$):

Each decision-maker ranks all the criteria ($x_j$) based on the importance degree they define. No importance degree is given to the most important criterion and the remaining criteria were compared with the $(j+1)^{th}$ criterion by assigning an relative importance score denoted by $s_j$ ($0 \leq s_j \leq 1$).

Step 2. Determination of coefficient values ($c_j$):

Relative importance scores obtained from the decision makers' assessment are used in Eq. (1) to obtain coefficient values. The coefficient value of the most important criterion is equal to "1".

$$c_j = \begin{cases} 1 & ,j = 1 \\ s_j + 1 & ,j > 1 \end{cases} \tag{1}$$

Step 3. Calculation of revised weights ($v_j$):

Eq. (2) is used to obtain the revised weight value of the decision elements. By this way, importance values of criteria are formed in a descending order of importance rank.

$$v_j = \begin{cases} 1 & ,j = 1 \\ \frac{v_{j-1}}{c_j} & ,j > 1 \end{cases} \tag{2}$$

Step 4. Calculation of relative weights for each decision-maker ($w_j$):

Relative weight values of the decision elements are calculated using vector normalization of the revised weight values. The mathematical expression of the calculation is given by Eq. (3).

$$w_j = \frac{v_j}{\sum_{j=1}^{n} v_j} \tag{3}$$

Step 5. Calculation of final weights ($W_j$):
The arithmetic mean of the relative weight values for each decision-maker is used to obtain the final weights of the decision elements. In other words, the sum of individual weight values is divided by the number of decision-makers to obtain final weight values.

### 2.2. WASPAS

WASPAS was introduced into the literature in 2012 by Zavadskas et al. [16] as an integrated form of the Weighted Sum and Weighted Product models. The decision-making procedure in this method follows six steps, including the formation and normalization of the decision matrix, calculation of weighted sum and weighted product values and aggregation of the results of these two models. WASPAS have taken a significant attention of researchers and have been applied in several decision problems like digital library evaluation [19] and green supplier selection [20]. The decision-making process with WASPAS consists of the following steps:

Step 1. Formation of the decision matrix ($D$):

Decision alternatives are evaluated in this step with respect to each criterion. Either the real numerical values of alternative scores or linguistic or scaled values can be used in the decision matrix. For a decision problem with *n* criteria and *m* alternatives, decision matrix (*D*) can be shown as follows, where $d_{ij}$ denotes the score of alternative *i* with respect to criterion *j*.

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix}$$

Step 2. Determination of a normalized decision matrix ($N$):

In order to mitigate the effects of unit and range differences between alternative scores within the decision-making process, normalization procedures are commonly applied in MCDM methods. In the same sense, a normalization step is applied in WASPAS, too. Eq. (4) and Eq. (5) are applied to obtain normalized values for benefit type and cost type criteria, respectively. In these equations, $n_{ij}$ denotes the normalized value of alternative *i* with respect to criterion *j*.

$$n_{ij} = \frac{d_{ij}}{\max_i d_{ij}} \quad (4)$$

$$n_{ij} = \frac{\min_i d_{ij}}{d_{ij}} \quad (5)$$

A normalized decision matrix is formed using normalized values in the following form:

$$N = \begin{bmatrix} n_{11} & \cdots & n_{1n} \\ \vdots & \ddots & \vdots \\ n_{m1} & \cdots & n_{mn} \end{bmatrix}$$

Step 3. Calculation of weighted sum values for alternatives ($Q_i^{(1)}$):

Alternative scores from the weighted sum model are calculated using the summation the multiplication values of the alternative scores with respect to each criterion and corresponding criterion weight. The mathematical formulation of weighted sum calculation is given by Eq. (6) as follows, where $W_j$ denotes the weight of criterion *j*.

$$Q_i^{(1)} = \sum_{j=1}^{n} W_j n_{ij} \quad (6)$$

Step 4. Calculation of weighted product values for alternatives ($Q_i^{(2)}$):

Alternative scores from the weighted product model are calculated by the multiplication the $W_j^{th}$ power of alternative scores with respect to each criterion. The mathematical formulation of weighted product calculation is given by Eq. (7) as follows.

$$Q_i^{(2)} = \prod_{j=1}^{n} n_{ij}^{W_j} \quad (7)$$

Step 5. Aggregation of weighted sum and weighted product values for alternatives ($Q_i$):

In order to ease decision making, results obtained from the weighted sum and weighted product models are aggregated. The resulting value is calculated using Eq. (8), where the effect of weighted sum and weighted product models are assumed to be equal.

$$Q_i = 0.5 * Q_i^{(1)} + 0.5 * Q_i^{(2)} = 0.5 * \sum_{j=1}^{n} W_j n_{ij} + 0.5 * \prod_{j=1}^{n} n_{ij}^{W_j} \quad (8)$$

The assumption of equal effect of weighted sum and product on the final decision can be generalized using an effect coefficient of $\lambda$ ($0 \leq \lambda \leq 1$) for the weighted sum model as it is given in Eq. (9) as follows:

$$Q_i = \lambda * Q_i^{(1)} + (1-\lambda) * Q_i^{(2)} = \lambda * \sum_{j=1}^{n} W_j n_{ij} + (1-\lambda) * \prod_{j=1}^{n} n_{ij}^{W_j} \quad (9)$$

The final decision converges to the results of the weighted sum model by the increasing values of $\lambda$ and converges to the results of the weighted product model by the decreasing values.

### 2.3. Steps of the Proposed Model

Since the proposed model consists of the steps of two MCDM models, the decision-making process by using the integrated model is explained in this part. The process starts with the problem definition phase, which contains the definition of the problem goal, criteria and alternatives and decision-making group. The second phase of the process is the calculations made by SWARA, which are as the weight calculations from the individual assessments of each decision-maker and determination of final weights by aggregation. The last phase of the proposed approach is the evaluation of alternatives by WASPAS method. Criteria weights obtained in the second phase are used in the WASPAS phase to obtain weighted sum and weighted product values. A flowchart for the proposed model is given in Figure 2 as follows:

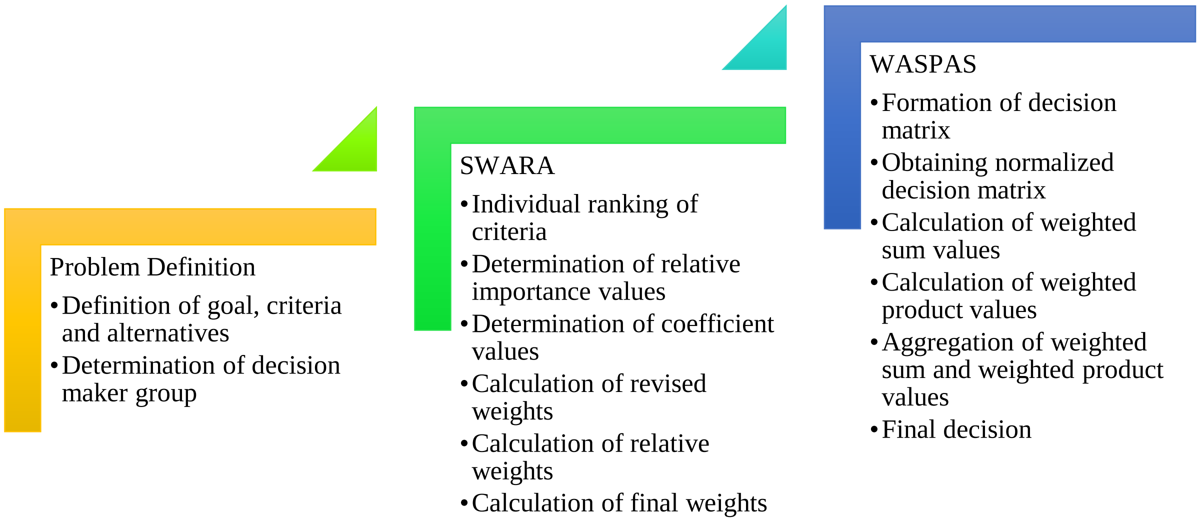


**Figure 2.** Flowchart of the proposed model

## 3. Case Study

The losses caused by the Marmara Earthquake in 1999 increased the awareness of the precautions to be taken in İstanbul. Furthermore, strike risk of a major earthquake with a magnitude greater than 7.5 in İstanbul is very high in the next decades. Therefore, preparedness planning for İstanbul is an urgent issue. However, İstanbul is a big city with 39 districts (Figure 3) and allocation of scarce resources on disaster management to all districts at the same time is not possible. For this reason, the prioritization of districts must be made using some analytical models.


**Figure 3.** Map of the city with its districts [21]

In this part of the study, a case study of districts' prioritization for earthquake preparedness planning in İstanbul is presented. To do so, definitions of decision goal and criteria were firstly given with the problem data for each district. Then, importance degree of each criterion was determined by an expert group of five people. The expert group consisted of two experts from the Earthquake and Soil Investigation Directorate of the Metropolitan Municipality of İstanbul, two experts from a state university's Civil Engineering Department and an expert in sociological studies. Their opinions were collected to determine the importance of criteria and finally, data provided by the Metropolitan Municipality was used to determine the rank of districts for earthquake preparedness planning.

### 3.1. Problem Definition

İstanbul is a big and beautiful city with a population greater than 15 million and it contains important financial institutions, production facilities and historical buildings. Due to its population, contributions to the country's economy and world heritage, this city needs to be protected against disasters. So the decision goal in this study is the determination of the rank of districts of İstanbul.

A set of meetings were established by the expert group to determine the factors that could be effective in the ranking decision. The criteria chosen by the expert group are listed as follows:

- Population ($x_1$): Population is an important aspect for preparedness planning. The number of people who will be affected by the possible earthquake in districts is considered an important factor.
- Disaster assembly points ($x_2$): In case of an earthquake, people should directly go to the nearest disaster assembly point. Since some districts may have high population density in İstanbul, this criterion is measured by the area per capita in disaster assembly points ($m^2$).
- Building damage ($x_3$): Strength of a considerable number of existing buildings in İstanbul have the risk of being damaged by the expected earthquake and building damage may worsen the effect of the earthquake on people. Therefore, building damage is an important factor in earthquake preparedness planning. In this study, this criterion is defined by the proportion of buildings expected to be heavily or very heavily damaged in a 7.5 magnitude earthquake.
- Expected number of deaths ($x_4$): The most important cause of damage related to disasters is the death of people in the disaster region and during preparedness planning, minimization of the expected number of deaths should be considered as an important factor.
- Expected number of heavy injuries ($x_5$): Similar to the $C_4$ criterion, heavily injuries suffered by people because of a disaster is an important factor. The less number of heavily injuries occur, the more efficient care services after the disaster can be.

Since the aim of the study is to rank districts of İstanbul, alternatives are these 39 districts. The hierarchical structure of the problem is represented in Figure 4 as follows:

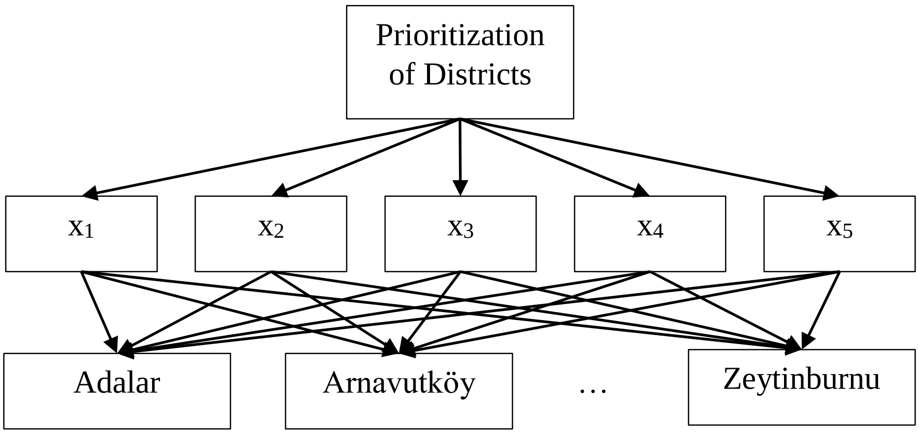


**Figure 4.** Hierarchical structure of the problem

### 3.2. Determination of Criteria Weights

As it mentioned earlier, an expert group of five people evaluated decision criteria and their assessments were used to calculate criterion weights using the SWARA method. Steps for weight calculation are given in this part.

Step 1. Ranking of the criteria and determination of relative importance scores:

Ranking of criteria and relative importance scores were collected from each member of the expert group separately and are given in Table 1 as follows:

**Table 1.** Criteria rankings and relative importance scores given by experts

| E1 | | E2 | | E3 | | E4 | | E5 | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | $s_j$ | Rank | $s_j$ | Rank | $s_j$ | Rank | $s_j$ | Rank | $s_j$ |
| $x_1$ | | $x_4$ | | $x_3$ | | $x_1$ | | $x_1$ | |
| $x_3$ | 0.700 | $x_5$ | 0.450 | $x_4$ | 0.900 | $x_4$ | 0.600 | $x_3$ | 0.800 |
| $x_5$ | 0.400 | $x_1$ | 0.600 | $x_5$ | 0.600 | $x_3$ | 0.400 | $x_4$ | 0.600 |
| $x_2$ | 0.200 | $x_3$ | 0.300 | $x_1$ | 0.500 | $x_5$ | 0.500 | $x_5$ | 0.500 |
| $x_4$ | 0.800 | $x_2$ | 0.100 | $x_2$ | 0.300 | $x_2$ | 0.200 | $x_2$ | 0.700 |

Step 2. Determination of coefficient values:

By using the data in Table 1 and Eq. (1), coefficient values for criteria evaluations made by experts were determined. The coefficient values of the criteria are given in Table 2 as follows:

**Table 2.** Coefficient values of the criteria

| E1 | | | E2 | | | E3 | | | E4 | | | E5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | $s_j$ | $c_j$ | Rank | $s_j$ | $c_j$ | Rank | $s_j$ | $c_j$ | Rank | $s_j$ | $c_j$ | Rank | $s_j$ | $c_j$ |
| $x_1$ | 0.000 | 1.000 | $x_4$ | 0.000 | 1.000 | $x_3$ | 0.000 | 1.000 | $x_1$ | 0.000 | 1.000 | $x_1$ | 0.000 | 1.000 |
| $x_3$ | 0.700 | 1.700 | $x_5$ | 0.450 | 1.450 | $x_4$ | 0.900 | 1.900 | $x_4$ | 0.600 | 1.600 | $x_3$ | 0.800 | 1.800 |
| $x_5$ | 0.400 | 1.400 | $x_1$ | 0.600 | 1.600 | $x_5$ | 0.600 | 1.600 | $x_3$ | 0.400 | 1.400 | $x_4$ | 0.600 | 1.600 |
| $x_2$ | 0.200 | 1.200 | $x_3$ | 0.300 | 1.300 | $x_1$ | 0.500 | 1.500 | $x_5$ | 0.500 | 1.500 | $x_5$ | 0.500 | 1.500 |
| $x_4$ | 0.800 | 1.800 | $x_2$ | 0.100 | 1.100 | $x_2$ | 0.300 | 1.300 | $x_2$ | 0.200 | 1.200 | $x_2$ | 0.700 | 1.700 |

Step 3. Calculation of revised weights ($v_j$):

$c_j$ values in Table 2 and Eq. (2) was used to calculate revised weights of criteria. The revised weight values are given in Table 3 as follows:

**Table 3.** Coefficient values of the criteria

| E1 | | | E2 | | | E3 | | | E4 | | | E5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | $c_j$ | $v_j$ | Rank | $c_j$ | $v_j$ | Rank | $c_j$ | $v_j$ | Rank | $c_j$ | $v_j$ | Rank | $c_j$ | $v_j$ |
| $x_1$ | 1.000 | 1.000 | $x_4$ | 1.000 | 1.000 | $x_3$ | 1.000 | 1.000 | $x_1$ | 1.000 | 1.000 | $x_1$ | 1.000 | 1.000 |
| $x_3$ | 1.700 | 0.588 | $x_5$ | 1.450 | 0.690 | $x_4$ | 1.900 | 0.526 | $x_4$ | 1.600 | 0.625 | $x_3$ | 1.800 | 0.556 |
| $x_5$ | 1.400 | 0.420 | $x_1$ | 1.600 | 0.431 | $x_5$ | 1.600 | 0.329 | $x_3$ | 1.400 | 0.446 | $x_4$ | 1.600 | 0.347 |
| $x_2$ | 1.200 | 0.350 | $x_3$ | 1.300 | 0.332 | $x_1$ | 1.500 | 0.219 | $x_5$ | 1.500 | 0.298 | $x_5$ | 1.500 | 0.231 |
| $x_4$ | 1.800 | 0.195 | $x_2$ | 1.100 | 0.301 | $x_2$ | 1.300 | 0.169 | $x_2$ | 1.200 | 0.248 | $x_2$ | 1.700 | 0.136 |

Step 4. Calculation of relative weights for each decision-maker ($w_j$):

Relative weight values of decision elements were calculated using Eq. (3) and the resulting values are given in Table 4 as follows:

**Table 4.** Relative weights of criteria

| E1 | | | E2 | | | E3 | | | E4 | | | E5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | $v_j$ | $w_j$ | Rank | $v_j$ | $w_j$ | Rank | $v_j$ | $w_j$ | Rank | $v_j$ | $w_j$ | Rank | $v_j$ | $w_j$ |
| $x_1$ | 1.000 | 0.392 | $x_4$ | 1.000 | 0.363 | $x_3$ | 1.000 | 0.446 | $x_1$ | 1.000 | 0.382 | $x_1$ | 1.000 | 0.440 |
| $x_3$ | 0.588 | 0.230 | $x_5$ | 0.690 | 0.250 | $x_4$ | 0.526 | 0.235 | $x_4$ | 0.625 | 0.239 | $x_3$ | 0.556 | 0.245 |
| $x_5$ | 0.420 | 0.165 | $x_1$ | 0.431 | 0.157 | $x_5$ | 0.329 | 0.147 | $x_3$ | 0.446 | 0.171 | $x_4$ | 0.347 | 0.153 |
| $x_2$ | 0.350 | 0.137 | $x_3$ | 0.332 | 0.120 | $x_1$ | 0.219 | 0.098 | $x_5$ | 0.298 | 0.114 | $x_5$ | 0.231 | 0.102 |
| $x_4$ | 0.195 | 0.076 | $x_2$ | 0.301 | 0.109 | $x_2$ | 0.169 | 0.075 | $x_2$ | 0.248 | 0.095 | $x_2$ | 0.136 | 0.060 |

Step 5. Calculation of final weights ($W_j$):

Final weights of criteria were calculated using arithmetic mean of relative weight values of the corresponding criteria and are given in Table 5 as follows:

**Table 5.** Final weights of criteria

| Criteria | $W_j$ |
|---|---|
| $x_1$ | 0.265 |
| $x_2$ | 0.099 |
| $x_3$ | 0.252 |
| $x_4$ | 0.222 |
| $x_5$ | 0.162 |

As it is seen from Table 5, the most important criterion is determined as the population. This means that population must be considered primarily for disaster preparedness planning ranking of districts based on the aggregated opinions of the expert group. Building damage and expected number of deaths follow the population criterion, respectively. The disaster assembly points criterion is seen as the least important aspect of district ranking.

The calculated values in this phase will be used in the Weighted Sum and Weighted Product models as weighting factors.

### 3.3. Ranking of Districts

The WASPAS method was used in this study to determine the rank of districts. The steps applied to obtain district ranking are given in this part as follows:

Step 1. Formation of the decision matrix:

Score values for each district in terms of each criterion were collected from different data sources. For example, population data of districts were obtained from the population statistics shared by the Turkish Statistics Institute [22], districts' scores in terms of disaster assembly points criterion were gathered from an article on a news website [23] and data on building damage, expected number of deaths and heavy injuries were collected from some reports about the possible losses of the expected earthquake in each district published by the Istanbul Metropolitan Municipality [24]. The decision matrix for the case study is given in Table 6.

**Table 6.** Decision matrix

| Districts | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | Districts | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Adalar | 16372 | 3.45 | 0.2363 | 76 | 61 | Gaziosmanpaşa | 493096 | 0.55 | 0.0544 | 140 | 83 |
| Arnavutköy | 312023 | 1.96 | 0.0409 | 0 | 0 | Güngören | 283083 | 0.67 | 0.1198 | 754 | 415 |
| Ataşehir | 427217 | 1.86 | 0.0583 | 89 | 47 | Kadıköy | 485233 | 0.78 | 0.0724 | 190 | 93 |
| Avcılar | 457981 | 0.42 | 0.0915 | 465 | 239 | Kağıthane | 454550 | 0.94 | 0.0466 | 84 | 44 |
| Bağcılar | 744351 | 0.53 | 0.1007 | 1179 | 652 | Kartal | 480738 | 0.38 | 0.0647 | 176 | 87 |
| Bahçelievler | 605300 | 0.18 | 0.1296 | 1633 | 879 | Küçükçekmece | 805930 | 0.51 | 0.1448 | 1515 | 925 |
| Bakırköy | 228759 | 0.93 | 0.2216 | 1046 | 581 | Maltepe | 525566 | 0.65 | 0.0743 | 234 | 130 |
| Başakşehir | 503243 | 1.96 | 0.0696 | 71 | 45 | Pendik | 741895 | 0.68 | 0.0645 | 195 | 101 |
| Bayrampaşa | 274884 | 1.73 | 0.1353 | 520 | 340 | Sancaktepe | 474668 | 1.22 | 0.0512 | 48 | 24 |

**Table 6.** Decision matrix (cont.)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Beşiktaş | 178938 | 4.45 | 0.0552 | 26 | 14 | Sarıyer | 349968 | 1.35 | 0.0472 | 33 | 21 |
| Beykoz | 248595 | 0.60 | 0.0521 | 25 | 16 | Şile | 41627 | 3.33 | 0.0387 | 0 | 0 |
| Beylikdüzü | 398122 | 4.05 | 0.1477 | 527 | 276 | Silivri | 209014 | 2.29 | 0.1010 | 58 | 27 |
| Beyoğlu | 233322 | 1.63 | 0.1084 | 217 | 150 | Şişli | 284294 | 0.98 | 0.0490 | 55 | 27 |
| Büyükçekmece | 269160 | 1.57 | 0.1148 | 288 | 154 | Sultanbeyli | 349485 | 0.90 | 0.0585 | 73 | 38 |
| Çatalca | 76131 | 2.02 | 0.0599 | 4 | 2 | Sultangazi | 543380 | 3.13 | 0.0340 | 57 | 27 |
| Çekmeköy | 288585 | 0.95 | 0.0285 | 1 | 0 | Tuzla | 284443 | 1.27 | 0.1182 | 268 | 169 |
| Esenler | 447116 | 0.86 | 0.0909 | 638 | 352 | Ümraniye | 726758 | 0.44 | 0.0428 | 42 | 17 |
| Esenyurt | 977489 | 0.86 | 0.0936 | 1003 | 543 | Üsküdar | 525395 | 1.03 | 0.0470 | 95 | 42 |
| Eyüpsultan | 417360 | 2.11 | 0.0866 | 168 | 110 | Zeytinburnu | 293839 | 0.76 | 0.1315 | 668 | 374 |
| Fatih | 382990 | 0.83 | 0.1783 | 1484 | 985 | | | | | | |

Step 2. Determination of the normalized decision matrix:

As mentioned in section 2.3., normalization of the decision matrix was made using Eq. (4) and Eq. (5). In this case study, $x_2$ is a benefit type criterion and the other criteria ($x_1$, $x_3$, $x_4$, and $x_5$) are cost type criteria. Therefore, Eq. (4) was used to calculate normalized values for criterion $x_2$ and Eq. (5) was used to obtain normalized values of other criteria. A normalized decision matrix is given in Table 7.

**Table 7.** Normalized decision matrix

| Districts | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | Districts | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Adalar | 0.017 | 0.052 | 1.000 | 0.047 | 0.062 | Gaziosmanpaşa | 0.504 | 0.327 | 0.230 | 0.086 | 0.084 |
| Arnavutköy | 0.319 | 0.092 | 0.173 | 0.000 | 0.000 | Güngören | 0.290 | 0.269 | 0.507 | 0.462 | 0.421 |
| Ataşehir | 0.437 | 0.097 | 0.247 | 0.055 | 0.048 | Kadıköy | 0.496 | 0.231 | 0.307 | 0.116 | 0.094 |
| Avcılar | 0.469 | 0.429 | 0.387 | 0.285 | 0.243 | Kağıthane | 0.465 | 0.191 | 0.197 | 0.051 | 0.045 |
| Bağcılar | 0.761 | 0.340 | 0.426 | 0.722 | 0.662 | Kartal | 0.492 | 0.474 | 0.274 | 0.108 | 0.088 |
| Bahçelievler | 0.619 | 1.000 | 0.548 | 1.000 | 0.892 | Küçükçekmece | 0.824 | 0.353 | 0.613 | 0.928 | 0.939 |
| Bakırköy | 0.234 | 0.194 | 0.938 | 0.641 | 0.590 | Maltepe | 0.538 | 0.277 | 0.315 | 0.143 | 0.132 |
| Başakşehir | 0.515 | 0.092 | 0.295 | 0.043 | 0.046 | Pendik | 0.759 | 0.265 | 0.273 | 0.119 | 0.103 |
| Bayrampaşa | 0.281 | 0.104 | 0.573 | 0.318 | 0.345 | Sancaktepe | 0.486 | 0.148 | 0.217 | 0.029 | 0.024 |
| Beşiktaş | 0.183 | 0.040 | 0.234 | 0.016 | 0.014 | Sarıyer | 0.358 | 0.133 | 0.200 | 0.020 | 0.021 |
| Beykoz | 0.254 | 0.300 | 0.221 | 0.015 | 0.016 | Şile | 0.043 | 0.054 | 0.164 | 0.000 | 0.000 |
| Beylikdüzü | 0.407 | 0.044 | 0.625 | 0.323 | 0.280 | Silivri | 0.214 | 0.079 | 0.427 | 0.036 | 0.027 |
| Beyoğlu | 0.239 | 0.110 | 0.459 | 0.133 | 0.152 | Şişli | 0.291 | 0.184 | 0.207 | 0.034 | 0.027 |
| Büyükçekmece | 0.275 | 0.115 | 0.486 | 0.176 | 0.156 | Sultanbeyli | 0.358 | 0.200 | 0.248 | 0.045 | 0.039 |
| Çatalca | 0.078 | 0.089 | 0.254 | 0.002 | 0.002 | Sultangazi | 0.556 | 0.058 | 0.144 | 0.035 | 0.027 |
| Çekmeköy | 0.295 | 0.189 | 0.121 | 0.001 | 0.000 | Tuzla | 0.291 | 0.142 | 0.500 | 0.164 | 0.172 |
| Esenler | 0.457 | 0.209 | 0.385 | 0.391 | 0.357 | Ümraniye | 0.743 | 0.409 | 0.181 | 0.026 | 0.017 |
| Esenyurt | 1.000 | 0.209 | 0.396 | 0.614 | 0.551 | Üsküdar | 0.537 | 0.175 | 0.199 | 0.058 | 0.043 |
| Eyüpsultan | 0.427 | 0.085 | 0.367 | 0.103 | 0.112 | Zeytinburnu | 0.301 | 0.237 | 0.557 | 0.409 | 0.380 |
| Fatih | 0.392 | 0.217 | 0.755 | 0.909 | 1.000 | | | | | | |

Step 3. Calculation of weighted sum values for districts:

By using Eq. (6) with normalized values presented in Table 7 and criteria weights given in Table 5, weighted sum values for each district were determined. Weighted sum values are presented in Table 8.

**Table 8.** Weighted sum values of districts

| Districts | Weighted Sum | Districts | Weighted Sum | Districts | Weighted Sum |
|---|---|---|---|---|---|
| Adalar | 0.282 | Büyükçekmece | 0.271 | Maltepe | 0.302 |
| Arnavutköy | 0.137 | Çatalca | 0.094 | Pendik | 0.339 |
| Ataşehir | 0.207 | Çekmeköy | 0.128 | Sancaktepe | 0.208 |
| Avcılar | 0.367 | Esenler | 0.383 | Sarıyer | 0.166 |
| Bağcılar | 0.610 | Esenyurt | 0.611 | Şile | 0.058 |
| Bahçelievler | 0.768 | Eyüpsultan | 0.255 | Silivri | 0.185 |
| Bakırköy | 0.555 | Fatih | 0.679 | Şişli | 0.159 |
| Başakşehir | 0.237 | Gaziosmanpaşa | 0.257 | Sultanbeyli | 0.193 |
| Bayrampaşa | 0.356 | Güngören | 0.402 | Sultangazi | 0.201 |
| Beşiktaş | 0.117 | Kadıköy | 0.273 | Tuzla | 0.281 |
| Beykoz | 0.159 | Kağıthane | 0.211 | Ümraniye | 0.292 |
| Beylikdüzü | 0.387 | Kartal | 0.285 | Üsküdar | 0.230 |
| Beyoğlu | 0.244 | Küçükçekmece | 0.766 | Zeytinburnu | 0.396 |

According to the results of the weighted sum model, Bahçelievler is ranked as first. It is followed by Küçükçekmece and Fatih, respectively. The population in Kağıthane is a bit higher than that in Bahçelievler, but the expected number of deaths in Bahçelievler is extremely high. Also, the population of Fatih is less than many districts, but the building damage criterion score of this district requires the district to be considered primarily. Şile has the last priority, which has almost the least risky values for damage from the earthquake.

Step 4. Calculation of weighted product values for districts:

Eq. (7) was used to obtain the weighted product values for districts. The results of the weighted product model are given in Table 9.

**Table 9.** Weighted product values of districts

| Districts | Weighted Product | Districts | Weighted Product | Districts | Weighted Product |
|---|---|---|---|---|---|
| Adalar | 0.082 | Büyükçekmece | 0.241 | Maltepe | 0.261 |
| Arnavutköy | 0.000 | Çatalca | 0.027 | Pendik | 0.254 |
| Ataşehir | 0.143 | Çekmeköy | 0.000 | Sancaktepe | 0.116 |
| Avcılar | 0.356 | Esenler | 0.376 | Sarıyer | 0.094 |
| Bağcılar | 0.587 | Esenyurt | 0.552 | Şile | 0.000 |
| Bahçelievler | 0.743 | Eyüpsultan | 0.206 | Silivri | 0.111 |
| Bakırköy | 0.473 | Fatih | 0.611 | Şişli | 0.108 |
| Başakşehir | 0.147 | Gaziosmanpaşa | 0.200 | Sultanbeyli | 0.135 |
| Bayrampaşa | 0.324 | Güngören | 0.390 | Sultangazi | 0.105 |
| Beşiktaş | 0.064 | Kadıköy | 0.226 | Tuzla | 0.251 |
| Beykoz | 0.086 | Kağıthane | 0.144 | Ümraniye | 0.127 |
| Beylikdüzü | 0.326 | Kartal | 0.229 | Üsküdar | 0.152 |
| Beyoğlu | 0.213 | Küçükçekmece | 0.737 | Zeytinburnu | 0.381 |

According to the results of the weighted product model, Bahçelievler is ranked as first, again. However, there were some small changes in the ranking of the districts. For example, Arnavutköy's priority value was decreased, since it has the least risky value in terms of expected number of deaths criterion. The utilization of a single model may lead decision-makers not take some points into account correctly. Therefore, an aggregated result of these two models may provide better results.

Step 5. Aggregation of weighted sum and weighted product values for districts:

Eq. (8) was used to determine the aggregated values of districts obtained from the weighted sum and weighted product models. Both of the weighted sum and weighted product models were considered to affect decision-making process equally, so λ value is assumed to be 0.5 and the resulting values are presented in Table 10.

**Table 10.** Aggregated values of districts

| Districts | Aggregated value | Districts | Aggregated value | Districts | Aggregated value |
|---|---|---|---|---|---|
| Adalar | 0.182 | Büyükçekmece | 0.256 | Maltepe | 0.282 |
| Arnavutköy | 0.069 | Çatalca | 0.061 | Pendik | 0.296 |
| Ataşehir | 0.175 | Çekmeköy | 0.064 | Sancaktepe | 0.162 |
| Avcılar | 0.362 | Esenler | 0.380 | Sarıyer | 0.130 |
| Bağcılar | 0.598 | Esenyurt | 0.582 | Şile | 0.029 |
| Bahçelievler | 0.755 | Eyüpsultan | 0.230 | Silivri | 0.148 |
| Bakırköy | 0.514 | Fatih | 0.645 | Şişli | 0.134 |
| Başakşehir | 0.192 | Gaziosmanpaşa | 0.229 | Sultanbeyli | 0.164 |
| Bayrampaşa | 0.340 | Güngören | 0.396 | Sultangazi | 0.153 |
| Beşiktaş | 0.091 | Kadıköy | 0.249 | Tuzla | 0.266 |
| Beykoz | 0.122 | Kağıthane | 0.177 | Ümraniye | 0.209 |
| Beylikdüzü | 0.356 | Kartal | 0.257 | Üsküdar | 0.191 |
| Beyoğlu | 0.228 | Küçükçekmece | 0.751 | Zeytinburnu | 0.389 |

It can be concluded from the aggregated values of districts that disaster preparedness planning in İstanbul must start from Bahçelievler district. The crowded population of the district and expected number of deaths and building damages in the district makes it be considered primarily in this context. Küçükçekmece, Fatih, Bağcılar, and Esenyurt follow the district, respectively.

## 4. Conclusion and Suggestions

Disaster management is of critical importance for policymaker in countries. There are four phases in this context, which can be listed as mitigation, preparedness, response and recovery. If it is too late to mitigate the disaster, detailed plans should be prepared for emergency response when the disaster occurs. Otherwise, the recovery process after the disaster could be harder for the community.

Istanbul is a major city in Turkey and it is expected that earthquakes at a magnitude greater than 7.0 will occur in the forthcoming decades. The crowded population and economic activities in the city show that it is impossible to mitigate the effects of the expected earthquake. For this reason, preparedness planning is crucial for policy makers in this city. However, scarce resources to be allocated for the preparation of these plans require a prioritization study among the districts in the city. In this study, ranking of Istanbul's districts was determined using a hybrid decision-making model based on SWARA and WASPAS.

The location of each district causes different levels of risk, and the possible damage in case of the earthquake is various. So, proposed multi-criteria analysis model provides an analytic basis for the ranking of districts. According to results obtained from the case study taking five criteria into account, Bahçelievler seems to have a priority for a preparedness planning for the expected earthquake and Şile seems to be the district, which will be affected less by the earthquake.

Many complex decisions related to disaster management requires consideration of several criteria simultaneously. Therefore, multi-criteria analysis of disaster management decision problems could be focused on by researchers in further studies for any type of disasters. The main limitation of this study is the limited number of criteria considered. In further studies, ranking results obtained by inserting other criteria that could affect the ranking of districts into analysis can be examined. Also, a comparison of ranking results of other weighting and ranking methods could also be presented.

Policy making for disaster preparedness is a key issue for governments and municipalities, because they have limited planning resources and they must successfully respond to the disaster. The results of the study could provide a scientific basis for preparedness planning to the expected İstanbul earthquake and may lead other researchers to use such analyses for other types of disasters.

**Statement of Research and Publication Ethics**

The study is complied with research and publication ethics.

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