Integrated Multi-Hazard Map Creation By using AHP and GIS

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Abstract: - Several scientific studies up to now propose that Istanbul may face a big scale earthquake as far as 30 year with an uncertainty of 15 years. Since 1999 the city of Istanbul received several studies based on earthquake hazard assessment, mitigation and recovery branches of disaster management. The main axis of those studies was to assess the vulnerability and estimate the possible results due the adverse conditions of the earthquake. However, the other hazards that can affect the life in Istanbul or that can occur following the earthquake were ignored. This study focus on ingesting all possible hazards that can occur in Istanbul with the weights give each of them by the expert opinions and creating a GIS toolbox to do these automatically.

Key-Words: - Hazard Assessment, Multi-Hazard Map, Disaster Management, AHP, GIS, Weighted Sum

1 Introduction

Istanbul has been the capital of several civilizations throughout the history. One of the most important features of this land is also the reason for the attraction on it. The city that unifies the two continents, Asia and Europe. Unfortunately this feature not only collect attraction but the consequence of the clash of continents that creates great earthquakes. As mentioned above, almost all of the civilizations confronted the earthquakes and its devastating consequences. These consequences were also take part inside the history and many researchers focused on them like Ambraseys did [1].

However, Istanbul is not only prone to earthquake hazards. There several other hazards, which were hit or have a possibility to hit Istanbul like earthquakes did. The main hazards for Istanbul are defined both in the disaster laws of Turkish Republic and Disaster and Emergency Management Directorate (AFAD) of Turkey. Those are;

- Earthquake
- Landslide
- Flood
- Fire
- Hazmat Leakage
- Tsunami

The aim of this study is to get all possible hazard's maps as raster maps, classify them into 7 classes, and merge them as multi-hazard map using geographical information systems (GIS).

The word disaster implies a sudden overwhelming and unforeseen event. At the household level, a disaster could result in a major illness, death, a substantial economic or social misfortune. At the community level, it could be a flood, a fire, a collapse of buildings in an earthquake, the destruction of livelihoods, an epidemic or displacement through conflict. When occurring at district or provincial level, a large number of people can be affected. Most disasters result in the inability of those affected to cope with outside assistance. At the household level, this could mean dealing with the help from neighbors; at the national level, assistance from organizations such as the International Federation of Red Cross and Red Crescent Societies, the United Nations, various non-governmental organizations (NGOs) and government agencies themselves. As the limiting factor in disaster response is often the coping capacity of those affected, improving their resilience when responding to disasters is a key approach to lessening the consequence of a disaster [2].

Disasters can be classified into two classes as natural and man-made disasters.

Natural disasters occur in proximity to, and pose a threat to, people, structures or economic assets. They are caused by biological, geological, seismic, hydrologic or meteorological conditions or processes in the natural environment (e.g., cyclones, earthquakes, tsunami, floods, landslides, and volcanic eruptions) [3].

Man-made disasters are disasters or emergency situations where the principal, direct cause(s) are identifiable human actions, deliberate or otherwise. Apart from "technological" and "ecological"

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disasters, this mainly involves situations in which civilian populations suffer casualties, losses of property, basic services and means of livelihood as a result of war or civil strife, for example: Human-made disasters/emergencies can be of the rapid or slow onset types, and in the case of internal conflict, can lead to "complex emergencies" as well. Human-made disaster acknowledges that all disasters are caused by humans because they have chosen, for whatever reason, to be where natural phenomena occurs that result in adverse impacts of people. This mainly involves situations in which civilian populations suffer casualties, losses of property, basic services and means of livelihood as a result of war, civil strife, or other conflict [4].

United Nations-International Strategy for Disaster Reduction's Terminology on disaster risk reduction defines the disaster management as "the systematic management of administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards" [5]. The disaster management accepted as a cycle with the connection of four phases as, preparedness, mitigation, response and recovery.

All those phases requires the hazard maps of respective area to design the phase accordingly. Up to now, strategies for disaster management were developed based on singular hazard events and singular hazard maps. This strategy lacks on taking the multiple hazards into account at the same time. At this stage multi-hazard maps acts when an area is exposed to more than one hazard. Organization of American States (OAS) [6] explains the multi hazard maps as "*a map helps the planning team to analyze all of the hazards for vulnerability and risk. By facilitating the interpretation of hazard information, it increases the likelihood that the information will be used in the decision-making process. In either the planning of new development projects or the incorporation of hazard reduction techniques into existing developments, the MHM can play a role of great value.*" OAS [6] also listed the benefits of multi-hazard maps as "*an excellent tool to create an awareness in mitigating multiple hazards. It becomes a comprehensive analytical tool for assessing vulnerability and risk, especially when combined with the mapping of critical facilities*".

2 Problem Formulation

As mentioned above, Istanbul has the potential to confront several hazards either simultaneously or by triggering each other. This situation has never been taken into account by the researchers by using the multi-hazard approach. Until now, most of the researchers studied each hazard one by one. But, merging all couldn't been established because of the units of all those different hazards.

For example, an earthquake hazard map created with the peak ground acceleration demand cannot be easily merged with a fire hazard map created with ignition or spread possibilities. This can also be explained with a saying in Turkey as summing the apples with the pears. So, to make a tasty fruit salad, first you need to select the proper pot, proper size for the fruits to be mixed and the proper fruits to be mixed.

The base of this study is to generate a simple method to merge various hazard maps together. By this way, the most effective way to bring different demand parameters is to classify them into number of classes based on national and international standards. After the classification each class represents an importance factor regarding to the respective hazard. The key factor on integrating the hazard maps is to have the same number of classes on each hazard map and to attain the class values based on the total or final decision of the final product. Which means, if the most dangerous areas on hazmat leakage are represented with the pixels with the highest class values on a five class representation, the most dangerous areas for the earthquake shaking intensity on a five class earthquake hazard map should be represented with the pixels of the highest class values. This strategy allows the integration based on classes. However, only classifying the zones are not enough for the hazard assessment. In disaster management every hazard may have different weight on others or overall. So, based on the study area, every hazard has to have a weight factor on each other. This canalize the study to the multi-criteria decision making process.

Multi-criteria decision problems include a set of alternatives from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria [7, 8]. Because of the inclusion of an explicit geographic component, spatial multi-criteria decision analysis (SMCDA) is quite different from conventional multi-criteria decision analysis (MCDA). Therefore, two components are of supreme importance for SMCDA. The first is the GIS component to acquire, store, retrieve, manipulate, and analyze data, and the second is the

MCDA component to aggregate the spatial data and decision makers' preferences into discrete decision alternatives [7, 9].

Generally, since the mid-1970s when it was first introduced, MCDA users choose to use an Analytic Hierarchy Process (AHP) tool which allows consideration of both objective and subjective factors in ranking alternatives. Since the 1970s, AHP has been applied in a wide variety of application areas such as location analysis [10], allocation [11], marketing [12], energy policy [13], education [14], risk analysis [15], environmental impact assessment [16], suitability analysis [17], and site selection [18]. AHP assists the decision making process by providing the decision makers with the opportunity to organize the criteria and alternative solutions of a decision problem in a hierarchical model.

This study, examines the weight of broad parameters which are accepted all over the world. All of the parameters discussed with the professional judgement. The AHP is used for factor weighting of each parameter and GIS are used for simulating the results of the AHP on a spatial environment.

AHP is a method that solves multi-criteria decision making problems involving objective as well as subjective criteria. Following four steps of AHP are used in this study. As the first step, the decision making problem is decomposed and the criteria and alternatives of the problem are exposed. Then linear hierarchy is constructed consisting of a finite number of levels and elements. In step 2, pairwise comparison matrices of all criteria are constructed. In step 3, individual weights of the criteria are determined from the pairwise comparison matrices obtained by using the eigenvalue method. At the end of the process, whole set of weights are synthesized by using the principle of hierarchical composition and then overall or global weights for the alternatives are obtained as the fourth step.

In this study, it is aimed to generate a hierarchical structure of the model for the simulation of an integrated multi-hazard map. The parameters of the integrated hazard map are selected by the criterion of non-correlated factors. Selected parameters are earthquake, tsunami, fire, landslide, flood, and hazmat leakage. Following the selection of the parameters, a pairwise comparison matrix is formed by comparing the parameters each other.

2.1 Earthquake

Istanbul is the biggest city of Turkey in terms of population, industry, and construction. Unfortunately, it is also one of the most seismically active cities in Turkey. In fact, the probability of an M ≥ 7 earthquake rupturing beneath the Sea of Marmara at the south of Istanbul is approximately 35–70 % in the next 30 years [19]. This has alarmed the citizens and the scientists into taking precautions against possible earthquakes. Several scientific and technical studies have been carried out for the region, and all suggest that the city must be prepared for earthquakes in accordance with the mitigation, response, and recovery activities based on the disaster management cycle.

The required earthquake hazard criteria input for this study were chosen from those that are required in attenuation relations. The most common form of an attenuation relation is found in Eq. (1) [20]:

$$\ln Y = F_M(M) + F_D(R_{JB}, M) + F_S(V_{S30}, R_{JB}, M) + \varepsilon\sigma_T$$

where F_M , F_D , and F_S represent the magnitude scaling, distance function, and site amplification, respectively, while M is the moment magnitude, R_{JB} is the Joyner–Boore distance, and V_{S30} is the inverse of the average shear-wave slowness from the surface to a depth of 30 m. This attenuation relation is used to create the earthquake hazard map of Istanbul for peak ground acceleration (PGA). Then the resulting hazard map classified into seven classes in order to show the lowest PGA demand value as the highest class value to determine the most suitable location with the highest class value as shown in Fig 1.

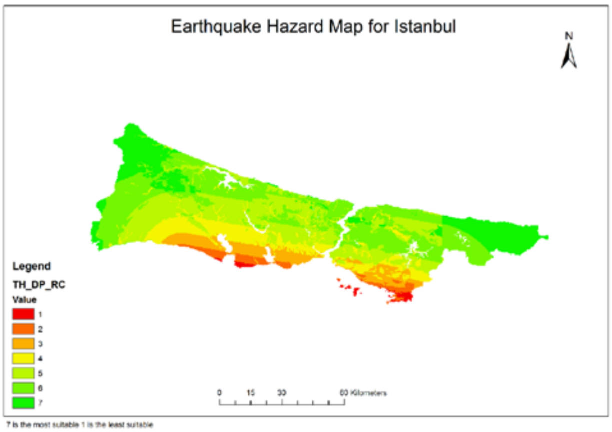

Figure 1. Istanbul Earthquake Hazard Map with 7 classes

2.2 Landslide

Cruden and Varnes [21] defines the landslides as a general term for gravitational movements of rock or soil down a slope (as a mass along discrete shear surfaces). According to [21], landslides can involve

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flowing, sliding, toppling, or falling, and many landslides exhibit a combination of two or more types of movements, at the same time or during the lifetime of a landslide.

Landslides are present in all continents, and play an important role in the evolution of landscapes. They can also cause catastrophic events in many areas of the world. According to [22], for a study area, preparing landslide maps is important to document the extent of landslide event, also it helps to investigate the distribution, types, pattern, recurrence and statistics of slope failures, to determine landslide susceptibility, hazard, vulnerability and risk, and to study the evolution of landscapes dominated by mass-wasting processes.

Duman et al. [23] states the landslides statistics in Turkey for the period of 1959–1994 from [24] as, “landslides damaged 76995 buildings throughout Turkey in addition to death of people, destroyed farming lands and roads etc.

Istanbul is also in a landslide prone region inside the Marmara region, due to having almost all the triggers together, like high seismicity because of the North Anatolian Fault Zone, medium to heavy rain rates and slope topographic conditions.

The landslide hazard maps are determined from the Istanbul Metropolitan Municipality (IBB) Microzonation Project [25]. The landslide susceptibilities are first classified into seven classes. Then the lowest class values are selected as the most hazardous regions for the landslide event to determine the most suitable location with the highest class value. The final landslide hazard map is created as in Fig. 2.

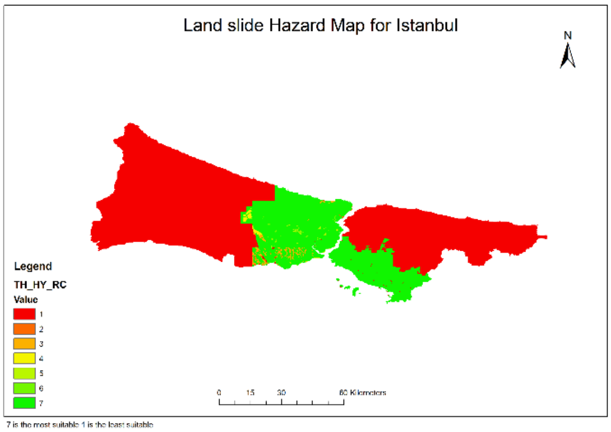

Figure 2. Istanbul Landslide Hazard Map with 7 classes

2.3 Flood

(National Flood Insurance Program) [26] defines the flood in Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems as “a partial or complete inundation of normally dry land areas from 1) the overland flow of a lake, river, stream, ditch, etc., 2) the unusual and rapid accumulation or runoff of surface waters; and 3) mudflows or the sudden collapse of shoreline land.”

Since the flood is accepted as a major hazard event and the city of Istanbul hit by the flood that cause almost tens of deaths and millions of dollars, it is important to determine a flood hazard map and ingest into the analyses. In September 2009 Istanbul consequence a flood event and lost 26 lives, with 9 missing people, 100 damaged vehicles and 2 billion Turkish Lira economic loss. Following the event, many scientists studied the flood event for Istanbul and now we have the ability to estimate the flood hazard for Istanbul. One of the major supplier for the flood hazard studies is IBB and their microzonation projects. The data which was acquired from the municipality for another study was used to determine flood hazard map of Istanbul. The map created by taking into account overland flow of all lakes, rivers, streams and ditches, the unusual and rapid accumulation of surface waters.

The resulting flood hazard map then classified into seven classes in order to show the highest floodplain susceptibility, flood depth and flood elevation value as the lowest class value to determine the most suitable location with the highest class value as shown in Fig 3.

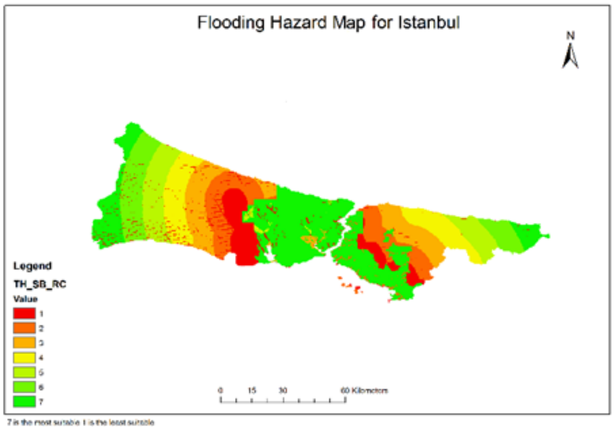

Figure 3. Istanbul Flood Hazard Map with 7 classes

2.4 Fire

Erden and Coskun [18] stated that in Istanbul, fire incidents tend to increase year by year in parallel with city expansion, population and hazardous material facilities. As they indicate in [18], Istanbul has seen a rise in reported fire incidents from 12769 in 1994 to 30089 in 2009 according to the interim report of IBB Department of Fire Brigade. The fire

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hazard map of Istanbul is determined from the Erden and Coskun [18] and classified into six classes. The reason for the one less class unlike the other hazards is in the fire ignition probability the highest class number is only six. As in previous hazard maps the lowest class value is matched to the areas that has the highest fire ignition possibility to determine the most suitable location with the highest class value as in Fig 4.

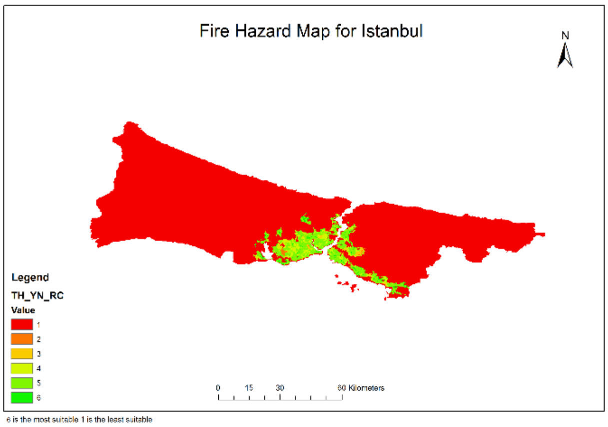

Figure 4. Istanbul Fire Hazard Map with 6 classes

2.5 Tsunami

As several researchers indicate at the TRANSFER (Tsunami Risk and Strategies for the European Region) project, shores of Istanbul exposed to tsunamis throughout the history starting from the year of 358 to 1935 [27]. Altinok et al. (2011) [27] also declares that "*the earthquakes in the Sea of Marmara and co-seismic slope failures usually cause damaging tsunamis in certain coastal areas, depending on their source characteristics, distance to the source and bathymetry. Such tsunamis may pose an important threat to the coastal settlements and installations on the shores of Istanbul.*" So, Istanbul has tsunami in the hazard inventory too. Most of the studies on tsunami also highlights that earthquakes are not the only reason for the tsunamis. Another important factor that can trigger the tsunami is underwater landslide.

The IBB microzonation project [25] generate the first tsunami hazard map for Istanbul. The importance of this hazard map is to have all factors that can generate a tsunami in Istanbul. That's why this map is determined for this study and classified again to determine the most suitable location with the highest class value. So, highest tsunami possibility regions represented with class value 1 and the lowest possibility regions which are the most of the city shown with seven class value as n Fig 5.

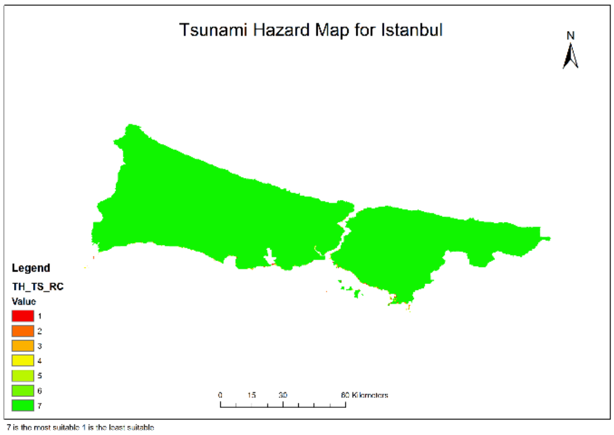

Figure 5. Istanbul Tsunami Hazard Map with 7 classes

As it can be seen from Fig 5, only some locations at the shorelines of Istanbul have the high tsunami possibility. That's why Fig 6 shows a large scale map of a sample shoreline of Istanbul with the highest tsunami possibility.

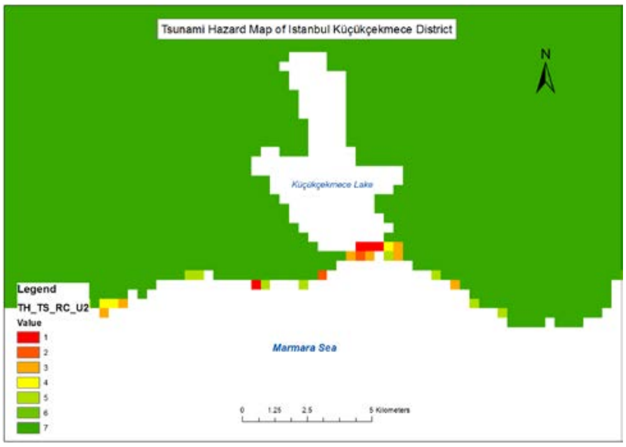

Figure 6. Kucukcekmece District Tsunami Hazard Map with 7 classes

2.6 Hazardous Material Leakage

Chemical, toxic or nuclear leakage generally taking into account as hazardous material (Hazmat) release within the disaster management society. Young et al. [28] explains the importance of this criterion as "*disaster-associated hazardous material releases are of concern, given increases in population density and accelerating industrial development in areas subject to natural disasters. These trends increase the probability of catastrophic future disasters and the potential for mass human exposure to hazardous materials released during disasters.*" As confronted in 2011 Tohoku earthquake and tsunami in Japan, Fukushima Dai-ichi nuclear power plant release radioactive material, which was

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the second largest nuclear disaster following Chernobyl event in 1986 [29].

To create a haz-mat hazard map of Istanbul all resources that can generate, stock, distribute chemical, toxic or nuclear materials in Istanbul city borders are investigated. After the investigation the type and capacity of all resources assigned as haz-mat points. Then a what if scenario is run to estimate the radius of each haz-mat point. The radiuses are applied by using a buffer analysis and as a result of these processes the haz-mat hazard map is created. Then the resulting map is converted to a raster map and classified into seven classes. Those classes are assigned just like the previous hazard maps to determine the most suitable location with the highest class value as in Fig 7.

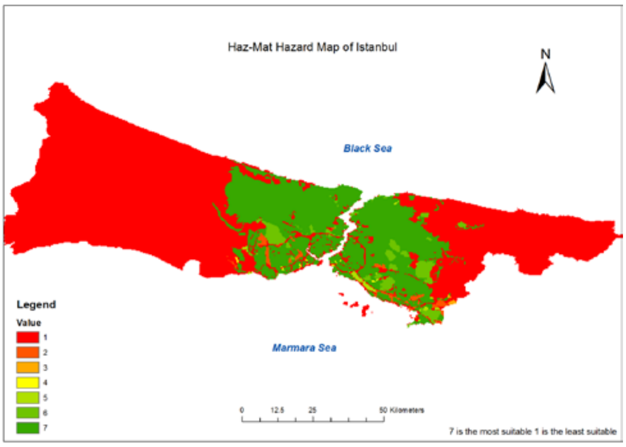

Figure 7. Istanbul Haz-Mat Hazard Map with 7 classes

3 Problem Solution

The AHP theory, published by Saaty [30], has now taken its place in decision making processes and studies. Since its invention, it has become one of the most widely used MCDA tools all over the world [31].

The third step of AHP includes the pairwise comparison. The pairwise comparison is the relative measurement of the dominance of one element over another according to the pairwise comparison scale (Table 1). At the final step, a synthesis of priorities or constructing an overall priority ranking is involved [30]. As a result of series of calculations which can be seen from the Saaty (1980) [30] study, consistencies of the expert's opinions are determined, after the inconsistent ones eliminated, from the consistent ones the weights of all hazard maps determined.

Table 1. Pairwise comparison scale [30]

Intensity of Importance	**Definition**
1	Equal Importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

According to the aim of this study, map creation is achieved by using geographic information systems (GISs). Map drawing must be based on cartographic standards to visualize the spatial data with respect to the aims and possible users of the product. Cartography science is interested in the usage and features of the graphic signs, drawing techniques, and projection, plotting and usage methods of maps in production and in use. Schoppmeyer [32] emphasized that the tone scale should not include more than seven tone values in cartographic representations of thematic maps. This visual and perceptive restriction is obeyed by constraining the number of the classes into five tone values. The ranges of the classes are determined with respect to scientific codes and approaches.

The data classification methods in GIS can be named as: manual, equal interval, quantile, natural breaks (jenks), and standard deviation. While the manual classification divides the total range of features from maximum to minimum into user specified ranges, the equal interval classification divides the total range of features from maximum to minimum into equal subranges. Both of these methods create an easy to understand legend and work best with continuously distributed data [33]. The data in this study are classified using both manual and equal interval methods.

Basic priority/weight determination for the criteria is achieved by carrying out questionnaires of people related to this subject area. The questionnaires are given to academics from different disciplines related to disaster management and are based on the pairwise comparison technique of AHP. To determine the criteria priorities/weights of the data, the questionnaire in Table 2 for forming the pairwise comparison matrix is prepared according to pairwise comparison scale of [30].

Table 2. Questionnaire for Integrated Hazard Map

Criteria	Pairwise Comparisons																	Criteria
	Extreme importance	Very, very strong	Very strong or demonstrated importance	Strong plus	Strong importance	Moderate plus	Moderate importance	Weak or slight	Equal Importance	Weak or slight	Moderate importance	Moderate plus	Strong importance	Strong plus	Very strong or demonstrated importance	Very, very strong	Extreme importance	
	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	
Earthquake (DP)									X									TS
										X								HY
										X								SB
											X							KM
												X						YN
Tsunami (TS)										X								HY
										X								SB
											X							KM
												X						YN
Landslide (HY)									X									SB
										X								KM
											X							YN
Flood (SB)										X								KM
											X							YN
Hazmat (KM)										X								YN
Name, Surname																		
Title																		
Profession																		
Institution																		

The questionnaire forms given in Table 2 are distributed to expert classes given in Table 3. The experts filled the forms based on their own opinions and understandings and by this way a different pairwise comparison matrix is determined for each expert.

Table 3. Institutions that participated in questionnaire

Institution Name	***Class***
Istanbul Technical University – Civil, Geomatics, Geology Engineering Departments	University
Bogazici University – Kandilli Observatory	University
Bogazici University – Economy Department	University
Middle East Technical University – Sociology Department	University
TU Wien	University
University of Tabriz	University
DASK (Natural Hazards Insurance Agency)	Public Enterprise
Turkish Red Crescent	Public Organization
Istanbul AFAD	Public Institution
Istanbul Metropolitan Municipality	Local Authority
AKUT (Search & Rescue Association)	NGO
MAG (Neighbourhood Disaster Volunteers)	NGO
GEA (Search & Rescue Group) INSARAG Member	NGO

Geometric means of all the paired comparison judgments from each expert are calculated for each question in order to reveal the aggregated group judgments. For a group decision making, the weight vector for the six criteria is computed in Table 3.

Criteria	***Weight***
Earthquake (DP)	0.074002659
Tsunami (TS)	0.074003731
Landslide (HY)	0.131638371
Flood (SB)	0.131638371
Hazmat (KM)	0.227223997
Fire (YN)	0.361492871
Sum	**1.000**

The creation of an integrated multi-hazard map requires spatial information and data of the related region. This information and data can only be managed by the use of a GIS following the rules of coordinate systems. This study achieved this by using an ArcGIS platform with the help of the ModelBuilder application, a tool of the ArcGIS software package that can create, edit, and manage spatial GIS models for special spatial studies. By using the created and determined various hazard maps in raster format as mentioned in section 2, the weighted sum analyses compiled.

The result of the weighted sum defines a constant parameter is generated to normalize the 1 to 7 classifications and the resulting map for the study is given in Fig 8. The coordinate system of both inputs and outputs are selected per the World Geodetic System 1984 (WGS84) Geographic Coordinate System (GCS) to minimize the deformation of the projections to distance and area calculations with the spatial data. Another advantage of the model is the ability to combine the maps of the model with the real-time Global Positioning System (GPS) data. Since the GPS coordinates are also in the WGS84 GCS system, there will be no loss of time in disaster management activities to project and operate both data.

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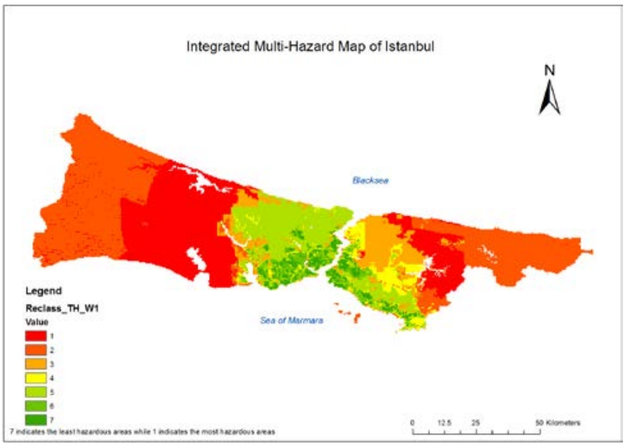

Figure 8. Integrated Multi-Hazard Map of Istanbul with 7 classes

An important contribution of this study is to compile a toolbox that can automatically generate the integrated multi-hazard maps for any given region with the presence of the required separate raster hazard maps. Fig 9 shows the toolbox flow in ArcMap.

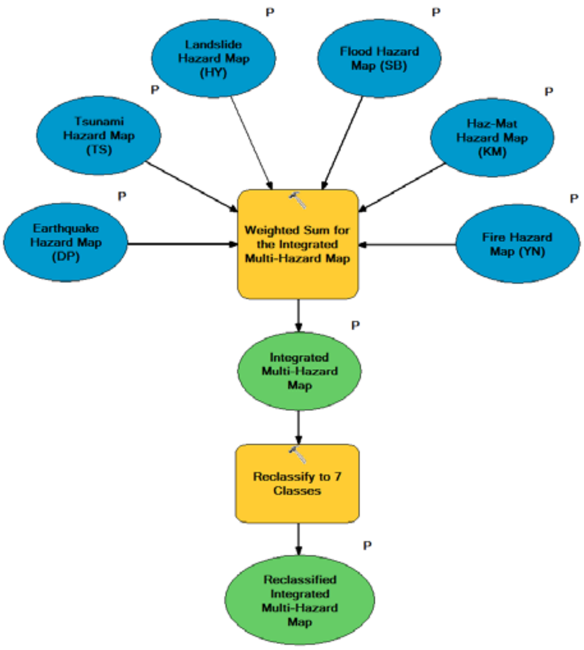

Figure 9. Integrated Multi-Hazard Map model chart from the modelbuilder

4 Conclusion

As a result of the study the map in Fig 8 represents an integrated hazard map of Istanbul with respect to most common and hazardous events. The integration compiled based on expert opinions of 16 experts of various disciplines interested on disaster management. One of the most valuable contribution of the study comes from the AHP, which takes various opinions and approaches into account, computes a geometric mean of all of those different points of view, and generates a consensus of them by creating a group decision. By this way, more comprehensive results can be obtained in integrated multi-hazard map generation.

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