Prediction of flood hazard map based on hybrid fuzzy geographic information system and its application for Ayamama watershed

Abdüsselam Altunkaynak and
Hussein Bizimana*

Istanbul Technical University,
Civil Engineering Department,
Maslak, 34467, Istanbul, Turkey
Email: altunkay@itu.edu.tr
Email: bizhu7@yahoo.fr
*Corresponding author

Abstract: This research aims to bring a new methodology to early flood management and warning. It proposes modelling one of Istanbul watersheds, the Ayamama watershed in Istanbul, Turkey for possible flood hazard using a new fuzzy-geographical information system hybrid approach. It expands the domain of flood hazard early warning and management that usually uses conventional hydraulic and hydrology approaches to a newly developing area of artificial intelligence in flood early warning and management. The research opted for a more technical study using both GIS and MATLAB software to model the flood hazard levels in Ayamama watershed. The methodology takes into account three factors to model the flood hazard map. Elevation, Euclidian distance from Ayamama creek and local urbanisation degree are the chosen factors. Results on how to identify flood hazard were demonstrated by providing a map of flood hazard zones with their respective negative levels of impacts.

Keywords: fuzzy-GIS; hybrid; flood; hazard; map; prediction; geographic information system; model; Ayamama; flood management.

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Biographical notes: Abdüsselam Altunkaynak is a Professor in the Civil Engineering Department at the Istanbul Technical University. He is the Head of Coastal Engineering Program and Head of Hydraulic Laboratory at the Istanbul Technical University. He has been an active International Researcher since 1999. He is an active member of the American Society of Civil Engineering (ASCE). He has published more than hundred scientific and research articles in his career and received numerous research awards.

Hussein Bizimana is a PhD candidate at the Istanbul Technical University and a active Young Researcher from the Rwanda. He works in the Department of Civil Engineering, program of the Hydraulic and Water Resources Engineering. His current PhD research focuses on the modelling the threshold of sediment entrainment using soft computing techniques. He previously has published numerous articles related to food risk and hazard modelling, irrigation optimisation and modelling and landslides mapping.

1 Introduction

Among natural disasters, flood has been found to be one of the most happening and destroying disasters in human society. In the ten year prior to 2011, the economic loss induced by floods was estimated to reach US $185 billion: nearly 31% of economic losses caused by natural hazards account for flood related disasters. Technically, flood occurs when, in a given time, normal dry land, which does not contain water or is not under planned inundation areas, is covered by water in a very short or short time (Alderman et al., 2012; Belmonte et al., 2011). Nearly 20% of the population in the world lives in coastal areas with highest population density and most of time subjected to the high risk of flooding. In developing countries, especially in countries located in regions with monsoon climate condition, most frequently are subjected to river flooding (Alderman et al., 2012). With the actual climate change happening all over the world, increase in soil moisture, deforestation to a high level, rapid urbanisation, open river channel and many floodplain modifications are actually identified as the very causing reasons around the earth which are increasing frequency and intensity of flooding and making its more destructive (AKOM Report, 2010). A meso-scale convective system, which affected the Marmara region (specifically the city of Istanbul) in north-western Turkey, produced intense rainfall events and caused catastrophic flash floods during the period of September 7–12, 2009. Intense rainfall events induced in accumulated rain totals of approximately 10 times the long-term average rainfall in Istanbul during the month of September. Torrential rain events caused the worst flooding in decades in the region. At least 24 people died in Istanbul only and with at least seven people died elsewhere in the Marmara region, in addition to considerable damages to property and losses of life (AKOM Report, 2010). Due to the increase in the frequency and intensity of flooding, observed very destructive flood impacts and a rapid increase in urbanisation, it is necessary and very important to improve how determination, localising and mapping of the flood hazard are done. Urban flooding maps can be used as robust, hazard assessment, supporting and appropriate tools for city and regional planning system, city expansion and their growth management (Al-Hanbali et al., 2011).

The objective of this study is to develop an urban flood hazard map based on hybrid fuzzy geographic information system (fuzzy-GIS) model. Moreover, this study aims to develop a decision support system for local decision makers, especially when there are flood hazards. Decision support can be commonly useful as a tool in industry, residential homes, workplaces, business and governmental institutions to improve quality and consistency of decision makers. It is of high importance during planning and scheduling of tasks in order to select appropriate decision factors and so that decision makers can easily select the optimum choice from the available alternatives (Tran at al., 2009). According to Nigussie and Altunkaynak (2016), the peak discharge in Ayamama Watershed increased as the urbanisation level and rainfall intensity increased. A number of studies have also showed this fact. Urbanisation modifies natural processes such as runoff and transpiration that it generates higher storm water runoff peaks and nutrient loads with the potential to cause damage to existing waterways, increase the risk of erosion and sedimentation and diminish water quality (Ridd, 1995; Arnold and Gibbons, 1996; Clarke et al 1997). Urbanisation is known to decreases the availability of pervious and permeable surfaces and as a result, smaller more frequently occurring storms can increased runoff and create flooding problems (Ackerman and Stein, 2008). In this study, therefore, urbanisation levels are taken as input variable for urban flood hazard map based on hybrid fuzzy-GIS model. A new predictive model was developed to predict flood hazard based on fuzzy model. For this objectives, elevation, distance from mainstream and urbanisation level were used as inputs into the fuzzy model. Then the fuzzy model results were used as input into the fuzzy-GIS to produce flood hazard map.

The presented mixture of processing topographical information and other geographical information system data in ArcMap using GeoRAS gives us the capacity to create and export a geometry file to be investigated by river analysis system (RAS). The created geometry file holds information on river, catchment and all station cross-section cut lines, bank stations, flow path. It achieves lengths for left and right overbanks and channel and roughness coefficients and furthermore can contain blocked obstructions. The results of RAS reproduction, as an example, river profiles, can be sent thematically and specifically to a fuzzy-GIS environment, where the aide of the GeoRAS tool can analyse them further (Malczewski, 1999).

The objectives of this study are to:

1 Predict flood hazard based on fuzzy model.

2 Develop hybrid predictive model by combining fuzzy logic and GIS-based model.

3 Use the results of fuzzy model as inputs into fuzzy GIS in order to develop flood hazard map.

2 Material and methods

2.1 Description of the study area

The study area is located in North-western Turkey, the part of Turkey that comprises Marmara region and especially the city of Istanbul (41.01_N, 28.58_E) as depicted in Figure 1. Istanbul city is known to be highly an urbanised city, where the city has grown rapidly over the past 50 years and therefore showed large expansion in settlements. The Bosporus strait, which connects the Black Sea with the Sea of Marmara, is a natural boundary between Europe and Asia and the current urban Istanbul is located on both sides of the southern half of it. Protected forest patches mostly cover the northern part of the city near the Black Sea and thus the expansion of the city in that direction is mostly confined to the cliffs along the Bosporus strait. Therefore the city expands Southward, with the most densely populated parts of the city lying in the south, along the Sea of Marmara. The study area, particularly focus on the Ayamama Watershed in the province of Istanbul which has a gentle surface with small hills, a shallow valley and mountains up to an altitude of 220 m. The southern parts of Istanbul province show generally the characteristics of the Mediterranean climate, instead in the northern parts of the city; this Mediterranean climate is somehow modified by the cooler Black Sea and northerly colder air masses of maritime (AKOM Report, 2010).

2.2 The weather condition of the study area

Istanbul city knows moisture contained mid-latitude cyclone winds during winter months (AKOM Report, 2010); thus, most of the precipitation falls in winter. Summer months are known to have the lowest rainfall amounts (AKOM Report, 2010). During the summer and partially during fall, the contribution from convective or mesoscale rainfall becomes important, especially when they are embedded in synoptic-scale disturbances. Under these cases, the location of mature convective cells determines the type of precipitation whether it is dominantly convective or frontal. The diversity of the geographic structure, extension of the mountains and effects of the seas in the vicinity of the land determine the climate types and precipitation regimes of the region. Over a given period from 2006 through 2009, much of the rainfall in Istanbul is seen in November to February with the maximum-recorded rainfall 180.0 mm in February only in 2009 and the lowest level of rainfall is recorded in from June through July with the lowest rainfall value recorded as 5.0 mm in June 2009. Figure 2 indicates different annual weather characteristics of Istanbul (AKOM Report, 2010).

Figure 1 Ayamama region (see online version for colours)

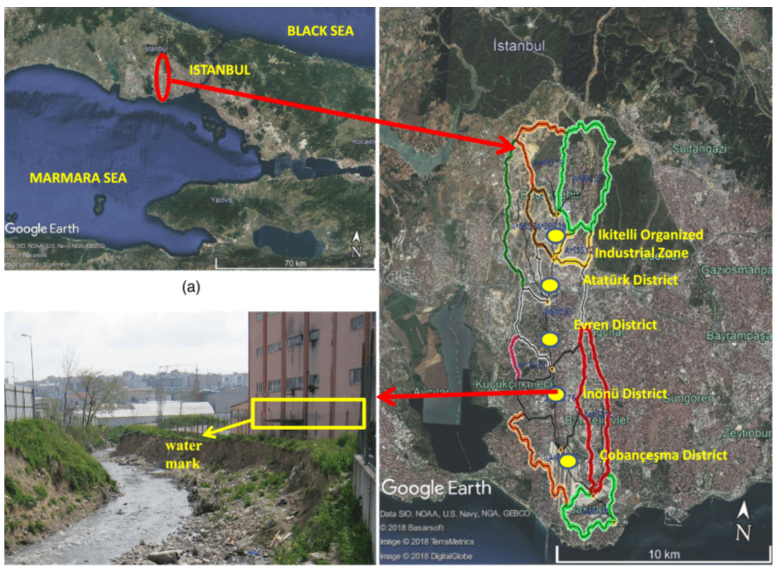
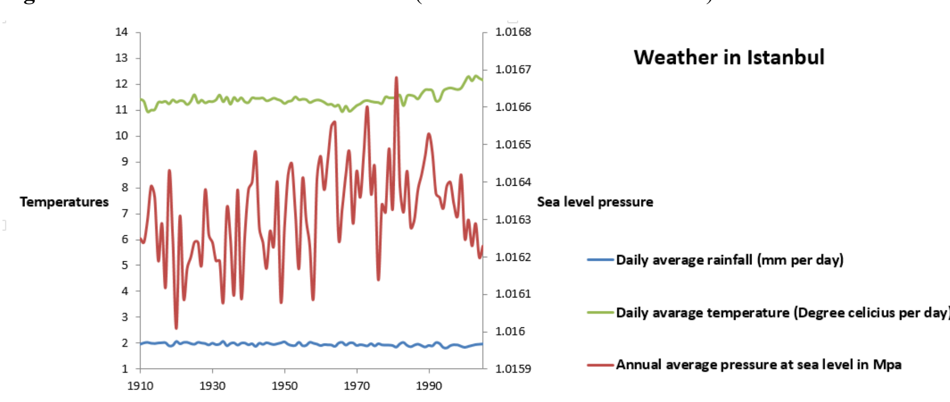


Figure 2 Weather conditions in Istanbul (see online version for colours)



Source: AKOM Report (2010)

2.3 Data collection and analysis

Data were obtained from topographical maps of the study area collected from Istanbul Metropolitan Municipality Water Works and Canalization Administration (ISKI). Data comprise of a digital elevation map (DEM) of the study area, population density maps from 1987 to 2015. Data analysis and calibration of fuzzy-GIS models were made by the help of expert knowledge.

2.4 The negative impacts of floods in Ayamama watershed

Flood can be defined as one of the most dangerous, devastating and most frequent natural disasters in human civilisation. It causes water to leave its natural way and to overflow in the areas which are not usually subjected to water flows or not planned for such inundations and water level rises rapidly more than in a normal situation and this happens in a relatively short time. Flood disaster as other natural disaster is found to bring with it tremendous short term and long term impacts on human and animal lives, on sanitation and disturbing the normal quite environment, socio-economic conditions within a given society. Technically, following are the flood's direct impacts; property and infrastructure loss, damages found on building and negative impacts in agriculture sector are considered and found health related problems, diminish water quality, water-borne infection related, chemical pollution related are known as indirect flood's effects (AKOM Report, 2010). Urban extent is related with mega projects and human settlements based activities such as unstudied and unplanned urban expansion, land use and land cover changes, unplanned building constructions, high deforestation rates are tending to be followed by high rate of erosion. Deforestation and change in vegetation cover affect the hazard's occurrence and most dangerously increase its frequency to happen (AKOM Report, 2010). Consequently, urban expansion level tends to increase runoff coefficient. In the other words, volume of runoff into the urbanised area brings in a boosting impact on flood increase due to the increment of peak discharge and water volume (Al-Habali et al., 2011). Turkey knows multiple flood events all over the country as the most common natural disaster that causes multiple hard to the population and livestock. Ayamama Watershed in Istanbul has been affected by several flash flood events following high rainfall frequency and intensity, snowmelts and urbanisation with lack of proper planning prior to floods. In July 1995, Ayamama Creek in Istanbul flooded and damages caused were valued at 40 million US Dollars. In 2009, this same Ayamama Creek flooded and killed 31 people and this time damages were valued at 150 million Euros. In this study, a developed fuzzy-GIS model was carried out in Ayamama Watershed to provide flood hazard map. Fuzzy logic was considered herein for its robustness to solve uncertainties, quickness and reliability. Moreover fuzzy logic is preferred on hydraulic approaches that were previously used to map flood problems in the Ayamama watershed because of their entanglement in calibration, high amount of data needed and unreliability to solve flood hazard uncertainties.

2.5 The effects of variables on the flood hazard map

In this study, a robust and intensive reading of different literature of almost similar works was conducted and researchers assessed all possible factors that take influence through similar research studies to identify and define appropriate variables to determine the most probable flood hazard maps in Ayamama watershed. Following variables were selected: elevation, Euclidian distance from Ayamama creek and urbanisation level were used as inputs into fuzzy model in order to predict flood hazard. The results of fuzzy model were used as input into fuzzy-GIS based model to produce urban flood hazard map in Ayamama watershed.

2.5.1 Distance from main stream

It is found that regions located near the water sources such as streams and rivers are highly subjected to high hazard of flooding. Water overflow happening during the flood incident makes the regions adjacent to the water source much more negatively affected and repeatable vulnerable and influenced by flooding. Moreover, this becomes more severe if no flood protection structures such as embankments or levees are present (Chang and Franczyk, 2008; Jacobson, 2011; Hladík, 2014).

2.5.2 Elevation

Topography and physical characteristic found in any environment must be considered with respect to its risk exposure to hazard vulnerability in the environment. Topography affects the severity of the flood, flow size and volume and its direction (Aydi et al., 2013). Normally, region that has a low elevation is affected by flood more than a region or land with high elevation if no flood protection structures are available alongside the water sources. Additionally, it was observed that water remains in the lower regions or places for relatively longer time when compared to higher region or places (Chang and Franczyk, 2008). Low placed region is defined as the most vulnerable region at the time of flooding following the happening of a quick inundation. Because of water gravity, water is pulled toward low placed region that makes the flood impact highly significant (Phong et al., 2009; awal et al., 2012).

2.5.3 Land use and land cover

Flood disaster incidents are also highly influenced by the types of land use and land cover found in any floodplain environment. Measured infiltration capacity is very different from a type of land use to another type of land use category. The impervious surfaces that cover most parts of urbanised region, have the lowest infiltration capacity. In this regard, we only can say that flood events conversely relates to the present type of vegetation and its density. Vegetation cover and present green places protect the land cover at the same time bringing into control runoff and water over flow speed to relatively slow and not scouring velocity by reducing flow kinematic energy (Camarasa et al., 2011; Shoueler et al., 2009). Therefore urbanised areas with many impermeable covered surfaces and lack of vegetation and green spaces, is not prepared enough to tackle with flow velocity and water stagnation followed by the increase of peak discharge. The latter leads to flash floods and brings the whole region to be highly influenced by floods (Malczewski, 1999; Liu et al., 2008; Mirzapour et al., 2011).

2.5.4 Population density and urbanisation level

Population density and urbanisation extent are provide the information that helps to recognise the area found with higher density of the population. It can be concluded that an area with higher population density goes with more people, infrastructure components and is likely to be affected by the flood. A high runoff coefficient indicates the acceleration of the runoff which is turned into floods (Mohd et al., 2006; Itami and Cotter, 2012; Tao et al., 2008; O'Driscoll et al., 2010; Schueler et al., 2010).

2.6 Description of the present methodology

2.6.1 Fuzzy-GIS and types of membership functions

In this study, the proposed methodology consists of a fuzzy inference system comprising of three inputs and one output. The fuzzy model constructs a link between inputs and output. Three inputs variables used herein are the elevation, distance from Ayamama creek and urbanisation level. These variables were used to predict flood hazard based on the fuzzy logic approach. Furthermore, the results of the fuzzy model were used as inputs into the fuzzy-GIS to further produce urban flood hazard probable maps. For this purpose, each variable was divided into a number of fuzzy sets. Moreover, in order to categorise the variables' impact to flooding, weights were assigned to each of fuzzy sets and fuzzy IF-THEN rules, by basing on the expert view and knowledge to specify the level of importance to flooding (Aydi et al., 2013; Ridd. 1995; Sonmez and Bizimana, 2018).

The type of fuzzy membership functions (MFs) has to be set for each criterion to assign the level of risk and find the right layout (Alderman et al., 2012). Fuzzy memberships have to be selected based on the data characteristic and mostly the way that data affect the hazard of flooding (Phong et al., 2009). In this study, the researchers use three types of fuzzy membership functions. The latter are the fuzzy MS small, fuzzy small and fuzzy large. The types of MFs are used to generate the fuzzy data layer in GIS environment (Chang and Franczyk, 2008; Sonmez and Bizimana, 2018). Additionally, fuzzy MS small is used when very a small value is having higher probability to be part of a given dataset (Chang and Franczyk, 2008). For example, the elevation layer dataset is defined in the range from 7 m to 220 m; considering an area of elevation less than 5 m as the highest possibility in terms of flood occurrence. Therefore, the methodology used herein consider the elevation layer to be extremely very small; therefore the elevation in the methodology presented herein was evaluated and fuzzified by using fuzzy MS small function in GIS (Chang and Franczyk, 2008, Sonmez and Bizimana, 2018). Furthermore, fuzzy large was used when a larger value is having more probability to be a member of a given dataset while fuzzy small was used when the value with smaller amount have more probability to be part of a given dataset (Chang and Franczyk, 2008, Sonmez and Bizimana, 2018). As a fact, fuzzy large membership function can be used to set the slope level of impact (in terms of angle) and population density layers where the higher the data means the higher the risk (Aydi et al., 2013). It is found that other layers like distance from river or discharge channels were arranged by using the fuzzy small function if the distance in question is not that large if large it will be fuzzy MF small (Aydi et al., 2013; Demir and Kisi, 2016). The application of MFs as a modelling method provides a way to classify given data in the range from 0 to 1 regarding level of membership. For example, values which are assigned 0 do not have any possibility for flood occurrence at all, while the value of 1 defines the locations with highest possibility of flooding (Aydi et al, 2013). Finally, weights are assigned to each variable based on its implication level in flooding.

In fuzzy logic, the effects of variables are connected using IF-THEN based rules. To represent a given scenario, one or more variables can be connected using IF-THEN rules and assigning different weights to them in order to give the most probable input-output relationship. For example, three different variables X, Y and Z can be connected using IF-THEN rule base to give a targeted output T:

R_1 IF X(1), Y(2) and Z(3) THEN T

R_2 IF X(2), Y(1) and Z(1) THEN T

R_3 IF X(3), Y(2) and Z(2) THEN T

These rules were used to converts inputs into outputs. Where R_1, R_2 and R_3 are fuzzy base rules and fuzzy membership functions legend such as low, medium and high. For every output, T, IF-THEN fuzzy rules are used to obtain numerical values, with different techniques used for defuzzification such as centre of centroid method (Ross, 2004). Combining variables into fuzzification also different types of connectors are used, among them logical AND, logical OR, SUM (Upadhyay et al., 2017). In order to be able to make a correct decision, the outputs from each rule in a fuzzy inference system is taken into aggregation. Then truncated output functions that are the result of implication process of each rule are subjected into aggregation too in order to form the final fuzzy set (Altunkaynak, 2010; Altunkaynak et al., 2005).

2.6.2 Developing flood hazard map based on hybrid fuzzy-geographic information systems model

In order to develop flood hazard map, a fuzzy logic based model, physical variables that effects the occurrences of floods in any given region must be studied (Camarasa et al., 2011; Malczewski, 1999). There are mainly two different fuzzy inference systems including by Mamdani (1974) and Takagi and Sugeno (1985). The Mamdani approach works very well with verbal data or expert knowledge (Altunkaynak, 2010; Tutmez and Hatiboglu, 2010; Altunkaynak, 2014; Gondesi et al., 2017). It can be applicable and useful where numerical data is not available (Mondal and Roy, 2017; Sonmez and Bizimana, 2018). On the other hand, the Takagi-Sugeno approach is very effective when a length amount of numerical data is available. In this study, the Mamdani method (Mamdani, 1974; Bizimana et al., 2016) was used to predict flood hazard. The elevation, distance from Ayamama creek, urbanisation level variables were used as inputs into fuzzy model based the vulnerability assessment to flooding hazard of different locations in Ayamama watershed. Then the results of fuzzy model were used as inputs into fuzzy-GIS based model to produce urban flood hazard map.

2.6.2.1 Elevation

In this study, the elevation variable of dataset is defined in range from 0 to 220 m; considering an area of elevation less than 5 m as the highest possibility in terms of flood occurrence. Therefore, membership function of the elevation variable is categorised into three fuzzy sets legend as low, medium and high as shown in Figure 3. It became standardised by using fuzzy MS small function small in GIS environment. In this study, elevation variable of the study area change from a lowest elevation of 7 m up to the river 220 m upland.

Figure 3 Elevation variable fuzzy sets

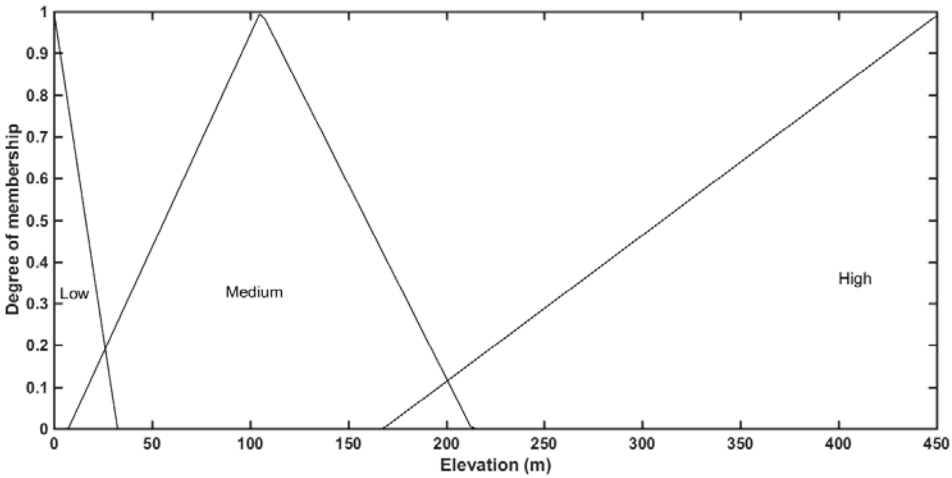
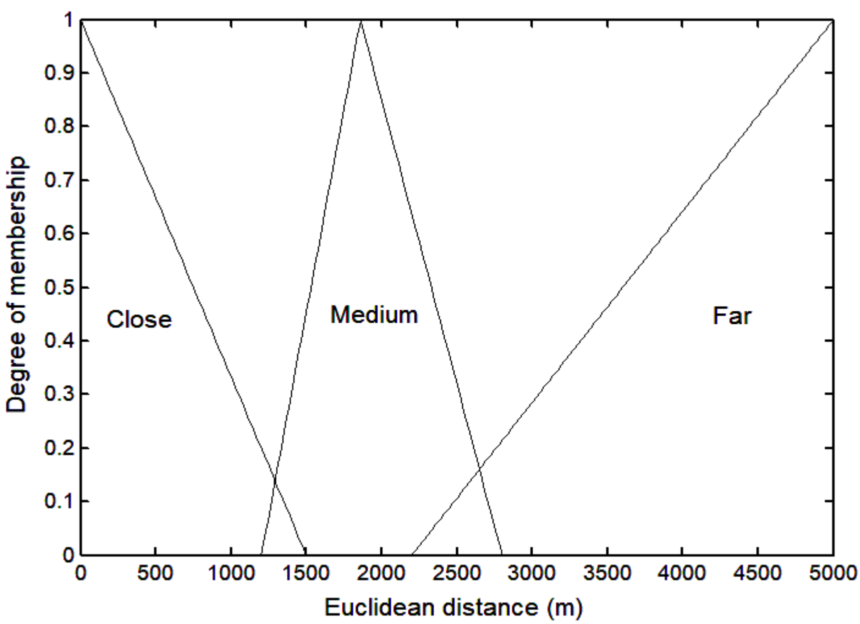


Figure 4 Euclidian distance fuzzy sets



2.6.2.2 Distance

In this study, distance from river bed (discharge channels) was calculated by using the fuzzy small function in GIS; but if the distance in question is not that large if the distance being evaluated very large it will be fuzzy MS small a buffer zone of 5,000 m from Ayamama creek. With 0 m to 1,500 m as the close zone or zone 1, 1,200 m to 3,000 m as the average zone or zone 2, from 2,700 m to 5,000 m as a far zone or zone 3. This variable requires the use of fuzzy MS Small in GIS, because a place at 5 m from the River is far more under high danger that a place at 1000 m (Mirzapour et al., 2011; Demir and Kisi, 2016). The Euclidean distance is divided into three fuzzy sets labelled as close, medium and far as shown on Figure 4.

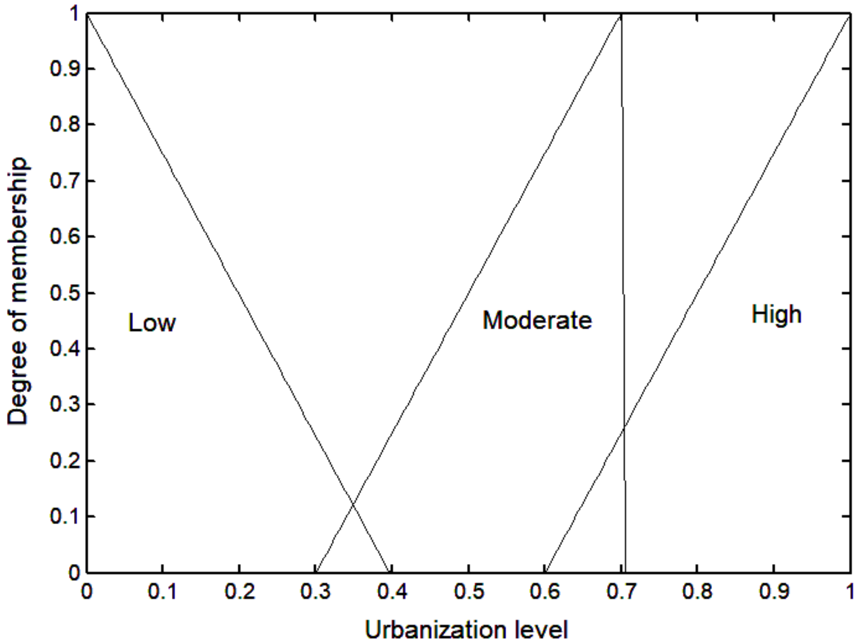
2.6.2.3 Urbanisation level

Urbanisation distribution in Ayamama is complex with many people residing in this part of Istanbul city and closer to the Ayamama creek. Moreover, many commercial and industrial properties in the region make those people and properties residing or working in a close distance from Ayamama creek likely to be highly effected by floods. In this study, subclasses aiming at assigning the level of negative impacts that result from floods when any flood happens are formed. Furthermore, places with high urbanisation level are the ones defined as the zone with high flood hazard probability. Urbanisation level categorised subsets are assigned in the range between 0 and 1 with 0 no urban areas to 1 with high densely urbanised areas. In this study, urbanisation level is categorised into three fuzzy sets named as low, moderate and high as depicted on Figure 5.

In this study, relationship between considered variables including elevation, distance and urbanisation level to predict flood hazard using fuzzy-Mamdani inference system. flood hazard membership function is divided into five fuzzy sets legend as very low (VL), low (L), average (A), high (H) and very high (VH) indicated on Figure 7. In fuzzy logic approach, fuzzy rules are determined based on expert knowledge or available data for calibration of fuzzy model (Altunkaynak, 2010; Altunkaynak et al., 2005).

In this study, 19 IF-THEN fuzzy base rules are identified based on expert knowledge and the interaction of considered physical variables that cause floods in Ayamama Watershed. It was noted in Ayamama watershed that based on field visits and previous floods history in Ayamama watershed, the best modeling results are found when elevation variable is given higher weightage than other variables namely distance from Ayamama Creek and urbanisation level. High risk to flood damages is characterised by low elevation, close distance to Ayamama Creek and high urbanisation level, in fuzzy logic membership degree. When Low elevation is combined with far distance with also urbanisation level, then flood hazard intensity reduces to low hazard. Furthermore, if high elevation is combined with far distance and high urbanisation level, the Flood risk intensity reduces to Low hazard. 19 combinations IF-THEN rules base are determined in order to provide the best flood hazard map based on hybrid fuzzy-GIS model as presented in Table 1. Some rules are given as follow: IF elevation is low and distance is close and urbanisation level is high THEN flood hazard is high, this rule is given weight 1, which means full impact, following its played role in flood hazard intensity modelling. IF elevation is medium and distance is far and urbanisation level is high THEN flood hazard in low, this rule is given weight 1, which means also full impact to flooding in Ayamama watershed.

Figure 5 Urbanisation level fuzzy sets



The relationship between elevation, distance and urbanisation level variables is further depicted as these following three fuzzy rule examples (R4, R7 and R8) with their membership degrees depicted in Table 2. In the defuzzification process, the elevation, distance and urbanisation level values are calculated as follows: 129, 873 and 0.343, respectively. Given the elevation = 129 m with Moderate and High fuzzy subsets of elevation, distance = 873 m with Close fuzzy subset of distance and urbanisation level = 0.343 with low and moderate fuzzy subsets of urbanisation level were triggered. Based on triggered minimum membership degrees the elevation, distance and urbanisation level variables were converted into truncated trapezium for each rule on the consequent part as depicted on Figure 7. It is required to obtain a numerical value from these combined fuzzy subsets for hydraulic engineering design aims. This process is termed as defuzzification in the fuzzy logic approach and on Figure 7. The targeted crisp result calculated as 0.331 is displayed after defuzzification process. In addition, in this study, the centroid defuzzification method was used to obtain a crisp numerical value as shown in Figure 6. Given the fuzzy set for any x variable in range $[x_1, x_2]$ with membership degree $\mu(x)$, generally the centroid defuzzification result, R can be calculated as (Ross, 2004; Altunkaynak, 2010):

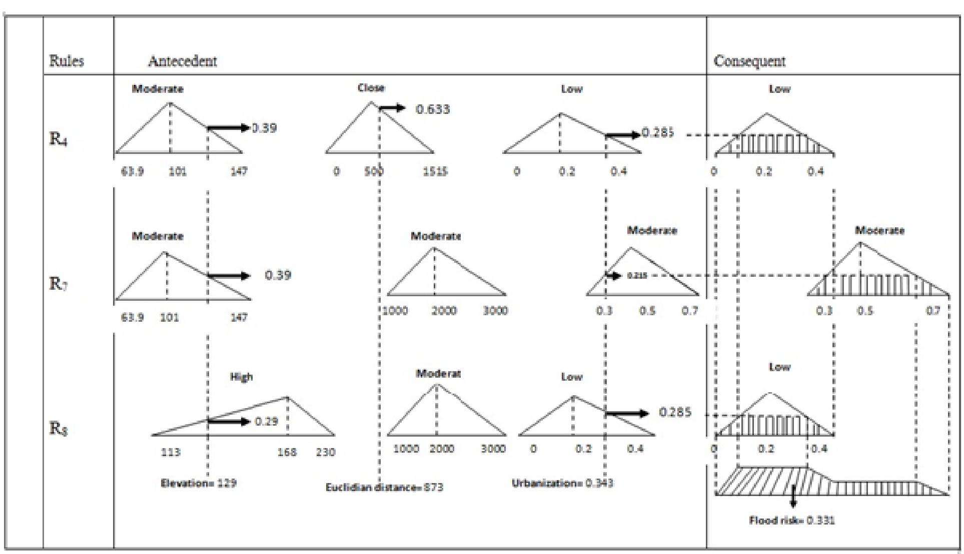
$$R = \frac{\int_{x_1}^{x_2} x\mu(x)dx}{\int_{x_1}^{x_2} \mu(x)dx} \tag{1}$$

A numerical value can be computed by this formula using fuzzy inference sets as shown on Table 2.

Table 1 Fuzzy IF-THEN rules

Rule	*Inputs*		*Output*		*Weightage*
	IF antecedent		*THEN consequent*		*W*
Numbers R	*Elevation*	*Euclidean distance*	*Urbanisation level*	*Flood risk*	*1*
1	Low	Close	High	Very high	1
2	Low	Close	Moderate	Very high	1
3	Moderate	Close	High	Moderate	1
4	High	Close	High	Low	1
5	High	Moderate	High	Very low	1
6	High	Far	Low	Very low	1
7	Moderate	Moderate	Moderate	Low	1
8	Moderate	Far	Moderate	Very low	1
9	Moderate	Moderate	High	Low	1
10	Moderate	Close	High	Average	1
11	Moderate	Close	Moderate	Low	1
12	High	Far	Low	Very low	1
13	Low	Close	Low	Average	1
14	Low	Moderate	Low	Average	1
15	Low	Far	Low	Low	1
16	Moderate	Far	Low	Very low	1
17	Moderate	Moderate	Low	Very low	1
18	Moderate	Moderate	Moderate	Low	1
19	Moderate	Moderate	Moderate	Average	1

Figure 6 Elevation, distance and urbanisation level antecedent and consequent of fuzzy rules



The proposed methodology herein combines the geospatial capacity and robustness of the GIS and the expert knowledge based fuzzy logic approach that accurately deals with the flood hazard uncertainties. It is named as the hybrid fuzzy-GIS. Additionally, where the hydraulic and hydrological approaches are not efficient to solve flood geospatial uncertainties, the proposed approach offer a solution.

3 Results and discussion

In this study, a new hybrid fuzzy-GIS model is developed to provide a flood hazard map. Flood risk is predicted using three variables including elevation, distance and urbanisation level as inputs into the fuzzy model. Then the results of fuzzy models were used as input into fuzzy-GIS based model to produce urban flood hazard map. The each physical variables including elevation, distance and urbanisation level were divided into three fuzzy sets (see Figures 3 to 5). Likewise, the output variable, which is flood hazard, was categorised into five fuzzy sets. Subsets for elevation were assigned as low (L), medium (M) and high (H). The subsets for distance were defined as close (C), medium (M) and far (F) and subset for urbanisation level were defined as low (L), medium (M) and high (H). Finally, the flood hazard was divided into five subsets too as very low (VL), low (L), average (A), high (H) and very high (VH) as shown in Figures 3 to 5 and Figure 7, respectively. In fuzzy approach, after partitioning process of variables into subsets, the fuzzy rule base is determined relying on expert knowledge or available data. In this study, 19 fuzzy base rules and fuzzy sets are identified based on expert knowledge as presented in Table 1. The results of fuzzy model were used as input into fuzzy-GIS model in order to provide flood hazard map. The developed fuzzy GIS model was implemented in Ayamama Watershed to determine urban flood hazard map with flood hazard zones. The flood hazard map is produced using a hybrid fuzzy-GIS model as shown in Figure 8. Using fuzzy-GIS hybrid model a total area of 10.42 km^2 is covered by flood hazard of very high to high fuzzy sets. In fuzzy logic, the level of hazard to occur is given in fuzzy sets varying from very high to high level of flood hazard rather than being said to be definitely high. The results of fuzzy-GIS based model are categorised into five fuzzy subsets representing flood hazard danger as, very low (VL), low (L), average (A), high (H) and very high (VH) as shown on Figure 7.

The fuzzy flood hazard map as indicated on Figure 8 shows that the flood hazard decreases to the East of the Ayamama creek towards Bahçelievler and to the West of the creek towards Küçükçekmece following the change in topography, land use and land cover in East and West of the Ayamama creek. Regions with very high and high level of flood hazard are found at both sides along the Ayamama creek and are highlighted by clear and dark blue colors on the flood hazard maps. The latter vary with the highest risk region located close to Ayamama creek, which to our knowledge, has no flood protection structure. This risky region gets wider downstream of the Ayamama creek towards Bakırköy, following considerable decrease in elevation and its considerable high intensity in urbanisation. Regions having low flood hazard risk are within the far reach from the Ayamama creek.

Figure 7 Flood hazard fuzzy sets

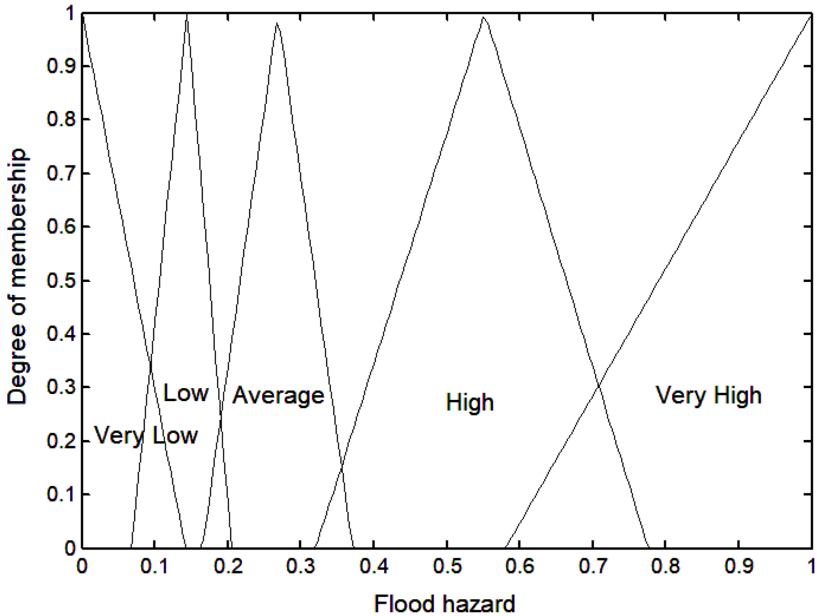
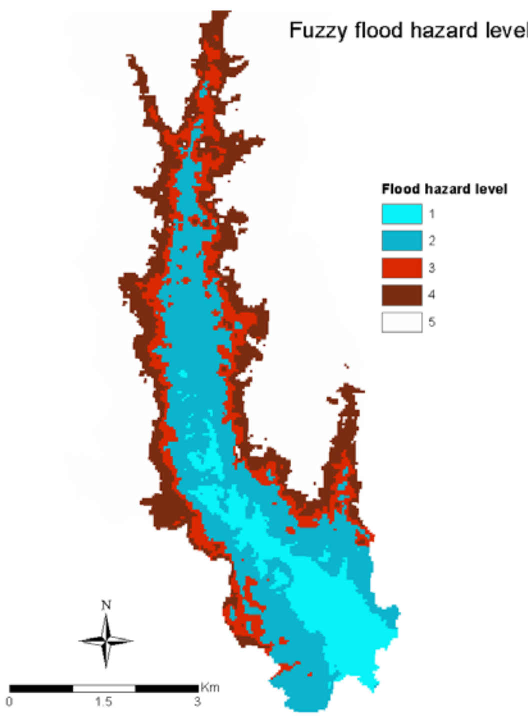


Figure 8 Fuzzy GIS flood hazard map for Ayamama watershed (see online version for colours)



4 Conclusions

Flood risk is a product of the flood hazard with the damage caused by that flood event. Finding the most probable flood is mostly made using different hydrological and hydraulic modelling. It is highly uncertain to measure the flood hazard and risk of a given flood event using straight hydrological models on time. This is because a lot of time, expertise and enough financial means are required. In this study, a new predictive hybrid fuzzy-GIS model was developed to predict flood hazard on a map. The elevation, distance and urbanisation level were used as inputs to fuzzy model in order to predict flood hazard. Then the results of fuzzy model were used as inputs to fuzzy-GIS model in order to produce urban flood hazard map. The developed fuzzy-GIS model was implemented in Ayamama Watershed to provide flood hazard map. The most important outcome of this study is that hybrid fuzzy-GIS is an accurate, practical and reliable alternative method to hydraulic models. Because this method is basing on the expert knowledge and uncertainty of flood hazard level in different area of the watershed and quickly does flood hazard mapping and hence could allow decision makers to quickly reach a tangible platform to use in natural hazard mitigation and management cases such as floods, earthquakes, landslides, wild fires, etc. Different hydrological and hydraulics based models such as HEC-1, Hec Ras, MIKE 11, SOBEC and others can be used to find the extent of a possible flood extents, but they have several drawbacks that they are time consuming and very expensive. Fuzzy-based approach and its application in GIS as shown in this study does not have any complicated mathematical equations and can provide a quick reliable solution for local decision makers. The hazard and urban risk map can be produced using hybrid fuzzy-GIS model in a very short time and this provides enough lead time necessary to evacuate places under high risk, allowing decrease in flood damages.

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