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Research Article

Determining the Overflow of Kalecik Basin Using Fuzzy SMRGT Method

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ABSTRACT

Floods have always been an important issue and have caused great losses of life and property in human history with their hydrological and hydraulic aspects. Excessive urbanization, increases flows into a basin or region, in other words, increase the flow coefficient. Also, the reduction in stream sections by converting streambeds into habitats causes an increase in human-induced floods. Additionally, when the effects of global climate change, the increased extreme meteorological events (i.e. heavy rains), and the temporal and spatial changes of these extreme events are considered, the flood risk is increasing for almost every region and basin. Measures must be taken to prevent flood, which is a natural event, from turning into a disaster. To take precautions, floods must be predicted in advance as accurately as possible. Since some natural events such as earthquakes are difficult to predict, it is also difficult to prevent them from turning into disasters. However, floods are relatively easy to predict. The literature on this subject is quite old. On the other hand, the methods proposed in the current literature are either classical methods of old technology and have low predictive power, or they are black-box methods that do not rely on a physics cause-effect relationship, and for this reason, do not give enough confidence. Relatively better ones also have some disadvantages as well as advantages. In the present study, a fuzzy model has been developed to estimate the flow rate. To construct the membership functions and to generate the fuzzy rules of the model the SMRGT method, which novel in literature, have been used. On the other hand, the main advantage of SMRGT makes estimation with physical cause - effect relationship (not only based on the data at hand). As results, the flow coefficient has been determined particularly for Kalecik Basin as an application. Furthermore, a flood risk map obtained for the same Basin. It can be concluded that the fuzzy SMRGT can be used for this aim and it gives more precious and realistic results compared with the conventional methods.

Introduction

Water resources have vital importance for all living beings. However, constantly increasing excessive and unplanned urbanization, irrigated agriculture, global climate changes, population growth, industrialization, and environmental pollution are important factors causing pollution and insufficiency of water resources. Because of the heterogeneous distribution of all water resources and precipitation in both temporal and spatial terms, some basins or regions have water scarcity, while others have excessive water. As a result of excessive precipitation, many floods occur in hydrological terms. Knowingly or unknowingly, people destroyed and reduced natural and untouched places in our globalizing world with each passing day. Humans transform natural events into disasters by interfering with the balance of nature, and for this reason, the loss of life and property because of disasters is increasing. The construction of roads, tunnels, mines, dams, and similar gigantic structures in the world where mountains play roles in balance now brings the risk of disrupting this balance.

Natural events with a high potential to turn into disasters can be listed as earthquakes, floods, landslides, fires, hurricanes, storms, avalanches, volcanic eruptions, etc. The role of humans in the triggering of natural events and their transformation into disasters and the deterioration of the natural balance is very great. In the past, human beings, who established settlements in areas that were close to the water edges, did not interfere much with the soil structure and permeability of the ground. However, developing metropolitan cities, rising buildings, widening asphalt roads, and similar interventions have increased a lot in today's world. A waterway (streambed morphology), which was eroded by a stream that flowed throughout history, is increased or decreased in depth or width by human hands today. This causes the water to overflow from the streambed also causing a flood to occur. Earthquakes rank first in the loss of life and property caused by natural disasters on a global scale, while floods take second place [1].

To prevent floods partially or completely, or take measures against them, they must first be accurately estimated, risk maps must be created, and temporal variations of such a risk must be determined. For this purpose, models developed with statistical and black-box methods and artificial intelligence (Artificial Neural Networks, Genetic Algorithm, etc.) techniques, which are generally merely databases and used widely today, are generally valid only for whichever basin or region they are generalized to. In other words, they cannot be generalized any further [2].

However, physics-based models have the characteristic of being generalizable for almost every basin. In the present work, the overflow debit in any basin, the contour map of the debit, and the settlements that may be affected by overflows were determined using the Rational Method.

Floods cause losses of life and property damaging the environment considerably. It is the natural events that turn into disasters causing the most losses of life and property after earthquakes at the global level. Also, it is a type of disaster with serious social and cultural damage. One of the most important details distinguishing overflows from floods is that although floods bring large piles of stones and unproductive soil with them from places with sloping topography, overflows carry fertile soils since they remove the surface soil. Especially, the increased groundwater in the basin, the fertile soil, and minerals brought with it by the overflows increase the productivity required for agriculture, the overflows that come at regular intervals in arid or semi-arid areas are essential for the creatures living there, and they carry some nutrients necessary for aquatic creatures to the rivers and lakes, which are some of the benefits of overflows [3]. Akay and Baduna Koçyiğit reported that although overflows play very beneficial roles for hydrological and biochemical aquifer recharge, sediment, and nutrient transport, they are still natural disasters that cause losses of life and property during a year [4]. Although Akay and Baduna Koçyiğit refer to overflows as a "natural disaster", this statement is not considered correct and it must be noted that it is more correct to say "natural event that turns into a disaster". Trend analyses regarding natural disasters show that flood events and their damages have increased in recent years [5]. The floods occurring in five cities in the Western Black Sea region in May 1998 affected approximately 2 million people and caused 30 people to die, 151 streams and rivers to overflow their beds, and 478 houses to be completely submerged [6]. Also, in the overflow disasters between 2002 and 2013, Turkey suffered a financial loss of 867 million US Dollars in total. Since 1980, there has been an increase in the frequency of water-based natural disasters around the world, and therefore, serious attention and concentration on scientific studies on overflows and floods [7]. The water disasters that happened in Europe between 1998 and 2004 correspond to 43% of all natural disasters. The 100 major floods occurring during these years caused the death of 700 people in Europe, the displacement of half a million people from their homes, and the economic loss of approximately 25 billion Euros [8]. According to the emergency disaster data on an international scale between 1900 and 2008, 2238 floods occurred on a global scale, approximately 2 billion people were affected, nearly 3 million people lost their lives, and a loss of more than 200 billion US dollars occurred [9]. When the average of the years 2005-2015 is taken around the world, nearly 183 million people were affected by natural disasters (overflows, floods, earthquakes, etc.) every year and an average of 83 thousand people lost their lives [10]. Based on the above data, the prediction of overflows is very important both in terms of protection from the damage of overflows and benefiting from what they bring. By using the stochastic method, the overflow rates of the Bird Stream in Oklahoma and the Salt River in Arizona with Markov Chains [11]. These processes, which are called stochastic processes, are usually probability models varying according to time and space. Non-generalizability is common in such processes.

Stronska et al. made the hydrological modeling of a 500 km long area by using the MIKE 11 NAM package program and the deterministic approach. In the modeling, the precipitation data that were measured at 92 stations surrounded by the Odra River in the Wroclaw basin in Poland were used. Also, in the same study, the flood extent of the basin with an area of 49.000 km^2 was determined 2D by using MIKE FLOOD WATCH [12]. Later, Irfan et al. used the same model in the measurements in the Uğrak Basin of Tokat which has a 7 km^2 area, and reported that the model did not yield the desired output due to the excessive input variables, which could not reflect the basin completely [13]. Barbero et al. performed a flood modeling with MIKE FLOOD WATCH by using a total of 70 flow meters and 200 precipitation measurement stations in the Po river basin, which has an area of 37.000 km^2 in the Piemonte Region of Italy. The measurements were made in 50 regions for approximately 48 hours and these values were integrated into the values that were calculated with the MIKE 11 NAM Module [14].

Seçkin et al. presented a model to predict annual maximum flow values based on area, latitude, longitude, elevation, and recurrence periods by using black-box methods. Artificial Neural Networks were used for modeling and the West Black Sea Basin was chosen as the study area. The authors, who used Multiple Linear Regression (MLR) and Multiple Nonlinear Regression (MNLR) methods for the same purpose, also compared the results. They concluded that the MLR model yielded distant predictions in the test stage compared to the ANN model and that the success of the ANN model for calculating flood flow in the future is better than the performance of MLR and MLR [15]. However, based on our opinions, since these methods are Black Box methods, their relative success or failure cannot yield adequate confidence.

Burgan and Icaga, who approached the events with synthetic methods, chose the Akarçay basin as the study area for their article using different methods (Regression, Mockus, and SCS) for the calculations of the debits of overflows. He also made the flood routing calculation in the computer medium, prepared the 3D visual results, and examined the situation of the basin creating videos of time-dependent overflow simulations dynamically [16]. Like Burgan and Icaga, Ozkoca et al. brought a different perspective to the synthetic methods D.S.I and Mockus. The authors reported that the Mockus Method gave results that are more meaningful in areas of 5-60 km^2 showing the D coefficient used in this method, which is the main source of the flooding, as precipitation time. For the D.S.I. synthetic method, they argued that the results in areas that were smaller than 60 km^2 were greater than the expected values [17].

Aşıkoğlu used the 24-hour annual maximum precipitation intensities of six precipitation stations, which were the most suitable for studies among 23 stations in the Aegean Region with statistical methods in overflow calculations. The author stated in his study that he also used four statistical methods in total and that the robust statistics method yielded close results to the other three methods (MLM, MOM, PWM). He also argued that the robust statistics method yielded values closer to the truth than other variable analysis methods emphasizing the necessity of producing and analyzing synthetic data to evaluate the performance of the method more clearly [18]. On the other hand, Gülbaz et al, who used all of the three statistical, synthetic, and deterministic methods in their study and made comparisons, also made overflow calculations on the Alibeyköy basin. In this study, they reported the results of the statistical methods Log-Normal III and Log-Pearson III trials to be small for 50-year overflows. In the Mockus and SCS analyses, which are synthetic methods, it was found that the values in the Mockus Method were extremely high, especially from the 50 and 100-year overflow rates. The authors concluded that the results in MIKE 11 NAM analysis, which is a deterministic method, were larger than those of the statistical methods but smaller than synthetic methods [19]. For this reason, the authors' approaches to overflows were given above from 5 different perspectives, namely stochastic, deterministic, black box, synthetic and statistical, and were discussed separately and given in detail.

The Methods

To minimize the economic and social damages of overflows, it is very important to determine the overflow size accurately. The purpose for which overflow calculations will be made is important for determining the dimensions of the hydraulic structures to be designed. Although it is adequate to know the values of the overflow peak flow rates in the project designed for the construction of a bank or canal, it is also important to know the volume in the design of the spillway or overflow trap. Solving this issue with a single discipline, namely, instead of merely finding the overflow flow rate, taking an interdisciplinary approach and determining the areas that might be affected by overflows with a map will yield more accurate, clearer, and more reliable results. When the flow coefficient known, well known, empirical (i.e., The Rational Method and The Mc. Math Method), synthetic (i.e., The Mockus Method, The S.C.S Method, The DSI Synthetic Method, and The Synder Method) or any other classical (statistical or deterministic) methods are employed in overflow calculations. However, for all methods the flow coefficient is needed. Therefore first, flow coefficient must be correctly determined. It is well known that the researchers do not calculate or determine this coefficient, mainly it is obtained from the literature. In this study, different from the previous, flow coefficient is determined by using SMRGT. The above-mentioned methods used for overflow are welknown so they are not explaned in detail [20-49], however since SMRGT is new the calculation steps of this method presented. Here, six methods, two of which are empirical and four of which are synthetic, widely used, and not directly data-based, are explained briefly. Statistical methods are not mentioned here because they are considered data-based merely. Because, in case of incomplete or lack of precipitation-flow data, empirical or synthetic unit hydrograph methods are preferred for use [50].

It was determined that the flow coefficient (C) varies between 0 and 1 in the literature and was calculated in advance for many regions or basins and is included in the literature or the database of relevant institutions in tables. According to these tables, it is seen that the flow coefficient is determined through different variables e.g. the settlement status, the type of coating, and the variables that depend on the territory. Practitioners employ the flow coefficient values in the tables without questioning most of the time. Depending on the development of technology and novel and more sensitive methods on the subject, it is useful to update these coefficients. For this reason, using the values directly from the tables may not yield healthy results. The flow coefficient depends on many factors e.g. the location of each basin, geomorphological condition, climatic conditions, and drainage network in the area. The flow coefficient that is found with the fuzzy SMRGT Method for the Kalecik Basin was 0.28 [35]. This coefficient will be used in the rational method of overflow calculations.

Empirical Methods

The Rational Method

This method is employed in basins where observation data are not available, in calculating peak flow rates from small streams, in estimating rain and sewage flow rates in cities and in sizing water transfer facilities e.g. trench bridges and culverts. In this method, it is assumed that the flow coefficient does not change in time and the precipitation is distributed uniformly throughout the entire basin. The basin size is taken as the basis of the usage criterion in the method. The area range where the method is employed in DSI studies varies between 0.5 and 5 km^2 [51].

In this method, the maximum flow rate is calculated as follows;

$$Q = C \times i \times A \tag{1}$$

Here;

Q: Overflow debit (m^3 / s)

C: Basin flow coefficient (without dimension)

i: Rainfall intensity (m/s)

A: Basin area (m^2)

One of the disadvantages of this method is that the basin area is limited to 0.5 to 5 km^2, and the second is that the precipitation duration must be greater than the basin transition period. However, it must also be noted that the method has different application areas in practice.

The Mc. Math Method

This method yields good results on flat terrain of almost any size, especially in surface drainage channel sizing, and must not be applied to streams fed from steep slopes [50].

$$Q = 0.0023 \times C \times I \times S^{\frac{1}{5}} \times A^{\frac{4}{5}} \quad (2)$$

Here;

Q: Flood flow (m^3/s)

C: A coefficient depending on the topography, vegetation, and soil type

I: Rainfall intensity (mm/h)

S: Bed slope x 1000

A: Basin drainage area (m^2)

Synthetic Methods

The Mockus Method

Although this method is a kind of unit hydrograph, it is preferred because of its practicality in calculation and ease of drawing the triangular hydrograph. To apply the method, the collection time Tc must be less than 30 hours and the basin area must be less than 1000 km^2 [52].

Peak flow per unit area of the basin is calculated as;

$$Q_p = K \times A \times \frac{h_a}{T_p} \quad (3)$$

Here;

Q_p: Unit hydrograph flow rate ($m^3 / s/mm$)

K: Coefficient of the basin

A: Basin area (km^2)

h_a: Unit hydrograph depth (mm)

T_p: Time to reach the peak (hours)

The S.C.S Method

The method employed by DSI in Turkey is also called the Flow Curve Number. The United States Land Conservation Service (SCS) developed this method. A dimension-free unit hydrograph is used in drawing the synthetic unit hydrograph in the method [53]. It is generally preferred for sizing floodgates in water storage structures e.g. dams and ponds in basins smaller than 30 km^2. They are the structures that allow possible overflows or full floodgates to be transferred to downstream without causing any danger if ponds or dams are full. When calculating the peak flow rate of overflows, two-hour excess precipitation is taken into account [54].

According to this method;

$$Q_p = A \times h_a \times q_p \times 10^{-3} \quad (4)$$

Here;

Q_p: Peak flood flow rate ($m^3 / s/mm$) of two-hour excess precipitation

A: Basin area (km^2)

h_a: Surface flow height in the basin (mm)

q_p: The flow that will come from each square kilometer of the basin when the overflow reaches its peak value ($L / sn/km^2 / mm$).

The DSI Synthetic Method

Synthetic unit hydrographs are used to calculate overflow debit that may occur in basins where safe flow monitoring stations are not available. This method is used for basin areas up to 1000 km^2. When larger basin areas are in question, unit hydrographs are obtained by dividing areas smaller than 1000 km^2. If the Tp, namely, the unit hydrograph peak time, is less than 2 hours, the use of this method will not yield accurate results [55].

$$Q_p = q_p \times \quad (5)$$

Q_p: Total debit (m^3 / s)

q_p: Debit rate per unit area of 1 mm flow height ($m^3 / s/mm$)

A: Basin area (km^2)

$$q_p = 414(A^{0.225} \times E^{0.16}) \quad (6)$$

E is a parameter and is calculated as follows;

$$E = L \times \frac{Lc}{\sqrt{S}} \quad (7)$$

Here;

L: Main waterway length (km)

L_c: The waterway distance between the projection of the center of gravity of the basin on the main waterway and the exit point of the basin (km)

S: Basin harmonic slope (%)

The Synder Method

In drainage areas where precipitation flow records are not available, various physical characteristics of the basin are employed for calculating the unit hydrograph. For this reason, it is the most employed method among the proposed methods. Used in areas larger than 1000 km^2, this method is based on the principle of obtaining the unit hydrograph of the basin by using the unit hydrograph time, unit hydrograph delay time, peak consumption, and hydrograph width at 50% and 75% of the flood peak [56].

The rising time of the unit hydrograph is calculated with the following equation.

$$t_p = 0.75 \times C_t \times (L \times L_c) \tag{8}$$

Here;

t_p: Rising time of unit hydrograph ($hours$)

C_t : Coefficient depending on field conditions

L: Basin length (km)

L_c: The farthest distance from the center of gravity of the basin to the entrance or exit point of the basin in the form

C_t; It is taken at 0.35 in valleys, 0.72 in plains, and 1.2 in mountainous areas. The chosen C_t value is empirically multiplied by 0.89 for the peak value, and the C_t value is obtained.

$$C_p = 0.89 \times C_t \tag{9}$$

The heavy rain duration of the unit hydrograph t_r is calculated with the following formula.

$$t_r = \frac{tp}{5.5} \tag{10}$$

Here;

t_r: Heavy rain duration per unit hydrograph ($hours$)

The flood run-off (q_p) value at the peak of the overflow hydrograph is calculated with the following formula (lt/s/km^2/cm).

$$q_p = 2760 \times \frac{Cp}{tp} \tag{11}$$

Based on this, the flow rate (Qp) value at the overflow peak is;

$$= q_p \times A \times 10^{-3} \tag{12}$$

Here;

A: Basin area (km^2)

This value, which is calculated later, is multiplied by the rainfall height taken for 100 years (ha), and the overflow flow rate for 100 years is obtained.

Artificial Intelligence Methods

Fuzzy SMRGT Method

1. First, the decision is made for the current event's dependent and independent variables. Dependent variables are taken as input, and independent variables are taken as output. Herein, the dependent variable is flow coefficint and the independent variables are chosen as rainfall, evaporation, landuse/cover, and the mean basin slope.

2. All variables must have a specific limit range, and their minimum and maximum values must be known. Xmin and Xmax values must be chosen based on an expert's opinion. They must be expanded as desired, considering the problem's situation. The XR change interval is calculated as in Equation 13.

$$X_R = (X_{mak}) - (X_{min}) \tag{13}$$

Please see the variation interval of the variables particularly used in current study in Table 1.

3. The shape of the membership functions is decided. When defining the membership functions, choosing the right triangle or trapezoidal for the first and last and choosing the trapezoidal or isosceles triangle for the membership functions in the middle will be more efficient for the model. Herein all the fuzzy sets are chosen as triangular since this method gives more positive results on triangular and trapezoidal membership functions.

The key values of each variable (K1, K2, K3, ... Kn) unit width (UW), extended unit widths (EUW) symmetrically extended for each membership function, and two neighboring membership function's overlapping value (O) is determined. Also, the number of right triangles (nu) in Fuzzy triangular sets must be known (Figure 1). For example, for a membership function with five Fuzzy subsets in Figure 1, K1 and K5 are the values at the centroid of the first and last right triangles, and the remaining middle key values (K2-K4) are the centroids of the triangles in between (Ci-1, Ci, Ci+1). These magnitudes of the dependent and independent variables for the Fuzzy SMRGT model are calculated with equations 13-21 using the formulas below.

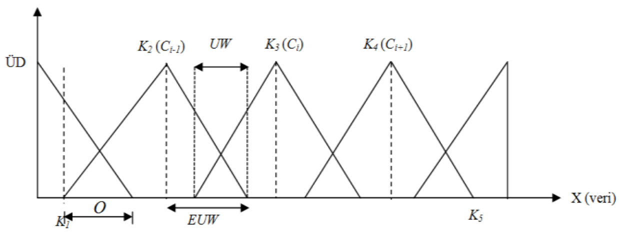

Figure 1. The notation of key value, core value, and unit width for the model

$$C_{i-1} = K_i = \frac{C_i - X_{min}}{2} + X_{min} \tag{14}$$

$$C_i = \frac{X_R}{2} + X_{min} \tag{15}$$

$$C_{i+1} = X_{mak} - \left(\frac{X_{mak} - K_i}{2}\right) \tag{16}$$

$$UW = \frac{X_R}{n_u} \tag{17}$$

$$O = \frac{UW}{2} \tag{18}$$

$$EUW = \frac{X_R}{n_u} + O \quad (19)$$

$$K_1 = X_{min} + \frac{EUW}{3} \quad (20)$$

$$K_5 = X_{max} - \frac{EUW}{3} \quad (21)$$

4. According to SMRGT, membership functions of all independent variables must consist of at least three fuzzy sets. If more clusters are selected, it must be an odd number. The model error decreases, and the processing volume increases as the number of fuzzy sets in membership functions increases. The number of the fuzzy sets are 5 for all independent variables.

5. Overlapping the right triangle parts of fuzzy sets up to the centroid (1/3 and 2/3) in membership functions reduces the error.

6. The key values of the first and last fuzzy sets in the membership function of each independent variable determine the validity range of the fuzzy model. In other words, the model will be valid between the first and last key values of that variable(s). For this reason, it is always helpful to expand the limit ranges of the independent variables. In such a case, the error percentage will automatically decrease when the centroid method is used in the defuzzification process.

7. Key values such as K1, K2, and K3 are inputs of the fuzzy model.

8. After these processes and work, the dependent variable, in other words, the values of the output, will be determined in response to these selected values of each variable. Output values against these calculated values of the inputs are obtained either experimentally or by an experienced expert. A safe formula in the literature can be used for this purpose. The values obtained in this way will be the key values of the fuzzy sets of the output. The membership function of the output is found in this way. The membership function of the output will give the fuzzy rule base. Therefore, each key value of the output will yield a rule. Then, the number of fuzzy sets in the membership function of the output will be equal to the number of fuzzy rules, and no combination will be skipped.

9. In this way, after determining both membership functions and rules, the next step is the process. In this process, the fuzzy SMRGT model is optionally run in a package program. The most suitable package program for this job is MATLAB.

10. Input and output files prepared in this program are loaded into the program with a ".dat" extension. If necessary, 4 data files (input and output) can be prepared and loaded into the program for each test and calibration stage. The program is loaded into the program with a ".fis" extension. Then, a file with the ".m" extension is prepared to run the program. Model results are obtained by running this file with the ".m" extension.

11. Preparing the program with this method will save it from the trial and error process. The process volume will be low and short even if it does not. If the membership functions of the output are more intertwined than they usually are, two or more intertwined membership functions must be reduced to one [20-24].

As noted above for the Rational Method, each method has specific watershed, meteorological, or hydrological conditions. However, the fuzzy SMRGT Model does not need boundary conditions. The modeler can choose the minimum-maximum ranges of the model variables as desired. This range is also the range for which the model is valid and freely determined by the modeler. This makes the Fuzzy SMRGT Method easier and more reliable to use and is the reason why it is preferred over the existing methods reported in the literature.

Finding and Discussion

Determining Overflow Debits

The Rational Method, which is frequently used for this purpose, was used for flood calculation. Since the main independent variable is flow coefficient in all the related equations including Rational Method, realistically determining the flow coefficient is vitally important. In this study for determining flow coefficient SMRGT method was used. Results of SMRGT model, relatively, can be accepted as more precies, because the methodology has a physical cause and effect base. The average flow coefficient of the Kalecik basin is 0.28, and the flow coefficient map of the basin is given in Figure 2. However, it is also known that the area of use of this method is 0-5 km^2 [51]. The basin area is 5460 km^2. An objection can be made here at this point. To avoid such an objection, the area was not taken as a whole when the flood map was drawn, and equivalent overflow debit curves were drawn depending on the increase in the basin area (i.e. per unit area). For this reason, the area limitation that was foreseen in the Rational Method does not prevent the drawing of the contour map (equivalent overflow debit curves).

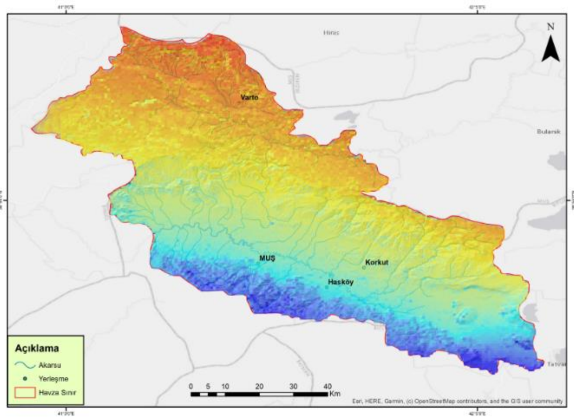

Figure 2. Map of the flow coefficient [35].

A contour map (in other words, a contour map of overflow debit curves) is a three-variable and two-dimensional graph. The variable X represents time in hours in a year, the variable Y represents the result of the overflow coefficient and the area *(C*A, m^2)*, and the Z variable represents the overflow debit (*Q, m^3/hour*). The equivalent overflow map that was obtained by using the Surfer Program is given in Figure 3 However, this map shows only the variation of the overflow debit over time and the area multiplied by the average flow coefficient. The precipitation data obtained from the station in Korkut County in the center of the basin are in hourly kg/m^2/hour format and cover the years 2015 – 2020 (24 hours of 365 days were brought one after the other for each year and the average of 5 years was taken). For this reason, 8760 data were used in total. Then, the basin area was divided by 8760 and an equal number of area data was obtained. However, the area data are supplementary and valid for all basins that have an area between 0 - 5460 km^2. Here, the number of variables was 4 (area, precipitation intensity, flow coefficient, and flood flow rate), and the contour map was drawn with only three variables. For this reason, the number of variables was reduced to 3 by multiplying 2 of them (area and flow coefficients). The overflow debit was drawn depending on the X (time) and Y (C*A) variables, which were set as isocurves as the product of all three

variables.

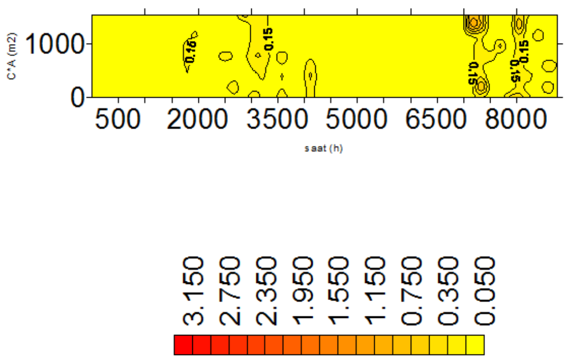

Figure 3. Equivalent flow rate curves (contour map)

It can easily be seen in Figure 3 that the values that corresponded to the spring and winter months were high and there was no overflow risk in the remaining dry seasons. Regarding the variables in the map, Figure 3 shows that the curves are more frequent, similar, and uniformly circular, and the color is darker for the values of C*A 1000 and above, h values between 7500-8000 and 8500. The visual in this part of the map means that the overflow debit values were higher and changed more and more smoothly depending on the variables, especially C*A in the given ranges of the variables. For the smaller values of C*A between 0-1000 and of h between 2000-5000, it is obvious that the curves are different, independent, flatter, sparse, and lighter in color. It can also be said that the overflow debit values change less and irregularly depending on the smaller variables in this part of the map.

Although the rainfall intensity data that are needed to create the map were obtained from the Korkut station that was closest to the Kalecik Basin, the map given in Figure 3 is not specific to Kalecik. In general, it provides the variation of the equivalent overflow debit depending on the two independent variables mentioned. To produce it specifically for Kalecik Basin, the overflow coefficient map given in Figure 2 must be taken as the basis and the overflow debit must be processed on it. The current situation was discussed in this study, and it is also considered to obtain a special map for the Kalecik basin as a separate prospective study. Also, the flood risk assessment of the settlements in the basin was made based on the flow coefficient map given in Figure 2. In this respect, the risk was divided into 5 groups insignificant (1), low-risk (2), medium-risk (3), risky (4), and very risky (5). There are 250 settlements in total in the area, including the center of Muş, its counties, and villages in the basin. The results of the evaluation of some of the settlements according to the overflow risk are given in Table 1 according to the risk levels. A certain number of settlements are given because the number of pages is high in the table.

Table 1: The results of the evaluation of some of the settlements according to the overflow risk

No	Insignificant (1)	Low-risk (2)	Moderate-risk (3)	Risky (4)	High-risk (5)
1	Demirci	Gedikpınar	Oduncular	Yazıkonak	Örenlik
2	Elçiler	Çıtak	Güroymak Merkez köy	Tahtalı	Kuştaşı
3	Üçsırt	Yolgözler	Güroymak	Arpacık	
4	Keçidere	Sarmaşık	Yamaçköy	Yukarı Kolbaşı	
5	Alagün	Yünören	Günkırı	Çallı	
6	Mescitli	İçboğaz	Büvetli	Kekliktepe	
7	Aligedik	Bahçe	Değirmenköy	Aşağı Kolbaşı	
8	Kumlukıyı	Değirmitaş	Sütderesi	Kavunlu	
9	Sanlıca	Durucak	Ortanca	Kaleli	
10	Değerli	Tanköy	Otaç	Saklı	
11	Kayalıdere	Çalaplı	Gökyazı	Küllüce	
12	Ulusırt	Balkır	Budaklı	Üzümveren	
13	Karapınar	Çınarardı	Koçköy	Kapaklı	
14	Kayalık	Güven	Gölbaşı	Koğuktaş	
15	Tepeköy	Taşlıca	Düzova	Böğürdelen	
16	Kuşluk	Karakale	Yukarı Üçdam	Karakütük	
17	Bağiçi	Yazla	Güzelli	Azıklı	
18	Aşağı Hacıbey	Kırköy	Sarıbahçe	Yarkaya	
19	Dönertaş	Boyuncuk	Umurca	Dağdibi	
20	Özenç	Aşağı Sızma	Özkavak	Derecik	

According to Table 1 given partially, the places that had the highest overflow risks were Örenlik and Kuştaşı villages. Also, 26 settlements were found to be in the risky group, 84 settlements in the medium-risk group, 65 settlements in the low-risk group, and the remaining 73 settlements were in the insignificant group. When the chart is examined, it has been found, in general, that the multi-risk group was the least and the medium-risk group was the highest.

Conclusions

To take precautions, floods must be predicted in advance as accurately as possible. For the aim, in the present study, a fuzzy model has been developed to estimate the flow rate. To construct the membership functions and to generate the fuzzy rules of the model the SMRGT method, which novel in literature, have been used. On the other hand, the main advantage of SMRGT makes estimation with physical cause - effect relationship. As the results, the flow coefficient has been determined particularly for Kalecik Basin as an application of fuzzy SMRGT model. Furthermore, a flood risk map obtained for the same Basin. It can be concluded that the fuzzy SMRGT can be used for modeling and it gives more precious and realistic results compared with the conventional methods. The flood map of the basin was drawn and necessary explanations/legend were made on the map. It is considered that these maps will be beneficial for the local governments in the basin to revise the development plans of urbanization according to the results obtained in the scope of this study. Further, it is also hoped that the present study will bring a humble benefit to the mapping of the flood and overflow areas of different basins and regions in a great manner.

References

[1] O. Ozcan, "Evaluation of flood risk analysis in the Sakarya river subbasin by using remote sensing and GIS," M.S. thesis, Technical Univ. of Istanbul, 2008.

[2] Z. Toprak, M. Savci, and C. Avci, "Comparison of the dispersion model results using the contour map method," in *Proc. 6th Int. Congr. Advances in Civil Engineering (ACE2004)*, 2004, pp. 1407–1417.

[3] T. Cosgun, İ. B. Peker, B. Sayin, S. Gülbaz, and R. Durgut, "Assessment of flood event based on numerical models and legal statute: A case of Eşkinoz Stream in Istanbul, Turkey," *Arab. J. Geosci.*, vol. 15, no. 7, p. 585, 2022.

[4] H. Akay and M. Baduna Koçyiğit, "Comparison of Direct Runoff Hydrographs of Two Ungauged Sub-Basins Using Instantaneous Unit Hydrograph Approach," *J. Nat. Hazards Environ.*, vol. 5, no. 2, pp. 1–8, 2019.

[5] G. Berz, "Flood disasters: lessons from the past—worries for the future," *Proc. Inst. Civ. Eng. Water Marit. Eng.*, vol. 142, no. 1, pp. 3–8, 2000.

[6] A. Ü. Kömüşçü, S. Çelik, and A. Ceylan, "Rainfall analysis of the flood event that occurred in Marmara Region on 8–12 September 2009," *Turk. J. Geogr. Sci.*, vol. 9, no. 2, pp. 209–220, 2011.

[7] M. Sunkar and A. Toprak, "Importance of historical data sources in flood and overflow studies," in *Proc. Int. Geogr. Symp.*, Ankara, Turkey, Oct. 2016.

[8] M. A. Trigg *et al.*, "The credibility challenge for global fluvial flood risk analysis," *Environ. Res. Lett.*, vol. 11, no. 9, p. 094014, 2016.

[9] L. Wang *et al.*, "A review of the flood management: from flood control to flood resilience," *Heliyon*, vol. 8, no. 11, 2022.

[10] EM-DAT, "The OFDA/CRED–International Disaster Database," Univ. Catholique de Louvain, Brussels, Belgium, 2016.

[11] P. Yapo, S. Sorooshian, and V. Gupta, "A Markov chain flow model for flood forecasting," *Water Resour. Res.*, vol. 29, no. 7, pp. 2427–2436, 1993.

[12] K. Stronska *et al.*, "Flood Management and Flood Forecasting Tool for the Odra River, Poland," in *Proc. 3rd DHI Softw. Conf.*, Helsingør, Denmark, 1999.

[13] O. İrfan, K. Yürekli, and F. Öztürk, "Modeling Daily Flows in Tokat Uğrak Catchment," *Int. J. Agric. Nat. Sci.*, vol. 3, no. 1, pp. 7–11, 2010.

[14] S. Barbero, D. Rabuffetti, G. Wilson, and M. Buffo, "Development of a Physically-Based Flood Forecasting System: 'MIKE FloodWatch' in the Piemonte Region, Italy," in *Proc. 4th DHI Softw. Conf.*, Helsingør, Denmark, 2001.

[15] N. Seçkin, A. Güven, and A. Yurtal, "Modeling Flood Discharge Using Artificial Neural Network: Case Study—The Middle Black Sea Watershed," *Cukurova Univ. J. Fac. Eng.*, vol. 25, no. 1, pp. 45–56, 2010.

[16] H. I. Burgan and Y. Icaga, "Flood analysis using adaptive hydraulics (AdH) model in Akarcay Basin," *Teknik Dergi*, vol. 30, no. 2, pp. 9029–9051, 2019.

[17] T. Özkoca and A. Ü. Keskin, "Analysis of the Effect of Climate Change on Flood Flows of Kemer Ağva River, Antalya," *J. Nature*, vol. 1, pp. 6576, 2022.

[18] O. L. Asikoglu, "Parent flood frequency distribution of Turkish Rivers," *Pol. J. Environ. Stud.*, vol. 27, no. 2, pp. 529–539, 2018.

[19] S. Gülbaz, C. M. Kazezyilmazalhan, R. Nasirzadehdizaji, and M. Dikici, "A calibrated

hydrological model for Alibeyköy Watershed in Istanbul, Turkey incorporating LID implementation," *Fresenius Environ. Bull.*, vol. 26, no. 10, pp. 6112–6120, 2017.

[20] Z. F. Toprak, "Flow discharge modeling in open canals using a new fuzzy modeling technique (SMRGT)," *Clean Soil Air Water*, vol. 37, no. 9, pp. 742–752, 2009.

[21] R. Barati, "Analysis and evaluation of optimization algorithms application for parameter estimation of Muskingum flood routing models in rivers," Jun. 2014, pp. 1–8.

[22] S. Toprak, A. Atay, and Z. F. Toprak, "SMRGT yöntemi ile bulanıklaştırılmış veriler için bulanık doğrusal regresyon," *Erciyes Univ. J. Inst. Sci. Tech.*, vol. 31, no. 3, pp. 1–7, 2015.

[23] S. Yalaz and A. A. Atay, "Fuzzy linear regression for the time series data which is fuzzified with SMRGT Method," *Süleyman Demirel Univ. J. Inst. Sci. Tech.*, vol. 20, no. 3, pp. 405–413, 2016.

[24] Z. F. Toprak, A. Toprak, and Z. Aykaç, "Bulanık SMRGT yönteminin pratik uygulamaları," *Dicle Univ. J. Eng.*, vol. 8, no. 1, pp. 123–132, 2017.

[25] V. Arslan and S. Ulubeyli, "Bulanık veri zarflama analizi ile beton pompası seçimi," *Dicle Univ. J. Eng.*, vol. 8, no. 1, pp. 1–12, 2017.

[26] E. Altaş, M. C. Aydın, and Z. F. Toprak, "Açık kanal akımlarında su yüzü profilinin bulanık SMRGT yöntemiyle modellenmesi," *Dicle Univ. J. Eng.*, vol. 9, no. 2, pp. 975–981, 2018.

[27] R. Jain, N. Jain, S. Kapania, and L. H. Son, "Degree approximation-based fuzzy partitioning algorithm and applications in wheat production prediction," *Symmetry*, vol. 10, no. 12, p. 768, 2018.

[28] G. Bayri, "Zeminlerin Basit Üyeli Fonksiyonlar ve Bulanik Kurallar Üretim Tekniği (SMRGT) ile Sınıflandırılması," M.S. thesis, Bitlis Eren Univ., 2018.

[29] İ. Dabanlı, "Kuraklık riskinin bulanık mantık yardımıyla Türkiye genelinde değerlendirilmesi," *Dicle Univ. J. Eng.*, vol. 10, no. 1, pp. 359–372, 2019.

[30] F. Üneş *et al.*, "River flow estimation using artificial intelligence and fuzzy techniques," *Water*, vol. 12, no. 9, p. 2427, 2020.

[31] D. Topuz and N. Şahinler, "Arı sütü miktarının tahminine yönelik olarak elde edilen kategorik verilerin bulanık aralık regresyon modeli ile analizi," *Turk. J. Agric. Nat. Sci.*, vol. 7, no. 2, pp. 471–479, 2020.

[32] F. Şevgin and Z. F. Toprak, "Meteorolojik akış katsayısının bulanık SMRGT yöntemi ile belirlenmesi: Murat Havzası örneği," *Dicle Univ. J. Eng.*, vol. 12, no. 2, pp. 401–409, 2021.

[33] C. Sezen and T. Partal, "Utilization of stochastic, artificial neural network, and wavelet combined models for monthly streamflow," *Bilecik Şeyh Edebali Univ. J. Sci.*, vol. 8, no. 1, 2021.

[34] Z. Kınık and Z. Aykaç, "Atıksu arıtma tesislerinde karşılaşılan problemler ve çözüm önerileri," *Turk. Hydraul. J.*, vol. 5, no. 1, pp. 59–65, 2021.

[35] F. Şevgin, "Bulanık SMRGT yöntemi ile taşkın modellenmesi ve Kalecik havzası örneği," Ph.D. dissertation, Dicle Univ., Inst. Sci. Tech., Diyarbakır, 2021.

[36] E. E. Er, F. Üneş, and B. Taşar, "Estimating dam reservoir level change of Istanbul Alibey Dam with the fuzzy SMRGT method," *Osmaniye Korkut Ata Univ. J. Inst. Sci. Tech.*, vol. 5, Special Issue, pp. 80–95, 2022.

[37] A. Y. Gunal and R. Mehdi, "The study of land use and slope role in flow coefficient determination," in *Proc. Adv. Eng. Days (AED)*, vol. 4, pp. 64–66, 2022.

[38] Y. Zhou *et al.*, "Waste management within the scope of environmental public awareness based on cross-sectional survey and social interviews," *Front. Environ. Sci.*, vol. 10, p. 1030525, 2022.

[39] A. Y. Gunal and R. Mehdi, "Forecasting the flow coefficient of the river basin using adaptive fuzzy inference system and fuzzy SMRGT method," *J. Ecol. Eng.*, vol. 24, no. 7, 2023.

[40] S. Demirel, B. Taşar, Y. Z. Kaya, F. Üneş, and M. Demirci, "Adana ili referans evapotranspirasyon miktarının bulanık SMRGT, ANFIS ve çoklu doğrusal regresyon kullanılarak tahmini," *Osmaniye Korkut Ata Univ. J. Inst. Sci. Tech.*, vol. 6, no. 1, pp. 106–120, 2023.

[41] R. Mehdi and A. Y. Gunal, "Computation of flow coefficient via non-deterministic approach of fuzzy logic called 'SMRGT' based on meteorological properties," *Jordan J. Civil Eng.*, vol. 17, no. 4, 2023.

[42] A. Y. Gunal and R. Mehdi, "Flow coefficient determination in catchment based on analysis of temperature and wind speed data using the fuzzy SMRGT method," in *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 1222, no. 1, p. 012014, Aug. 2023.

[43] M. Ruya and A. Y. Gunal, “A comparative study of using adaptive neural fuzzy inference system (ANFIS), Gaussian process regression (GPR), and SMRGT models in flow coefficient estimation,” *3C Tecnol.*, vol. 12, no. 2, pp. 125–146, 2023.

[44] H. Kocabaş, F. Üneş, B. Taşar, and Ö. F. Cansız, “Türkiye karayollarındaki karbondioksit emisyonunun yapay zekâ yöntemleri ile tahmini,” *Turk. J. Technol. Appl. Sci.*, vol. 4, no. 2, pp. 82–101, 2023.

[45] R. Zainalabdeen, “Flow coefficient modeling using the fuzzy SMRGT method compared with ANFIS and ANN methods: An example of the Aksu River Basin,” Ph.D. dissertation, Gaziantep Univ., Grad. Sch. Nat. Appl. Sci., Gaziantep, 2023.

[46] A. Y. GÜNAL and R. Mehdi, “Application of a new fuzzy logic model known as ‘SMRGT’ for estimating flow coefficient rate,” *Turk. J. Eng.*, vol. 8, no. 1, pp. 46–55, 2024.

[47] E. Karabacak and H. A. Kutlu, “Evaluating the efficiencies of logistics centers with fuzzy logic: The case of Turkey,” *Sustainability*, vol. 16, no. 1, p. 438, 2024.

[48] A. Ç. Aydın, “İşitsel peyzajda ses çevresi memnuniyet düzeyinin bulanık mantık ile tahmin edilmesi: Diyarbakır Suriçi uygulaması,” Ph.D. dissertation, İstanbul Tech. Univ., Inst. Sci. Tech., Mar. 2017.

[49] D. Karakaya, “Akış katsayısının bulanık SMRGT yöntemi ile modellenmesi,” M.S. thesis, Dicle Univ., Inst. Sci., National Thesis No: 540658, Dec. 10, 2018.

[50] H. Oshikawa and T. Komatsu, “Flood control mechanism of multiple dams constructed in a series based on cascade method,” *J. Disaster Res.*, vol. 10, no. 3, pp. 475–485, 2015.

[51] J. Warner, “The struggle over Turkey’s Ilısu Dam: Domestic and international security linkages,” *Int. Environ. Agreements*, vol. 12, pp. 231–250, 2012.

[52] V. Te, D. R. Maidment, and L. W. Mays, “Applied hydrology,” *J. Eng. Educ.*, 1962.

[53] R. K. Linsley, M. A. Kohler, and L. H. Paulhus, *Hydrology for Engineers*, 1975.

[54] P. Novak, A. I. B. Moffat, C. Nalluri, and R. A. Narayanan, *Hydraulic Structures*, CRC Press, 2017.

[55] H. Apaydin, M. T. Sattari, K. Falsafian, and R. Prasad, “Artificial intelligence modelling integrated with singular spectral analysis and seasonal-trend decomposition using Loess approaches for streamflow predictions,” *J. Hydrol.*, vol. 600, p. 126506, 2021.

[56] S. Gülbaz, C. M. Kazezyılmaz-Alhan, A. Bahçeçi, and U. Boyraz, “Flood modeling of Ayamama River watershed in Istanbul, Turkey,” *J. Hydrol. Eng.*, vol. 24, no. 1, p. 05018026, 2019.