Eurasian Journal of Agricultural Research 2021; Vol:5, Issue:2, pp:193-202

Investigation of the Efficiency of Some Methods Used in the Estimation of Basin Water Yield

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Abstract

Computing flood discharge of a watershed reliably is of great importance in the design of hydraulic structures. Many empirical methods used for this purpose produce different results. Therefore, methods taking regional climatic conditions and watershed characteristics should be employed. In this study, effectiveness of unitless Turc, Mc Math and Rational methods were investigated through comparing the calculated surface run off from these methods to the directly measured values and also calculated values of an individual methods to those of the others. Using Turc Method, which also includes coefficient suggested for the regional similar sub-basins, water yields were underestimated in comparison to the other methods. Having considered all the calculated and measured results, empirical methods with the new optimised coefficients representing the regional conditions were suggested in order to build reliable hydraulic structures and their spillways. In this way, total cost will be decreased and, on the top of that, the lives and properties will be secured.

Keywords: Edirne, hydrology, hydraulic structures, basin water yield

Research article
Received Date: 8 Novemberr 2021
Accepted Date: 10 December 2021

INTRODUCTION

The importance of water for all living things is known by everyone. The main ingredient of all living things is water. Increasing world population, changing climate conditions and economic activities are growing with each passing day makes it more important than water (Bağdatlı and Bellitürk, 2016). The efforts of people to benefit from water and to protect it from harm started in the early ages. Rich civilizations were established by utilizing water resources. If these resources are used in a disproportionate and irresponsible way, or if their damage cannot be controled, great disasters have occurred. In our age, benefiting from water resources has become much more important. The country's precipitation generally falls in the winter and spring months, and the summers are very dry. Although there is an excessive need for water in the summer months, the streams whose flow increases in the winter and spring are not utilized.

Global warming and climate change gradually reduce available water resources for irrigation in various parts of the world. Increasing domestic and industrial water demands are also reducing available water resources (Uçak and Bağdatlı, 2017). The Thrace region is the place where the industry and population increase is the most in Turkey. It is stated that the population will reach 32,8 million in 2050 and its current resources will be sufficient only for drinking and utility water after 2060 (Istanbulluoğlu et al., 2007). The fact that precipitation, which is of vital importance for living creatures around the world, tends to decrease especially in the seasons when rain is frequent will cause water resources to decrease (Bağdatlı and Arslan, 2019). In parallel with climate change, water resources the emergence of change also manifests itself as a result that cannot be ignored (Bağdatlı et al., 2014a). Soil and water resources potentials are one of the most important factors that shape the agricultural course of a Region (Bağdatlı et al., 2014b). Considering all these mentioned, the protection and development of water resources is very important for the future.

Various water structures, especially dams and ponds, are facilities that store, swell and canalize water so that it can be used for various purposes. The design of these structures, on the other hand, requires knowing the basin water yields. Currently, these estimates are made using empirical methods developed by the United States (US) Soil Conservation Service (SCS). The validity of these methods developed in the US conditions for the conditions of a certain region of our country is a matter of debate and has not yet been proven by research. However, there are many studies on a regional basis for the estimation of basin water yield. (Hawley and McCuen 1982, Karaş 1997, Demiryürek et al., 1999, Istanbulluoglu et al., 2002, Sadati et al., 2014, Rawat et al., 2021).

This study aims to overcome the problem encountered in the estimation of basin water yield in the water structures to be built in the rural areas of Edirne province in the Thrace Region and their spillway planning, by using which empirical method. For this, three sub-basins with different sizes were selected as research areas, and the application of Turc, Mc Math, and Rational methods was carried out.

MATERIAL and METHOD

Material

The research basins are located at a distance of 10 km to the northeast of the central of Edirne province in the Thrace Region. The basins, whose altitude is between 55 and 154 m above sea level, are between 26°40'- 26°45' east longitudes and 41°35'–41°45' northern latitudes. The basins consist of three sub-basins with different sizes. These are the Subaşı, Musabeyli and Kumdere Basins. Edirne province is generally under the influence of continental climate. Figure 1 shows the map of the area where the study was carried out.

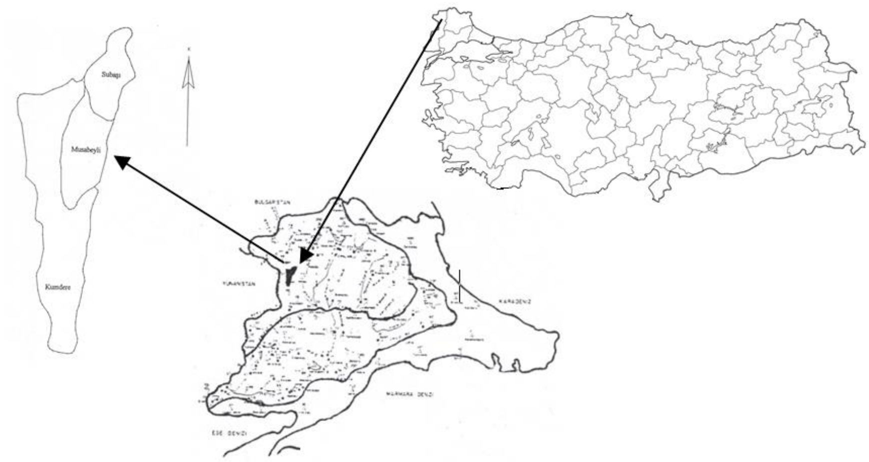

Figure 1. Research area

In terms of climate characteristics, the research basin is cold and rainy in winters and hot and dry in summers. Almost all of the precipitation in the region is in the form of rain, and according to annual averages, the number of days with snowfall is 9 and the number of days covered with snow is 17 days. Some annual and monthly average climate data of Edirne province are shown in Table 1.

Table 1. Some annual average climate data of Edirne province (DMI, 1984; 2004)

Months	Avarage temperature (°C)	Average relative humidity (%)	Wind speed (m s^{-1})	Total precipitation (mm)	Total evaporation (mm)	Sunshine duration (hour)
January	2,1	81	2,0	65,6	19,2	2,36
February	3,9	77	2,3	49,0	27,4	3,53
March	7,1	73	2,2	47,7	48,1	4,48
April	12,6	68	1,9	49,2	72,9	6,41
May	17,9	67	1,6	50,1	92,9	8,29
June	22,0	63	1,5	51,3	116,5	9,52
July	24,4	56	1,6	31,9	158,6	11,27
August	23,9	56	1,6	24,2	159,1	10,52
September	19,6	63	1,4	33,8	108,4	8,26
October	14,2	73	1,4	56,7	64,5	5,55
November	9,3	81	1,5	70,6	31,5	3,26
December	4,4	83	1,9	73,6	23,5	2,28
Yearly	13,5	70	1,7	603,7	922,5	6,34

The majority of the soils of the research basins are Limeless Brown, and only a few of them are made up of Vertisol large soil groups. The soils in the basins are deep, the topography of the basins is moderately sloping (6-12%) and has a corrugated structure. Most of the basins are third class land (Anonymous, 1984). Basin characteristics are parameters that have very important contributions, especially in comparing one basin with another. These are geomorphological such as area, shape, slope; hydrogeological such as stream shape, seepage; pedological characteristics such as soil physics and vegetation. Some basin characteristics and their values in the research basins are shown in Table 2 collectively.

Table 2. Some basin characteristics used to define the research basins

Basin characteristics	Basins		
	Subaşı	Musabeyli	Kumdere
Basin area, A (km^2)	4,4	10,2	27,3
Basin perimeter, P (km)	9,5	16,8	31,3
Basin length, L_H (km)	3,5	7,4	13,0
Basin width, W_H (km)	2,0	2,0	4,0
Basin maximum height, hmax (m)	154	154	154
Basin lowest height, hmin (m)	115	85	55
Basin relief, r (m)	39	69	99
Basin relative relief, r_n (%)	0,41		
Basin direction	North-South	North-South	North-South
Average height of the basin, hort (m)	140		
Basin median height, h_{med} (m)	135		
Basin mean slope, S_H (%)	4,0		
Figure index depending on the main stream path, S_1	2,7		
Length of main stream road, L (km)	3,6	7,8	14,5
The length of the basin center of gravity to the basin exit point, L_c (km)	1,9	3,7	8,4
Main stream road profile slope, S_s (%)	1,3		
Main stream path harmonic slope, S (%)	0,9	0,8	0,7

Edirne province has 627.595 hectares of land. Of this, 446.105 ha (71,1%) is cultivated land, 349.077 ha is dry fallow, 90.032 ha is irrigated, and the rest is vineyard-orchard farming. 117.888 ha (18,8%) of the province's land is covered with forest-heathland and 44.229 ha (7,1%) is covered with meadow-pasture areas (Anonymous, 1993). Wheat, sunflower and rice come to the fore in the plant production of the province. These products are produced in approximately 92% of the cultivated lands. Modern agricultural practices are carried out throughout the province. Animal husbandry is another important agricultural activity in the province, and high-yielding cultural breeds dominate the animal population (Anonymous, 2004).

Fallow dry farming is practiced in all the lands of the research basins. The dominant crop pattern is wheat–sunflower rotation system. In the plant rotation system, wheat is the plant that is predominantly planted.

Among the research basins, which have different sizes within themselves, the Subaşı basin is the smallest and upstream. There are a total of three precipitation stations, two of which are in this basin and one very close to the basin, and one flow station to measure the surface runoff at the exit of the basin.

The distribution of precipitation in place and time was monitored by placing a pulviograph at a height of 115 m at the outlet of the basin, at an altitude of 145 m in the middle of the basin, and at a height of 150 m outside the basin, very close to the upper border of the basin. For runoff observations, a 110 m high 1/5 sloped triangular flume was constructed at the basin outlet. A flow meter (limnigraph) was placed on the stilling pool, which is connected to the flume with a channel, right next to the flume construction, and the time distribution of the flow passing through the stream bed was measured with the help of the flume. The measurement values recorded from the mentioned precipitation and flow stations during the years 1985-2004 (20 years) were used in the research (Bakanoğulları and Günay, 2011).

Method

In the calculation of basin water yields to be obtained from the research basins; besides the direct runoff values measured in the Subaşı sub-basin, the following empirical equations are used.

a. Direct surface flow measurement

For this purpose, a limnigraph was placed in the stilling pool connected to the 1/5 inclined triangular channel built at 110 m height at the outlet of the Subaşı basin, and the time distribution of the flow passing through the stream bed was measured. Then, the curves in these measurement records were analyzed on a daily basis and direct flow values were obtained (Bakanoğulları and Günay, 2011).

b. Turc method

The method was developed by Turc as a result of basin studies in different climatic conditions. The following equations are used to calculate the annual water yield of the basin (Özer, 1990; Shaw, 1994).

$$h = P - E \qquad \text{(Eq.1)}$$

In equation; h is the amount or height of runoff from the basin (mm); P is the annual average precipitation amount falling on the basin (mm) and E is the annual average real evapotranspiration amount (mm) from the basin. The determination of the actual evapotranspiration amount is calculated with the following equation.

$$E = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}} \qquad L = 300 + 25\,t + 0{,}05\,t^3 \qquad \text{(Eq.2) (Eq.3)}$$

In equation; L is the parameter and t is the annual avarage temperature (°C) of the basin. This value should be corrected by taking into account the latitude and height differences between the structure to be built in the basin and the observation station. In addition, if the 300 coefficient in the equation used to determine the L parameter is used the same for all river basins, it turns out that it will be inaccurate since it has different characteristics. In order to eliminate this, the average precipitation and runoff values of the river basins in Turkey based on the observation results were taken, this time the calculation was reversed, and different coefficients were obtained instead of the A coefficient 300 value by using the basin average temperature in the L equation. This value was stated as 285,9 for the Meriç-Ergene basin, where the research basins are located (Özer, 1990).

The annual water yield of the basin is calculated by multiplying the amount of runoff obtained by the basin area.

$$Q = h \times A \times 10^3 \qquad \text{(Eq.4)}$$

In equation; Q is the basin water yield (m^3 y^{-1}) and A is the catchment area (km^2). Also, the solution can be solved by the modified Turc method using the coefficients obtained for the region from the results of multi-year direct measurements and observations made in the sub-basins of the Thrace Region in Turkey. In the equation, the coefficient of 300 in the L parameter is used as 601 (Istanbulluoglu et al., 2002).

c. Mc Math Method

This method is especially used in calculating the capacity of surface drainage channels. However, it is recommended for side streams fed by steep slopes. The method is expressed with the following equation (Kızılkaya, 1988).

$$Q = 0.0023 \times C \times I \times S^{1/5} \times A^{4/5} \qquad \text{(Eq.5)}$$

In equation; Q is the amount of runoff (m^3 s^{-1}); C, flow coefficient depending on basin vegetation, soil type and topography conditions; I is rainfall intensity (mm h^{-1}) equal to the collection time of precipitation for the chosen recurrence frequency; S is the main stream course bed slope x 1000 and A is the catchment area (hectares).

The first of the procedures followed in the use of this method is to find the basin surface flow coefficient by using the basin soil, topography and vegetation. The second is to find the rainfall intensity for a precipitation period equal to the collection time in the selected recurrence period, and finally to calculate the bed slope of the basin main stream road.

d. Rational Method

This method is widely used in the capacity calculations of side streams and surface drainage channels in small basins that do not have enough observations. It is expressed by the following equation (Kızılkaya, 1988).

$$Q = 0.0028 \times C \times I \times A \qquad \text{(Eq.6)}$$

In this equation; Q, runoff (m^3 s^{-1}); C is the flow coefficient depending on the basin conditions; I is the rainfall intensity (mm h^{-1}) equal to the collection time of the precipitation for the selected frequency and A is the basin area (hectares). Although the surface flow coefficient (C) in this method is different from that described in the Mc Math method, it is calculated in a similar way. However, the calculation of the rainfall intensity (I) value equal to the collection time for the selected recurrence frequency of precipitation is completely different.

RESULTS and DISCUSSION

Basin rainfall and runoff characteristics

The average of the annual total (1985-1999) precipitation values of the region was 609,6 mm. The least precipitation was 121,0 mm in 1991 and the highest precipitation was 895,7 mm in 1999. The basins received below average precipitation for fifteen years and above average precipitation for ten years. Precipitation fell mostly in autumn and winter. November was the month with the most precipitation. The precipitation regime of the basin was very similar to the annual precipitation values of Edirne province, where it is located. Because the annual precipitation values of the province are 603,5 mm.

When the total annual (1985-1999) runoff values were examined, it was observed that no runoff occurred in 1987. The highest runoff was 130,05 mm in 1999. The average total runoff amount was 21,30 mm. The runoff was highest in the autumn months, when the amount of precipitation also increased. Considering the basin rainfall-runoff relations, no relationship was observed between years or even between months. However, the amount of runoff showed a significant decrease in the spring months. The reason for this can be said to be the development in the basin vegetation.

Turc method

The directly measured surface flow values in the basins in the research area and the values obtained as a result of the application of the Turc method to these basins were compared. The water yield calculation with the Turc method was made with the coefficients that were recommended and classically applied for the Meriç-Ergene basin, where the research basin is located. The runoff heights calculated for different probability percentages for different sized research basins and their corresponding runoff volumes are shown in Table 3. The values obtained here were much higher than the runoff values directly measured from the basin.

Table 3. Water yield values to be obtained from the research basins according to the Turc method (classic)

Research basins	Probability (A = 285.9)				
	50%	60%	70%	80%	90%
Subaşı	122,6* 539.440**	102,1 449.240	82,1 361.240	61,1 268.840	36,8 161.920
Musabeyli	1.250.520**	1.041.420	837.420	623.220	375.360
Kumdere	3.346.980**	2.787.330	2.241.330	1.668.030	1.004.640

*: Runoff height (mm y^{-1})
**: Runoff volume (m^3 y^{-1})

Subsequently, runoff heights and corresponding runoff volumes were calculated by using the Turc method, which includes the coefficients obtained by using the direct runoff values measured in different basins in the Thrace Region by Istanbulluoglu et al., (2002). These values shown in Table 4 were more for 50%, 60%, and 70% probabilities, approximately for 80% probability, and less for 90% probability compared to the values measured from the basins. This means that in the ponds built so far, a larger pond volume than it should be is planned.

Table 4. Water yield values to be obtained from the research basins according to the Turc method (recommended)

Research basins	Probability (A = 601.0)				
	50%	60%	70%	80%	90%
Subaşı	59,9* 263.560**	47,1 207.240	35,0 154.000	23,3 102.520	10,0 44.000
Musabeyli	610.980**	480.420	357.000	237.660	102.000
Kumdere	1.635.270**	1.285.830	955.500	636.090	273.000

*: Runoff height (mm y^{-1})
**: Runoff volume (m^3 y^{-1})

Mc Math and Rational methods

The flow values obtained by applying McMath and Rational methods to the basins in the research area are shown separately in Tables 5 and 6 for different recurrence intervals.

Table 5. Flood flows that will occur from the research basins according to the Mc Math method

Research basins	Recurrence intervals (year)*					
	2,33	5	10	25	50	100
Subaşı	3,4	4,2	5,3	6,1	6,8	7,5
Musabeyli	7,9	9,8	12,2	14,0	15,7	17,5
Kumdere	20,5	25,6	32,9	36,5	40,9	45,3

*: All flood flows, $m^3\ s^{-1}$

Table 6. Flood flows that will occur from the research basins according to the rational method

Research basins	Recurrence intervals (year)*					
	2,33	5	10	25	50	100
Subaşı	13,7	17,0	21,4	24,4	27,4	30,3
Musabeyli	38,6	48,0	60,0	68,5	77,1	85,7
Kumdere	128,4	160,5	206,4	229,3	256,8	284,4

*: All flood flows, $m^3\ s^{-1}$

Although two different methods were applied to the same basins, the results obtained were very different. Because the flow values obtained from the Rational method were greater than all the values obtained from the Mc Math method. While this size was 4 times in small basins, it increased 6 times in large basins. This means that the dimensions of the water structures to be constructed using the rational method, especially the channel cross-sectional areas, will be larger. In addition, these values were much higher than the runoff values directly measured from the mentioned basins.

CONCLUSION

A total of 609,6 mm of annual precipitation (1985-1999) fell on the research basins. 21,3 mm of this precipitation left the basin as runoff. Accordingly, the basin surface flow coefficient was calculated as 0,035. This value was much smaller than the flow coefficient of 0,13 (Bayazıt, 1995) for the Meriç-Ergene basin where it is located.

The results obtained with the Turc method, in which the annual water yield of the basin is calculated, were much higher than the direct measurement results obtained from the basin. For this reason, calculations were made with the Turc equation, in which the coefficients of the Turc method were developed using directly measured surface flow data. The values obtained from here gave results close to the values obtained for 80% probability within the method calculated in practice.

For the same basins, the flood flows calculated for different recurrence intervals by McMath and Rational methods were very different from each other. Rational method always gave larger values than Mc Math method. These differences have increased as the basin areas have grown.

The fact that the basin surface flow coefficient is very small makes it necessary to store the precipitation where it falls. This requires the water storage structures to be built in the region to be planned on a sub-basin basis.

In the calculation of pond volumes, the equations containing the new coefficients proposed for the Turc method should be used. Because under these conditions, more accurate pond volumes will be obtained with the calculated watershed water yields. Most of the time, it will allow the emergence of much more economical water structures.

ACKNOWLEDGMENT

This study was produced from the Master's thesis.

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