DETERMINATION OF THE WATER YIELDS FOR SMALL BASINS IN SEMI-ARID AREAS: APPLICATION OF THE MODIFIED TURC METHOD TO THE TURKEY'S CONDITIONS

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Manuscript received: April 4, 2005; Reviewed: May 30, 2005; Accepted for publication: June 1, 2005

ABSTRACT

The Turc Method is used widely in Turkey to determine runoff depths therefore, water yield from a particular watershed and subsequently the reservoir's volume by Turkish General Directorate of Rural Services which is responsible for the investments on agricultural and rural infrastructures. However the method over predicts the water yield markedly when compared to the directly measured long-term water yields, which increases the total cost for the instruction of reservoirs and leads to environmental hazards due to disturbing more agricultural areas. In this research, the Turc Method was modified through replacing the new coefficients with the original coefficients of the 300 and 0.9 by fitting the calculated values to the directly measured long-term, a total of 223 years, in 22 sub-basin distributed throughout Turkey. Coefficients 566 and 0.68 were proposed as average values for Turkey in general instead 300 and 0.9, respectively, though the new coefficients for a particular watershed varied widely from 20 to 1135 and from 0.4 to 1.32, respectively. The country's sub-basins divided into three groups in terms of basin characteristics affective on these coefficients and new coefficients were also suggested for each group. Employing the modified Turc Method with these new coefficients for the research sub-basins can reduce the reservoir's volume by 45 % and this may decrease the total cost of the reservoirs by about 20-25 % through reducing occupied surface area, embankment and crest height.

KEY WORDS: rainfall-runoff, reservoir, Turc Method, water yield, Turkey

INTRODUCTION

The water yield of a watershed may either be measured directly on a single outlet on the main stream or be calculated through empirical equations based on important physical properties of a particular watershed.

Using the directly measured runoff values is, of course, the best way, but since it takes a long time and investments are delayed, the empirical method is preferred in applications. Therefore, precise prediction of the water yield from a watershed is curical for investigating the design capacity of water collecting structures and other hydraulic structures on the down streams.

As in many other countries, the Turc Method is used widely in Turkey to determine the water yield and thus the reservoir volume by Turkish General Directorate of Rural Services which is responsible for the investments on agricultural and rural infrastructures. However, the method over predicts the water yield in comparison to the directly measured volumes for a region of Turkey in consideration. Therefore the method cannot be applied in Turkey's conditions without any major modifications. This necessitates that this issue should be carefully evaluated in economical and technical aspects. In the previous study[1] the modification of the method for Thrace Region was done.

In this research, the Turc method is aimed to be modified to determine the water yield of sub-basins located at different part of Turkey using long time directly measured runoff values.

MATERIALS AND METHODS

The locations of the 22 sub-basins under study are shown in Figure 1. The measurements of water yield from the sub-basins were done between the years 1975 and 1999. Some important characteristics of the research basins[2] are given in Table 1.

Although the climate is generally characterised by the continental type, it varies widely from one to the other basin. Present land use is mainly dry farming with fallow and some part is occupied by pasture and forest.

Precipitation was measured using three raingauges in each sub-basins: one was placed near the outlet of the sub-basins. The runoff against time in the triangular weir constructed at the outlet point was recorded by a stage recording gauge connected to this weir by a channel[3].

The measured runoff values were compared to the ones computed using the Turc method. A widely used formula to estimate annual values of areal evapotranspiration for basin areas was published by Turc[4],[5].Taking basin data from 254 drainage basins, representing all different climates in Europe, Africa, America and the Eastern India, he used the water balance equation to evaluate ET from P and Q, the precipitation and runoff. The annual water yield expressed in the Turc method may be reported by Shaw[6].

$$V = h.A.10 \qquad (1)$$

Where, V is the annual water yield of the basins (m^3 $year^{-1}$), A is the area of the basin (hectare) and h is the surface runoff height that occurred in the basin (mm $year^{-1}$). The surface runoff height is calculated as:

$$h = P - ET \qquad (2)$$

ET is the areal evapotranspiration (mm $year^{-1}$) and P is the mean precipitation (mm $year^{-1}$). ET is defined as:

$$ET = \frac{P}{\sqrt{0.9 + (P^2 / L^2)}} \qquad (3)$$

in which the correlation parameter L is described as:

$$L = 300 + 25T + 0.05T^3 \qquad (4)$$

and T is the mean air temperature (°C).

First, annual surface runoff values were calculated for each basin using the above calculation procedure. Then these were compared to the directly measured ones. To fit the calculated values to the measured values, the Turc method was modified through either replacing the coefficient 300 in Eq (4) or coefficient 0.9 in Eq (3) with the new coefficients. Finally, taking the arithmetic mean of the research years for each basin and their standard deviations into account, new coefficients instead of 300 or 0.9 for research basins and similar basins in Turkey were suggested.

RESULTS AND DISCUSSION

Average of annual precipitation, directly measured at the outlet point of each basin and calculated runoff depths using the original Turc Method (1954, 1955) were given in Table 2. The realised water yield ratio (directly measured runoff depth / calculated depth) * 100 was calculated (column 5, Table 2). New coefficients for each sub-basin instead of 300 in Eq (4) and 0.9 in Eq (3) were also suggested in the last two columns of Table 2 in order to realise the actual water yield.

Against overall sub-basins' average rainfall depth of 536.0 mm, only 64.91 mm directly measured runoff depth was recorded. The magnitude of the measured runoff depth was to small when compared to the precipitation, corresponding 11.5 % of the rainfall. This is because climate, vegetation, topographic and soil conditions are quite different from the condition which Turc[4],[5] produced the coefficients.

The calculated average annual runoff depth was 106.5 mm while the average of all sub-basins' directly measured depth was 64.91 mm, which is considerably smaller than the calculated values by a factor of 1.64. To fit the computed value to the average of long term directly measured value, either coefficient 300 in Eq (4) or coefficient 0.9 in Eq (3) is modified. However both coefficients were modified here. Only one of these new coefficients should be used, for the other one the original coefficient is to be used. The suggested average coefficients for Turkey in general instead of 300 and 0.9 were 566 and 0.68, respectively.

There are no statistically (ANOVA) significant differences among the new suggested coefficients for each sub-basins. Therefore the average values of 566 and 0.68 can be used. However, the wide variations from 20 to 1135 for coefficient 300 and from 0.40 to 1.32 for coefficient 0.9 among the sub-basin may be related to their topographic, land use and climatic conditions. Baring this in the mind, three different groups are distinguished based on the differences between the new coefficients to be used instead 300.

Group 1: The sub-basins KVV, ICD and EMK whose new coefficients are the top three, are located in the Thrace (European) part of Turkey. The average slope of these sub-basins is 4.3 % whereas it is 17.2 % for the sub-basins in the Anatolian (Asian) part of Turkey. Soil profiles are deep and textures vary from medium to heavy in the Thrace sub-basins, however some part of the Anatolian sub-basins are covered by bare rocks. These features of Thrace sub-basins decrease the runoff. Moreover, in Thrace, most of the precipitation falls during the period when the land surface is covered by wheat and sunflower in crop rotation. As a result, only an average of 23.7 mm runoff depth was measured in these three sub-basins. Whereas the calculated average depth was 138.0 mm, which is about 5.8 times largess than the directly measured.

Group 2: The sub-basins TZA, EKC, SVA, ITC, KMK, KCC, IMU2, SMO, BPK, YSI, ITT, KSG, TMU and KBK, whose new coefficients are close to the Turkey's

Fig. 1: Location of the studied sub-basins. 1: Edirne Merkez Kumdere (EMK), 2: Kirklareli Vize Vizederesi (KVV), 3: Istanbul Catalca Damlica (ICD), 4: Izmir Menemen Ulucak-1 (IMU-1), 5: Izmir Menemen Ulucak-2 (IMU-2), 6: Bilecik Pazaryeri Kurukavak (BPK), 7: Kutahya Merkez Kocacesme (KMK), 8: Eskisehir Karapazar Cayir (EKC), 9: Konya Seydisehir Glabbera (KSG), 10: Konya Beysehir Karabalcik (KBK), 11: Konya Cumra Cicek (KCC), 12: Ankara Yenimahalle Kayaonu (AYK), 13: Cankiri Sabanozu Mahmuthacili (CSM), 14: Samsun Merkez Otekoy (SMO), 15: Samsun Vezirkopru Ayvali (SVA), 16: Tokat Zile Akdogan (TZA), 17: Tokat Merkez Ugrak (TMU), 18: Yozgat Sorgun Ikikara (YSI), 19: Icel Tarsus Cavuslu (ITC), 20: Icel Tarsus Topcu (ITT), 21: Adiyaman Kahta Harabe (AKH), 22: Sanliurfa Merkez Kizlar (SMK).

Table 1: Some important characteristics of the research sub-basins.

Name of sub-basin	Area (km^2)	Altitude (m)	Temperature (°C)	Curve Number (%)	Average basin slope (%)
KVV	4.640	215	11.8	67	3.00
ICD	8.260	184	12.8	88	5.90
EMK	4.400	139	13.0	77	4.00
TZA	7.376	1133	11.6	75	22.50
EKC	9.410	1197	10.7	80	13.48
SVA	3.610	634	12.6	81	8.00
ITC	12.030	565	17.9	84	21.10
KMK	11.300	1334	10.5	73	16.00
KCC	98.000	1306	11.6	75	12.0
IMU2	0.342	65	16.7	80	30.00
SMO	1.200	141	14.3	88	11.90
BPK	4.250	953	18.8	80	17.00
YSI	13.000	1215	8.8	80	16.80
ITT	1.690	117	17.9	82	16.70
KSG	1.200	1352	11.5	82	0.22
TMU	7.000	1292	12.1	85	20.60
KBK	10.600	1416	11.3	70	13.00
SMK	26.250	706	18.0	74	8.95
AYK	16.125	1236	10.4	86	21.00
IMU1	0.199	65	16.7	80	38.00
CSM	23.500	1305	11.1	82	24.00
AKH	11.662	686	16.4	81	15.70

average value of 566, are classified into this group and show average basin characterises; moderate in soil profile depth. The basins are partly plateau, pasture dry farms land and partly loose forest. The average directly measured depth of runoff form these sub-basins 66.8 mm which is quite close to the average of calculated depth of rainfall (119.4 mm).

Group 3: While the predicted average runoff value is 51.3 mm $year^{-1}$, the average measured value is 84.4 mm, from the sub-basins, SMK, AYK, IMU1, CSM and AKH. The reason why, unlike other sub-basins, the predicted value is smaller than the directly measured value is because the average slope of the sub-basins are too steep (21.5 %), the pastures are heavily grazed, vegetation of the plateau is weak and dry farming system is practised.

The same classification may also be done for the new coefficients to be used instead 0.9.

CONCLUSIONS AND RECOMMENDATONS

Calculated water yield applying the original Turc Method to Turkey's conditions is significantly greater than the directly measured long-term values, which necessitates that the method should be modified in order to compute reliable values. Instead 300 and 0.9, the new coefficients of 556 and 0.68 were suggested as an average value for Turkey in general. The variation in the suggested new coefficients was found to be statistically non-significant, implying that these average values may be used without leading significant deviations. However, based on the range in the suggested coefficients and basin characteristics effective on these coefficients three groups of sub-basins were identified to improve further the reliability of the calculated water yield.

In the calculation of a particular sub-basins' water yield, coefficients proposed for one of the studied sub-basins similar to that sub-basin may be chosen.

Implying the modified Turc Method, reservoirs' volume is reduced by 45 %. This may decrease the total cost of the reservoirs by about 20-25 % through decreasing occupied surface area, embankment and crest height.

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Table 2: Rainfall, runoff and suggested new coefficients for sub-basins during the research years

Name of sub-basin	Mean rainfall (mm year^{-1})	Annual runoff (mm year^{-1})		Realised water yield rate (%)	Suggested coefficients	
		Direct measurement	Calculated by Turc Eq.		Instead of 300	Instead of 0.9
KVV	535.5	6.61	101.4	6.5	1135	0.40
ICD	707.4	43.20	187.2	23.1	1035	0.19
EMK	609.6	21.30	125.4	17.0	1026	0.39
Average of the group 1					1065	0.33
TZA	607.6	28.02	145.3	19.3	994	0.27
EKC	426.8	3.35	60.9	5.5	926	0.56
SVA	609.7	38.46	131.7	29.2	831	0.41
ITC	841.3	78.40	168.1	46.6	762	0.56
KMK	352.5	3.76	33.7	11.2	689	0.70
KCC	502.1	33.10	87.2	38.0	644	0.61
IMU2	587.9	30.89	68.8	44.9	620	0.73
SMO	580.5	60.16	93.7	64.2	485	0.72
BPK	660.3	130.17	192.0	67.8	485	0.46
YSI	426.2	43.97	77.2	57.0	473	0.65
ITT	654.2	57.03	80.4	70.9	460	0.80
KSG	932.4	305.95	382.4	80.0	450	0.24
TMU	497.0	61.86	79.5	77.8	390	0.79
KBK	461.5	59.86	71.0	84.3	357	0.82
Average of the group 2					612	0.59
SMK	443.1	21.97	16.9	130.0	232	0.93
AYK	441.5	94.53	70.1	134.9	205	1.11
IMU1	587.9	99.42	68.8	144.5	144	1.07
CSM	345.6	66.44	28.3	234.8	89	1.25
AKH	588.5	139.63	72.3	193.1	20	1.32
Average of the group 3					138	1.14
Average of Turkey	563.6	64.91	106.5	61.0	566	0.68

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