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MRRSSW/MODEL OF RAINFALL–RUNOFF IN SMALL SUB-WATERSHED

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Abstract. A hydrologic model called MRRSSW (or KAHYAM in Turkish) was developed to simulate surface runoff of small watershed, which small earth dams may be built on its creeks to store storm water during rainy season and make this water available in dry season. The model computes monthly surface runoff rates employing daily rainfall data. Curve number method of Soil Conservation Service (1972) is used to simulate surface runoff amounts whereas the Blaney and Criddle equation (1950) is used to calculate evapotranspiration. The developed model was tested in 2 small watersheds, namely, Kirklareli-Vize and Istanbul-Catalca-Damlica creeks. Comparison of the simulated surface runoff values with the long-term directly measured data revealed that the model simulated the runoff precisely in the months with relatively smaller surface runoff. However, it slightly over-predicted the runoff amounts in November and December when relatively higher runoff rates occurred. It was concluded that the model can be safely applied in similar small sub-basins to simulate rainfall-runoff relationship with an acceptable deviation.

Keywords: small watershed, rainfall–runoff relationship, antecedent precipitation index, CN-SCS method, hydrologic model.

AIMS AND BACKGROUND

Hydrologic models describing rainfall–runoff relationship are intensively and increasingly used recently, particularly after the technological development in the study area.

Hydrologic models formed by the mathematical expressions are based on hydrological cycle. This cycle is composed of several parameters following the precipitation event such as evaporation, abstraction on the plants and soil surface, percolation, surface runoff by the control of gravity, and also, sediment and other chemical contaminants becoming a significant issue nowadays.

Many models have been developed employing these parameters and used by the researchers. Stanford Watershed Model[1] may be considered as the first study

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among others. This has been followed by new and well-known models: These are: Precipitation, Runoff Modelling System (PRMS) (Ref. 2), Systems Hydrologique European (SHE) model[3,4], Hydrological Simulation Program Fortran (HSPF) (Refs 5 and 6), Watershed Modelling System (WMS) (Ref. 7), TOPMODEL-Topography based hydrological model[8], Small Watershed Monthly Hydrologic Modelling System (SWMHMS) (Ref. 9), Soil and Water Assessment Tool (SWAT) (Ref. 10), Hydrologic Engineering Centre Hydrologic Modelling System (HEC HMS) (Ref. 11) and Soil and Water Integrated Model (SWIM) (Ref. 12). For further information, Singh[13] and Singh and Frevert [14,15] may be referred to.

Although hydrologic models succeeded to simulate future forecast using limited available data, they still need improvements for accounting specific regional conditions.

The objective of this study was to develop a rainfall–runoff model to simulate future runoff rates and to test this model with the long-term observed data.

EXPERIMENTAL

Here, MRRSSW (or KAHYAM in Turkish: 'Kücük Alt Havzalarda Yagis-Akis Modeli') stands for Model of Rainfall–Runoff in Small Sub-watershed. This model was developed to predict water yield of small watersheds on which small earth reservoirs might be built to collect water from small running or dry creeks during a rainy season and used in dry spells.

A flow diagram including all components of the model is presented in Fig. 1. Monthly surface runoff rates were computed in the model using daily rainfall data. Curve number method of Soil Conservation Service (CN-SCS) was applied to compute surface runoff rates[16]. Evaporative losses were obtained using the Blaney and Criddle equation[17].

HYDROLOGICAL PROCESSES

Hydrological processes start with the calculation of curve number for each individual year. For this, land usage pattern of the watershed, soil conservation measures, sowing type and land cover and a hydrologic soil class were considered and a curve number is obtained between 0 and 100, where 100 represent water surfaces. Other surfaces are smaller than 100. This curve number is classified as CN II or AMC II (Antecedent moisture condition II). This should provide the condition that the amount of rainfall occurring within antecedent 5 days is between 23 and 40 mm. If the rainfall is smaller than this value it is classified as CN I and if greater it is categorised as CN III (Ref. 18).

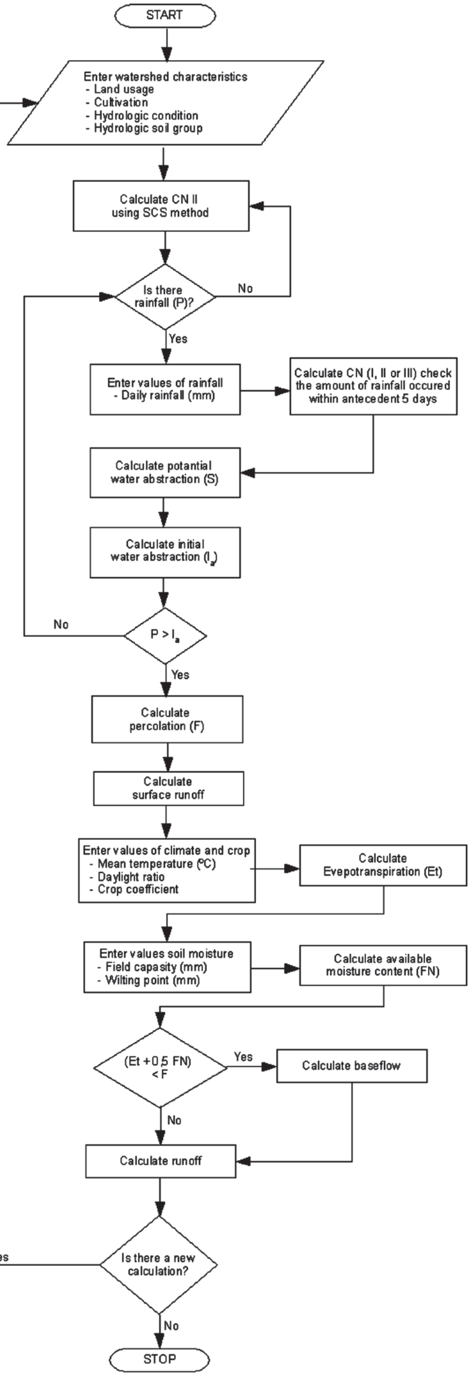

Fig 1. Flow diagram of MRRSSW (Model of Rainfall–Runoff in Small Sub-watershed)

To convert antecedent 5 days soil moisture condition to the other conditions, the following equations are used[19,20]:

$$\text{CN I} = \frac{4.2\ \text{CN II}}{10 - 0.058\ \text{CN II}}, \tag{1}$$

$$\text{CN III} = \frac{23\ \text{CN II}}{10 + 0.13\ \text{CN II}}. \tag{2}$$

CN is a critical criterion in the determination of initial water abstraction in the watershed. Potential (S) and initial water abstraction (I_a) in mm may be calculated using equations (3) and (4), respectively:

$$S = \frac{25400 - 254\ \text{CN}}{\text{CN}}, \tag{3}$$

$$I_a = 0.2\ S \tag{4}$$

In this method[16], the relationship between rainfall and runoff is expressed as:

$$\frac{F}{S} = \frac{Q}{P - I_a}, \tag{5}$$

where F is percolation (mm); Q – cumulative runoff rate (mm) and P – cumulative rainfall rate (mm). Considering also the continuity principle, equation (5) can be re-arranged as follows:

$$P = Q + I_a + F. \tag{6}$$

Solving equations (5) and (6) together for $P > I_a$ condition, F percolation and $Q_{\text{SurfaceRunoff}}$ surface runoff equations are obtained.

$$F = \frac{S\,(P - I_a)}{(P - I_a) + S}; \tag{7}$$

$$Q_{\text{SurfaceRunoff}} = P - (I_a + F). \tag{8}$$

Evapotranspiration (Et in mm) for 10-days intervals are calculated during the growth period of the plants and taking the early and late freezing dates into account using the Blaney and Criddle method[17].

$$\text{Et} = \frac{(1.8\,t + 32)(0.79\,t + 6.1)\,p\,k_c}{100}, \tag{9}$$

where t is seasonal average air temperature (ºC); p – average yearly ratio of day time to night time durations, and k_c – seasonal plant growth constant.

Among the hydrological processes of the model, top 0–30 soil depth and available moisture content (mm) of this layer were considered. The calculation procedure of surface runoff rate Q_{Baseflow} (mm), according to this assumption, is done using the following equation:

$$Q_{\text{Baseflow}} = F - (\text{Et} + 0.5\ \text{FN} + D), \tag{10}$$

where FN is the available water amount in the soil (mm), and D – the amount of drained water (mm). After all these hydrological processes, the total surface runoff of a watershed is obtained from the sum of surface and base flows on monthly base.

$$Q = Q_{\text{SurfaceRunoff}} + Q_{\text{Baseflow}}. \tag{11}$$

RESULTS AND DISCUSSION

The model, developed for surface runoff prediction from small sub-watersheds located in arid and semi-arid regions, was tested for reliability. To do this, long-term recorded rainfall–runoff data from 2 watersheds, namely, Kirklareli-Vize creek[21] and Istanbul/Catalca-Damlica creek[22] were used.

Important characteristics of watersheds are presented in Table 1, whereas their rainfall–runoff data for 1998 are given in Table 2.

Table 1. Characteristics of the Vize and Damlica creeks

Watershed	Location	Area (km^2)	Latitude (m)	Land class	Soil class	Land cover (%)
Vize creek Kirklareli	41º31′ N 27º41′ E	5.83	185–244	II and III	silty-clay-loam	38 forest 29 wheat 28 sunflower 5 range
Damlica creek Catalca–Istanbul	41º06′ N 28º25′ E	8.26	110–258	II and III	clay-loam	60 wheat 30 sunflower 10 range

Table 2. The Vize and Damlica creeks rainfall and observed and simulated runoff values

Values	Months												Yearly
	J	F	M	A	M	J	J	A	S	O	N	D	
the Vize creek/Kirklareli													
Rainfall	36.0	23.0	64.2	67.6	49.9	28.4	5.5	3.2	30.0	42.8	214.0	128.6	691.1
Observed	–	–	–	–	–	–	–	–	–	–	–	0.8	0.8
Simulated	–	–	–	–	–	–	–	–	–	–	67.8	6.5	74.3
the Damlica creek/Catalca–Istanbul													
Rainfall	33.7	53.8	61.1	75.5	13.5	64.8	52.6	–	23.9	75.8	192.9	184.9	832.5
Observed	0.2	0.1	0.2	1.8	0.6	–	–	–	–	–	3.8	36.4	43.1
Simulated	–	–	0.1	7.2	–	1.3	1.8	–	–	0.9	70.6	113.2	195.1

Although climate, soil and topography of the watersheds are similar, land cover is different and this difference is reflected in the simulated results.

The amount and distribution of rainfall were the most critical parameters determining surface runoff rate among others. A considerable runoff rates were observed after heavy successive precipitation. It was also observed that no runoff was occurred after a rainfall below a certain limit. Monthly-based simulation results were similar with the observed data in the months when no or small amounts of runoff occurred. However, in more rainy months like November and December, the model over-predicted the runoff rates for both watersheds. It may be assumed that all recorded runoff amounts were realised during these months.

It is promising when the simulation results are considered in terms of water resources development projects. Use of original Soil Conservation Service (SCS) curve number method[16] without modification significantly overpredicts the runoff rates. This has lead large design of infrastructures than they should be and therefore more cost. This model has been criticised for this[23]. The results produced by MRRSSW are more reliable and safely applicable.

CONCLUSIONS

Rapidly developing hydrologic models in parallel to the advancement in technology have significant role in predicting future events, planning and management of resources according to these predictions using past limited data, particularly, climatic data[24].

In this study, a model was developed to predict water yield of small watersheds with the name MRRSSW (or KAHYAM in Turkish): Model of rainfall–runoff in small sub-watershed. In this model monthly surface runoff rates were computed using daily rainfall data. Curve number method of Soil Conservation Service (SCS) was applied to compute surface runoff rates[16]. Evaporative losses were obtained using the Blaney and Criddle equation[17].

The model was tested with the long-term recorded rainfall–runoff data from 2 watersheds, namely, the Kirklareli-Vize creek[21] and Istanbul/Catalca-Damlica creek[22].

Monthly-based simulation results were similar with the observed data in the months when no or small amounts of runoff occurred. However, in more rainy months like November and December, the model significantly overpredicted the runoff rates for both watersheds. Amount and distribution of rainfall were the most critical parameter determining surface runoff rate among others.

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REFERENCES

1. N. H. CRAWFORD, R. K. LINSLEY: Digital Simulation on Hydrology: Stanford Watershed Model IV. Stanford University. Tech. Report No 39, Palo Alto, Cal., Stanford University, 1966.
2. G. H. LEAVESLEY, R. W. LICHTY, B. M. TROUTMAN, L. G. SAINDON: Precipitation-runoff Modeling System: User's Manual. USGS Water Resources Investigative, 83–4238. Washington, D.C., U.S. Geological Survey, 1983.
3. M. B. ABBOTT, J. C. BATHURST, J. A. CUNGE, P. E. O'CONNELL, J. RASMUSSEN: An Introduction to the European Hydrological System – Système Hydrologique Europèen, 'SHE', 2: Structure of a Physically Based Distributed Modeling System. J Hydrol, **87** (1–2), 61 (1986).
4. J. C. REFSGAARD, B. STORM: MIKE-SHE. In: Computer Models of Watershed Hydrology (Ed. V. J. Sing). Water Resources Publication, Highlands Ranch, Colo, 1995, 809–846.
5. B. R. BICKNEL, J. C. IMHOFF, J. L. KITTLE, A. S. DONIGIAN, R. C. JOHANSON: Hydrologic Simulation Program – Fortran (HSPF): User's Manual for Release 10. Report No EPA/600/R-93/174. Athens, Ga., U.S. EPA Environmental Research Lab., 1993.
6. A. S. DONIGIAN, B. R. BICKNELL, J. C. IMHOFF: Hydrological Simulation Program – Fortran (HSPF). In: Computer Models of Watershed Hydrology (Ed. V. P. Sing). Ch. 12, Water Resources Publications, Highlands Ranch, Colo., 1995, 395–442.
7. A. D. FELDMAN: HEC-1 Flood Hydrograph Package. In: Computer Models of Watershed Hydrology (Ed. V. P. Sing). Water Resources Publication, Colorado, USA. 1995, 119–150.
8. K. J. BEVEN, R. LAMB, P. QUINN, R. ROMANOVICZ, J. FREER: 'TOPMODEL'. In: Computer Models of Watershed Hydrology (Ed. V. P. Sing). Water Resources Publication, Colorado, USA. 1995, 627–668.
9. B. ALLRED, C. T. HAAN: SWMHMS – Small Watershed Monthly Hydrologic Modeling System. Water Resources Bulletin. J Am Water Resour As, **32** (3), 541 1996.
10. J. G. ARNOLD, R. SRINIVASAN, R. S. MUTTIAH, J. R. WILLIAMS: Large-area Hydrologic Modeling and Assessment: Part I. Model Development. J Am Water Resour As, **34** (1), 73 (1998).
11. U. S. Army Corps of Engineers: Summary: Missouri River Revised Draft Environmental Impact Statement. Master Water Control Manual, Review and Update. Northwestern Division, Omaha, NB, 2001.
12. R. KOSKOVA, C. HESSE, S. NEMECKOVA, V. KRYSANOVA: Implementation of the SWIM Model at the Meso-scale Basin: The Malse Case Stady. Geophys Res Abstr, (9), 03562.21 (2007).
13. V. P. SINGH (Ed.): Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colo., 1995.
14. V. P. SINGH, D. K. FREVERT (Eds): Mathematical Models of Large Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colo., 2002a.
15. V. P. SINGH., D. K. FREVERT (Eds): Mathematical Models of Small Watershed Hydrology and Applications. Water Resources Publications, Highlands Ranch, Colo., 2002b.
16. Soil Conservation Service: Hydrology. National Engineering Handbook, Supplement A, Section 4, USDA-SCS, Washington, D.C., 1972.

17. H. F. BLANEY, W. D. CRIDDLE: Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data. USDA Div. of Irrigation and Water Consv. SCS TP-96, 1950.
18. J. BOONSTRA: Estimating Peak Runoff Rates. In: Drainage Principles and Applications (Ed. H. P. Ritzema). The Netherlands International Institute for Land Reclamation and Improvement, Wageningen, (16), 111 (1994).
19. Soil Conservatıon Service: Urban Hydrology for Small Watersheds. Tecech. Rel. No 55, USDA-SCS, Washington, D.C., 1975.
20. V. T. CHOW, D. R. MAIDMENT, L.W. MAYS: Applied Hydrology. McGraw-Hill Book Company, New York. 1998. 557 p.
21. F. BAKANOGULLARI, S. AKBAY: Rainfall–Runoff Characteristics of Kirklareli-Vize Creek Watershed. Ataturk Soil and Water Resources Research Institute, Kirklareli, 2000. 72 p.
22. F. BAKANOGULLARI: Rainfall–Runoff Characteristics of Damlica Creek Watershed. Ataturk Soil and Water Resources Research Institute, Kirklareli, 2008. 110 p.
23. A. ISTANBULLUOGLU, F. KONUKCU, I. KOCAMAN, F. BAKANOGULLARI: Effects of Antecedent Precipitation Index on the Rainfall–Runoff Relationship. Bulg J Agr Sci, **12**, 35 (2006).
24. H. H. TOK, Y. KURUCU, F. PEKER, E. ERCAL, E. TOK: A Rural Development Model for the Thrace Region, Organised Agricultural Zone. J Environ Prot Ecol, **12** (1), 228 (2011).

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