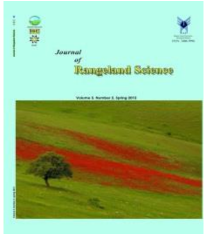
Contents available at ISC and SID

Journal homepage: www.rangeland.ir



Research and Full Length Article:

Assessment of the Monthly Water Balance in an Arid Region Using TM Model and GIS (Case Study: Pishkouh Watershed, Iran)

Jalal Barkhordari[A], Ali Asghar Semsar Yazdi[B]

[A]Faculty Member, Agricultural Natural Resource Reserch Center of Yazd, Iran (Corresponding Author), Email: Barkhordari@alumni.itc.nl
[B]Assistant Professor, Director of International Center on Qanats and Historic Hydraulic Structures (ICQHS)

Received on: 07/03/2013
Accepted on: 19/08/2013

Abstract. Monthly discharge is one of the most important factors considered in designs and hydrological works. Some watersheds are not equipped with needed hydrometric equipment. In such a case average monthly discharge could be estimated from regional monthly water balance models of representative watersheds. In this study, Thornthwaite & Mather (TM) model were used in the Pishkouh watershed in arid climate of Yazd, Iran. The water balance was used for computing seasonal and geographical patterns of water availability to facilitate better management of available water resources. The water balance study using the TM model with the help of remote sensing and Geografhic Information Systems (GIS) is very helpful in finding out the periods of moisture deficit and moisture surplus for an entire basin. This study indicates that there is an annual deficit of 442.7 mm in the study basin and an annual surplus of 26.4 mm. The Pishkouh watershed has a period of moisture surplus from June to August and the remaining months are a period of deficit. Generally these mean estimated runoff values fall between the 90% confidence intervals for the measured runoff and quality of the model was satisfactory (Q_{ual}=2.86). These results indicate that the TM model can be satisfactorily applied to estimate mean monthly stream flow and potential runoff map in the arid regions of central Iran, too.

Key words: Pishkouh watershed, Geografhic Information Systems, TM model, Water balance, Water deficit, Water surplus

Introduction

The reliable assessment of river flow characteristics is basic for the development of water resources. For a few small basins there exist stream gauging records of sufficient length to make an accurate assessment of the water yield characteristics. However, a vast majority of small basins have either no stream flow records or only a few years of records. On the other hand, most catchments have representative meteorological records or records which can be estimated from nearby meteorological stations (Barkhordari, 2013). Consequently, the Thornthwaite & Mather (TM) model was suggested for the water balance assessment of the temporal and spatial patterns of water surplus and water deficit status (McCabe & Wolock, 1999). In a research project in north part of Iran, TM model was used in 12 basins in semi-arid climate of Azarbayejan as well as North of Khorasan province. Following collection of data for temperature, precipitation and average monthly discharge in theses basins, Remaining parts of water balance equation including: Actual evapotranspiration and soil moisture supply of basin in each month and later month were estimated from TM model. The model analyzed at 5% confidence level. The results of the t test showed that difference between observed and estimated runoff, from model, was not significant. Thus using the TM monthly water balance model the series for mean monthly discharge could be generated (Mahdavi & Azarakhshi, 2004). In two other research projects, TM model was used with the help of remote sensing and GIS in Nana Kosi and Devak–Rui watersheds of India and compared runoff calculation data of model with observation data of hydrometric station. It was found that the computed runoff follows the trend of observed runoff with underestimation, even if the model does not match the observed maximum value and the Nana Kosi watershed undergoes a period of moisture deficit during the months of January–June; from July to August the region has a surplus, which is again followed by a period of deficit (Singh & Hariprasd, 2003 and Jasrotia *et al*., 2009). A water balance model for the Roxo catchment's in Portugal was developed based on field data and satellite imageries. The model used the TM method for analyzing the recent (2001–2003) climatological records. The amount of annual runoff from the catchment predicted by the model was 29 million m^3, which was accumulated in the Roxo reservoir. Almost all the discharge was contributed by the direct runoff and the groundwater contribution was non significant. A rainfall-runoff water balance model at a meso level estimates the total catchment runoff produced in a watershed in a monthly time step. Such a model investigates the contribution of surface runoff to the total catchment runoff. One of such models is based on the TM method, which estimates the amount direct runoff in the catchment by taking into consideration the Water Holding Capacity (WHC) of soil. The WHC is characterized by two factors: soil texture and type of land cover. Therefore, for a successful implementation of the model, it is required to prepare a soil texture map, a land cover map, and then a WHC map. Based on these maps, it is possible to estimate the spatial and temporal distribution of runoff flow in a watershed (Sen & Gieske, 2005).

This study evaluates the utility of the Graphical version of TM model with the help of remote sensing, GIS techniques and limited input data in predicting water yields in one gauged watershed in the arid regions of central Iran.

Materials and Methods

Study area

The mountainous Pishkouh watershed with the area about 69235 ha is located in the east of Yazd city, central part of Iran (Fig. 1). This watershed is important for ground water recharge of Yazd and Taft cities. This area has been extended between the longitudes of 53° 42' to 54° 09' and latitudes of 31° 33' to 31° 50'. The altitude of the watershed varies from 1400 to 4044 m and average elevation is 2370 m above sea level. This area is surrounded by mountains with a general slope from East to West. The Mediterranean climate predominates in the area. Like any other parts of central Iran, the area is much warmer and receives less rainfall than the country average. The temperature reaches a maximum of 40 °C in summer (i.e., July or August) and a minimum of 5 °C in winter (i.e., December). The mean annual rainfall in the area is estimated to be 230 mm. The period from May to October is very dry. The area is wet from the month of November to April. In average, 85 percent of the total annual rainfall occurs during this period. The highest amount of rainfall occurs in December, while July and August are the driest months.

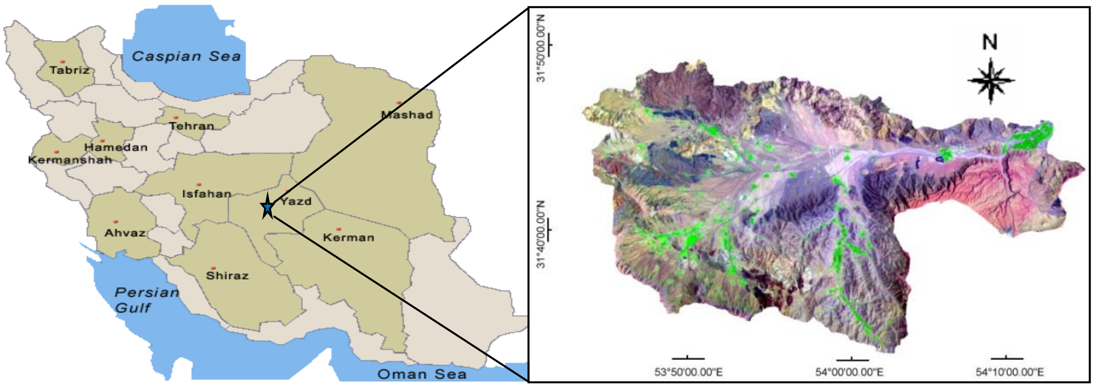


Fig. 1. Location of Pishkouh watershed

Research method

The base map of the study area was produced using topography maps on a scale of 1: 50000. Remote sensing data of ETM+ acquired on 15 July 2007 were procured. The satellite data were first rectified, corrected and geo referenced to the UTM projection system. Digital image-processing techniques were applied on the image, making use of various image enhancement techniques in order to bring out the desired information. Then the watershed boundary and drainage network of the study area were delineated using topography map and satellite imagery. A field survey was made in order to collect the training sets for preparation of a land use/land cover map of the study area. During the field visit, actual ground conditions were verified and training sets were marked for different land uses. Five different land use/land cover features were identified using hybrid method (supervised & unsupervised classification). (Fig. 2), shows land use map of Pishkouh watershed that have been prepared by hybrid method in GIS (Barkhordari & Vartanian, 2012).

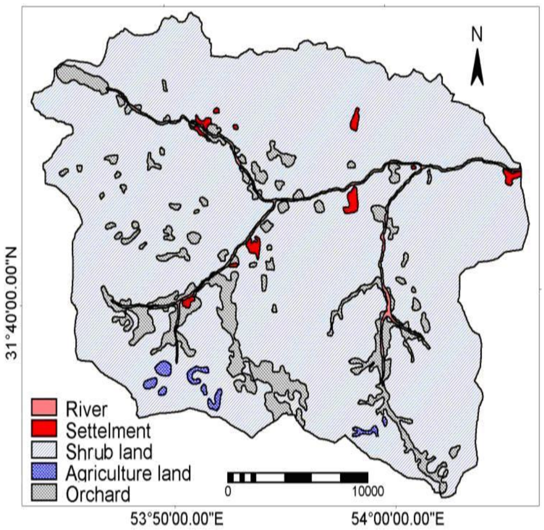


Fig. 2. Land use/land cover map of the study area

Ilwis 3.3 GIS software was used for digital image processing operations such as image rectification and classification. The relative area for different land use features include: shrub land (range land) 87%, agricultural land 1%, orchard 8%, river 1.4%, settlement 2.6%. A soil texture map of the study area was prepared using a soil map of previous study by Organization of Forest and Rangeland (2004) and a limited field checks. Three different soil textures, namely loam, sandy loam and loamy sand, were identified within the study area. The mean monthly precipitation, temperature and observed runoff for the period January 1973–December 2009 were collected from related offices. Graphical version of TM model downloaded from the internet at http://water.usgs.gov/lookup/get?crresearch/mms/thorn has been used in this study (McCabe & Markstrom, 2007). The TM model was used to calculation the water balance of watershed from rainfall and temperature data. The runoff calculation from the TM model was used to prepare a runoff potential map.

The TM water-balance model

The TM model has the advantage of being one the simplest models. It can be used to determine a general estimate of the water balance regime, for individual field to small watershed (McCabe & Markstrom, 2007). Inputs to the model are monthly P and T (Fig. 3). Potential evapotranspiration (PET) is calculated from monthly T using the equation that was presented by Hamon in 1961. The Hamon equation is (Equation 1):

$$PET_{Hamon} = 13.97 d D^2 W_t \quad \text{(Equation 1)}$$

Where:

PET_{Hamon}= is Hamon PET mm per month;
d= is the number of days in a month;
D= is the mean monthly hours of daylight in units of 12 hours (average day length over the month); and

W_t= is a saturated water vapor density term calculated by (Equation 2):

$$W_t = \frac{4.95 e^{(0.062 T)}}{100} \quad \text{(Equation 2)}$$

Where:

T= is the monthly mean temperature in degrees Celsius (°C).

In this study, PET was set to zero when mean monthly temperature was -1°C or lower. This model has been used successfully to estimate monthly and annual PET for various parts of the world (McCabe & Markstrom, 2007).

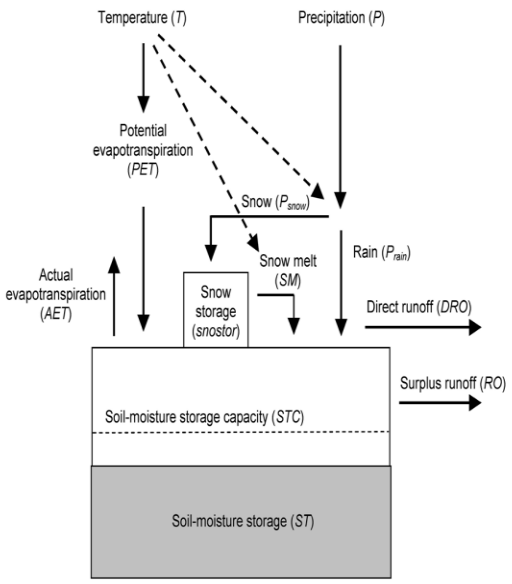


Fig. 3. Diagram of the TM water-balance model (Thorentwaite, 1948)

In the TM model, when P for a month is less than PET, actual evapotranspiration (AET) is equal to P plus the amount of moisture that can be removed from the soil. The fraction of soil-moisture storage that can be removed decreases linearly with decreasing soil-moisture storage; that is, as the soil becomes drier, water becomes more difficult to remove from the soil, and less moisture is available for AET. When P exceeds PET in a given month, AET is equal to PET. Water in excess of PET replenishes soil moisture storage. When soil-moisture storage reaches field capacity during a given month, the excess water becomes surplus. In a given month some percent (RO_{fac}) of the total surplus becomes runoff (McCabe & Markstrom, 2007) (Equation 3).

$$Q = S * RO_{fac} \qquad \text{(Equation 3)}$$

Where
Q = the monthly runoff
S =the surplus.
RO_{fac}= runoff factor

The remaining surplus is carried over to the following month. For each part of watershed the soil-moisture-storage capacity (water-holding capacity WHC) and the percent of surplus that becomes runoff in a month (runoff factor, RO_{fac}). The WHC of soil depends on soil texture and type of vegetation grown on the surface. Different soil textures have different capacity to hold water per unit depth (TAM). At the same time, different vegetation types have different root depths where water can be stored. Hence, WHC in the area can be determined by multiplying TAM of the soil by corresponding root depth of the vegetation grown over there, which is shown in Table 1.

In some locations, such as the arid regions of the central Iran, much of the P occurs during only a few short-lived P events. Many of these P events produce runoff immediately. Thus, the methodology of subtracting monthly PET from monthly P used in most water-balance models exaggerates the effects of PET on water inputs for these regions. To account for this, in this study a PET factor (PET_{fac}) was used to modify PET so that the fraction of total monthly PET that could affect the water input during short-lived P events could be estimated. The PET_{fac} was determined for Pishkouh watershed through model calibration. The snow accumulation and melt model used in this study is based on concepts often used in monthly water-balance models (Barkhordari, 2013). The occurrence of snow is computed as (Equation 4):

$$SN = \begin{cases} P, T_a \le T_{snow} \\ P\left(\frac{T_{rain} - T_a}{T_{rain} - T_{snow}}\right), T_{snow} < T_a < T_{rain} \\ 0, T_a \ge T_{rain} \end{cases}$$

(Equation 4)

Where
SN= is monthly snow fall (mm);
P= is monthly precipitation (mm);
T_a is monthly air temperature in degrees Celsius (°C);
T_{rain} is a threshold above which all monthly precipitation is rain; and
T_{snow} is a threshold below which all monthly precipitation is snow. Between T_{rain} and T_{snow} the proportion of precipitation that is snow or rain changes linearly (McCabe & Markstrom, 2007).

If snow occurs in a given month, it is added to the snow pack, and is subject to melt if conditions are such that melting can occur. Thus, for some cases, snow, rain, and snow melt can occur in the same month. For this study, T_{snow} and T_{rain} were determined for Pishkouh watershed through model calibration. Snow melt is computed as a fraction of the snow storage by (Equation 5):

$$MF = \begin{cases} 0, T_a \le T_{snow} \\ MF_{max}\left(\frac{T_a - T_{snow}}{T_{rain} - T_{snow}}\right), T_{snow} < T_a < T_{rai} \\ MF_{max}, T_a \ge T_{rain} \end{cases}$$

Where
MF is the fraction of snow storage that can be melted in a month. In the past, the maximum fraction (MF_{max}) of snow storage that could be melted in a month was set to 0.5 (McCabe & Markstrom, 2007).

Results and Discussion

In this study, MF_{max} was determined for Pishkouh watershed through model calibration. The fraction of snow storage that can be melted in a month increases from 0 to T_{snow} to MF_{max} and above T_{rain}. Table 1 shows results of parameters calibration for Pishkouh watershed (Barkhordari, 2013). Table 2 shows computation of water holding capacity in the root zone area, available water capacity (AWC) for different land uses and soil textures.

Table 1. Sensitivity range and optimal values of model parameters

Parameters	Parameters of TM Water Balance Model				
	T_{rain}	T_{snow}	PET_{fac}	Ro_{fac}	MF_{max}
Sensitivity Range	-5 to 15	-20 to 0	0 to 1	0 to 1	0 to 1
Optimal Value	12	-1	1	0.04	0.25

Ref. (McCabe & Markstrom, 2007)

Table 2. Computation of available water capacity (AWC)

Land Use	Soil Texture	Area (ha)	AWC (%volume)	Rooting Depth (m)	AWC of Root Zone (mm)
Agriculture	Sandy loam	134.9	15	0.4	60
Agriculture	loam	535.4	20	0.75	150
Orchard	Sandy loam	2300.6	15	1	150
Orchard	loam	2790.0	20	1.2	240
Orchard	Loamy Sand	339.6	10	1.5	150
River	Sandy loam	209.5	15	0.2	30
River	loam	385.3	20	0.3	60
River	Loamy Sand	266.4	10	0.6	60
Settlement	Sandy loam	216.1	15	0. 3	60
Settlement	loam	166.2	20	0.75	150
Settlement	Loamy Sand	62.7	10	0.6	60
Rangeland	Sandy loam	35296.9	15	0. 2	30
Rangeland	loam	21078.2	20	0.4	60
Rangeland	Loamy Sand	2799.9	10	0.6	60

In this study a model has been run for different water holding capacity (WHC) and some other parameters that have been shown output of model on the outside Table 2. It can be seen from Table (3) that the annual deficit is minimum for orchard and agricultural land (439 mm) followed by settlement/river (440.3 mm) and Shrub land (467 mm).The annual surplus exist just for shrub land (26.4 mm). The maximum annual runoff results from the shrub land (37 mm) and decreased for other land uses (10.5 mm). The area-weighted total runoff from Pishkouh watershed was calculated as 10.2 mm from the total precipitation of 230 mm. It gives a great deal of information regarding the water balance of Pishkouh watershed.

Besides showing the seasonal pattern of precipitation, actual evapotranspiration (AET), potential evapotranspiration (PET) and runoff, it indicates the periods of moisture deficit, soil moisture recharge and soil moisture utilization.

The moisture deficit indicated that plants were under some stress during that period, indicating the need for irrigation. The area is relatively dry in the months of May–October. Soil moisture recharge takes place from November to April. The period of water surplus is from February to April.

Table 3. Average monthly water balance computation for all the land use features (Barkhordari, 2013)

Parameters	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Shrub land , available water capacity (AWC=30)													
Soil Moisture	22	30	30	30	0	0	0	0	0	0	0	6.8	118.8
Snow storage	0	9.4	0	0	0	0	0	0	0	0	0	0	9.4
AET	18	18	28.3	43	47	4.3	1.2	0.6	0.3	3.2	8.2	20	192.1
Deficit	0	0	0	0	24	92	116	100	73	42	20	0	467.0
Surplus	0	3.2	20.5	2.7	0	0	0	0	0	0	0	0	26.4
Runoff	1.5	2.9	13.1	9.3	4.3	1.9	0.9	0.5	0.2	0.3	0.5	1.5	37.0
Settlement and river (AWC=60)													
Soil Moisture	5.8	22	33	53.6	56	0	0	0	0	0	0	6.8	177.2
Snow storage	0	9.4	0	0	0	0	0	0	0	0	0	0	9.4
AET	18	18	28.3	43	67	10	1.2	0.6	0.3	3.2	8.2	20	217.8
Deficit	0	0	0	0	3.3	86	116	100	73	42	20	0	440.3
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0
Runoff	1.5	1.3	2.1	2.4	0.9	0.2	0.1	0	0	0.2	0.4	1.4	10.5
Agriculture land (AWC=150)													
Soil Moisture	23	34	54.6	57	37	14	3.3	1.1	0.6	0.4	0.4	7.1	232.5
Snow storage	0	9.4	0	0	0	0	0	0	0	0	0	0	9.4
AET	20	8.3	3.4	0.8	2.8	12	27	37	43	28.3	18	18	218.6
Deficit	0	0	0	0	33	69	105	98	72	42	20	0	439.0
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0
Runoff	1.5	1.3	2.1	2.4	0.9	0.2	0.1	0	0	0.2	0.4	1.4	10.5
Orchard (AWC=240)													
Soil Moisture	27	38	58.4	61	47	29	15	8.9	6.2	5.1	4.7	11	311.3
Snow storage	0	9.4	0	0	0	0	0	0	0	0	0	0	9.4
AET	18	18	28.3	43	31	22	15	7	3	4.3	8.7	20	218.3
Deficit	0	0	0	0	40	74	101	94	70	41	19	0	439.0
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0
Runoff	1.5	1.3	2.1	2.4	0.9	0.2	0.1	0	0	0.2	0.4	1.4	10.5

A statistical comparison of the estimated and the measured stream flow is summarized in Table 4, This shows the mean monthly and mean annual estimated and measured stream flows, the correlation coefficient between measured and estimated stream flows, the mean monthly and annual percentage error of estimation and the 90% confidence interval for the mean stream flow. The months of December, June, July, September and October showed the highest correlation coefficients between measured and computed stream flow. These months also had the highest percentage error of estimation. Because of these two reasons, the correlation coefficient alone apparently cannot be considered an accurate indicator of a satisfactory estimation. On a monthly and annual basis, the method provides conservative estimated values. It is important to point out that the months associated with the dry season (May-October) showed the most conservative estimations, and at the same time they match very well with the pattern of measured values. Table 5 shows the complete output from a run of the averages of 35 years of data with calibrated model parameters for the Pishkouh watershed.

Table 4. Comparison of observed and simulated runoff on Pishkouh watershed

Months	Observed Runoff (mm)		Simulated Runoff (mm)		90% CI**		Error (%)	R^2
	Average	SD	Average	SD	Min	Max		
Jan.	1.10	0.35	1.05	0.240	1.30	0.98	-8.61	0.63
Feb.	1.50	0.36	1.30	0.185	1.69	1.37	-14.61	0.49
Mar.	1.54	0.38	1.35	0.210	1.71	1.37	-10.66	0.37
Apr.	1.50	0.37	1.40	0.190	1.67	1.34	-6.55	0.44
May	1.10	0.26	1.15	0.205	1.22	0.98	4.96	0.47
Jun.	1.23	0.96	0.85	0.355	1.67	0.80	-20.01	0.87
Jul.	0.66	0.30	0.55	0.230	0.79	0.52	-10.48	0.74
Aug.	0.43	0.19	0.35	0.145	0.52	0.35	20.04	0.57
Sep.	0.31	0.11	0.20	0.100	0.36	0.27	-34.87	0.72
Oct.	0.41	0.45	0.20	0.215	0.62	0.21	-46.60	0.76
Nov.	0.64	0.38	0.65	0.225	0.81	0.47	2.01	0.4
Dec.	1.15	0.39	0.95	0.255	1.32	0.97	13.01	0.72
Year	11.65	2.45	10.19	1.440	12.76	10.55	-12.55	0.51

SD: Standard Deviation, R^2: correlation coefficient
90% CI: 90% confidence intervals for measured stream flow

In addition, in this study optimization method developed by Vandewiele *et al.* (1992) is employed to quality evaluation of the proposed model. This quality evaluation method is a powerful global optimization technique, originally designed to deal with the peculiarities encountered in the conceptual watershed model calibration. It can be seen that the computed runoff follows the trend of observed runoff with underestimation, even if the model does not match the observed maximum value that were used by Vandewiele *et al.* (1992), Barkhordari (2013) and Mahdavi & Azarakhshi (2004). For assessing the quality of the model in calculation of monthly discharge have been used 35 years observation data (1973-2009) and following (Equations 6 &7):
Where

Q_{ual}=O.cv / M.cv (Equation 6)

CV=S/q (Equation 7)

Q_{ual} is model quality,
O.cv is observed runoff coefficient of variation;
M.cv is calculated runoff coefficient of variation.
For evaluation of model quality (Q_{ual}), If Q_{ual} <2, 2<Q_{ual}<3, 3<Q_{ual}<4 or Q_{ual} >4 can take into week, satisfactory, good or excellent respectively (Vandewiele *et al.* 1992). The calculated data were compared with 35 years observation data which showed quality of the model was satisfactory (Q_{ual}=2.86) that is same approximately as results of Mahdavi & Azarakhshi (2004) in north part of Iran, too. The results of other researches about application of TM model for simulation of watershed potential runoff in India with tropical climate (by Singh & Hariprasd, 2003 & Jasrotia *et al.*, 2009) and in Portugal with semi-arid climate have had same satisfy conclusions then can accepted results of this research , too. (Fig. 4), has been compared monthly simulated and observed runoff data as graphical representation.

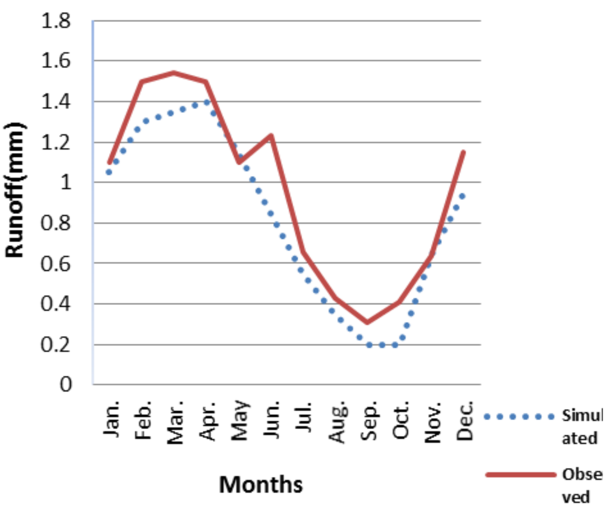


Fig. 4. Comparison monthly simulated and observed runoff

Table 5. Summary of the P, PET, AET and runoff for Pishkouh watershed (mm)

Parameters	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
P	34.9	39.9	41.4	48.1	17.8	4.54	1.2	0.67	0.28	3.4	8.7	28.5	230.0
PET	18.3	18	28.3	42.9	70.7	95.9	117	101	73	45	28	20.3	658.1
AET	18.3	18	28.3	42.9	69.9	4.3	1.2	0.6	0.3	3.2	8.2	20.3	215.4
Runoff	1.05	1.3	1.35	1.4	1.15	0.85	0.55	0.35	0.2	0.2	0.65	0.95	10.2

Runoff potential map

The thematic map of land use/land cover and soil were crossed. Then runoff was calculated for each land use/land cover and soil texture classes using the water balance calculations method as suggested by Thornthwaite (1948).The calculation of average annual runoff for different land use and soil class from the study area is given in Table 2. The annual values of each land use and soil texture class were obtained from the available water capacity of each class using the TM model. The runoff value calculated from the TM model was used in GIS to generate the runoff potential map (Fig. 5). The runoff potential map was classified into low and moderate runoff potential zones. More than half of the area (i.e. 54%) is dominated by medium runoff potential zones, where as low runoff potential zone covers an area of 46% and the suitable zone for selecting rainwater harvesting structure i.e. moderate runoff potential zone covers an area of 54% of Pishkouh Watershed.

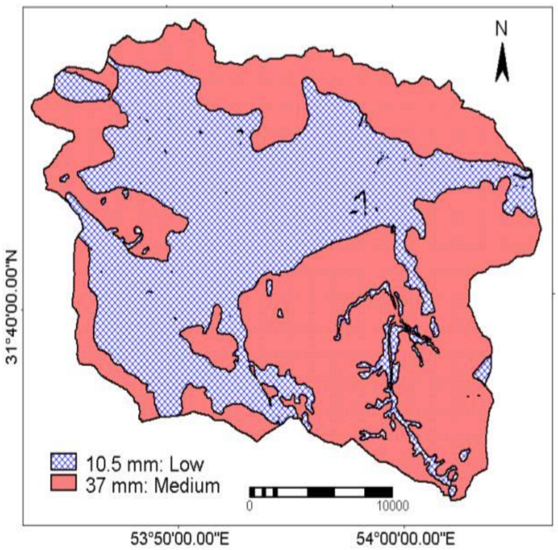


Fig. 5. Runoff potential map of the study area

Conclusions

The study of water balance using the TM model with the help of remote sensing and GIS was found to be very helpful in determining the periods of moisture deficit and moisture surplus in an arid region like the Pishkouh watershed. The water balance model shows that an annual deficit is 442.7 mm and the annual surplus is 26.4 mm. Pishkouh watershed undergoes a period of moisture deficit during the months of May to November. The region has a surplus, which is again followed by a period of deficit. Such studies can be very beneficial for the local population, who can decide their crop calendar and irrigation requirements based upon the periods of deficit or surplus. Water conservation measures can also be planned efficiently in advance based upon the duration of deficit and surplus. The total runoff from Pishkouh watershed was calculated as 10.2 mm from the total precipitation of 230 mm for the study period. The method was tested by comparing observed and predicted runoff over a 35 water-year period. The study shows that this method provides mean annual and monthly estimates in close agreement with measured values. Generally these mean estimated values fall between the 90% confidence intervals for the measured runoff and quality of the model was satisfactory (Q_{ual}=2.86). Thus using the TM model, the series for mean monthly discharge could be generated. Since the study of water balance using the TM model with the help of remote sensing and GIS was found to be very helpful in determining the periods of moisture deficit, moisture surplus and estimate mean monthly stream flow and potential runoff map in the arid regions of central Iran, too.

Acknowledgements

This paper was made possible thanks to the support of Water Resources Management of Iran and Department of Geography & Geology, Yerevan State University. We would like to thank the anonymous referees for providing positive comments.

Literature Cited

Barkhordari, J., 2013. The Calculation of potential Runoff and Selection of the Sites for Underground Dams in Yazd region of Iran (with use of RS, GIS and DSS), Ph.D. thesis, Yerevan State University, P.151.

Barkhordari, J. and Vartanian, T., 2012. Using Post-classification Enhancement in Improving the Classification of Land use/cover of Arid Region (A case study in Pishkouh watershed, Center of Iran). *Jour. rangeland science*, 2(2): 459-465.

Hamon, W. R., 1961. Estimating potential evapotranspiration: *Jour. the Hydraulics Division*, Proceedings of the American Society of Civil Engineers, 87: 107-120.

Jasrotia, A.S., Majhi, A. and Singh, S., 2009. Water Balance Approach for Rainwater Harvesting using Remote Sensing and GIS Techniques, Jammu Himalaya, India. Water Resource Manage, DOI: 10.1007/s11269-009-9422-5, p

Mahdavi, M. and Azarakhshi, M., 2004. A determination of an appropriate monthly water balance in small watershed of Iran. *Natural Res. Jour, Iran*, 57(3): 415-427, (In Persian).

McCabe, G. J. and Markstrom, S. L., 2007. A monthly water-balance model driven by a graphical user interface: U.S. Geological Survey Open-File report, 1088, P.1-6

McCabe, G.J., and Wolock, D.M. 1999. Future snow pack conditions in the western United States derived from general circulation model climate simulations: *Jour. the American Water Resources Association*, 35 (1): 473- 484.

Organization of Forest and rangeland, 2004. Soil survey of Pishkouh watershed, Report of Natural resource office in Yazd, unpublished, P.80. (In Persian).

Singh, R. K. and Hariprasd, V, 2003. Remote sensing and GIS approach for assessment of the water balance of a watershed. Hydrological Sciences Jour. Des. Sciences Hydro., 49(1): 131-141.

Sen, P. K. and Gieske, A, 2005. Use of GIS and Remote Sensing in Identifying Recharge Zones in a semi-Arid Catchments: A case Study of River Basin, Portugal. *Jour. Nepal Geological Society*. 31: 25-32.

Thornthwaite, C. W, 1948. An approach toward a rational classification of climate: *Geographical Review*, 38: 55–94.

Vandewiele, G. L., Chong XU, and Ni-lar-Win., 1992. Methodology and Comparative Study of Monthly water Balance Models in Belgium, China, Burma, *Jour. hydrology*, 43: 317-347.

ارزیابی ماهانه بیلان آبی با کمک مدل تورنت وایت-مدر و سیستم اطلاعات جغرافیایی در منطقه خشک (مطالعه موردی: حوزه آبخیز پیشکوه استان یزد- ایران)

جلال برخورداری[الف]، علی اصغر سمسار یزدی[ب]

[الف] عضو هیئت علمی مرکز تحقیقات کشاورزی و منابع طبیعی یزد، ایران (نگارنده مسئول)، پست الکترونیک: Barkhordari@alumni.itc.nl
[ب] استادیار و رئیس مرکز بین اللملی قنات و سازه های تاریخی آب

تاریخ دریافت: ۱۳۹۱/۱۲/۱۷
تاریخ پذیرش: ۱۳۹۲/۰۵/۲۸

چکیده. آبدهی ماهانه حوزه یکی از مهمترین فاکتور ها در طراحی و مطالعات هیدرولوژی می-باشد. بسیاری از حوزه‌های آبخیز فاقد داده‌های اندازه‌گیری شده دبی هستند. در چنین حالتی می‌توان متوسط دبی ماهانه را با استفاده از مدل‌های تجربی بیلان آبی حوزه برآورد نمود. در این تحقیق از مدل بیلان آبی ماهانه تورنت وایت مدر در حوزه آبخیز پیشکوه با شرایط اقلیمی خشک استان یزد استفاده گردید. از روش بیلان آبی حوزه برای محاسبه تغییرات زمانی و مکانی رواناب مازاد برای مدیریت بهتر منابع آبی استفاده گردیده است. مطالعه بیلان آبی حوزه با استفاده از سنجش از دور و سیستم اطلاعات جغرافیایی در تعیین دوره‌های کمبود و مازاد آب بسیار موثر خواهد بود. نتایج این تحقیق نشان داد که کمبود رطوبت سالانه حوزه ۴۴۲/۷ میلیمتر و رواناب مازاد حوزه در فصل بارندگی ۲۶/۴ میلی‌متر می‌باشد. به طور کلی این مقادیر متوسط رواناب ماهانه برآورد شده بین فاصله اطمینان۹۰٪ داده‌های رواناب اندازه‌گیری شده ایستگاه هیدرومتری قرار داشته است و کیفیت مدل رضایت بخش(Qual۲/۸۶) می باشد. این نتایج نشان می‌دهد که مدل تورنت وایت مدر می‌تواند، به منظور برآورد متوسط جریان جریان ماهانه و نقشه رواناب بالقوه در مناطق خشک مرکزی ایران مورد استفاده قرار گیرد.

کلمات کلیدی: حوزه آبخیز پیشکوه، سیستم اطلاعات جغرافیایی، مدل تورنت وایت مدر، بیلان آبی، کمبود آب، آب مازاد