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Assessment of Runoff in the High Humid Foot-hill Areas of Arunachal Himalayas Using Thornthwaite Equation

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ABSTRACT: Present study examines daily runoff trend in Dikrong river catchment which is located in the lower foot-hills of Arunachal Himalaya. The river catchment is characterized by the monsoon dominated hydrologic regime. For the purpose daily statistics of temperature, rainfall and discharge were collected from the various sources of state Government of Assam, Guwahati and Government of Arunachal Pradesh, Itanagar and used for testing the validity of Thornthwaite-Mather [T-M] method in Dikrong river catchment of high humid areas of Arunachal Himalayas. It is found that this method is not suitable for the correct assessment of daily Potential Evapotranspiration [PET] as well as daily runoff [RO]. The fluctuation in predicted RO are found more than the observed RO with an over estimation during high rainfall intensity and under estimation in the period of low rainfall regime.

Keywords: Runoff, Potential Evapotranspiration, Thornthwaite-Mather method, Arunachal Himalayas, discharge rate

1. INTRODUCTION

There are numerous studies on the assessment of runoff in a river catchment using universally accepted Thornthwaite equation for the quick and correct prediction of runoff [1], [2], because this method is implicitly based on water balance equation and simple to use with universally available statistics of two hydro-meteorological parameters, namely, precipitation and temperature.

In India especially in the most-humid areas where 'saturation excess' processes of runoff generation are more prevalent rather than 'infiltration' processes in the monsoon dominated hydrologic regime [3], there is a need of testing the validity of Thornthwaite-Mather [T-M] procedure to assess the runoff in such high rainfall conditions. There are other methods than T-M procedure used for the assessment of reference ET not only in Indian conditions but across the world. In this regard, Indian references are important to compare the suitability of these methods. For example, Mishra, *et al.* [4] used T-M method for tropical regions of the country. Meshram, *et al.* [5] used other methods and found suitability of FAO Penman-Monteith method, while Lenka, *et al.* [6] tested the validity of different methods like Blaney-Criddle [7], Hamon method [8], Hargreaves and Samani [9], Papadakis [10], FAO Penman-Monteith [11] that have different bases of PET calculation for the prediction of reference ET. It is argued and found that T-M procedure of the assessment of PET is simpler than the other methods because it is water balance based equation that is more appropriate to analyze the hydrologic cycle while the other methods are based on atmospheric energy parameters. Such other methods may be useful for the study of meteorological phenomena rather than hydrological regime of a river catchment.

For the purpose, present paper examines the daily runoff trend and its associated factors and also evaluates the significance of the application of T-M procedure taking into account Dikrong river catchment of about 1,556 sq km area of which more that 80% is under the hill topography with an average annual rainfall of 3,294mm.

1.1 Study Area

Dikrong river catchment is located in the foot-hills of Arunachal Himalayas between 26˚55´N to 27˚22´N latitudes and 93˚13´E to 94˚0´E longitudes with its transitional characteristics of its location as it falls under Inter Tropical Convergence Zone [ITCZ] where climate is monsoonal in this part of Asian region [Fig.-1]. Being its location in the loop of Eastern Himalayas, it is more humid and has different hydrological characteristics than the other parts of North-East Region of the Country. The length of the main river is recorded 145 km with an average slope of 5-15% with the perimeter of 264 km. Topographically, hill slopes are steep covering a area of about 61.54% with its narrow flat valleys located in the upper parts of the river catchment. Such topography helps in accelerating the saturation processes and fast flow while the lower part is gentle plain accommodating about a quarter part of the catchment [27.01%] with sediment deposition [Fig.-2].

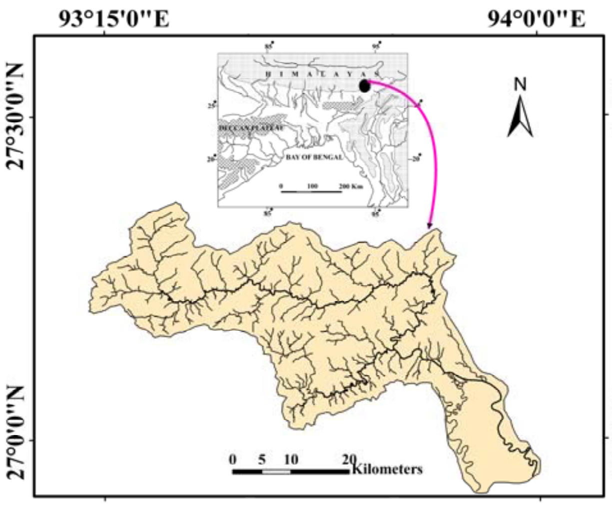
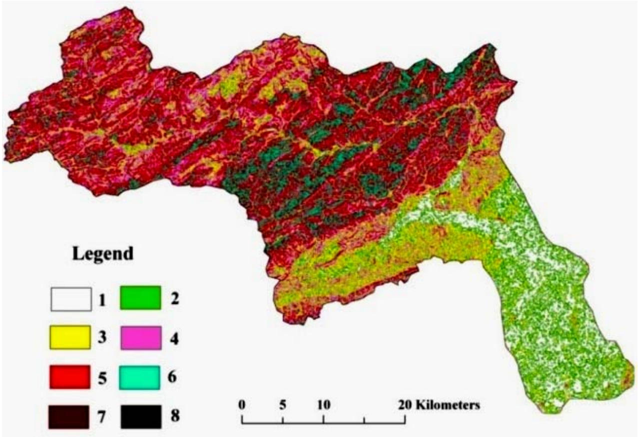


Fig.-1: Location of the Dikrong river catchment



Abbreviations: Slope in percent; 1= Very Gentle (2- 4), 2= Gentle (4-10), 3= Moderate (10-20), 4= Moderately Steep (20-35), 5= Steep (35-60), 6= Very Steep (60-100), 7= Most Steep (100-175), 8= Extremely Steep (above 175).

Fig-2: Slope Variations in the Dikrong River Catchment

Land use/ land cover pattern of Dikrong river catchment is dominated by forest [75% areas are under dense and open forests] in the upper parts and agricultural and abandoned land [12% of total area] in the lower parts of the catchment. In such land surface conditions, the runoff has peculiar trend to develop erratic floods in the lower parts of river catchment. Soils are fine loamy and coarse silty which have high faction of sand helping in retaining more water to regulate runoff. As a result, runoff has also been recorded in the dry weather of winter seasons in spite of less rainfall and moderate PET conditions [Fig.-3].

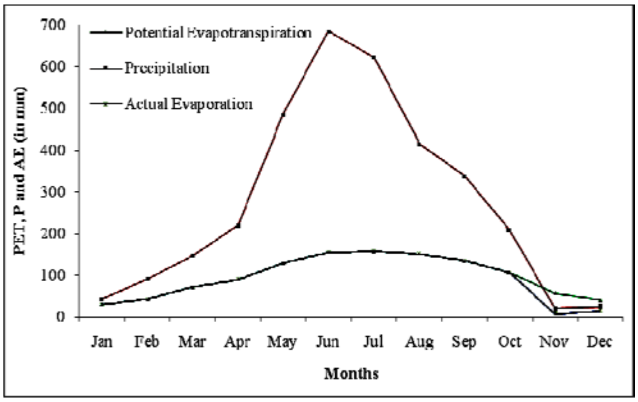


Fig.-3: Normal water balance for Dikrong river catchment

2. METHODS AND MATERIALS

Of course, there are various methods of assessing the reference evapotranspiration [ET_0] mainly classical method forwarded by Blaney-Criddle establishing relation of day time duration with temperature, Hamon method that is based on water vapor density in the environment, Hargreaves and Samani on radiation balance and temperature variation, and Papadakis method which is saturation deficit based [12], [13], [14]. Such methods are largely dependent on field observations used for different environmental conditions. The PET calculation by T-M procedure which is first introduced by Thornthwaite [15] and, later on, Thornthwaite and Mather [16] with its notebook procedure has been used by many geographers [17], meteorologists and climatologists [18], and found its suitability especially for the monsoon based hydrologic regime. In this method, temperature- based heat index, i.e., i= $[T^{0c}/5]^{1.514}$ with a location specific correction factor of unadjusted PET is used for the assessment of soil moisture and runoff variability over time. In order to compare daily runoff with other parameters of water balance equation [P= RO+PET+ΔST, where RO= Runoff, P= Precipitation, PET= Potential Evapotranspiration and ΔST= Changes in soil moisture], the T-M procedure is used. In order to make data standard, daily statistics of temperature and rainfall for three consecutive years [2004-2006], its average figures were used for Itanagar station [that is centrally located in the study area]. The concerned statistics were collected from the Rural Works Department, Government of Arunachal Pradesh, Itanagar. While daily discharge statistics of the same period of time were collected from the Water Resource Department, Government of Assam, Guwahati for Sisapather gauge station [that is at the mouth of river catchment]. Calculations of daily soil moisture availability and runoff were made to set the water holding capacity of 200 mm as specified by NBSS & LUP, Jorhat [19] with adopting standard procedure of water retention capacity analysis.

3. RESULTS AND DISCUSSION

Of course, rainfall-runoff relationship always becomes positive with its strong degree though with Curve Number [CN] method was adopted by USDA [20] to evaluate the effect of land cover/land use and soil types on runoff. Similarly, this relationship is significantly strong [r=0.996] with its regression gradient of slightly lesser than unity [1:1 relationship shows CN=100 in the situation that there is no effect of land use and soil on runoff generation in the river catchment] as b=0.925 [Fig.-4]. The rainfall-runoff ratio is therefore calculated 0.5624 for Dikrong river catchment. It means 56.24 % rainfall becomes runoff in this catchment and shows the effect of surface condition [slope, soil and land use] on runoff processes. Runoff regression equation shows interestingly that daily rainfall below 1.24 mm does not produce any runoff in this area as [a= -1.242] that is indicative of the origin of runoff. Such runoff production level in the river catchment clearly shows that there is production of runoff during winter season varying from 4.80mm per day in November to 4.24mm in January [Fig.-5]. Runoff of about 4.47mm daily was observed in these days due to sub-surface flow, while its amount is influenced by soil and land use factors. Concentration period of two days to reach the runoff at mouth is also factor which shifts the runoff trend.

Rainfall does not correspond much to PET because PET is more associated with temperature variation. The relationship between them is too week [r=0.475] to draw some conclusions. However, the degree of fluctuation of rainfall is observed much higher [CV=124.78%] than PET [CV=47.9 %] [Table-1].

In the event of increasing rainfall-intensity with wet antecedent moisture conditions, the rainfall-runoff ratio becomes higher that produces more discharge in the month of late June to August. There are fast changes in soil moisture conditions during the dry winter season when rainfall is occasional that infiltrates its total amount and fluctuates soil moisture availability. The summer does not have much change in antecedent soil moisture conditions. They are fully saturated and generate more surface and subsurface runoff.

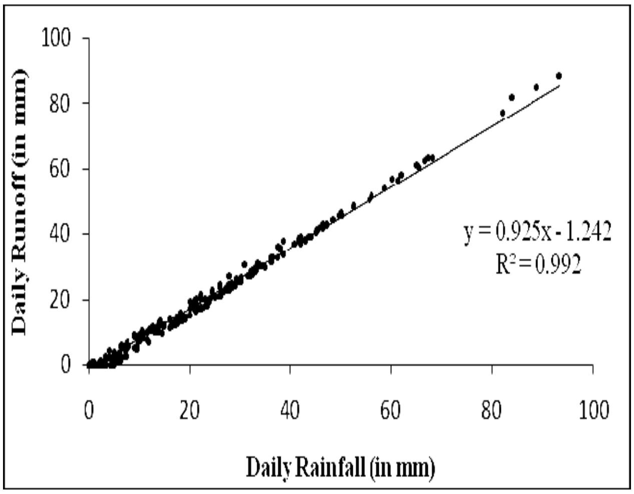


Fig.-4: The relationship between daily rainfall and daily RO

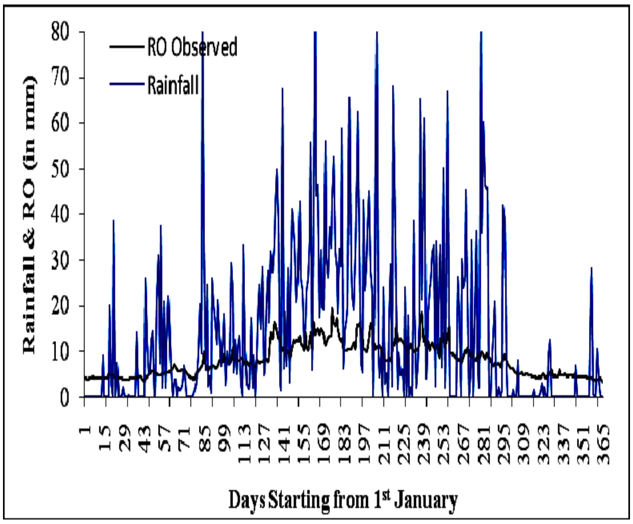


Fig.-5: Daily trends rainfall and observed RO

Table-1: Daily Mean, Standard Deviation and Coefficient of Variation of Hydrologic Parameters

Parameters	Daily Mean	Standard Deviation	Coefficient of Variation (%)
Mean daily Temperature (T^0 C)	22.57	4.19	18.58
Rainfall (mm)	14.44	18.02	124.78
Heat Index (unit less)	9.92	2.72	27.38
PET (mm)	3.12	1.49	47.96
AE (mm)	2.33	1.98	84.85
Runoff (mm)	8.12	16.75	138.1
Runoff Ratio (%)	56.24	-	-

A total runoff is predicted 4,426mm annually with its rainfall-runoff ratio of 0.8398 that deviates 27.74 % from observed runoff. Comparing observed with predicted runoff over time, it is obvious to highlight that at the time of high rainfall intensity during the wet monsoon season, T-M Procedure made over estimation of runoff trend and it was under-estimated during the dry winters. On the whole, the annual prediction of RO is over estimated as it predicts higher rainfall-runoff ratio. However, the trend of observed runoff is found much smoother than predicted one [Fig.-6] as the main features of such trends are given below.

i. Increasing rainfall increases fluctuation in runoff. For example, the month of July and August [peak monsoon season] has its very high fluctuation.

ii. On account of over estimation of runoff by T-M method, the error term in distribution becomes too high that reduces the significance level with low degree of determinant [R^2=0.306] [Fig.-7].

iii. There is fast fluctuation in the soil moisture availability during winter season when there is an occasional rain. But on the other hand, PET trend is quite smooth, increases gradually during pre-monsoon months [April-May], becomes flat during monsoon period and again fall down during the post-monsoon period. PET follows the temperature variation rather than rainfall trend [Fig.-8].

iv. The ratio of rainfall-runoff recorded very high during the monsoon period because of the fully saturated soil and its wet antecedent soil moisture conditions.

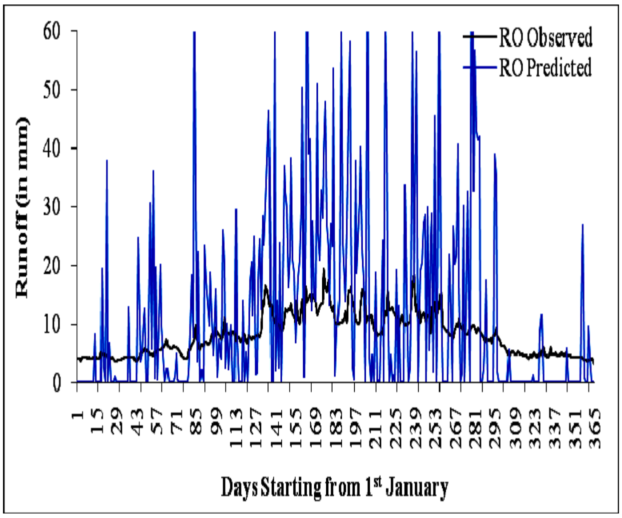


Fig.-6: Daily trends of observed and predicted runoff

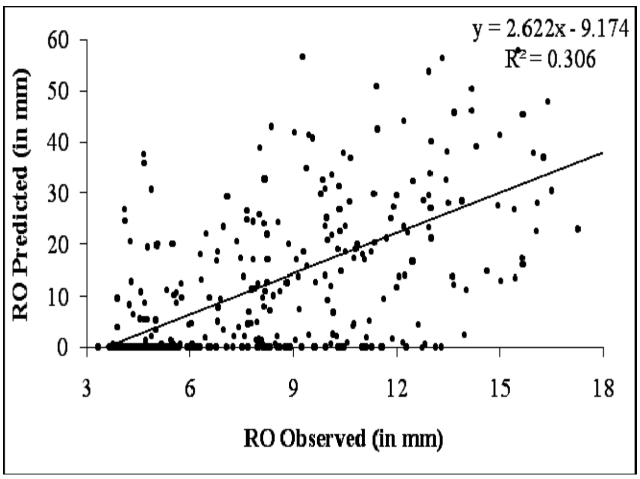


Fig.-7: The relationship between daily observed and predicted RO

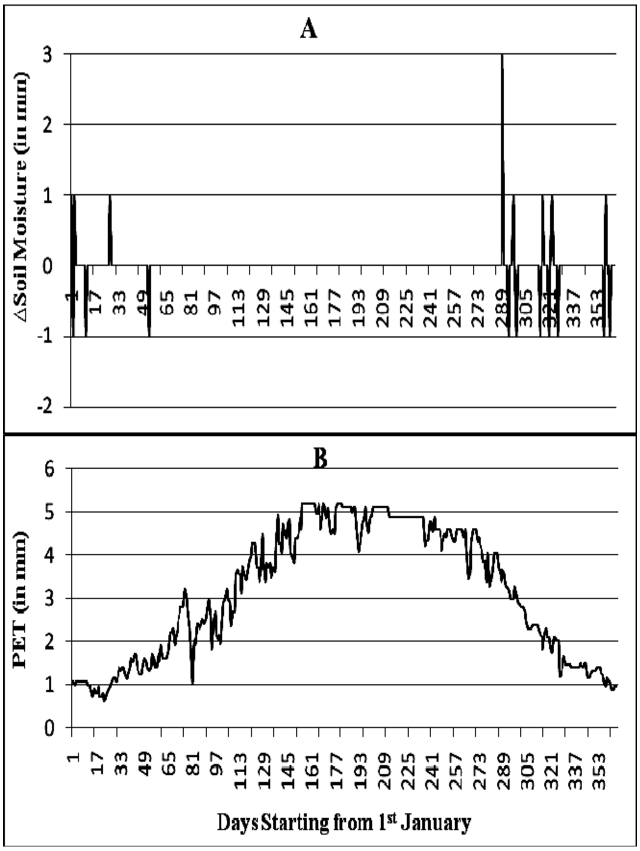


Fig.-8: Trends of daily **A**. Changes in Soil Moisture, **B**. Potential Evapotranspiration

CONCLUSION

In the specific high humid conditions of landforms in the foot-hills of Arunachal Himalayas, where temperature varies from 10^0-35^0C during the hydrologic regime of monsoon climate, there are some general conclusions regarding the trend of daily RO. Daily RO is not so smooth in this region as it happens in the sub-tropical region of the world. Dry winters have one-third discharge conditions in the river catchments when rainfall was recorded very low. On the other hand, the amount of RO is concentrated during the monsoon season when more that 80% rain is precipitated. There are some specific findings inferred from the present analysis:

a. No doubt, T-M procedure is simple to use with available parametric statistics of meteorological phenomena. However, it fails to predict correctly the PET as well as RO parameters for this region of high humidity.
b. T-M procedure estimate more fluctuation in daily predicted RO phenomena than the observed one.
c. It over estimate the RO at high rainfall intensity.

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