International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

A Simple and Effective Method for Modelling a Catchment: A Case Study

Falguni Baliarsingh[Å*]

[Å]Department of Civil Engineering, College of Engineering and Technology, Bhubaneswar, Odisha, India

Accepted 29 May 2014, Available online 01 June2014, **Vol.4, No.3 (June 2014)**

Abstract

Considering the scarcity of water all over the world and need to estimate the same in an accurate manner, the present work was aimed to find a simple but effective method for estimation of catchment yield for independent catchment and a group of catchments as a whole. In this study, various hydro-meteorological data and catchment characteristics are used as the independent variables of catchment yield. Catchment characteristics data like drainage density, length of catchment, forest area percentage are obtained by the interpretation of aerial photographs by a simple table stereoscope. Hydro-meteorological data like rainfall, temperature and wind velocity data is collected from Tamilnadu Meteorological Department. Step wise regression analysis is carried out and effective relationship among the above variables are found out which helps us to predict the catchment yield in monthly and yearly basis with a satisfactory accuracy level.

Keyword: *Aerial Photograph, Catchment Characteristics, Hydro-meteorology, Stepwise Regression Analysis, Rainfall-Runoff relationship, catchment yield*

1. Introduction

The deficit of good and portable water is a matter of concern in whole of the globe. It should very effectively be used for various purposes like drinking water, power generation, industrial and municipal use etc. This objective can be fulfilled only when the major portion of precipitation in the form of rainfall can very accurately be estimated. In the past many researchers have tried to estimate the catchment yield (Runoff of a basin) in catchment wise (Chow et al, 2010); using various techniques such as Empirical formulae (Raghunath, 2006), Unit hydrograph methods like Instantaneous unit hydrograph and Synthetic unit hydrograph (Rami, 2013); Flood frequency studies like Gumbel and Log-Pearson distributions (Subramanya, 2008). Minns and Hall used a feedforward artificial neural network to predict runoff from rainfall data (Minns, 1996). Zhu and Fuzitha compared the performance of fuzzy reasoning and feedforward ANN model in rainfall-runoff modeling for predicting 3-hours lead runoff (Zhu et al, 1994). Sajikumar and Thandaveswar compared the performance of rainfall-runoff models by temporal backpropagation (Sajikumar 1999). Fernado and Jayawardena applied Radial Basis Function type of ANN using the Orthogonal Least-Square algorithm for the rainfall-runoff relationship (Fernando et al, 1998). In these methods very few independent variables are used for estimation of catchment yield. But large number of variables and their interrelationships are to be taken into consideration for accurate estimation of catchment yield (Viessman et al, 2003). In the present research work a limited but effective number of independent variables are tried to consider for estimation of catchment yield.

2. Study area

Seven catchments are taken as study area from the north eastern part of western ghats in Kodaikanal district of Tamil Nadu. They are 1. Pulavachiar 2. Konar 3. Kumbar 4. Gundar 5. Porandalar 6. Thevankariar and 7. Kodavanar.

3. Acquisition of data

3.1 Meteorological data

The Runoff, rainfall data for 19 years were obtained from Tamil Nadu Electricity Board (TNEB). Temperature and Wind velocity data were obtained from Meteorological Department, Meenambakkam, Madras (State Meteorological Department, 1983).

3.2 Catchment characteristic data

The catchment characteristics such as drainage density, length of catchment, forest area percentage were obtained from 36 aerial photographs covering the total study area. The aerial photographs were obtained from centre for water studies, Madras. The aerial photographs were examined under the stereoscopes to find out the drainage map and forest maps of the catchment (Institute of remote sensing, Anna University, 1986; Floyd, 1978). Then the lengths of catchment, total length of channels of each

*Corresponding author: **Falguni Baliarsingh**

Table 1: Correlation coefficient of runoff and forest area percentage for Pulavachiar basin.
Vegetative area in January 1969 = 0.0569

S.No.	Yearly Increment Factor	Monthly Increment and Decrement Factor Combination								
		0.00 0.00	0.02 0.01	0.04 0.02	0.06 0.03	0.08 0.04	0.10 0.05	0.12 0.06	0.14 0.07	0.16 0.08
1	-0.015	-0.097	-0.033	-0.006	0.006	0.017	0.021	0.023	0.025	0.029
2	-0.010	-0.084	-0.024	-0.001	0.018	0.022	0.024	0.027	0.034	0.040
3	-0.005	-0.091	-0.015	0.012	0.028	0.034	0.042	0.047	0.051	0.054
4	0.00	-0.120	0.065	0.049	0.025	0.033	0.039	0.043	0.047	0.050
5	0.005	0.120	0.165®	0.149	0.130	0.107	0.082	0.058	0.042	0.040
6	0.010	0.121	0.160	0.181	0.169	0.150	0.139	0.125	0.108	0.091
7	0.015	0.124	0.155	0.178	0.186	0.175	0.157	0.150	0.142	0.132
8	0.02	0.126	0.151	0.171	0.187	0.188(M)	0.179	0.164	0.156	0.150

M - Maximum Correlation Coefficient R - Real Maximum Correlation Coefficient

catchment were measured from the drainage map by curvimeter (map measurer). The total areas of catchment, area of forest cover were measured from the forest map. The forest cover was classified into 1. High density forest 2.Medium density forest 3. Low density forest depending on tone and texture of aerial photograph (Kothyari, 1985). Then following data were calculated as below.

Drainage density = $\frac{Total\ Length\ of\ channel}{Total\ area\ of\ catchment}$

Forest area percentage- $\frac{Total\ forest\ area}{Total\ area\ of\ catchment}$

In this way drainage density, length of catchment, forest area percentage for each catchment were found out from the aerial photographs (Paul, 1974).

4. Analysis

The stepwise regression analysis for monthly and yearly basis was carried out as follow by taking the basin parameters, interpreted from aerial photographs and the available hydro meteorological data.

4.1 Stepwise regression analysis –monthly basis.

In this case, the rainfall, forest area percentage, temperature and wind velocity were considered as independent variables for predicating runoff on monthly basis. From the available 19 years (228 months) data, 15 years (180 months) were considered as historic data for finding out the runoff equation and the remaining 4 years (48 months) data were kept of checking the efficiency of prediction.

As only one set of aerial photographs (January, 1969) was available, only one set of forest area percentage could be obtained for each catchment. So it was necessary to generate 180 forest area percentages for each catchment for the 15 historic year data, which led to determination of correlation coefficient between runoff and forest area percentage, as indicated in the following steps.

i) It was considered that there was monthly and yearly variation of forest area percentage. For monthly change, it was assumed that there will be decrement of percentage of forest area during non-monsoon season i.e. from January to August and increase during monsoon season i.e. from September to December. And monsoon increment factor was assumed twice that of non-monsoon decrement factor. In this way, all the possibility of monsoon increment factor from 0.0 to 0.16 at an interval of 0.02 and non-monsoon decrement factor from 0.0 to 0.08 at an interval of 0.01 were tried. The yearly increment was tried from -0.015 to 0.02 at an interval of 0.005.
ii) Totally there were 72 (9x8) alternatives for each catchment. By these alternatives, the forest area percentages were generated for 15years i.e. from 1965 to 1979 from analysed forest area percentage of January 1969 and the correlation coefficients between forest area percentage and runoff were calculated for each alternative. During generation of forest cover, these were restricted within 0.03 and 0.97.
iii) Two alternatives of good correlation coefficient were chosen from each catchment. One was absolutely greatest correlation coefficient and other one was alternative point where the correlation coefficient increases substantially over the previous alternative points. For convenience of writing this papers former one is called as maximum correlation coefficient and latter on is called real maximum correlation coefficient. Maximum correlation coefficient and real maximum correlation coefficient between runoff and forest area percentage for Pulavachiar basin are 0.188 and 0.165 respectively (refer table no.1)

The step-wise regression analysis was run with the runoff as dependant variable and rainfall, forest area percentage, temperature and wind velocity as independent variables.
Two sets of generated forest area percentages were considered. The variables were also analyzed by both absolute value and logarithmic value.

4.2Step-wise regression analysis –yearly basis

In this case, rainfall, forests area percentage, length of catchment and drainage density were considered as independent variables and runoff was considered as dependant variables. Considering 15 years of data as historical, annual average rainfall and runoff were found out. These data were analyzed by step-wise regression analysis as in the following steps.

Table 2: Pulavachiar basin (monthly basis analysis)

S.No.	Type of Selection	Equation of Selection	Percentage of Data (Historical)		Percentage of Data (Predicted)	
			Within 30% deviation	Within 50% deviation	Within 30% deviation	Within 50% deviation
1	Natural and Maximum correlation Coefficient	$R = 15.786 + 0.288P + 9.714F - 0.776T - 0.366W$	29	46	12	22
2	Logarithmic and Maximum correlation Coefficient	$R = \frac{1.07 * 10^7 P^{0.381}}{F^{0.077} T^{5.355} W^{0.797}}$ **(Selected Equation)**	31	57	35	52
3	Natural and Real Maximum correlation Coefficient	$R = 14.49 + 0.288P + 28.53F - 0.756T - 0.348W$	27	45	15	25
4	Logarithmic and Real Maximum correlation Coefficient	$R = \frac{8.89 * 10^6 P^{0.383}}{F^{0.094} T^{5.294} W^{0.812}}$	31	56	18	28

Table 3: Runoff Equation for Kodaikanal District taking all seven catchment simultaneously (Yearly basis analysis)

S.No.	Type of Selection	Equation of Selection	Maximum Percentage of deviation of all the historical data	Percentage of Data (Predicted)	
				Within 30% deviation	Within 50% deviation
1	Natural and Maximum correlation Coefficient	$R = 15.786 + 0.288P + 9.714F - 0.776T - 0.366W$	20.69	17	29
2	Logarithmic and Maximum correlation Coefficient	$R = \frac{1.07 * 10^7 P^{0.381}}{F^{0.077} T^{5.355} W^{0.797}}$ **(Selected Equation)**	12.7	25	50
3	Natural and Real Maximum correlation Coefficient	$R = 14.49 + 0.288P + 28.53F - 0.756T - 0.348W$	16.23	15	25
4	Logarithmic and Real Maximum correlation Coefficient	$R = \frac{8.89 * 10^6 P^{0.383}}{F^{0.094} T^{5.294} W^{0.812}}$	13.53	23	38

i) In the first step, runoff was determined taking rainfall, drainage density and forest area percentage as independent variables. It was found during regression analysis that among the above these inputs, forest area percentage helps least to improve the equation for computation of runoff.
ii) So in the second step, forest area percentage was replaced by length of catchment. Again the regression analysis was carried out by considering rainfall, drainage density and length of catchment as independent variables.

5. Results

The discussion of the previous section indicates that the following steps were adopted for determination of runoff equation on historical data and also for prediction of runoff for subsequent years.

5.1 Monthly basis

On monthly basis, determination of maximum correlation coefficient and real maximum correlation coefficient of runoff vs. forest area percentage; determination of runoff equation, considering both maximum correlation coefficient and real maximum correlation coefficient of runoff vs. forest area percentage and historical 15years data as input to the step-wise regression analysis in both natural and logarithmic forms; determination of percentage of computed runoff, which is estimated by above equations differs from the corresponding observed runoff, prediction of runoff for the next four years using the above determined equations and once again determination of percentage of deviation of computed runoff from observed runoff and selection of one runoff equation for each basin based on the result of prediction. For example, the result for Pulavachiar basin is given in table-2.

5.2 Yearly basis

On yearly basis one equation was tried to find out for prediction of runoff for Kodaikanal district. So here data of all seven catchments at a time were used. Determination of runoff equations on yearly basis was done in two steps. In first step rainfall, forest area percentage and drainage density were considered as independent variable in natural and logarithmic form. Then in second step rainfall, length of catchment and drainage density were considered as independent variable in natural and logarithmic form. These were analysed in the platform of stepwise regression analysis and proceeded to obtain a suitable equation as in the case of monthly basis. The results obtained are given in Table-3.

6. Discussion

6.1 General

The result obtained in monthly and yearly basis are discussed under the corresponding headings. The first paragraph discusses the percentage deviation obtained between observed and computed runoff, when the determined runoff equations were applied to the historical 15 years data. The second paragraph deals with the indication of results obtained, while the determined runoff equations were applied for prediction of next four years.

6.2 Monthly basis

It was found that Pulavachiar, Gundar, Porandalar, Thevankariar and Kodavanar showed good results, when the logarithmic values of data were used. The remaining two basins namely Koniar and Kumbar showed good results in the natural form of data. It was also seen Pulavachiar, Koniar, Porandalar and Kodavanar yielded better results, if the forests area percentage corresponding to the maximum correlation coefficient were used. Other three basins namely Kumbar, Gundar and Thevankariar seem to fall in the forest area percentage corresponding to real maximum correlation coefficient.

Considering whether maximum correlation coefficient or real maximum correlation coefficient yielded better results for historical 15 years data, the runoff of subsequent four years were predicted with the help of corresponding four years independent variable both in natural and logarithmic form by using corresponding runoff equations for each basin. Then the percentage of computed runoff within a deviation of 30% and 50% from observed runoff was calculated for each case. These results showed that the better results were obtained when logarithmic values of the data were used. Depending upon the predicted runoff results, the runoff equations, those can be used for prediction of runoff in future for each basin is indicated in the same tablets by the symbol “Selected Equation”. Thus it could be concluded that logarithmic values of data always yield better results.

6.3 Yearly basis

The resulting values using the natural and logarithmic form of historical data, by considering three out of four independent variables for each time in two steps. This analysis indicates that the combination of rainfall, drainage density and forest area percentage shows slightly better results as compared to the other step in which rainfall, drainage density and length of catchment were used as the independent variables. Here again, it was found that better result was obtained by using the logarithmic form of data.

The percentage difference between computed and observed runoff obtained using the corresponding variables for prediction is found out. The best selected runoff equation is indicted by the symbol “Selected Equation”, which can be applied in future for prediction of runoff for all the basins in common.

Conclusion

In monthly basis calculations, the equations were selected basin wise for future use. For example, the method of selecting a suitable equation for Pulavachiar basin is shown in table-2. It is observed that runoff is directly proportional to rainfall, forest area percentage and indirectly proportional to temperature and wind velocity in all the seven catchments except in Pulavachiar and Kumbar basin. In these two basins runoff is directly proportional to rainfall and indirectly proportional to temperature, wind velocity and forest area percentage due to low value of forest area percentage. In yearly basis, a single equation is found out for all basins, which is shown in table-3. The prediction capability of different equations in monthly and yearly basis is shown in table-2 and table-3. Maximum error in case of yearly basis prediction is 12%. The equation for yearly basis prediction is more efficient than that of monthly basis.

References

Chow V. T., Maidment D. R., Mays L. W, (2010), *Applied Hydrology*, Tata McGraw Hill.

Fernando D. A. K., and Jayawardena A. W, (1998), Runoff forecasting using RBF network with OLS algorithm, *Jl. Of Hydrologic Engg.*, ASCE, 3(3).

Floyd F. S. J, (1978), *Remote sensing principles and interpretation*, W. H. Freeman & Company.

Institute of remote sensing, Anna University, (1986), Familiarization workshop on remote sensing application to water resources planning and management.

Kothyari U. C., (1985), Estimation of annual runoff from catchment, *Central Board of Irrigation and Power report.*

Minns A. W., and Hall M. J, (1996), Artificial neural network as rainfall-runoff models, *Jl. Of Hydrological Science*, 41(3).

Paul R. W, (1974), *Elements of Photogrammetry*, McGraw-Hill Inc., 1974

Raghunath H. M, (2006), *Hydrology-Principle, Analysis, Design*, New Age International Publishers.

Rami Reddy P. J, (2013), *A Text book of Hydrology*, University Science Press.

Sajikumar N., and Thandaweswar B. S, (1999), A Non-linear rainfall-runoff model using an artificial neural network, *Jl. of Hydrology*, 21(6).

State Meteorological Department, Tamilnadu, (1983), *Meteorological data of various stations of Tamilnadu.*

Subramanya K., (2008), *Engineering Hydrology*, Tata McGraw-Hill Publishing Company Limited.

Viessman W., Lewis G. L, (2003), *Introduction to Hydrology*, Pearson Education Inc.

Zhu M-L., and Fuzitha M, (1994), Comparison between fuzzy reasoning and neural-networks methods to forecast runoff discharge, *Jl. of Hydroscience and Hydrologic Engg.*, 12(2).