International Research Journal of Earth Sciences E-ISSN 2321–2527
Vol. 4(10), 1-8, October (2016) Int. Res. J. Earth Sci.

Deterministic Annual Runoff Model for Selected Watersheds in Upper and Middle Godavari sub basin

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Available online at: www.isca.in, www.isca.me
Received 22nd July 2016, revised 30th September 2016, accepted 15th October 2016

Abstract

Watershed is an hydrological unit. The physio-hydrological behaviour of the watershed is studied by using the hydrologic modelling. Watershed proper scientific planning and management needs reliable detailed data for reliable predictions. In the study the multivariate statistical method is applied to development of dimensionally homogeneous and statistically optimal models for prediction of annual runoff in the selected watersheds in upper and middle sub basins in Godavari basin. The Principal component analysis (PCA) technique is applied in order to group similar geomorphological characteristics and to screen out the least importance parameters. The deterministic annual runoff model is developed on the basis of the geomorphological characteristics and annual rainfall and runoff data. The model is also validated. The developed models can be used to predict the annual runoff for upper and middle sub basins of Godavari basin. The developed model can be used to predict the annual runoff having similar hydrological conditions.

Keywords: Deterministic, Annual runoff, Multivariate, Watershed, Geomorphic Parameters, Godavari, Maharashtra.

Introduction

Soil and water are most important resources available in the country but these resources are limited[1]. According to National Commission on Agriculture (1976), about 175 million hectares of land constituting 53.3 % of the total geographical area of 329 M ha is subjected to different types of degradation[2]. About 6,000 m ton of top soil along with valuable nutrient are lost annually[3]. The displacement of soil material result in either loss of topsoil or terrain deformation or both. In agrarian country like India natural resources soil and water are high in demand. Day by day burden on such resources are increasing so its proper and efficient management is required.

Water resources of India are very divergent in their occurrence, distribution as well in their utilization. The Indians average annual precipitation aggregated as 4000 km^3 out of that utilizable resource are 1122 km^3 (28%). Out of which utilizable surface water resources are 690 km^3 and ground water resources are 432 km^3. As per the National Commission for Integrated Water Resources Development, basins-wise average annual flow in Indian River systems is 1953 km^3. India is divided into 12 major river basins covering 256 M ha, 46 medium river basins covering about 25 M ha besides other water bodies like tanks and ponds covering 7 M ha, with the ultimate irrigation potential of 140 M ha[2]. The Godavari river basin is second in size only to Ganga as compared with other basins; its delta on the east coast is also one of the country's main rice-growing areas. It is known as the *Ganga of the South* but despite the large catchment area having moderate discharge[4].

There is vast gap in between the resources available as well as used in our country. For such studies numerous models have been developed in the past, in India and abroad, based on climatological characteristics[5]. Among these models most of them are location specific so that cannot be used in other sites. In some cases all the possible combinations of basin characteristics have not been tried which makes the models biased[6]. The proper and efficient utilization of land and water resources needs watershed management. Hence it's always better to start management measures on priority basis from the most critical sub-watershed[7]. The proper scientific planning and management of the watershed require detailed data to make reliable predictions[6]. In India many watershed are not gauged for such cases deterministic geomorphic modelling is basic tool for the study of the hydrologic behaviour of a basin[7]. Based on the dimensionless geomorphic characteristics and rainfall parameters a deterministic rainfall runoff model can be developed. Such developed models will be useful for prediction of runoff in the watershed having similar physiographic conditions. Considering such approach the present study was undertaken.

Study Area: The present study was carried for 11 selected watersheds in upper and middle Godavari sub basin in Maharashtra state (India). The Godavari River originates at Brahmagiri hills at Trimbakeshwar in Nashik district of Maharashtra at an elevation of 1,067 m[8]. The Godavari river basin extends over states of Maharashtra, A.P., Telangana, Chhattisgarh and Odisha in addition to smaller parts in Madhya Pradesh, Karnataka and Union territory of Puducherry. The basin is lies between latitudes 16°16’0” North and 23°43’ longitudes 73°26’ to 83°07’ East, roughly triangular in shape. The basin extends over an area of 3,12, 813 km^2 approximately 10% of the total geographical area of the country[4]. The Pravara, the Manjra, the Purna, the Maner, the Penganga, the Wardha, the Pranhita, the Indravati and the Sabari are important tributaries of the Godavari River. The basin is having mostly fertile soil. The major soil types in the basin and its adjoining areas are viz. black soils (Regur), red soils, laterites and lateritic soils, alluvium, mixed red and black soils and red & yellow soils and saline & alkaline soils[4].

The Godavari basin is sub divided in to 8 sub basins viz. Upper, Middle, Lower, Indravati, Manjara, Wainganga, Wardha and Pranhita and other[8]. The land-use/land-cover of the basin shows that agriculture land is the predominant, having more than 50% (including current fallow) of the basin area. The major Land Use Land Cover (LULC) in Godavari basin are agricultural land 1,86,347.17 km^2 (59.57%), built up land 5,187.26 km^2 (1.66%), Forest 93142.06 km^2 (29.78%), Grassland 85.84 km^2 (0.03%), Wasteland 16785.92 km^2(5.36%), Water bodies 11,263.75 km^2 (3.60%)[8].

The water resources potential in Godavari basin assessed by CWC are 110.54 km^3. The utilizable surface water is about 76.3 km^3, the replenishable ground water is about 45 km^3. There is a vast potential for irrigation development and hydropower generation in the basin. The present utilization is of the order of only 40 km^3 in the case of surface water and 6 km^3 in the case of ground water. Considering the potential of the area the present study was taken in the upper and middle sub basin of the Godavari basin in Maharashtra state (India) with 11 sub watershed. The selected watershed are located in Nashik, Ahmednagar, Beed, Jalna, Parbhani, Aurangabad and Nanded district as shown in Figure-1.

Data Collection: The selected watershed are located upper and middle sub basin of Godavari basin. The rainfall and runoff data was collected from Unit of Hydrology, Department of Water Resources (MS), Nasik (Maharashtra). The geomorphological characteristics were derived from the Survey of India (1:50,000) top sheet and using SRTM DEM. The rainfall runoff data used in this study is shown in Table-1.

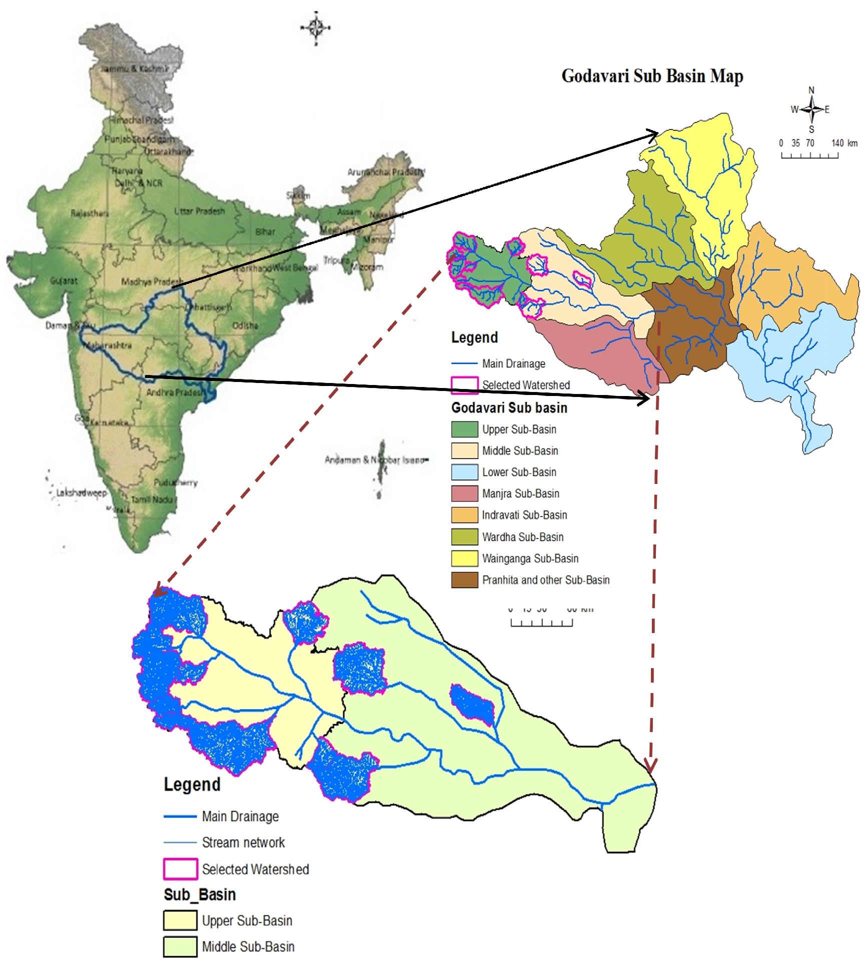

Figure-1
Location map of the study area

Materials and Methods

Geomorphic parameters of the watershed gives the idea about the hydrological behaviour of the watershed. The major morphological characteristics of selected 11 were carried out from the Survey of India top sheet where as slope map is derived using SRTM DEM. Ultimately these geomorphological characteristics were grouped in such a way as to obtain following 13 dimensionless parameters[9] known as geomorphic parameters for the 11 watersheds in upper and middle Godavari sub basin.

Table-1
Description, Nomenclature and Years of record of the Selected Watersheds

Sr. No.	Name	No.	Area (km^2)	Years of the record
1	Niphad (Kundewadi)	WS1	1445.1	1995-2012 (17)*
2	Nashik	WS2	708.553	1995-2012 (17)*
3	Samangaon	WS3	1153.6	1995-2012 (17)*
4	Vadangali	WS4	350.239	1998-2011 (14)*
5	Bhagur	WS5	429.752	1995-2012 (17)*
6	Chinchkhed	WS6	914.128	1995-2012 (17)*
7	Golapangri	WS7	1567.43	1995-2012 (17)*
8	Asegaon	WS8	684.461	1995-2012 (17)*
9	Mhaladevi	WS9	357.361	1995-2012 (17)*
10	Panegaon	WS10	2715.68	1995-2012 (17)*
11	Hirapur	WS11	1537.51	1995-2007 (12)*

*The values in parentheses shows number of years of record.

Table-2
Mean annual rainfall and runoff along with the of their factors values

Name	No.	Mean Annual rainfall (mm)	Mean Annual runoff (mm)	Rainfall factor (P/√A)	Runoff factor (R/√A)
Niphad (Kundewadi)	WS1	627.694	156.333	16.51	4.11
Nashik	WS2	825.227	170.574	31.00	6.41
Samangaon	WS3	774.851	196.082	22.81	5.77
Vadangali	WS4	602.886	153.675	32.21	8.21
Bhagur	WS5	565.920	170.949	27.30	8.25
Chinchkhed	WS6	717.036	104.898	23.72	3.47
Golapangri	WS7	580.085	63.814	14.65	1.61
Asegaon	WS8	812.724	134.678	31.06	5.15
Mhaladevi	WS9	667.445	173.163	35.31	9.16
Panegaon	WS10	527.142	98.408	10.12	1.89
Hirapur	WS11	636.723	181.320	16.24	4.62

Table-3(a)
Selected dimensionless geomorphic parameters of the selected watershed

Ws No.	Area (km^2)	Sa	Re	Rc	S_b	R_r	R_R	R_N
WS1	1445.1	0.7519	0.789	0.8121	0.609	0.5477	0.4974	0.6006
WS2	708.553	0.3364	0.545	0.5661	0.5599	1.0882	0.8116	0.2352
WS3	1153.6	0.0112	0.018	0.0212	0.019	0.0241	0.0103	0.0118
WS4	350.239	0.571	0.513	0.642	0.4781	0.5147	0.246	0.5889
WS5	429.752	1.2533	1.044	1.9315	3.4346	4.2467	3.1498	3.5313
WS6	914.128	0.4321	0.41	0.3542	0.4312	0.4919	0.4867	0.397
WS7	1567.43	1.5285	1.854	3.2959	0.7902	2.7392	2.9513	0.8979
WS8	684.461	0.0079	0.012	0.0135	0.0142	0.0163	0.0063	0.0116
WS9	357.361	0.0036	0.005	0.0067	0.0069	0.0101	0.0033	0.0048
WS10	2715.68	0.4875	0.456	0.3585	0.3187	0.4745	0.5328	0.5741
WS11	1537.51	0.1343	0.164	0.1296	0.1931	0.1559	0.124	0.1012

Table-3(b)
Selected dimensionless geomorphic parameters of the selected watershed

Ws No.	Area (km^2)	Sc	His	Df	Rl	Rb	L_b/L_w
WS1	1445.1	0.8892	0.8296	0.7211	0.6036	5.3457	1.8009
WS2	708.553	0.365	0.2457	0.7973	0.1601	4.4908	1.4885
WS3	1153.6	0.0125	0.0082	0.0065	0.0037	5.3352	1.5367
WS4	350.239	0.430	0.5899	0.5682	0.5518	3.0597	1.9138
WS5	429.752	1.6112	1.851	2.4499	3.4966	3.3433	1.8715
WS6	914.128	0.5947	0.4189	0.4824	0.4498	4.232	0.9432
WS7	1567.43	0.5611	0.7397	0.905	0.7382	3.2806	1.1441
WS8	684.461	0.0076	0.0057	0.0043	0.0012	2.4005	2.4442
WS9	357.361	0.0029	0.0024	0.0022	0.0014	6.5452	1.9967
WS10	2715.68	0.3075	0.6014	0.5952	0.996	4.0706	2.5720
WS11	1537.51	0.2117	0.0859	0.1339	0.2246	5.8987	1.4584

Grouping of the geomorphic parameters: Multicollinearity among the independent variables may always lead to wrong interpretations[10]. The geomorphic parameters are usually correlated with each other. The inter-correlations amongst the parameters is a useful to group the parameters into physically significant groups and to screen out the less important parameters. The Principal Component Analysis (PCA) technique is based upon the early work of Pearson with the specific adaptations of PCA suggested by the Hotellings[11]. The PCA along with the orthogonal and oblique rotations of the components for better interpretability was used to derive the following components which account for a large percentage of the total variance[6,10]. The geomorphic parameters can be grouped in to the following components, and its evaluated values is given in Table-3.

Slope or steepness components: Relative relief (R_R), average slope of the watershed (S_a), ruggedness number (R_N), relief ratio (R_r), main stream channel slope (S_c)

Shape components: Basin shape factor (S_b) length width ratio (L_b/L_w), and elongation ratio (R_e)

Drainage components: Bifurcation ratio (R_b), Stream length ratio (R_l)

The PCA of all these geomorphic parameters gives that Main stream channels slope (Sc) and hypsometric integral (Hsi) was found redundant and of least importance in explaining the component variance hence they are screened out of the analysis.

Development of Deterministic Models: Geomorphic parameters are grouped into physically significant components, the statistically optimal linear deterministic models is developed in the following form

$$Y=a_0+a_1 x_1+a_2 x_2+a_3x_3+a_4 x_4+a_5 x_5$$

where, Y= The dependent variable and x_1, x_2, x_3, x_4, x_5, are the independent variables whereas a_0, a_1, a_2, a_3, a_4, a_5, are the regression coefficients.

The rainfall factor *(X_1)* is considered independent variable for obtaining the best fit annual runoff prediction model. All the eleven geomorphic parameters are regrouped into three independent variable namely Steepness component *(x_2),* Shape component *(x_3)* and Drainage component *(x_4).* The grouping of these geomorphic parameters with best fit model is shown in Table-4.

Annual Runoff Model: After the grouping all selected geomorphic parameters the annual runoff equation is in folling form

$$Y=a_0+a_1 \text{ (rainfall factor)} + a_2 \text{ (Steepness component)} + a_3 \text{ (Shape component)} + a_4 \text{ (Drainage component)}$$

The multiple regression analysis techniques is applied and regression coefficients, multiple correlation coefficients, F-test value, standard error and the percentage variation explained by the model. Logarithmically transformed data used with above statistical parameters as mentioned above the developed log-linear models is obtained in the following form:

$$Y=a_0(X_1)^{a_1} (X_2)^{a_2} (X_3)^{a_3} (X_4)^{a_4}$$

The best fit annual runoff prediction model the data sets were used to regress the runoff factor, (R/√A) on four independent parameters (one each from the already established components and rainfall factor, (P/√A). The 48 combinations (4 x 4 x 3 x l) were tried for linear as well as log-linearly transformed data. On the basis of lowest standard error of estimate, highest correlation coefficient and F-test value, the best fit model is chosen from the 48 combinations.

Results and Discussion

The present study was carried out to develop optimal annual models to prediction of the mean annual runoff, which can be conveniently used for any watershed having similar physiographical condition to that of upper and middle Godavari river sub basin (Maharashtra). Deterministic linear and log linear annual runoff model are developed to prediction annual runoff for selected watershed.

The regression coefficients of the best fit linear and log linear annual runoff models for Godavari river basin, corresponding standard error (S), multiple correlation coefficient (r) and F-test value (F) are presented in Table-4. Using the 9 watersheds (WI to W9) parameters and annual rainfall and runoff data the model is developed. The three watersheds (W 1 to W 9) whereas two in upper sub basin and one in middle sub basin are kept out of analysis for validation of the model. The values of annual runoff estimated by Linear and log linear models are compared with the observed values in terms of relative deviations in per cent for all the watersheds in the upper and middle sub basin of Godavari river basin. The best fit linear and log linear model for annual and monthly data is shown in Table-4.

The Annual Runoff Model: The annual best fir linear model is given in the following linear form:

$$R_f = P/\sqrt{A}=-6.444+0.596\, R_N+0.936L_bL_w+0.791R_b+0.263P_f$$

The value of multiple correlation coefficient (r=0.959) and F-test value (F = 16.962) are found in case of the linear model.

Validation of the Model: The models developed was found satisfactorily significant, the validation is must in order to judge its practical reliability. The best fit model is selected on the basis of the minimum standard error (S), maximum correlation coefficient (r) and F-test value (F). The developed model was validated for the W9 to W11. The deviation of annual runoff is shown in Figure-2.

Table-4(a)
Best fit annual models (Linear and Log -linear) for runoff

Independent Variable	Annual		June		July	
	Linear	Log-Linear	Linear	Log-Linear	Linear	Log-Linear
(i) Steepness Component						
R_R		-0.474				
S_a				2.465		
R_N	0.959		0.288		0.337	0.477
R_r						
(ii) Shape Component						
S_b		0.576				
L_b/L_w	0.936					
R_e				-2.536		
Rc			-0.269		-0.080	-0.421
(iii) Drainage Component						
Df						
R_b	0.791	0.455	0.617	0.789	0.254	1.113
R_l						
(iv) Rainfall Factor						
P_f	0.263	0.978	1.340	0.888	0.222	1.331
(v) Runoff Factor						
R_f						
(vi) Intercept	-6.444	-0.881	-1.474	-1.102	-1.372	-1.547
Standard error (S)	0.931	0.078	0.116	0.182	0.106	0.081
Mul. Correlation Coeff. (r)	0.959	0.970	0.933	0.893	0.989	0.969
F - test value (F)	16.962	24.091	10.090	5.876	67.893	23.123

Table-4(b)
Best fit annual models (Linear and Log -linear) for runoff

Independent Variable	Aug		Sept		Oct	
	Linear	Log-Linear	Linear	Log-Linear	Linear	Log-Linear
(i) Steepness Component						
R_R						
S_a	0.330					
R_N		-0.526	-0.600			-0.037
R_r				-0.173	0.125	
(ii) Shape Component						
S_b			0.741	0.231		
L_b/L_w		0.649			0.524	0.926
R_e	-0.628					
Rc						
(iii) Drainage Component						
Df						
R_b	0.081		0.140	0.655	0.155	0.539
R_l		0.393				
(iv) Rainfall Factor						
P_f	0.247	1.363	0.307	1.709	0.362	1.589
(v) Runoff Factor						
R_f						
(vi) Intercept	-0.217	-1.097	-1.041	-1.494	-1.991	-1.466
Standard error (S)	0.272	0.112	0.229	0.079	0.267	0.088
Mul. Correlation Coeff. (r)	0.961	0.954	0.959	0.975	0.943	0.978
F - test value (F)	18.004	15.353	17.167	29.451	11.945	32.261

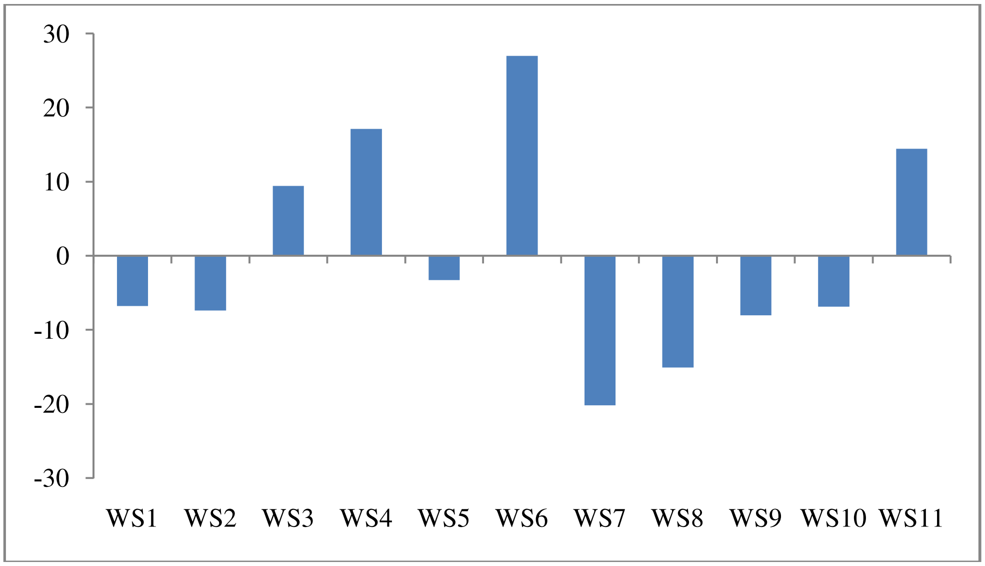

Figure-2
Percentage deviation of the annual runoff developed using linear model

Therefore, it may be concluded that these developed models in this study can be conveniently used to estimate annual runoff in upper and middle Godavari sub basin knowing the average annual runoff and some of the geo-morphological characteristics.

Conclusion

The geomorpological characteristics of the selected watershed used for the development of the deterministic model for prediction of runoff in upper and middle sub basin of Godavari river basin (Maharashtra). The annual rainfall runoff models developed shows that, the annual runoff deviation is ranges within -3.29 % to + 23.89 %. The developed model can be used to predict runoff for in Godavari basin by knowing the average annual rainfall and some geomorphic parameters. The developed deterministic annual runoff model can be used to predict the annual runoff for the watershed having similar geo morphological characteristic of the upper and middle sub basins of Godavari river basin.

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