International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2763
Issue 07, Volume 3 (July 2016) www.ijirae.com

Estimation of Annual Runoff in Indravati Sub Basin of Godavari River using Statistical Approach

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Abstract*— Prediction of runoff from known rainfall is one of the major problems confronted by hydrologists. There is lack of availability of long period runoff records in large number of catchments in India. Investigators have proposed many empirical relationships for runoff estimation in different catchments based on limited data of parameters affecting runoff. These regional relationships are useful in planning of water resource projects. This study was carried out to obtain simple yet effective relationship for estimation of annual runoff in Indravati sub basin of Godavari river. Regression analysis was carried out using annual rainfall, annual runoff and average annual temperature data to develop empirical models for annual runoff estimation. GIS software was used for preparing maps for the study area and to extract the precipitation and temperature data available in grid format from IMD. The best suited empirical model is then selected as per statistical criteria with lower values of standard error, standard deviation, mean absolute deviation (MAD), root mean square error (RMSE) and higher values of R square and correlation coefficient. Statistical significance of selected empirical model was evaluated by paired t test, F test and P value at 95 % confidence level. The developed relationship is then compared with the existing Khosla and Inglis and DeSouza relationships. Outcome of this comparison produces encouraging inferences to suggest an effective regional relationship for annual runoff estimation in the Indravati sub basin of Godavari river in India.

***Keywords*— Godavari river, runoff estimation, regression analysis, empirical relationship, ungauged catchments.**

I. INTRODUCTION

Estimates of annual runoff volumes are needed for efficient planning of water resources projects. There is lack of availability of long period runoff records in large number of catchments in India. Use of regional empirical relationships for annual runoff estimation is essential for planning of water resources projects in the absence of historical runoff data. These empirical relationships for estimation of annual runoff are based on factors affecting runoff like precipitation, temperature, vegetation cover and drainage density, for which data is readily available. The influence of these factors affecting runoff is studied using statistical approach and the relationships are proposed. The efficiency and applicability of these relationships is dependent on the number of independent variables considered along with the length and reliability of data used in developing such relationships. Further, these relationships cannot be easily generalized for a large region as the influence of various factors affecting runoff may vary from region to region due to climatic and physiographic changes.

Based on limited data, earlier investigators in India have developed empirical relationships for annual runoff relating to factors such as annual rainfall, annual temperature and catchment characteristics. Khosla (1949) [6] developed relationships for monthly and annual runoff based on a proposition that runoff can be expressed as a difference between rainfall and losses. He proposed that temperature can be taken as a major factor representing climatic parameters like sunshine, clouds and wind velocity which are responsible for loss due evaporation and transpiration. Kothyari and Garde (1991) [3] analyzed data of 55 non snow fed catchments in India and proposed relationships for estimation of mean annual runoff in five zones of India. They considered mean annual rainfall, mean annual temperature and vegetal cover as the factors influencing annual runoff.

Subsequently, several attempts have been made to modify the original formula proposed by Khosla (1949) [6] with varying degree of success in obtaining better results {Panchang (1954) [12], Seghal and Ghulati (1969) [14]}. However Raja Rao and Pentaiah (1971) [13] found that neither original Khosla formula nor the modified version yielded results that are comparable with observed runoff in some river basins in Andhra Pradesh. In the present study an attempt is made to obtain simple yet effective relationships for estimation of annual runoff for Indravati sub basin using statistical approach.

II. STATISTICAL APPROACH FOR RUNOFF ESTIMATION

The importance of estimating the water availability from the available data of hydrologic parameters for purposes of planning water-resource projects was recognized by engineers even in the last century. With a keen sense of observation in the region of their activity many engineers of the past have developed empirical runoff estimation formulae. However, these formulae are applicable only to the region for which they were developed. Moreover these relationships were developed based on limited data available during these studies. These formulae are essentially rainfall-runoff relations with additional third or fourth parameters to account for climatic and/or catchment characteristics. There is a scope to examine the existing relationships and a potential to develop new relationships based on long period data of hydrologic parameters like precipitation and temperature. Statistical analysis helps in the study of effect of various hydrologic parameters on annual runoff and development of such empirical relationships.

Regression analysis is a branch of statistical theory that is widely used in almost all scientific disciplines. It is the basic technique for measuring or estimating the relationship between a dependent variable and one or more independent variables. The form of simple linear regression is $Y = m X + c$ for one independent variable X. In multiple regression analysis two or more independent variables are used to estimate the values of the dependent variable. The general form of equation for multiple linear regression is, $Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots + \beta_n X_n$. The nonlinear form of equation involving one or more independent variables can be transformed into linear form by taking logarithm of both the sides of equation and applying least square method for sum of residuals. Statistical significance of obtained relationship is evaluated by conducting F test, t test, P value and some other measures like root mean square error (RMSE), standard error, standard deviation and mean absolute deviation (MAD).

III. STUDY AREA

The Indravati river originates in eastern ghats of Dandakaranya range in Kalahandi district of Odisha at an elevation of 914 m. It follows a westerly path and enters Jagadalpur in the state of Chhattisgarh. The river then moves towards south before uniting with the Godavari river at the borders of three states namely Maharashtra, Chhattisgarh and Andhra Pradesh at an elevation of 82.3 m. The Indravati river basin lies between longitude of 80^{0} 16' 19'' E to 83^{0} 07' 10" E and latitude of 18^{0} 43' 25'' N to 19^{0} 26' 46" N. Average annual rainfall over the basin is 1.588 m. It covers a catchment area of about 38306 km^2 and the length of Indravati river basin is 535 km. The important right bank tributaries of river Indravati are Bhaskal River, Narangi River, Boarding River, Nibra River, Kotri River and Bandia River, and the left bank tributary is Nandiraj River. The Upper Indravati hydropower project is one of the biggest dams in India (Fig. 1).

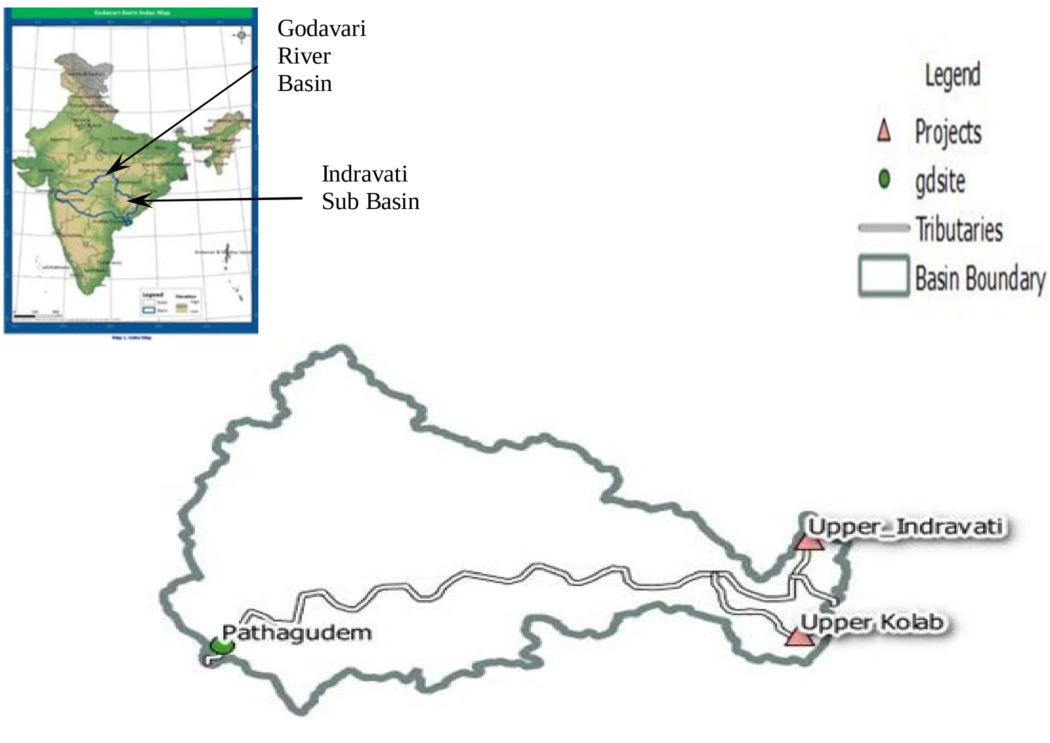

Fig. 1. Map of Indravati Sub Basin

IV. DEVELOPMENT OF EMPIRICAL RELATIONSHIPS

A. *Data and Methodology*

Daily data for runoff, precipitation and temperature for the period 1971 to 2005 is used in this study. The runoff data is collected from WRIS and the precipitation and temperature data from IMD. The daily gauge discharge data is converted to annual runoff data assuming a water year from 1st June to 31st May next year. The catchment area up to the gauge discharge site was used for this conversion. Precipitation and temperature data is available with IMD in grid format. A 1^0 grid data is used in this study. The geo referenced boundary of Indravati basin is clipped and superimposed on the precipitation and temperature grid provided by IMD to extract the data. The variation of rainfall, runoff and temperature is presented in Fig. 2 and Fig. 3.

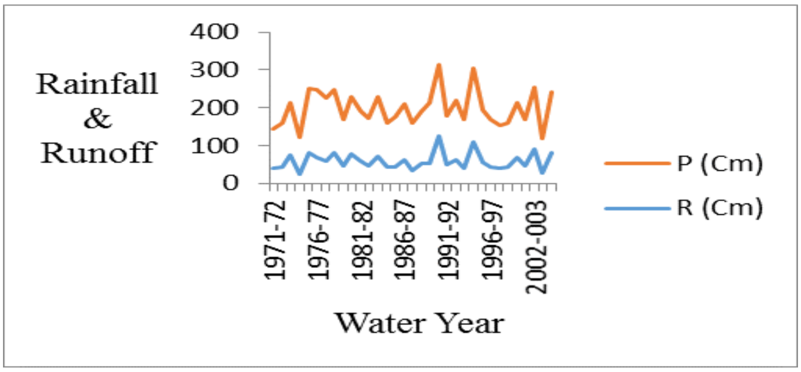

Fig. 2.

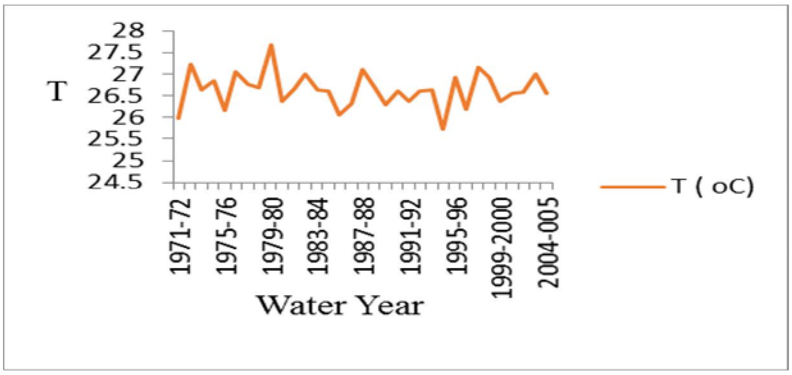

Fig. 3.

B. *Development of Relationships*

Relationships are proposed for annual runoff estimation in Indravati basin for the following two cases:

Case 1 – Relationship considering runoff as a function of rainfall. R = f (P)

Case 2 – Relationship considering runoff as a function of rainfall and temperature. R = f (P&T)

Where, R is annual runoff in centimetres, P annual rainfall in centimetres and T is average annual temperature in ^{0}C.

Simple regression analysis is employed for Case 1 and Case 2 to obtain empirical relationships. Three different form of relationships were attempted for the Case 1. In the Case 2, there are two independent variables P and T affecting the dependent variable R. Runoff is a function of the difference between precipitation and the losses. The evaporation and transpiration losses are assumed be a function of temperature [R = f (P – T)]. With this assumption (P - T) is considered as one independent variable and a simple regression is carried out for the Case 2. The best suited empirical model is then selected as per statistical criteria {Khabat et.al. (2013) [1], Horn (1987) [7]} with lower values of standard error, standard deviation, mean absolute deviation (MAD), root mean square error (RMSE) and higher values of R square and correlation coefficient. Statistical significance of selected empirical model was evaluated by paired t test, F test and P value at 95 % level of confidence.

V. RESULTS AND DISCUSSION

A. *Case 1: Relationship considering Runoff as a function of Rainfall*

In this case three models; (i) bivariate linear (R = a P) shown in Fig. 4, (ii) bivariate nonlinear ($R = a P^b$) shown in Fig. 5 and (iii) polynomial model shown in Fig. 6 were developed. The statistically significant model amongst these three models is selected with lower values of standard error, standard deviation, mean absolute deviation (MAD), root mean square error (RMSE) and higher values of R square and correlation coefficient. Statistical study is carried out in Microsoft Excel. The statistical measures for these three models are computed and presented in Table 1.

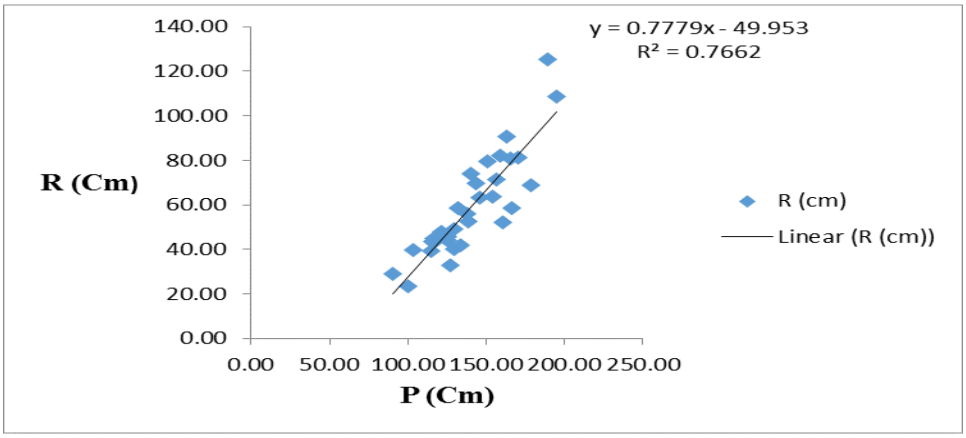

Fig. 4. Case 1 (i) Linear Variation of R and P

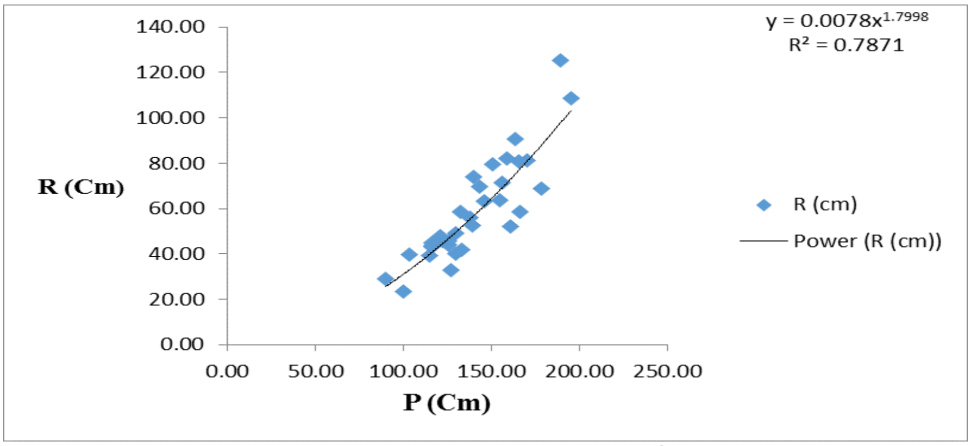

Fig. 5. Case 1 (ii) Nonlinear Variation of R and P

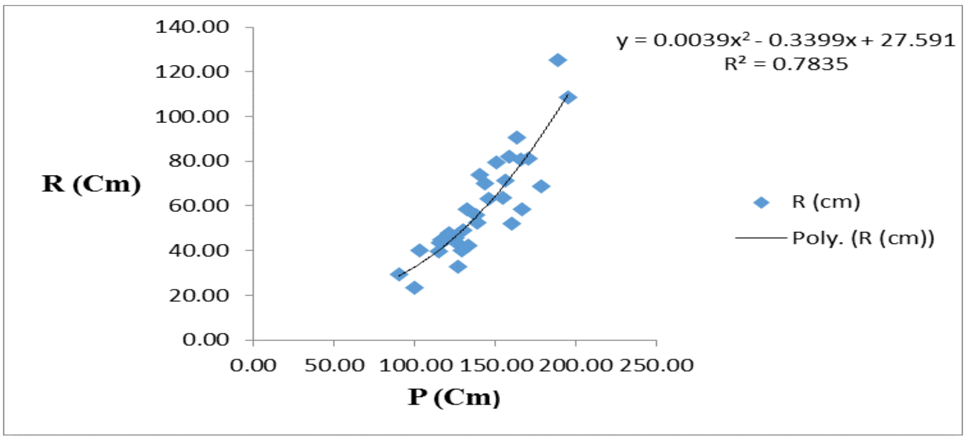

Fig. 6. Case 1 (iii) Polynomial Variation of R and P

TABLE 1. STATISTICAL MEASURES FOR SELECTION OF EMPIRICAL MODEL

Empirical Model	Mean Absolute Deviation	Standard Error	Standard deviation	R^2	Correlation Coefficient	Root Mean Square Error (RMSE)
R= 0.7779 P - 49.95	11.23	3.46	19.10	0.77	0.88	13.15
$R = 0.0078\ P^{1.7998}$	10.44	2.93	16.86	0.79	0.88	12.87
R = 0.0039 P - 0.34 P + 27.59	18.32	2.36	13.34	0.78	0.88	22

The selected model is of the form bivariate nonlinear ($R = a\ P^b$) and the recommended relationship is $R = 0.007\ P^{1.799}$. Some statistical tests are performed in Microsoft-Excel to check statistical significance of selected empirical model and the summary output is shown in Table 2.

TABLE 2. SUMMARY OUTPUT FOR CASE 1 SELECTED MODEL ($R = 0.0078\ P^{1.7998}$)

1 Regression Statistics

Multiple R	0.887
R Square	0.787
Adjusted R Square	0.780
Standard Error	0.173
Observations	33

2 Analysis of Variance

ANOVA	df	SS	MS	F	F critical	Significance F
Regression	1	3.462	3.462	114.63	4.16	$6.12^{*}10^{-12}$
Residual	31	0.936	0.0302			
Total	32	4.398				

3 Significance Tests

	Coefficients	Standard Error	t Stat	$t_{critical}$	P Value	Lower 95%	Upper 95%
Intercept	-4.855	0.83	-5.85	2.04	$1.83^{*}10^{-6}$	-6.554	-3.164
Variable (P)	1.799	0.17	10.71	2.04	$6.12^{*}10^{-12}$	1.456	2.142

The summary output Table 2 for Case 1 indicates that the correlation between R and P is positive because the correlation coefficient (multiple R) between R and P is 0.887. The coefficient of determination R^2 is 0.787 which indicates that 78% of variation in R is explained by the independent variable P. The standard error of regression is 0.173 which measures the variation of R about regression line. The reliability of individual coefficients is tested using paired t test. The coefficient of P is 1.799 which has a standard error of only 17% and t stat value of 10.71 which is greater than $t_{critical}$ having a value of 2.04 [$t_{critical} = t_{(P,n-k-1)}$]. Hence, the coefficient of P is statistically significant at 95% level of confidence. The overall significance of obtained relationship is tested by F test and P value. The F value is 114.63 which is greater than $F_{critical}$ [$F_{critical} = F_{(P,\ k,\ n-k-1)}$], and the P value is less than 0.05 which indicates that this relationship is statistically significant at 95% level of confidence.

Considering the test values obtained for F, Significance F, t Stat and P value; the null hypothesis is rejected and hence the proposed relationship is significant at 95% level of confidence.

*B. **Case 2: Relationship considering Runoff as a function of Rainfall and Temperature***

Several meteorological factors which are responsible for loss from rainfall due to evaporation and transpiration are directly or indirectly related to temperature. Average annual temperature can be taken as an independent variable to represent the losses from catchments during the year. Correlation between temperature (T) and observed runoff (R) was studied and plotted as shown in Fig.7.

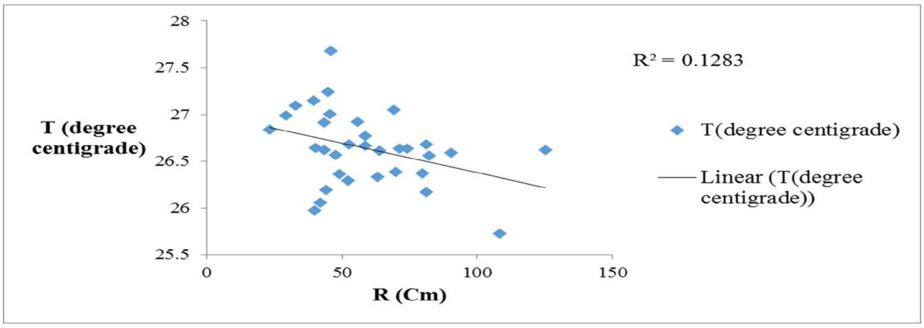

Fig. 7. Variation of R with T

The plot in Fig. 7. indicates that the runoff decreases with rise in temperature and has a negative correlation coefficient of -0.35. Khosla (1949) [6] analyzed the rainfall, runoff and temperature data for various catchments in India and USA to arrive at an empirical relationship. The relationship proposed by him is of the form R = P – xT. Kothyari and Garde (1991) [3] used the data from 55 non-snow-fed catchments in the Indian subcontinent to verify with existing relationship given by Kothyari et. al. (1985) [5] and obtained a better relationship for estimation of mean annual runoff using multiple regression analysis for five zones (Eastern, Western, Northern, Southern and Central) of India. This relationship is in the form of $R = P – a T^b$, where a and b are constants which vary for different catchments. With reference to previous studies {Khosla (1949) [6], Kothyari and Garde (1991) [3]}, the relationship for Indravati basin was assumed in the form of $R = P – a T^b$ and after making some trials the best values for correlation coefficient and R^2 were obtained for a = 1.8 and b = 1. Two additional trials were made assuming linear and exponential relationships for R versus (P - 1.8 T). However, the R^2 values for these trials were found to be inferior. Hence the power relationship was adopted. The variation of R with P – 1.8T as a power relationship is shown in Fig. 8.

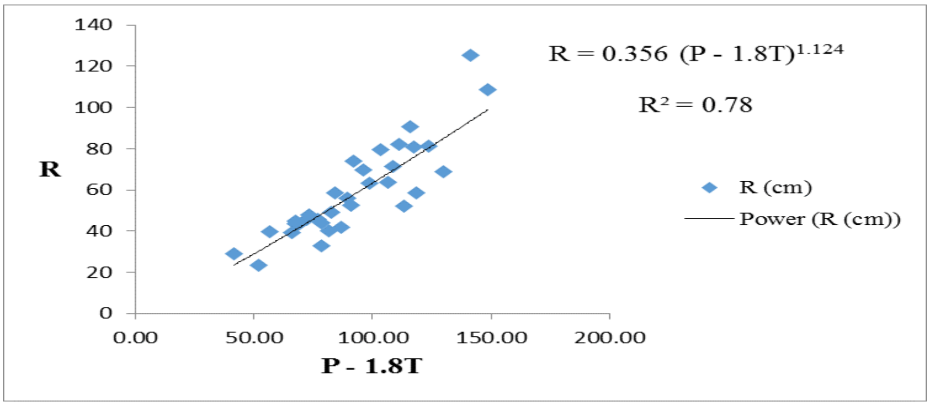

Fig. 8. Variation of R with P – 1.8T

Some statistical tests are performed in Microsoft-Excel to check statistical significance of selected empirical model and the summary output for the Case 2 is shown in Table 3.

TABLE 3. SUMMARY OUTPUT FOR CASE 2

1 Regression Statistics	
Multiple R	0.883
R Square	0.78
Adjusted R Square	0.77
Standard Error	0.176
Observations	33

2 Analysis of Variance						
ANOVA	df	SS	MS	F	$F_{critical}$	Significance F
Regression	1	3.431	3.431	109.94	4.16	$1.02^{*}10^{-11}$
Residual	31	0.967	0.031			
Total	32	4.398				

3 Significance Tests							
	Coefficients	Standard Error	t Stat	$t_{critical}$	P Value	Lower 95%	Upper 95%
Intercept	-1.031	0.482	-2.14	2.04	0.040	-2.014	-0.0487
Variable ln (P-1.8T)	1.124	0.107	10.48	2.04	$1.02^{*}10^{-11}$	0.905	1.343

Considering the test values obtained for F, Significance F, t Stat and P value; the null hypothesis is rejected and hence the proposed relationship is significant at 95% level of confidence. Results of the obtained rainfall runoff relationships for Case 1 and Case 2 are then compared with Inglis and DeSouza equation and the Khosla's formula. This comparison of statistical test results is presented in Table 4.

TABLE 4. COMPARISON OF CASE1 AND CASE 2 WITH EXISTING RELATIONSHIPS FOR STATISTICAL TESTS RESULTS

Equation	Mean Absolute Deviation	Root Mean Square Error (RMSE)	Standard Deviation	Standard Error
Case 1: $R = 0.0078\ P^{1.7998}$	10.44	12.87	16.86	2.93
Case 2: $R= 0.356\ (P\text{-}1.8T)^{1.124}$	8.07	10.79	17.93	3.22
Inglis and DeSouza: P / 254 P (P – 17.8)	11.83	16.52	26.94	4.69
Khosla's formula: R = P – T / 3.74	74.72	76.91	24.29	4.22

It is evident from the comparison of statistical test results that both the developed relationships for Case 1 and Case 2 are superior to the existing relationships. The relationship in Case 2 based on temperature as a parameter for representation of losses is better that the relationship developed for Case 1. The graphical representation of computed versus observed runoff is presented in Fig. 9.

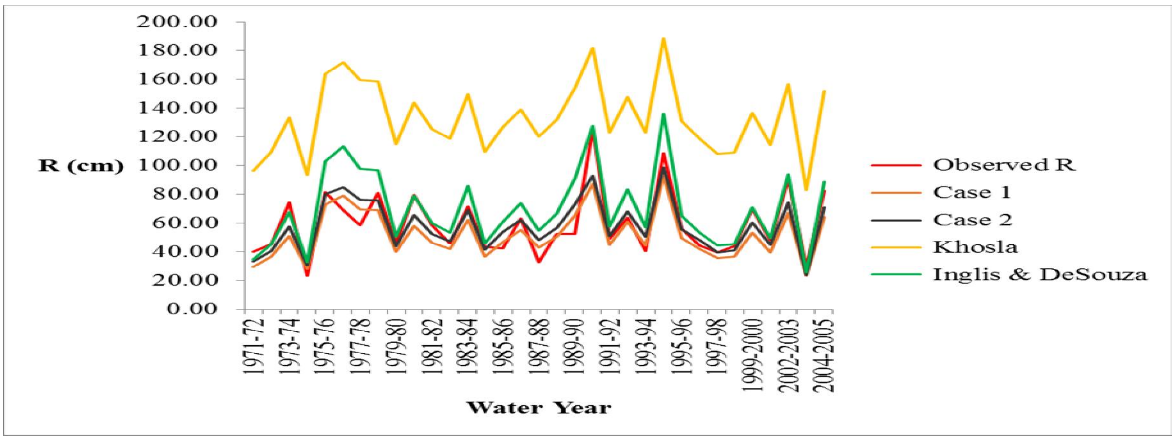

Fig. 9. Comparison of Case1 and Case 2 with existing relationships for computed versus observed runoff

The observation on superiority of the developed relationships for Case 1 and Case 2 is reinforced by the graphical representation of computed versus observed runoff presented in Fig. 9. The computed runoff by the proposed relationships is in close agreement with the observed runoff as compared to the computed runoff by the existing relationships.

VI. CONCLUSIONS

Two empirical relationships are developed for estimation of annual runoff in Indravati sub basin of Godavari river, using a statistical approach and a long period data record of thirty five years. Both the relationships developed are superior to the existing relationships. The relationship $R = 0.356\ (P - 1.8T)^{1.124}$ is recommended for estimation of annual runoff in Indravati sub basin. The relationship $R = 0.0078\ P^{1.7998}$ is recommended if the runoff estimation is to be done on the basis of only one parameter of annual rainfall. Such relationships are very useful for planning of water resource projects in ungauged catchments wherein measured runoff data is not available.

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