Reappraisal of Hydrological Studies for Computation of Dependable Flows

Shriniwas. S. Valunjkar

Professor, Department of Civil Engineering, Government College of Engineering, Karad, Distt: Satara (Maharashtra), India,

Abstract

The revision of hydrological data and precisely arriving at the availability of water resources will definitely indicate the change required in working system of the scheme. Accordingly, the monitoring operation of reservoirs can be safely and suitably modified. Generally, the hydrological data available is of short duration. Using more advanced methodologies it is possible to design the hydro-electric and irrigation schemes successfully. This paper attempts to verify the provisions made in earlier planning and also to examine the effect of record length of rainfall-overland flow (runoff) data on the availability estimates of a basin. Polynomial regression model relationship between two variables i.e. rainfall and runoff was established for 46, 66 and 80 years data series for computation of reliable flows.

Keywords: Rainfall- runoff relationship, Polynomial regression

1. Introduction

Assessment of correct water resources is a pre-requisite for the successful planning, execution and operation of project. Water is one of the essential commodities, which is available cheaply as a natural resource. This resource is random in nature, rare and become costly sometimes. It is necessary that, availability of water resources for the schemes be reviewed from time to time, as more and more historical hydrological data becomes available. The appraisal of hydrological data and precisely arriving at the availability of water resources is a science, at the same time; its utilization for proper planning is an art. Generally, the hydrological data available is of short duration. Using more advanced methodologies it is possible to design the hydro-electric and irrigation schemes successfully. Reappraisal of the project will definitely indicate the change required in working system of the scheme. Accordingly, the monitoring operation of reservoirs could be safely and suitably modified.

Pench river project complex is selected herein as a case study. The project [1] [2] comprises of (1) Pench hydroelectric project at Totladoh; and (2) Pench Irrigation Project [3], which is 23 km downstream from Totladoh at Navegaon-Khairy. Pench River is the largest tributary of Kanhan River, which joins the Wainganga in Godavari basin. It rises from Satpuda hills in Chhindwada district of Madhya Pradesh. It drains a total area of about 4921 km^2 up to its confluence with the Kanhan River. It is a sub-system of Godavari basin and the total length is about 274 km. The main tributaries of Pench River are namely, (i) Mandhan; (ii) Suki; (iii) Gatmali; (iv) Gunar; (v) Kajri; and (vi) Kulbhera.

2. Earlier Planning of the Project

Pench hydroelectric project includes a storage dam that impounds water of 1241 Million m3 (Mm3) gross storage at Totladoh across Pench river just near the inter-state border between Maharashtra and Madhya Pradesh. The project consists of masonry dam, intake structure, pressure shafts, and underground powerhouse with an installed capacity of 160 MW and tail race tunnel, 8 km long, through which water is released, after power generation, for irrigation at downstream. The drainage area up to Pench hydroelectric project site is 4273 km2 out of which only 34 km2 is in Maharashtra state and the rest lies in the state of Madhya Pradesh. The drainage area between hydroelectric project and Pench irrigation project is 388 km2 and lies in Maharashtra state. The reliable yield at 75 percent is 1835 M.m3, based on weighted annual rainfall of influencing raingauge stations, and the use of Strange's coefficients. The catchment area is hilly and was classified as 'Strange's good' for the purpose of yield calculations. Four

ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

raingauge stations were only considered and 42 year rainfall data from 1914 to 1955 were used for finding out annual yield. Subsequently, in 1969, project report [3] for Pench hydro-electric scheme was prepared. In this planning, seven raingauge stations in the vicinity of drainage area were considered and annual rainfall data of 46 years, from 1914 to 1959 were used in the analysis for finding out the annual yield. Raingauge stations are located at Tamia, Amarwada, Seoni, Deolapar, Junnardeo, Mokhed and Chhindwada which are shown in Figure 1.

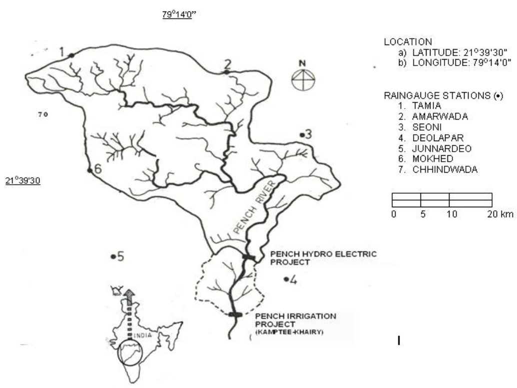

Figure 1 Pench River Project Complex

A second-degree equation, with correlation coefficient of 0.772 was obtained to work out annual yield for 46 years from 1914 to 1959. The adopted equation was,

$$y = -21.0773 + 1.1087x + 0.02003x^2$$

where, y = annual surface runoff in thousand million cubic feet (TMC) and x = weighted rainfall in inches.

Annual rainfall and surface runoff values were converted in SI units and equation was further modified as:

$$y = -596.901 + 31.398x + 0.56x^2 \qquad (1)$$

where, y = annual surface runoff in million cubic metre (M.m3) and x = weighted rainfall in cm.

Annual runoff data were used to estimate reliable yield values at different rainfall conditions. As per the Inter-state agreement upstream reservation of 991 M.m3 in normal year, i.e.75 percent reliable yield and 991/1700th of available yield in other years, limited to 566 M.m3 minimum was made in the project planning. Accordingly storage computations were carried out and capacities of 1241 M.m3 as gross storage, 1088 M.m3 as live storage were fixed at Pench hydroelectric project. The annual reliable flow values (or reliable flows) as per project provisions at 50, 75 and 90 percent are 2435 M.m^3, 1835 M.m^3 and 1532 M.m^3 respectively.

3. Revision of Hydrological Studies

The project is considered to verify the provisions made in earlier planning and also examine the overall performance of the project, as per the available data at present. Overland runoff and corresponding rainfall data (weighted) are used in the analytical studies. Generally more than 90 percent of annual rainfall occurs in the monsoon period from June to October. Rainfall series of 46 years is considered from the data available from seven raingauge stations.

4. Polynomial Regression Model

Author names and affiliations are to be centered beneath the title and printed in Times 12-point, non-boldface type. Multiple authors may be shown in a two- or three-column format, with their affiliations italicized and centered below their respective names. Include e-mail addresses if possible. Author information should be followed by two 12-point blank lines.

A polynomial curve for two variables (i.e. rainfall and runoff) is fitted by correlation and regression method. Polynomial Regression [4] an algorithm is developed to derive the first and higher order equations using least-square criterion. A strategy for fitting a best curve of mth degree through the data is to minimize the sum of the square of residual errors.

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 ....a_m P^m + e \qquad (2)$$

where e = residual or error between the model and observation.

For this case; the sum of the square of the residuals (Sr) is:

$$S_r = \sum_{i=1}^{n} (y_i - a_0 - a_1 x_i - a_2 x_i^2 - a_3 x_i^3 .... - a_m x_i^m)^2 \qquad (3)$$

Taking the derivative of Equation (3) with respect to each unknown coefficient of the polynomial and equating these set of derivatives to zero, the set of normal equations is generalized as:

$$a_0 \sum x_i^m + a_1 \sum x_i^{m+1} + a_2 \sum x_i^{m+2} + a_3 \sum x_3^{m+3} + ... + a_m \sum x_{i_i}^{2m} = \sum x_i^m y_i$$

(4)

where, all summations are from $i = 1$ to n. These generalized set of equations are linear and are in the order of m, m+1, m+2, m+3…..2m with corresponding unknowns ao, a1, a2, a3…am. The unknown coefficients of first degree equation are generated from the observed data, and for generating the coefficients of polynomial of higher order, the set of simultaneous equations are solved using Gauss elimination method. Thus, a first-degree equation is established as:

$$y = -338.392 + 20.486x \quad (5)$$

A graphical representation through a plot of actual rainfall and runoff points, first-degree regression line and second-degree curve developed by Valunjkar [5] based on Equation (1) and (5) are shown in Figure 2.

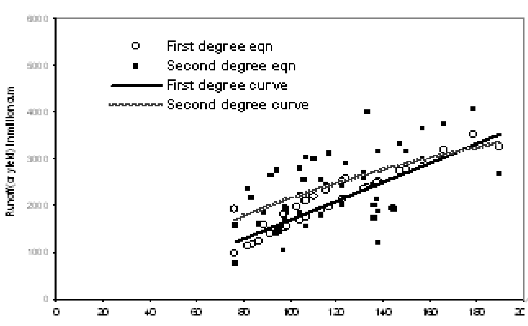

Figure 2 Plot of actual rainfall and runoff points, first and second degree

At later stage, with the availability of additional data, the analysis was carried for the series of 66 and 80 years [6]. The least square procedure can be extended to fit the data to an mth degree polynomial. A problem associated with implementing polynomial regression while computation was that the normal equations were found sometimes ill conditioned. This was true for regression of higher orders. In such cases, the computed coefficients were found to be highly susceptible to round-off error, and consequently the results could be inaccurate. Among other things, this problem was related to the structure of the normal equations and to the fact that for higher-order polynomials the normal equations could have very large and very small coefficients augmented matrix. The problem occurred for fourth and higher order polynomials. Hence the scope of the polynomial regression was restricted to second and third order polynomial equations.

Table1 shows the generated polynomial equations for computation of runoffs along with coefficients of correlation.

Table 1 Generated polynomial equations

Degree of the equation	Polynomial equation	Correlation coefficient	Determination coefficient
Record length 46 years			
First	$y = -338.392 + 20.486x$	0.925	0.856
Second	$y = -596.901 + 31.398x + 0.56x^2$	0.772	0.596
Third	$y = 790.78 - 10.877x + 0.276x^2 - 0.0008x^3$	0.816	0.727
Record length 66 years			
First	$y = -456.35 + 21.50x$	0.931	0.867
Second	$y = -970.32 + 30.124x - 0.0345x^2$	0.822	0.789
Third	$y = 915.880 - 17.038x + 0.3446x^2 - 0.001x^3$	0.833	0.751
Record length 80 years			
First	$y = -497.857 + 21.736x$	0.934	0.872
Second	$y = -903.621 + 28.535x - 0.0273x^2$	0.874	0.874
Third	$y = 1380.346 - 28.504x + 0.431x^2 - 0.0011x^3$	0.866	0.867

5. Computation of Annual Runoff Series

Annual runoff series based on the algorithm [7], are computed for 46, 66 [8] and 80 [9] years. As per the general practice established on actual observation, 10 percent of monsoon runoff was taken as post-monsoon flow. Accordingly runoffs are estimated adding monsoon runoff and post-monsoon flow for each year. Annual reliable flow values in M.m^3 at different percent for 46, 66 and 80 years of record length are computed and generated important results are shown in Table 2.

Table 2 Annual dependable flow values

Dependability in Percent	First degree equation	Second degree equation	Third degree equation
Record length 46 years			
50	2070.799	2435.000	1988.389
55	1983.002	2226.000	1918.876
60	1929.614	2141.000	1856.068
65	1826.246	1972.000	1791.546
70	1752.737	1930.000	1767.229
75	1678.618	1835.000	1647.798
80	1529.225	1737.000	1604.757
85	1461.689	1599.000	1581.753
90	1434.128	1532.000	1468.557
Record length 66 years			
50	1933.445	1939.048	1921.298
55	1899.787	1869.222	1849.69
60	1827.781	1815.444	1795.359
65	1752.734	1801.253	1781.149
70	1679.617	1775.326	1755.325
75	1662.210	1653.213	1636.401
80	1543.333	1596.734	1583.006
85	1461.686	1506.390	1499.915
90	1235.729	1360.519	1372.289
Record length 90 years			
50	1933.446	1922.626	1903.554
55	1899.758	1849.038	1827.751
60	1829.960	1814.301	1792.516
65	1752.738	1781.263	1759.356
70	1679.616	1754.749	1733.006
75	1655.424	1633.370	1615.609
80	1543.302	1577.356	1563.385
85	1447.573	1531.568	1521.675
90	1413.235	1361.804	1375.518

6. Result and Discussions

it is observed that the results of first degree equation was more consistent than the second degree equation since the second degree curve shows that the runoff values goes on reducing, with the increase in rainfall. Similarly, it was observed that, the rainfall increases runoff decreases in case of second and third degree equations. However in log-log correlation, the trend of runoff values was uncertain with the increase in record length. In case of 46 years of record length, the values of yields in case of first, third degree and log-log correlation values were close to each other at lower rainfall as compared with project provisions. However with the increase in record length i.e. 66 and 80 years this difference was found minimum at lower rainfall values with the subsequent decrease in runoff values. The values obtained from the first-degree equation were more consistent for 80 years of record length as compared with the record length of 46 and 66 years.

It could also be observed that the reliable values are decrease with the increase in the record length. However it may not be true for all the cases but it may have certain impact on hydrological studies of the project. It was observed that; the comparative percentage of reliabilities decreases with the increase in record length; however this was not found very correct for higher degree equations at lower side of record length but it may have certain effect over the computation. On the other side this comparative percentage increases with the increase in percentage of reliable yield. Table 2 shows the comparison of different polynomial curves for 46, 66 and 80 years of record lengths.

7. Concluding Remarks

In the present study, the reappraisal of rainfall-runoff relationship was examined using polynomial regression models. The different record lengths were considered for the estimation of annual reliable flow values. The results of the analysis indicate that for estimation of accurate yields, record should be sufficiently long in order to establish hydrologic phenomenon effectively. It was found possible to establish a relationship between reliable values and the length of data series. In a case study of Pench river project, annual runoff series worked out by first degree equation for the record length of 80 years was found more consistent. In recent years, the nature of rainfall was found scanty due to deforestation in the vicinity of case study area. This effect leads to decrease in reliable values which results in reduction of flow values from the reservoirs. Considering these aspects there is a need to revise the earlier planning provisions. Hence, the values of 50 percent, 75 percent and 90 percent reliable flow values could be taken as 1933 M.m3 1655 M.m3 and 1413 M.m3 respectively against the values as per project provisions (i.e. 2435 M.m3, 1835M.m3 and 1532M.m3 respectively) for further analysis.

8. References

1. Project Report. 1966, Pench Hydro-Electric Project Vol-1 Reports, Estimates and Appendices, Irrigation Department, Govt. of Maharashtra, Nagpur circle office, Nagpur.

2. Project Report. 1967, Pench Irrigation Project Vol-1 Reports, Estimates and Appendices, Irrigation Department, Govt. of Maharashtra, Nagpur circle office, Nagpur.

3. Project Report. 1969, Pench Hydro-Electric Project Supplement to Project Report Of 1966, Irrigation Department, Govt. of Maharashtra, Nagpur circle office, Nagpur..

4. Chapra S.C and Canale R.P., 1989. Numerical Methods for Engineers, McGraw-Hill Book Co. (International Edition), Singapore

5. Valunjkar S.S. 1996, Water Planning And Yield Studies for Pench River Projects Complex, Proceedings of All India Seminar on Hydraulic Engineering, Institution of Engineers (India), Nagpur, 27-28 Jan 1996, pp 128-132.

6. Mehrotra R. and Singh R.D.Singh, 1999. Impact of Record Length on the Water Availability Estimates, Journal of Institution of Engineers (India), Vol. 80, pp 117-122.

7. Press W.H., Teukolsky S.A., Vetterling W.T., and Flannery B.P. 2005, Numerical Recipes – The Art of Scientific Computing, Cambridge University Press.

8. Valunjkar S.S. 2005, Development of fuzzy logic system for optimal water resources and cropping planning in context with sustainable development, R&D Project Report (Unpublished), Submitted to the All India Council for Technical Education, New Delhi., India.

9. Valunjkar S.S. Reappraisal of rainfall - runoff studies for computation of reliable flows, Proceedings of National Conference on hydraulic and water resources (HYDRO 2012), IIT Bombay, India, 7 & 8 December 2012, pp 663-672.