Assessment of Empirical Methods for Runoff Estimation in Chaskaman Catchment of Western Maharashtra, India

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ABSTRACT

In water resource management the main basic requirement is the estimation of runoff resulted from precipitation. In present study, runoff from Chaskaman catchment estimated using different empirical methods such as Inglis and DeSouza formula, Khosla’s formula, Coutagine relationship, Department of irrigation India, and Strange’s table method. Hydrological data such as observed daily runoff of 15 years (2000-2014) was collected from Superintending Engineer, Department of Irrigation, Government of Maharashtra, Pune. Performances of the empirical methods were evaluated using various statistical performance evaluation indices. From the result of the study, it is concluded that, the Coutagine relationship is the best method for estimation of runoff in Chaskaman catchment. In this study, from the results of the statistical performance evaluation Inglis and Desouza method indicated as the second best method after Coutagine relationship, for runoff estimation in the catchment area. Department of irrigation India and Strange’s table method shows slightly high runoff as compared to all other methods.

Key words: Catchment, Empirical method, Precipitation, Runoff estimation, Statistical performance

Materials and Methods

Study area and data collection

Chaskaman irrigation project is located across Bhima River, near village Bibi, Khedtahsil of Pune district in Maharashtra state. The Bhima River situated in Western Maharashtra and is a tributary of Krishna River. The catchment area

Introduction

The estimation of runoff resulted from precipitation is prime important in planning and designing of water resources. Many researchers conducted research to estimate the surface runoff using various empirical equations. Surface runoff quantification is one of the most important factors in hydrologic problems analysis and water resources management. In India all watershed cannot be gauged therefore; indirect method of runoff quantification is needed. In this study, various empirical methods of runoff estimation are considered to estimate the runoff from catchment area of Chaskaman reservoir. The estimated results were compared with the observed data.
of Bhima River up to the dam site is about
300.82 sq. km. The geographical extent of the
project is between 73° 46' 50" E to 74° 30' 15"
E longitude and 18° 33' 28" N to 18°58' 09" N
latitude. The precipitation data of 15 years
(2000-2014) taken from the India
Metrological Department Pune. Hydrological
data such as observed daily Runoff was
collected from Superintending Engineer,
Department of Irrigation, Government of
Maharashtra, Pune

Estimation of runoff yield using different
empirical methods and Strange’s table

In this study various empirical equations such
as Inglis and DeSouza, Khosla’s Formula,
Coutagine relationship, Department of
irrigation, India and Strange’s table method
were used for estimation of runoff from
Chaskaman catchment. These empirical
equations are described as follows:

Inglis and DeSouza formula

Inglis and DeSouza (1929) evolved two
regional formulae between annual runoff R
and annual rainfall P in cm as follows
(Subramanya, 2008):

For Deccan plateau

\[ R = (\frac{1}{254} P) \times (P - 17.8) \] (1)

For Ghat regions of western India

\[ R = 0.85P - 30.5 \] (2)

Khosla’s Formula

In this method, the amount of monthly runoff
is calculated by following formula
(Subramanya, 2008):

\[ R_m = P_m - L_m \] (3)

\[ L_m = 0.48 T_m \] (4)

Where,

R_m is monthly runoff of watershed in cm,

P_m is monthly precipitation in cm and T_m is
mean monthly temperature in °C.

Coutagine relationship

Coutagine also after doing many studies on
various watersheds, presented a general
relationship as below (Alizade, 2009):

\[ D = P - \lambda \times P^2 \] (5)

\[ \lambda = \frac{1}{0.8 + 0.14 \times T} \] (6)

\[ R = P - D \] (7)

Where,

P is annual precipitation by m,

T is mean temperature by °C,

R is annual runoff by m and

D is annual flow shortage. Coutagine
relationship is applicable if, \( \frac{1}{2\lambda} < P < \frac{1}{8\lambda} \)

Department of irrigation, India

Management of Reihand plan presented the
following relationship between the amount of
annual precipitation and runoff of Reihand
River (Gupta, 1992):

\[ R = P - 1.17 \times P^{0.86} \] (8)

Where, P is annual precipitation in cm and, R
is annual runoff in cm.
Strange’s table method

One of the widely used empirical methods for computation of runoff yield is the one developed by Strange. He developed a set of curves for the catchments. In these curves the runoff is read as percentage of rainfall. According to the yielding qualities, he classified the catchments as good, bad and average. For a certain rainfall, if the catchment yields a copious runoff, it is classified as good. If the yield is poor, it is classified as bad. All those catchments lying between these two types are classified as average catchments.

Method for estimating the runoff volume in season is given (Subramanya, 2008). The correlation equation of best fitting lines relating percentage yield ratio ($Y_r$) to precipitation (P) could be expressed as,

| For Good catchment: | $Y_r = 7 \times 10^{-5}P^2 - 0.0003P$ | \( r^2 = 0.9994 \) \( \ldots(9a) \) |
|---------------------|--------------------------------------|----------------------------------|
| For 250<P<760 mm,   | $Y_r = 0.0438P - 7.1671$            | \( r^2 = 0.9997 \) \( \ldots(9b) \) |
| For 760<P<1500 mm,  | $Y_r = 0.0443P - 7.479$             | \( r^2 = 1.0 \) \( \ldots(9c) \) |

| For Average catchment: | $Y_r = 6 \times 10^{-5}P^2 - 0.0022P + 0.1183$ | \( r^2 = 0.9989 \) \( \ldots(10a) \) |
|-----------------------|-----------------------------------------------|----------------------------------|
| For 250<P<760 mm,     | $Y_r = 0.0328P - 5.3933$                      | \( r^2 = 0.9997 \) \( \ldots(10b) \) |
| For 760<P<1500 mm,    | $Y_r = 0.0333P - 5.7101$                      | \( r^2 = 0.9999 \) \( \ldots(10c) \) |

| For Bad catchment:    | $Y_r = 4 \times 10^{-5}P^2 - 0.0011P + 0.0567$ | \( r^2 = 0.9985 \) \( \ldots(11a) \) |
|-----------------------|-----------------------------------------------|----------------------------------|
| For 250<P<760 mm,     | $Y_r = 0.0219P - 3.5918$                      | \( r^2 = 0.9997 \) \( \ldots(11b) \) |
| For 760<P<1500 mm,    | $Y_r = 0.0221 - 3.771$                        | \( r^2 = 0.9997 \) \( \ldots(11c) \) |

Where, $Y_r$ = Percentage yield ratio = ratio of runoff to rainfall in percentage and P = Rainfall in mm.

Results and Discussion

Many empirical methods and relationships have been developed using analysis of limited data and the regional characteristics. Many researchers given their outcome as some relationships between precipitation and annual surface runoff. In this study following empirical methods and relationships including Inglis and DeSouza method, Khosla’s method, Coutagine relationship, Department of irrigation, India and Strange’s table method has been used to estimate the runoff for the Chaskaman catchment using the rainfall data of 15 years (2000-2014) taken from the India Metrological Department Pune. Using empirical methods and Strange’s table method, 15 years of rainfall data were analyzed.
Table 1 The results of statistical methods used for empirical models in Chaskaman catchment

| Methods   | Inglis and DeSouza formula | Khosla’s formula | Coutagine relationship | Department of irrigation, India | Strange’s table method |
|-----------|-----------------------------|------------------|------------------------|---------------------------------|------------------------|
| RMSE      | 101.61                      | 101.68           | 87.41                  | 103.15                          | 167.9                  |
| ISE       | 22.34                       | 22.18            | 17.85                  | 24.02                           | 55.12                  |
| MRE       | 0.06                        | 0.06             | 0.05                   | 0.06                            | 0.07                   |
| MBE       | 70.4                        | 74.36            | 36.2                   | 51.09                           | 119.66                 |
| NSE       | 0.93                        | 0.94             | 0.95                   | 0.89                            | 0.83                   |
| IA(D)     | 0.89                        | 0.82             | 0.91                   | 0.78                            | 0.79                   |
| r         | 0.84                        | 0.80             | 0.81                   | 0.69                            | 0.79                   |

Table 2 Ultimate results of ranking various empirical runoff estimation methods in Chaskaman catchment

| Methods   | Inglis and DeSouza formula | Khosla’s formula | Coutagine relationship | Department of irrigation, India | Strange’s table method |
|-----------|-----------------------------|------------------|------------------------|---------------------------------|------------------------|
| RMSE      | 2                           | 3                | 1                      | 4                               | 5                      |
| ISE       | 3                           | 2                | 1                      | 4                               | 5                      |
| MRE       | 3                           | 2                | 1                      | 4                               | 5                      |
| MBE       | 2                           | 3                | 1                      | 4                               | 5                      |
| NSE       | 3                           | 2                | 1                      | 4                               | 5                      |
| IA(D)     | 2                           | 3                | 2                      | 5                               | 4                      |
| r         | 1                           | 3                | 2                      | 5                               | 4                      |
| Overall   | 2                           | 3                | 1                      | 4                               | 5                      |

Fig. 1 Variation between observed and estimated runoff by various empirical methods
The runoff estimated by various empirical methods was compared with the observed values of runoff. The outcome obtained from statistical analysis methods used in this study have been presented for all tested empirical models in the Table 1. The results indicated that, the runoff yield results obtained from Inglis and DeSouza method, Khosla’s method and Coutagine relationship are relatively closer to the observed runoff whereas, the result obtained by Department of irrigation, India and Strange’s Table method are slightly higher than the observed one. Ultimate results of various empirical estimation methods ranking for Chaskaman catchment are presented in Table 2. The best model is the one with lowest amount of RMSE, ISE, MRE, MBE and optimum NSE, IA(D) and r. The variation between observed and estimated runoff graphically presented in Figure 1.

In this study, five runoff estimation equations were evaluated in Chaskaman catchment. Also, these equations were evaluated using observed and measured data in the catchment. The main aim of this study is to determine the most suitable equation for runoff estimation in Chaskaman catchment with minimum data requirement. From the results of the study it was revealed that, Coutagine relationship is the best method for estimation of runoff in Chaskaman catchment has the most efficiency and accuracy. Also, from the results of statistical tests Inglis and DeSouza formula indicated as the second best method after Coutagine relationship, for runoff estimation in the Chaskaman catchment area.

References

Alizade, A. 1989. Principle of Applied Hydrology. Mashhad, Ghods Boniad Press. Pp.860-861.

Khopade, D.K. and Oak, P.R.A. 2014. Estimation of runoff yield for Nira Deoghar catchment using different empirical equations. The International Journal of Engineering and Science. 3(1): 75-81.

Khosravi, K., Mirzai, H. and Saleh, I. 2013. Assessment of Empirical Methods of Runoff Estimation by Statistical test (Case study: Banadak Sadat Watershed, Yazd Province). International Journal of Advanced Biological and Biomedical Research. 1(3): 285-301.

Latha, M. and Rajendran, M. 2015. An empirical Approach to Estimate Runoff of an Ungauged Catchment–Strange Table Method. International Journal of Research in Advent Technology. 3(9): 125-128.

Praveen Kumar, B. J., Pradeep, H., Lokesh, A., Akarshraj, K. H., Surendra, H. J. and Avinash S. D. 2016. Estimation of Runoff using Empirical Equations and Fuzzy Logic method: A case study. International Journal of Scientific & Engineering Research. 7(5): 28-36.

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