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AN AUTOREGRESSIVE TIME SERIES MODEL FOR PREDICTION OF RUNOFF USING SCS-CN METHOD FOR MAHARUWA MICRO WATERSHED OF AMBEDKAR NAGAR DISTRICT (U.P.)

Vipin Kumar Roshan[1], Dr. Rajat Kumar Mehta[2], Dr. Harishchandra Singh[3], Er. Ramjeet Singh[4], Dr. Pramod Kumar Mishra[5], Er. Ashish Gupta[6]

M.Tech. Student, Deptt. of SWCE, MCAET, Ambedkar Nagar, Uttar Pradesh, India[1]

Dean, MCAET, Ambedkar Nagar, Uttar Pradesh, India[2]

Professor, Deptt. of SWCE, ANDUAT, Kumarganj, Ayodhya, Uttar Pradesh, India[3]

Associate Professor, Deptt. of FMPE, MCAET, Ambedkar nagar, Uttar Pradesh, India[4]

Assistant Professor, Deptt. of FMPE, MCAET, Ambedkar nagar, Uttar Pradesh, India[5]

Guest Faculty, Deptt. of CS&E, MCAET, Ambedkar nagar, Uttar Pradesh, India[6]

Abstract: In this study surface runoff is estimated using the USDA Soil Conservation Service curve number (SCS-CN) method and Autoregressive Time Series Model for Maharuwa micro-watershed. The total geographical area of the micro-watershed is 1028.00 ha, located between 83^0 54' 29'' to 82^0 54' 32" North latitude and 25^0 64' 44" to 25^0 55' 38" East longitude which is situated at Maharuwa village of Ambedkar Nagar district, Uttar Pradesh. Hydrological modeling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of water resources. The present study involved two hydrologic runoff model viz. SCS-Curve Number method and autoregressive time series model. In these study SCS-CN method has been applied for the estimation of surface runoff, CN and AMC condition for Maharuwa micro watershed. The Maharuwa micro watershed area is about 1028.00 ha. and is located under Ambedkar Nagar district of Uttar Pradesh.A total of 20 rainfall-runoff events were selected between the years 2001 and 2020 for the study. The SCS-CN is applied to generate curve number and to estimate the surface runoff with help of potential maximum retention the curve number of the watershed was estimated comparison of measured and estimation runoff show that the value is in close agreement with each other. The regression model between measured and estimated runoff was developed and also measured that the correlation coefficient was found to be 0.970450243. Autoregressive models of order 0,1 and 2 were tried for annual stream flow series and the annual stream flow was predicted. The goodness of fit and adequacy of models were tested by box- pierce portmanteau test, Akaike information criterion and by comparison of historical and generated datacorrelogram. For runoff the AIC value for AR(O) model 150.7629 which is lyingbetween 149.75 and 150.6924. Which one for AR(I) and AR(2) respectively. The mean forecast error is also very less in case of runoff in AR (l) models on the bases of the statistical test, AIC the AR (l) models with estimated model parameters was estimated for the best future prediction in Maharuwa micro watershed. This is also proved by graphical representation between measured and predicted correlogram, where is runoff there is a very close agreement. A comparison was mad between the estimated runoff from the SCS-CN method and the predicted runoff from the Autoregressive time series model with the measured data that were collected from the Maharuwa micro watershed. From comparison the measured data were is close agreement with the predicted data that was collected from the auto regressive time series model.

Index Terms: runoff, autoregressive time series model, micro-watershed, rainfall, AMC and SCS-CN method

I. INTRODUCTION

A watershed is a basin like as a natural feature of the landforms (earth's surface), defined by peaks which are connected by ridges that descend into lower elevations and small valleys. It carries rainwater falling on it drop by drop and

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channels it into soil, streams and rivulets flowing into large rivers and in due course sea. Rainfall is the primary source of water for runoff over the land surface. Uncontrolled runoff leads to soil erosion and posing serious threat to floods, environment, social and economic security in the country. To control soil erosion and water scarcity, it is essential to build up a strong base of water and land management and this can be achieved only through watershed development. In India, the availability of accurate information of runoff is scarcely available in few selected sites. However, quickening of the watershed management program for conservation and development of natural resources management programmed for conservation and development of natural resources management has necessitated the runoff information.

The SCS-Curve Number (also known as Curve Number-Method) is an empirical parameter used in hydrology for estimation of direct runoff depth or infiltration from rainfall excess. The curve number method was developed of USA by the USDA Natural Resources Conservation Service, which was formerly known as the Soil Conservation Service (SCS) — the curve number is still popularly known as a "SCS-CN method". The CN method was developed from an empirical analysis of small catchments and hill slope plots monitored by the USDA.

Curve Number method can be successfully used to estimate the runoff for fulfillment the need of permanent soil conservation and water harvesting structure. Keeping above in view the proposed study has been undertaken in Maharuwa Watershed construction of water impoundment structures and storage of runoff structure is the only solution.

an autoregressive (AR) model is a type of random process which is often used to model is a type of random process which is often used to model and predict. Some constraints are necessary on the values of the parameters of this model in order that the model remains wide-sense stationary. For example, processes in the AR(1) model with are not stationary. More generally, for an AR(p) model to be wide-sense stationary. Many observed time series exhibit serial autocorrelation; that is, linear association between lagged observations.

This suggests that past observations might predict current observations. An AR process that depends on past observations is called an AR model of degree p, denoted by AR(p)

Realizing the importance of the above mentioned variables, the present study entitled "Prediction of Runoff Using SCS-CN Method and Autoregressive Time Series Model for Maharuwa micro watershed of Ambedkar Nagar District (U.P.)" is undertaken with the following objectives:

1. To develop USDA SCS-CN method and Autoregressive time series model parameters for estimation of runoff from the study area.
2. To test the validity of the estimated runoff using statistical parameters and evaluate the performance of the model.
3. To develop a relationship between Estimated and observed runoff.

II. MATERIALS AND METHODS

In this chapter general feature of Maharuwa watershed, collection of hydrological data and its analysis, description of curve number method, estimation of rainfall, and runoff hydrographs have been described.

2.1 The Study Area

For the present study the Maharuwa micro-watershed situated in the Maharuwa village. in Bheti block of Ambedkar Nagar district has been chosen. It is located on Azamgarh to the Ayodhya highway and is 30 km away from the Ambedkar Nagar head quarter & 5 to 10 km from the block. The total geographical area of the micro-watershed is 1028.00 ha.

2.2 Data Collection

The Maharuwa micro watershed is being introduced under the Department of Land Development & Water Resource, IWMP-II, Ambedkar Nagar. Digital Elevation model (DEM) derived from USGS Website and Rainfall, Runoff Data collected daily rainfall data from year 2010 to 2020, from Indian Metrological Department of statical reports and Central Ground Water Board of India.

2.3 Generation of Curve Number

When the data of accumulated rainfall and runoff for long-duration, high-intensity rainfalls over small drainage basins are plotted, they show that runoff only starts after some rainfall has accumulated, To describe these curves mathematically, Soil Conservation Service assumed that the ratio of actual retention to potential maximum retention was equal to the ratio of actual runoff to potential maximum runoff, the latter was rainfall minus initial abstraction. In mathematical form, this empirical relationship is,

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad \dots (2.1)$$

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Where,
F = actual retention (mm)
S = potential maximum retention (mm)
Q = accumulated runoff depth (mm)
P = accumulated rainfall depth (mm)
I_a = initial abstraction (mm)

After runoff has started, all additional rainfall becomes either runoff or actual retention (i.e., the actual retention is the difference between rainfall minus initial abstraction and runoff).

$$F = P - I_a - Q \qquad \dots (2.2)$$

Combining Equations 2.1 and 2.2.

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \dots (2.3)$$

2.4 Estimation of potential maximum retention (S)

This potential maximum retention mainly represents infiltration occurring after runoff has started. The parameters S dependents upon the characteristics of the Soil-Vegetation-Land use (SVL) complex and antecedent soil moisture condition in a watershed. For each SVL complex, there is lower limit of S. The soil conservation services expressed S as a function of Curve Number.
This relationship is

$$CN = \frac{1000}{(S + 10)} \qquad \dots (2.4)$$

Where, S is in inches.
For SI unit of S (mm) the Eq. (2.4) is modified to

$$CN = \frac{25400}{254 + S} \qquad \dots (2.5)$$

2.5 Runoff curve number determination
The determination of the CN value for a watershed is a function of soil characteristics, hydrologic condition and cover or land use.

2.5.1 Hydrological Soil Group

Group	**Soil characteristics**	**Minimum infiltration rate(inch/h)**
A	Deep sand, deep loss, and aggregated silts	0.3-0.45
B	Shallow losses and sandy loam	0.15-0.30
C	Clay loams, shallow sandy loam, soils in organic content, and soils usually high in clay	0.05-0.15
D	Soils that swell upon wetting, heavy plastic clays, and certain saline soils	0-0.05

Source: (Anon. 2022d)

2.5.2 Antecedent Moisture Condition (AMC)

The soil moisture condition, in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in three Antecedent Moisture Condition (AMC) Classes:
AMC I: The soils in the drainage basin are practically dry (i.e., the soil moisture content is at wilting point).
AMC II: Average condition.
AMC III: The soils in the drainage basins are practically saturated from antecedent rainfalls (i.e., the soil moisture content is at field capacity).

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Table 2.1 AMC for determining the value of CN

AMC Type	Total Rain in Previous 5 days	
	Dormant season	**Growing Season**
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

Source: (Anon. 2022e)

2.6 Converting values of CN I and CN III to CN II

For conversion of CNI and CNIII into CNII, a method has been suggested by Chow et. al. (2002). In the study, the same method has been adopted for conversion of CN I and CN III into CN II. The procedure for conversion is given below-

$$\mathrm{CNI} = \frac{\mathrm{CNII}}{2.281 - 0.01281\ \mathrm{CNII}} \quad \text{... (2.6)}$$

$$\mathrm{CNIII} = \frac{\mathrm{CNII}}{0.427 + 0.00573\mathrm{CNII}} \quad \text{... (2.7)}$$

Weighted Curve Number for the entire selected Maharuwa micro watershed was calculated based on site information of the watershed. The equation is given below,

$$\mathrm{CN} = \frac{\sum(\mathrm{CNiXAi})}{\mathrm{A}} \quad \ldots (2.8)$$

Where,

CN = weighted curve number.
CNi = curve number from 1 to n.
Ai = area with curve number CNi
A = the total area of the watershed.

2.7 Autoregressive (AR) Model

In the Autoregressive model, the current value of a variable is equated to the weighted sum of a pre assigned no. of part values and a variant that is completely random of previous value of process and shock. The pth order autoregressive model AR (p), representing the variable Y_t is generally written as.

$$Y_t = \overline{Y}\Phi_1(Y_{t-1} - \overline{Y}) + \Phi_2(Y_{t-2} - \overline{Y}) + ... + \Phi_p(Y_{t-p} - \overline{Y}) + \varepsilon_t \quad (2.9)$$

$$Y_t = \overline{Y} + \sum_{j=1}^{p} \Phi_j(Y_{t-j} - \overline{Y}) + \varepsilon_t \quad (2.10)$$

Where,

Y_t = The time dependent series (variable)

ε_t = The time independent series which is independent of Y_t and is normally distributed with mean zero and variance σ^2

Y = Mean of normal rainfall and runoff data

$\Phi_1, \Phi_2 \ldots\ldots\ldots\ldots\ldots\ldots. \Phi_p$ = Autoregressive parameter

2.7.1 Estimation of Autoregressive parameter (Φ) maximum likelihood estimate.

For estimation of the model parameter method of maximum likelihood will be used (Box and Jenkins, 1970).
Consider the sum of cross-products,

$$Z_i Z_j + Z_{i+1} Z_{j+1} + \ldots\ldots\ldots\ldots\ldots + Z_{n+1-j} Z_{n+1-1}$$

and define

$$D_{ij} = D_{ji} = \frac{N}{N+2-i-j} \sum_{l=0}^{N+1-(i+j)} Z_{i+l} Z_{l+i}$$

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Where,
D=difference operator
N=sample size
i,j=maximum possible order

The maximum likelihood estimates of the parameters $\Phi_1,............,\Phi_p$ are found by solving the system of equations

$$D_{ij}= \Phi_1 \ D_{j2}= \Phi_2 \ D_{j3}+................+\Phi_p \ D_{j,p+1}, \ j=2, ..., p+1$$

$$\text{for } \Phi_1 ...., \ \Phi_p$$

in particular,

$$\text{AR (1)}: \ \Phi_1 = \frac{D_{1,2}}{D_{2,2}}$$

$$\text{AR (2)}: \ \Phi_1 = \frac{D_{1,2}D_{3,3} - D_{1,3}D_{2,3}}{D_{2,2}D_{3,3} - D_{2,3^2}}$$

$$\Phi_2 = \frac{D_{1,3}D_{2,2} - D_{1,2}D_{2,3}}{D_{2,2}D_{3,3} - D_{2,3^2}}$$

2.7.2 Autocorrelation function

The autocorrelation function r_k of the variable Y_t of equation (3.2) is obtained by multiplying both sides of the equation (3.2) by Y_{t+k} and taking expectation term by term. The relationship proposed by Kottegoda and Horder, (1980) for the computation of autocorrelation function of lag K was used which is expressed as:

$$r_k = \frac{\sum_{t=1}^{N-K}(Y_t - \overline{Y})(Y_{t+k} - \overline{Y})}{\sum_{t=1}^{N}(Y_t - \overline{Y})^2} \quad \text{.. (2.11)}$$

Where,
r_k= Autocorrelation function of time series Y_t at lag k
Y_t= Stream flow series (historical data)
$\overline{Y}$ = Mean of time series Y_t
k= Lag of K time unit
N= Total number of discrete values of time series Y_t

The autocorrelation or serial correlation is a graphical relationship of autocorrelation function r_k with lag k. The autocorrelogram was used for identifying the order of the model for given time series as well as for comparing the sample correlogram with model correlogram. For an independent time series the population correlogram is equal to zero for K≠1. However, sample of independent time series due to sampling variability have r_k fluctuating around zero but they are not necessarily equal to zero.
Therefore probability limits for the correlogram of an independent series is determined. The following equation was used to determine the 95 percent probability levels Anderson, (1942).

$$r_k(95\%) = \frac{-1 \pm 1.96\sqrt{N-K-1}}{N-K} \quad \text{.......................... ....(2.12)}$$

where, N=Sample size.

2.7.3 Partial Autocorrelation function

The partial autocorrelation function or partial correlogram is used to represent the time dependence structure of a series. The partial autocorrelation PC_{KK} is the autocorrelation remaining in the series after fitting a model of order K-1 and removing the line independence. It is used to identify both the type and order of the model.
The following equation was used to calculate the partial autocorrelation function of lag K. Durbin, (1960).

$$PC_{k,k}=\frac{r_k-\sum_{j=1}^{k-1}PC_{k-1,j}r_{k-j}}{1-\sum_{j=1}^{k-1}PC_{k-1,j}r_j} \quad \text{.....} \quad (2.13)$$

where,
$PC_{k,k}$=Partial auto correlation function
r_k= Autocorrelation function of time series Y_t at lag k

$$PC_{k,j}= PC_{k-1,j}- PC_{k,k}\, PC_{k-1,k-j} \quad \text{.....} \quad (2.14)$$

The 95 percent probability limit for partial autocorrelation function was calculated using the following equation Anderson, (1942).

$$PC_{k,k}(95\%)=\frac{1.96}{\sqrt{N}} \quad \text{.....} \quad (2.15)$$

The autocorrelation function and partial autocorrelation functions for the series Y_t was computed by the equation (2.12) and equation (2.15) respectively and were plotted against lag k with 95 percent probability limits. The general shape of correlogram was analyzed to select tentative order of model.

2.7.4 Parameter estimation of AR (p) models

The average of sequence Y_t was computed by following equation:

$$\overline{Y}=\frac{1}{N}\sum_{t=1}^{N}Y_t \quad \text{.....} \quad (2.16)$$

The average $$\sigma^2_\varepsilon=\frac{1}{(N-1)}\sum_{t=1}^{N}(Y_t-\overline{Y})^2 \quad \text{.....} \quad (2.17)$$

After computation of $\overline{Y}$ and σ^2_ε, the remaining parameters $\Phi_1, \Phi_2, \ldots\ldots\Phi_P$ of the AR models were estimated by using the sequence:

$$Z_t = Y_{t-}\overline{Y}, \quad \text{.....} \quad (2.18)$$

t= 1,2.........N

The parameters $\Phi_1, \Phi_2, \ldots\ldots\Phi_P$ were estimated by solving the p system of following linear equations (Yule and Walker equation):

$$r_k = \Phi_1 r_{k-1}+ \Phi_2 r_{k-2}+\ldots\ldots\ldots\ldots \Phi_P r_{k-P} \qquad K>0 \quad \text{.....} \quad (2.19)$$

or

$$r_k=\sum_{j=1}^{P}\Phi_j r_{k-j} \qquad K>0$$

Where, r_1, r_2 were computed from equation.. (2.20).

3.2.12 Goodness of fit of autoregressive (AR) models

The goodness of fit tests of AR models fitted to annual hydrologic series were accomplished by testing whether the residuals of a dependence model for correlation and whether the order of the fitted model is adequate compared with the order of the dependence model and whether the main statistical characteristics of measured series one preserved. The following tests were performed to test the goodness of fit of autoregressive (AR) models.

3.3 GENERATION USING AR (P) MODELS

The fitted autoregressive AR (P) model is used for prediction of rainfall and runoff in MAHARUWA watershed.

III. RESULTS ANDDISCUSSION

The whole study is done for prediction of runoff using soil conservation service curve number method. It was designed to find effectiveness of watershed in respect of rainfall and runoff.

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3.1 Rainfall-Runoff Analysis

The recorded data was taken from the year 2010 to 2020. The rainfall occurred in this region from the month January to December. The data used in prediction was taken as mean of rainfall and runoff. The given data is shown in Table 3.1. It can be easy visible in Fig. 3.1.

Table 3.1 Event Rainfall and Runoff Data Analysis

Year	Measured Rainfall (mm)	Measured Runoff (mm)
2010	1035.30	176.20
2011	1051.70	91.30
2012	958.00	110.55
2013	1336.20	161.30
2014	780.30	99.10
2015	660.06	56.22
2016	799.40	80.12
2017	783.30	115.56
2018	783.00	78.23
2019	907.00	134.34
2020	1144.52	105.20

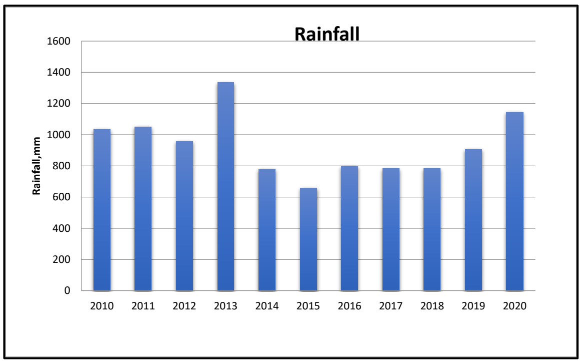

Fig. 3.1 Showing Rainfall from year 2010 to 2020

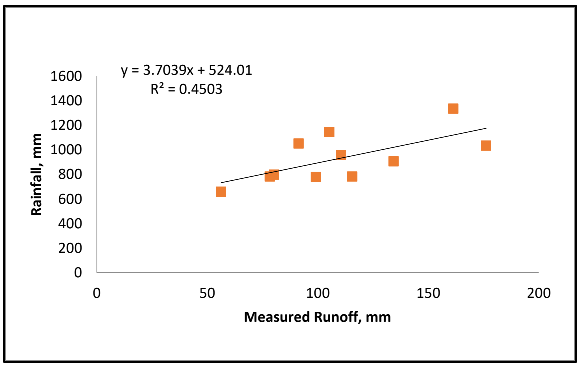

Fig. 3.2 Relation between Measured rainfall and measured runoff

3.2 Stochastic Time Series Model

3.2.1 Model of AR Family

The autoregressive models up to order 1 were tried in this study. The parameters of AR models up to order2 were determined through equation (3.2) and model is given as under:

Runoff: AR (1): $Y_t = 93.16 + 0.1262234(Y_{t-1} - \bar{Y}) + -1.5109778(Y_{t-2} - \bar{Y})\ \varepsilon_t$

Table 3.2 and 3.3 represents statistical characteristics of observed and predicted annual stream flow for runoff and evaluation of regeneration performance with statistical errors respectively. The results clearly shows that the skewness of the generated data by AR (1) and historical data is lying between -1 to +1 and therefore AR (1) model preserved the mean and skewness better.

TABLE 3.2 Statistical Parameters of Autoregressive (AR).Models for Runoff

Model	AR (0)	AR(1)	AR (2)
Autoregressive Parameters	-	$\Phi_1 = 0.4153957$	$\Phi_1 = -1.5109778$ $\Phi_2 = 0.1262234$
White Noise Variance,	29.193308	24.987332	37.324787
Akaike Information criterion, AIC (P)	116.71394	113.42454	123.06836
Value of Porte Moniteau statistics, Q	91.9493	75.6283	16.5862
Degree of freedom upto 5 lags	5	4	3

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Table 3.3 Statistical characteristics of observed and estimated annual Runoff.

S. No.	Statistical Characteristics	Observed Runoff	Predicted Runoff
1	Mean	48.40082	48.529737
2	Standard Deviation	48.612016	70.70
3	Swekness	0.102273	-1.0771612

Fig 3.3 Compristion between observed and, Predicted runoff

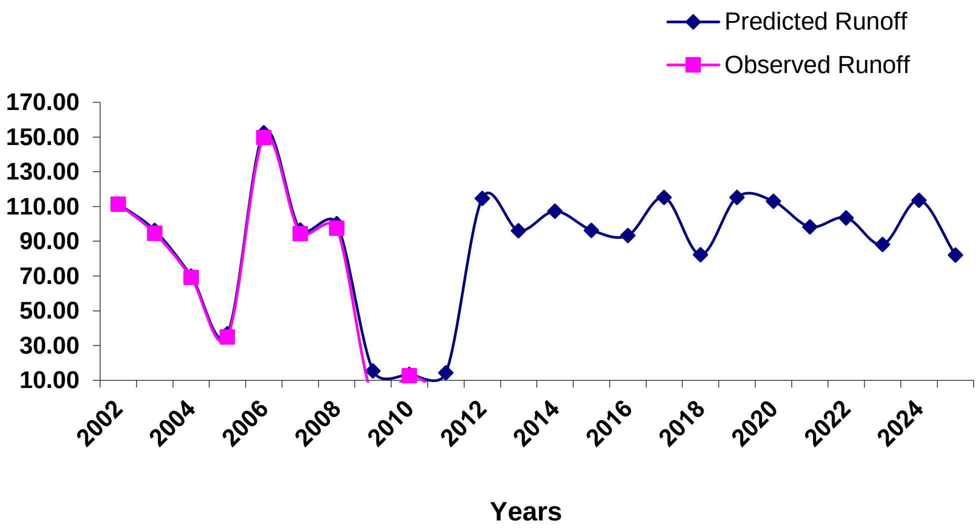

Fig. 3.4 comparison of correlogram of observed and predicted runoff

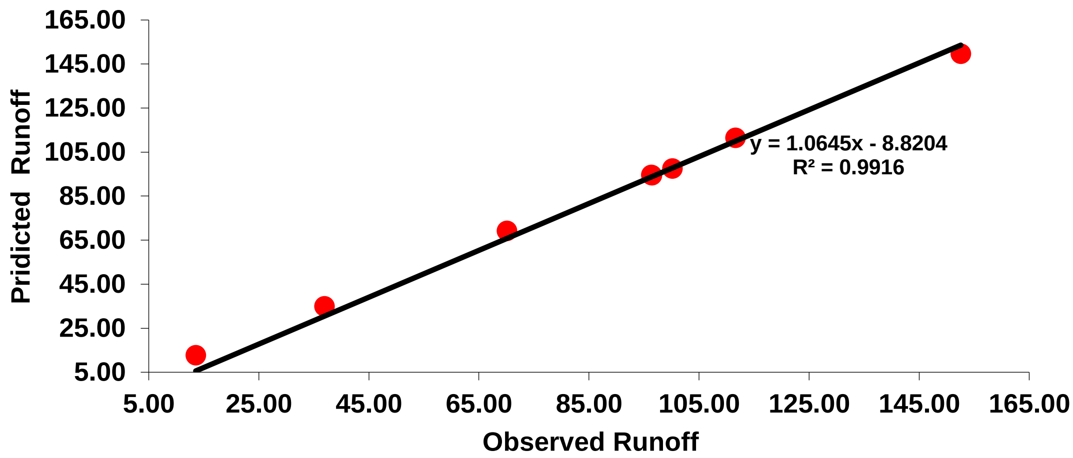

Table 3.4 Comparison of obscured runoff and Predicted runoff by AR(1) and SCS (CN) Method

Year	Measured runoff (mm)	Predicted runoff AR (1) Model	Predicted runoff By SCS (CN)
2004	111.48	111.61	168.80

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2005	94.7	96.31	138.09
2006	69.2	70.09	103.45
2007	35	36.93	66.85
2008	149.7	152.56	208.11
2009	94.5	96.46	142.75
2010	97.6	100.19	151.20

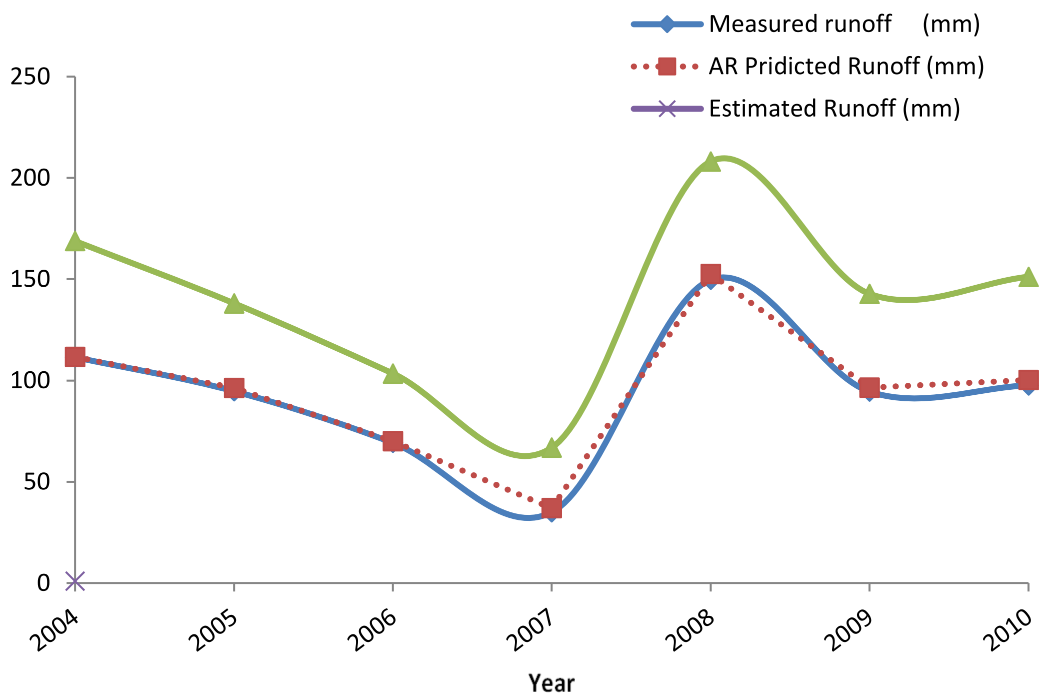

Fig.3.5 Relationship between the two model

IV. SUMMARY AND CONCLUSION

The study is conducted with the prime objective to estimated runoff for Maharuwa micro watershed of Ambedkar Nagar district, Uttar Pradesh, and total area of the Maharuwa watershed is 1080 ha. The rainfall data was collected of 22 years, from the year 2002 - 2024 and used to estimate the runoff.

(1) The first model adopted for estimated is soil conservation service Curve Number (SCS-CN) method. (SCS, 1956) and is widely used in hydrology and environmental engineering for computing the amount of runoff from given amount of rainfall. With the help of potential maximum retention, the Curve Number of the watershed was estimated. Comparison of observed and estimated runoff shows that the value is in close agreement with each other. The regression model between observed and estimated runoff was developed, and also observed that the correlation coefficient was found to be 0.995

(2) The second model used for prediction is Stochastic Time Series model in which Autoregressive (AR) models of orders 0, 1 and 2 were tried for annual stream flow series and different parameters were estimated by the general recursive formula proposed by Kottegoda (1980).

(3) The goodness of fit and adequacy of models were tested by Box-Pierce Portmanteau test, Akaike Information Criterion (AIC) and by comparison of historical and predicted correlogram. The AIC value for AR (2) model (116.713) is lying between AR (0) (123.068) and AR (1) (113.424) which is satisfying the selection criteria. The mean forecast error is also very less. On the basis of the statistical test, Akaike Information Criterion, AIC the AR (1) model with estimate model parameters was estimated for the best future predictions in the Maharuwa watershed.

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This is also proved by Graphical representation between historical and generated correlogram, where in runoff there is a very close agreement.

Thus Autoregressive shows

- The proposed Autoregressive AR (1) model for prediction of runoff is:

$$AR\ (1):\quad Y_t = 93.16 + (-1.5109778)(Y_{t-1} - \bar{Y}) + 0.1262234(Y_{t-2} - \bar{Y})\ \varepsilon_t$$

- In case of runoff generation there is a effective agreement between historical and generated data with mean forecast error, mean absolute error, mean, mean relative error, mean square error,

From the graph, (Fig. 3.5) it is clearly visible that, the results obtained by SCS-Curve Number is showing much more deviation by Autoregressive Time Series Model. SCS Method is not only showing the peak among three and there is rather showing the deepest valley too, which is compensated by the force coming peak.

(4) One more important result visible from the graph is that Autoregressive is giving much more better results or it can be concluded that Autoregressive Time Series Model is much more trust worthy than Curve Number.

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