Rainfall-Runoff Modelling Under Different Agricultural Land Uses of a Hilly Watershed

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Abstract

The study was carried out to develop dynamic models of rainfall-runoff under different land uses of a hilly watershed. Nine different land uses (*live stock based farming system -W_1, timber plantation-W_2, agro-forestry-W_3, agriculture in bench terrace-W_4, agri-horti-silvi-pastoral system-W_5, horticulture-W_6, natural vegetation-W_7, fallow under shifting cultivation-W_8 and pine plantation-W_{AEW})*were considered under farming system research project site at ICAR Research Complex for NEH Region, Umiam, Meghalaya. Linear and non-linear dynamic models of rainfall-runoff process were developed for all nine micro watersheds under different land uses of a hilly watershed using 18years (1983-2000) rainfall and runoff data. The qualitative performances of all linear and non-linear models were evaluated and they were found to be within the permissible limit. The validations of the best fit rainfall-runoff models were performed using 6years (2001-2006) data and they were also found to be within the permissible limit. Using these rainfall-runoff models; runoff of similar behavior micro watershed of a hilly area of a high rainfall region can be predicted in advance.

(Keyword: Rainfall-Runoff Model, Agricultural Land Uses, Hilly Watershed)

1. Introduction

Rainfall-runoff modelling were mainly used as a management tool, for example, in the management of storm water runoff for water quality and urban development. In the mountainous and remote areas like north eastern region there are problems of non-availability of the types of data needed to set up and run a model. The existing models were not tested over a wide range of conditions, physiographic and climatological regions for their wide use. Physically based models need too much detail in the form of input and are therefore, incapable of being applied in practice. The models like runoff prediction on hill slopes under different land use cover condition may be useful for designing hydrologic structure like runoff structure, flood control structure and water harvesting to achieve a sustainable agriculture in the perspective of climate change.

Since hydrological processes are dynamic in nature, the dynamic models are a better and more accurate representation of rainfall-runoff process, because these models consider the effect of past events, which are in the memory of the system. It is therefore the need of the hour is to develop runoff prediction dynamic models in the perspective of north eastern hilly topography. Dynamic modes are generally considered as a time–invariant for simplicity in operation. These models are developed by following the multiple regressions analysis procedure for which computer softwares can be used. Dynamic models for hydrological analysis are generally of two types: (i) linear models and (ii) non-linear models. In linear models the real values of variables are used, and in nonlinear models the values transported by power, log, etc are used.

2.Methods and Materials

2.1 Study Area and Collection of Data

In the north Eastern Hill (NEH) region of India, majority of the people are farmers and that too shifting cultivator. Initial studies on ‘Alternative farming systems to replace shifting cultivation’ have indicated that mixed land use system may prove much better from conservation and production point of view. The site of the current study area was at the ICAR Research Complex for North Eastern Hills Region situated at Barapani (presently Umiam) in the state of Meghalaya. Barapani (Umiam) is located between 25^{o}41’N latitude and between 91^{o}54’, and 91^{o}63’E longitudes and 22 km away from Shillong (Meghalaya). The area is a part of Ri-Bhoi District and comprises of rolling terrains and steep slopes interspersed with valleys and plateaus. The area consisted of typical hilly undulating terrain with the altitude varying between 952 and 1082 meters above mean sea level.

The soil belonging to typical paleaudalf series with clay loam texture has pH ranging from 5.4 to 6.2. Nine micro watersheds with areas ranging from 0.52 ha to 3.8 ha were identified to determine the effects of land use systems on runoff yield. The average slope of the experimental watersheds varied from 32.02 to 53.18 percent. Considering the potentialities of land uses in the hilly regions of North East India, the farming systems studies were live stock based farming system (W_1), timber based plantation (W_2), agro-forestry (W_3), agriculture in bench terrace (W_4), agri-horti-silvi-pastoral system (W_5), horticulture (W_6), natural vegetation (W_7), shifting cultivation (W_8) along with pine (W_{AEW}). Bench terraces, contour trenches, contour bunds, half-moon terraces were the major soil conservation measures.

In the present study rainfall data were collected for the period 1983-2006 from the Agro-meteorological Observatory adjacent to the farming system research project site, ICAR Research Complex, Umiam, Meghalaya. Daily rainfall was recorded with the use of both self recording and non-recording type of rain gauges. The runoff data were estimated by chart analysis collected from the various F type stage level recorders installed in the nine different micro watersheds of study area. Volumetric measurements of runoff were also taken daily to cross check the stage level data. The recorded runoff hydrographs for the study watersheds for each storm were analyzed for computation of runoff rate and runoff volume from the respective watersheds. Measured daily runoff volume at the outlet of the each watershed was converted to daily runoff depth (in mm) using area of the watershed

2.2 Model Development

The model development for rainfall-runoff process was done withthe causative factors i.e. rainfall (P), runoff (Q) antecedent precipitation Index (API) and antecedent runoff index (AQI). The mathematical expression of runoff, Q=f [P, API, AQI]was used to develop the rainfall-runoff models.
The functional linear relationship between the dependent and independent variable can be represented as,

$$Q= \alpha_0 + \alpha_1 P + \alpha_2 API + \alpha_3 AQI \quad \text{......... (1)}$$

A logarithmic relationship of the form as shown below has also been tried in the present study,

$$Q = \alpha_0 P^{\alpha 1} (API)^{\alpha 2} (AQI)^{\alpha 3} \quad \text{......... (2)}$$

The equation 2 can be linearlized by applying the log transformation and written as,

$$In (Q) = In\ \alpha_0 + \alpha_1 In (P) + \alpha_2 In (API) + \alpha_3 In (AQI) \quad \text{............. (3)}$$

Where, α_1's are regression coefficients

The antecedent precipitation index (API) and the antecedent runoff index (AQI) were estimated by the following equations (Pyasi and Singh, 2001, 2003 and 2004).

$$API = Y_1P_1 + Y_2P_2 + Y_3P_3 + \ldots + Y_jP_j + \ldots + Y_mP_m \quad \text{............ (4)}$$

$$API = \sum_{j=i}^{m} P j Y j \quad \text{.........(5)}$$

$$AQI = Y_1Q_1 + Y_2Q_2 + Y_3Q_3 + \ldots + Y_jQ_j + \ldots + Y_mQ_m \quad \text{.......... (6)}$$

$$AQI = \sum_{j=i}^{m} Q j Y j \quad \text{......... (7)}$$

Where, P_j = daily rainfall in the j^{th} day before the day under consideration, Q_j=daily runoff in the j^{th} day before the day under consideration, m=an integer, also called memory parameter and Y_j = the weightage value given to the rainfall and runoff events occurred in j^{th} day before the day under consideration, j=1 refers to event immediately preceding the current event. The weightage value for different past events, Y_j can be estimated by equation given by (Ojasvi *et al.* 1994).

$$Y_j = \frac{e^{[-j-1/m]}}{\sum_{j=1}^{m} e^{[-j-1/m]}} \qquad \text{.................. (8)}$$

j= 1, 2, 3..............m,

For model development on rainfall-runoff process processes, daily data on rainfall and runoff for the period June-September of 1983-2000 were used for the study. For validation of best fit rainfall-runoff models, rainfall and runoff data of the years 2001-2006 were used respectively. For nine micro watersheds, eighteen numbers of the best fitted rainfall-runoff models were developed.

2.3 Model Testing and Verification

Methods to determine the validity of regression models include comparison of model predictions and coefficients with theory, collection of new data to check model predictions. Comparison of results with theoretical model calculations, and data splitting or cross-validation in which a portion of the data is used to estimate the model coefficients and the remainder of the data is used to measure the prediction accuracy of the model. The impact of memory parameter on output will be carried out during the study for the area. The memory based rainfall-runoff time variant models have been developed by using the daily event data series of for the month of June-September of eighteen years i.e.1983-2000. The plausibility of both the models has been tested with the measured data for the period 2001-2006.

2.7Qualitative Evaluation of Model Performance

The acceptability of a model is judged by the goodness of fit between measured values and the values estimated or generated by a model. For qualitative comparison between measured and estimated or generated values, the following statistical measures were employed. The qualitative performance of the models was ascertained by estimating the value of absolute prediction error (*APE*), Integral Square Error (*ISE*) and Coefficient of Efficiency (*CE*) by the following relationships.

(a) Absolute Prediction Error (APE)

The APE values can be determined by the following equation proposed by the World Meteorological Organization Statistics (1975).

$$APE = \frac{\sum_{i=1}^{n}[M_{(i)} - E_{(i)}]}{\sum_{i=1}^{n} M_{(i)}} x100 \text{ .... (10)}$$

(b)Integral Square Error (ISE)

The goodness of fit between measured and estimated values by of a model was also determined by ISE, given by the following equation (Diskin *et al.* 1978)

$$ISE = \frac{\sum_{i=1}^{n}[M_{(i)} - E_{(i)}]^2}{\sum_{i=1}^{n} M_{(i)}} x100 \text{ .... (11)}$$

(c)Coefficient of efficiency (CE)

The coefficient of efficiency for evaluating the model performance has been recommended by many researchers. The CE is defined by Nash and Sutcliffe (1970) as the initial variance accounted for that model is determined by the equation no. 12.

$$CE = \frac{\sum_{i=1}^{n}[M_{(i)} - \overline{M}]^2 [M_{(i)} - E_{(i)}]^2}{\sum_{i=1}^{n}[M_{(i)} - \overline{M}]^2} x100$$

……......(12)

Where $M_{(i)}$ is the measured, $E_{(i)}$ is the estimated values at corresponding time and $\overline{M}$ is the mean of measured value.

2.7.1 Qualitative Evaluation of Rainfall-Runoff Model Performance

In the present study the permissible limits for APE, ISE and CE for **r**ainfall-runoff model performance are taken respectively as 30%, 10% and 65%. That means the prediction should satisfy the criteria's of APE less than 30%, ISE less than 10% and CE more than 65%.

3. Result and Discussion

3.1 Model Development for Rainfall-Runoff Process

The daily runoff prediction models based on rainfall-runoff processes were developed for nine micro watersheds under different land uses for the watershed of FSRP, Umiam. The daily data set for rainfall and runoff for all 18 years (1983-2000) were used for model development and daily data set for rainfall and runoff for all 6 years (2001-2006) were used for model validation. Using equations 1 and 2 both linear and nonlinear dynamic models was tried using multiple step regression for the monsoon period (June to September). All together total *eighteen* numbers of linear and non-linear models of rainfall-runoff relationship were selected for nine different micro watersheds having different land uses based on the highest value of R^2.

In case of micro-watersheds W_2, W_3, W_4, W_5, W_6, W_7, W_8 and $W_{AEW,}$ independent variables, i.e., precipitation (P), antecedent precipitation index (API) and antecedent runoff index (AQI) were found to be dominating to predict dependent variable runoff (Q) while developing linear rainfall-runoff models. In case of micro watershed $W_{1,}$ only variable AQI index had a significant role in developing linear rainfall-runoff models. The values of coefficient of multiple determinations (R^2) for the linear models had shown the range between 0.997-1.00 (Table 1). Analysis revealed that the values ISE, APE, CE and CC of linear models were in the range of $1.84x10^{-9}$ to 2.82%, $9.24x10^{-14}$ to $3.1x10^{-13}$%, 99.7 to 100% and 0.821-1.00 respectively for micro watersheds W_1 to W_{AEW} indicating the fulfillment criteria of a good model.

In case of micro-watersheds W_2, W_3, W_4, W_5, W_6, W_7, W_8 and $W_{AEW,}$ independent variables, i.e., precipitation (lnP), antecedent precipitation index (lnAPI) and antecedent runoff index (lnAQI) were found to be dominating to predict dependent variable runoff (lnQ) while developing non-linear rainfall-runoff models. In case of micro watershed $W_{1,}$ only variable lnAQI index had a significant role in developing linear rainfall-runoff models. The values of coefficient of multiple determinations (R^2) for the non-linear models had shown the range between 0.90-1.00 (Table 1). Analysis revealed that the values ISE, APE, CE and CC of linear models were in the range of $5.96x10^{-9}$ to $3.53x10^{-1}$, $7.90x10^{-14}$ to $7.13x10^{-1}$, 84.7 to 100% and 0.636 to 1 respectively for micro watersheds W_1 to W_{AEW} indicating the fulfillment criteria of a good model.

Generally compare to nonlinear models, linear models are simple to use. Hence, linear models were considered to be the best fit in this study.. The comparison of observed and predicted values of runoff (Q) using the best fit linear models for nine micro watersheds is also shown in the Figs. 1 to 9. For a particular storm event, if rainfall is zero the best fit models will predict runoff based on antecedent runoff which normally occurs before a particular storm event. In that situation antecedent runoff index (AQI) will take care of it while predicting the runoff.

3.2.1 Model validation for rainfall-runoff process

All the best fit models were validated for their applicability by using the daily rainfall and runoff yield data series for the years 2001 to 2006.The best fit prediction models generally satisfy the criteria's of Absolute Prediction Error (APE) less than 30%, Integral Square Error (ISE) less than 10% and Coefficient of Efficiency (CE) more than 65%. Analysis revealed that the ISE values of linear models were in the range of 0.00907 to 7.8% for micro watersheds W_1 to W_8. For micro watershed W_{AEW}, the value of ISE was observed to be 11.5 %. The Coefficient of Efficiency (CE) of linear models had shown very good performance with a value ranging from 99.2 to 100% which was also greater than the permissible limit (greater than 65%). The Coefficient of Efficiency (CE) normally describes the predictive accuracy of models as long as there is observed data to compare the model results. Essentially, the closer the model efficiency is to 100%, the more accurate the model is.The values of APE of best fit linear models were negative in nature and were in the range of 0.02 to 10% which is far below from the permissible limit (30%). The correlation coefficients (CC) of linear models are found to be quite high 0.78-1.00 except in the case of micro-watershed W_1 (agriculture based farming system). In all the cases linear models had shown under estimation less than 10% except in the case of micro-watershed W_{AEW} (pine and natural flora based farming system) (Table 2). The graphical presentation of validated best fit linear models was shown in the Figs. 10, 11, 12, 13, 14, 15, 16, 17 and 18 respectively.

4. Conclusion

Linear and non-linear dynamic models of rainfall-runoff process were developed for nine micro watersheds (W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8 and W_{AEW}) under different land uses of a hilly watershed. The qualitative performances of all linear and non-linear models were evaluated and they were found to be within the permissible limit. The validations of the best fit rainfall-runoffmodels were performed using 6years (2001-2006) data and they were also found to be within the permissible limit. Using these rainfall-runoff models; runoff of similar behavior micro watershed of a hilly area of a high rainfall region can be predicted in advance.

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Tables

Table 1 Rainfall-runoff models and their qualitative performance values (during model development-1983-2000)

Micro-watersheds and respective models	Qualitative performance parameters					Remark
W_1- Fodder based farming system	R^2	APE (%)	ISE (%)	CE(%)	CC	
Q=0.285-0.001P+0.115AQI	0.997	1.41×10^{-13}	2.82	99.7	0.998	BF
ln(Q)=-0.720-0.217ln(P)-0.084 ln(API) -0.928ln(AQI)	0.900	1.95×10^{-3}	9.23×10^{-2}	84.7	0.636	
W_2-Forestry based farming system						
$Q=3.33 \times 10^{-5}P+8.86 \times 10^{-6} \times API +0.116AQI$	1.00	2.37×10^{-13}	2.07×10^{-3}	100	1.00	BF
$\ln(Q)=-2.156-2.713 \times 10^{-10}\ln(P)-6.535 \times 10^{-11}\ln(API)+\ln(AQI)$	1.00	7.13×10^{-1}	3.53×10^{-1}	100	0.998	
W_3-Agroforestry based system						
$Q=9.11 \times 10^{-6}P+4.585 \times 10^{-6}API + 0.116AQI$	1.00	2.75×10^{-13}	1.83×10^{-3}	100	0.999	BF
$\ln(Q)=-2.156-3.953 \times 10^{-10}\ln(P) +1.988 \times 10^{-10}\ln(API)+\ln(AQI)$	1.00	1.31×10^{-13}	5.06×10^{-9}	100	0.999	
W_4-Agriculture(food crop) based farming system						
$Q=4.993 \times 10^{-10}-1.483 \times 10^{-11}P+ 5.371 \times 10^{-12}API+0.116AQI$	1.00	2.22×10^{-13}	4.69×10^{-9}	100	0.821	BF
ln(Q)=-1.069+0.015ln(P)-0.005 ln(API) +3.622ln(AQI)	0.997	7.90×10^{-14}	1.74×10^{-1}	99.7	0.983	
W_5-Agri-horti-silvi-pastoral system						
$Q=-1.367 \times 10^{-9}-1.456 \times 10^{-10}P+ 5.519 \times 10^{-11}API+0.116AQI$	1.00	2.02×10^{-13}	4.09×10^{-9}	100	0.999	BF
$\ln(Q)=-2.156-1.079 \times 10^{-10}\ln(P)+ 3.743 \times 10^{-11}\ln(API)+\ln(AQI)$	1.00	7.83×10^{-14}	1.69×10^{-1}	99.7	0.998	
W_6-Horticulture based farming system						
$Q=0.004-5.25 \times 10^{-5}P-6.215 \times 10^{-6}API + 0.116AQI$	1.00	9.24×10^{-14}	4.08×10^{-3}	100	1.00	BF
$\ln(Q)=-2.156-5.05 \times 10^{-10}\ln(P) +6.493 \times 10^{-11}\ln(API)+\ln(AQI)$	1.00	2.31×10^{-13}	2.64×10^{-9}	100	1.00	
W_7-Natural vegetation based farming system						
$Q=3.704 \times 10^{-10}-2.132 \times 10^{-11}P+ 1.787 \times 10^{-12} API+0.116AQI$	1.00	3.06×10^{-13}	3.62×10^{-9}	100	1.00	BF
$\ln(Q)=-2.156+9.294 \times 10^{-10}\ln(P)- 1.964 \times 10^{-10}\ln(API)+\ln(AQI)$	1.00	2.85×10^{-14}	1.53×10^{-8}	100	1.00	
W_8-Shifting cultivation based farming System						
$Q=-3.619 \times 10^{-10}-2.974 \times 10^{-11}P + 1.306 \times 10^{-11}API+0.116AQI$	1.00	3.1×10^{-13}	1.84×10^{-9}	100	1.00	BF
$\ln(Q)=-2.156-1.003 \times 10^{-10}\ln(P) +2.306 \times 10^{-10}\ln(API)+\ln(AQI)$	1.00	1.33×10^{-13}	5.96×10^{-9}	100	1.00	

W_{aew} Pine and natural vegetation based farming system						
Q=1.413x10^{-10}-2.240x10^{-11}P-9.036x10^{-12}API + 0.116AQI	1.00	1.29x10^{-13}	1.89x10^{-9}	100	1.00	BF
ln(Q)=-2.156-1.096x10^{-10}ln(P)-1.220 x 10^{-10}ln(API)+ln(AQI)	1.00	1.15x10^{-13}	4.41x10^{-9}	100	1.00	

UE: Under Estimation; OE: Over estimation; BF: Best Fit

Table 2 Validation of Rainfall-runoff models and their qualitative performance values (2001-2006)

Micro-watersheds and respective models	Qualitative performance parameters						Remarks
W_1- Fodder based farming system	R^2	APE (%)	ISE (%)	CE (%)	CC	Validation (%)	
Q=0.285-0.001P+0.115AQI	0.997	3.95	1.56	100	0.3633	-3.948982(UE)	BF
ln(Q)=-0.720-0.217ln(P)-0.084 ln(API) -0.928ln(AQI)	0.900	2.98x10^{3}	1.56x10^{3}	95.6	0.7847	29.79595(OE)	
W_2-Forestry based farming system							
Q=3.33x10^{-5}P+8.86x10^{-6}x API + 0.116AQI	1.00	3.953	1.56	100	1.00	-0.1841413(UE)	BF
ln(Q)=-2.156-2.713x10^{-10}ln(P)-6.53 x10^{-11}ln(API)+ln(AQI)	1.00	3.25x10^{2}	1.24x10^{2}	100	1.00	324.73290(OE)	
W_3-Agroforestry based system							
Q=9.11x10^{-6}P+4.585x10^{-6} API + 0.116 AQI	1.00	2.05	1.20x10^{1}	100	0.99	-0.2083920(UE)	BF
ln(Q)=-2.156-3.953x10^{-10}ln(P) + 1.988 x10^{-10}ln(API)+ln(AQI)	1.00	1.78x10^{-2}	2.18x10^{-2}	100	1.00	0.01777544(OE)	
W_4-Agriculture(Food Crop) based farming system							
Q=4.993x10^{-10}-1.483x10^{-11}P + 5.371 x10^{-12}API+0.116AQI	1.00	2.01x10^{-1}	9.07x10^{-2}	100	1.00	-0.2010500(UE)	BF
ln(Q)=-1.069+0.015ln(P)-0.005 ln(API) +3.622ln(AQI)	0.997	5.90x10^{-2}	2.12x10^{-1}	100	1.00	-0.0589632(UE)	
W_5-Agri-Horti-Silvi-Pastoral System							
Q=-1.367x10^{-9}-1.456x10^{-10} P +	1.00	2.14x10^{-1}	1.27x10^{-1}	100	1.00	-0.2136312(UE)	BF

5.519 x10^{-11}API+0.116AQI							
ln(Q)=-2.156-1.079x10^{-10}ln(P) + 3.74 x10^{-11}ln(API)+ln(AQI)	1.00	7.61x10^{-3}	5.60x10^{-3}	100	1.00	0.6539145(OE)	
W_6-Horticulture based farming system							
Q=0.004-5.25x10^{-5}P-6.215x10^{-6}API + 0.116AQI	1.00	2.15x10^{-1}	9.91x10^{-2}	100	1.00	-0.2267359(UE)	BF
ln(Q)=-2.156-5.05x10^{-10}ln(P) + 6.493 x10^{-11}ln(API)+ln(AQI)	1.00	9.34x10^{-3}	1.13x10^{-2}	100	1.00	0.00933562(OE)	
W_7-Natural vegetation based farming system							
Q=3.704x10^{-10}-2.132x10^{-11}P + 1.78 x10^{-12}API+0.116AQI	1.00	7.92	7.81	99.2	0.996	-7.9206156(UE)	BF
ln(Q)=-2.156+9.294x10^{-10}ln(P)-1.96 x10^{-10}ln(API)+ln(AQI)	1.00	13.9	13.9	100	0.999	-13.927316(UE)	
W_8-Shifting cultivation based farming System							
Q=-3.619x10^{-10}-2.974x10^{-11}P + 1.30 x10^{-11}API+0.116AQI	1.00	0.245	1.37x10^{-1}	100	1.00	-0.2453325(UE)	BF
ln(Q)=-2.156-1.003x10^{-10}ln(P) + 2.30 x10^{-10}ln(API)+ln(AQI)	1.00	0.0640	4.05x10^{-2}	100	1.00	-0.0640684(UE)	
W_{aew} Pine and natural vegetation based farming system							
Q=1.413x10^{-10}-2.240x10^{-11}P-9.036 x 10^{-12}API+0.116AQI	1.00	10.24	11.1	100	1.00	-10.247007(UE)	BF
ln(Q)=-2.156-1.096x10^{-10}ln(P)-1.22 x10^{-10}ln(API)+ln(AQI)	1.00	4.55	4.54	100	1.00	-4.5547948(UE)	

UE: Under Estimation; OE: Over estimation; BF: Best Fit

Figures

Graphical trend of observed and predicted runoff during model development (Figure 1-9)

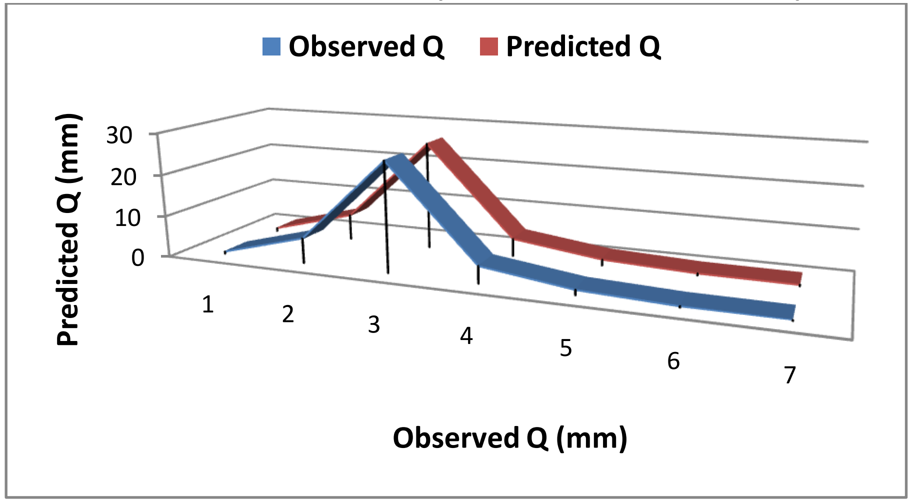

Fig. 1 Observed & predicted runoff(Q) in micro watershed W_1

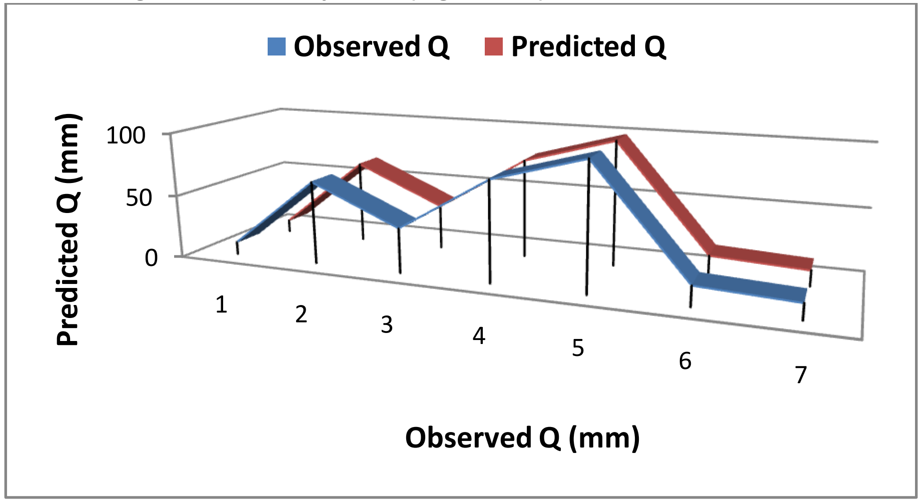

Fig. 2 Observed & predicted runoff(Q) in micro watershed W_2

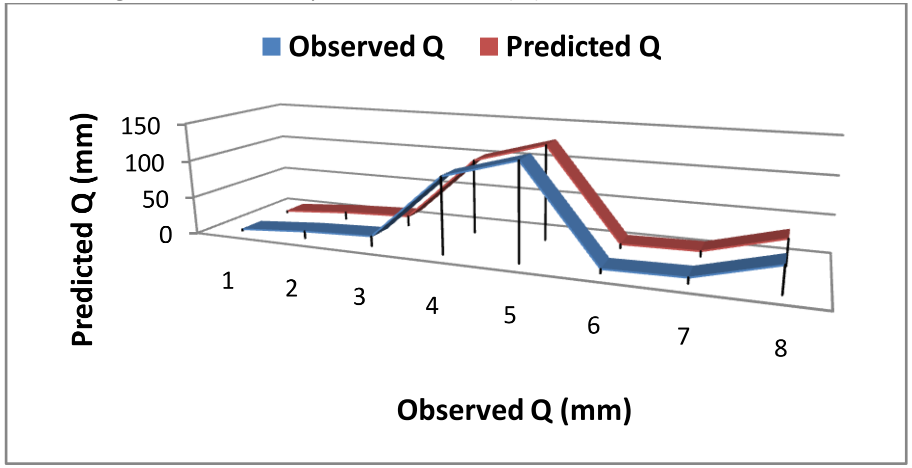

Fig. 3 Observed & predicted runoff(Q) in microwatershed W_3

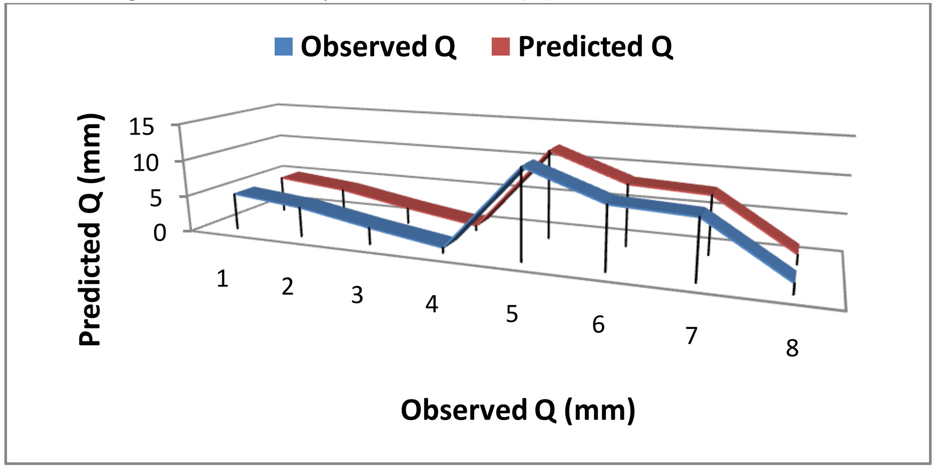

Fig. 4 Observed and predicted runoff(Q) in micro watershedw W_4

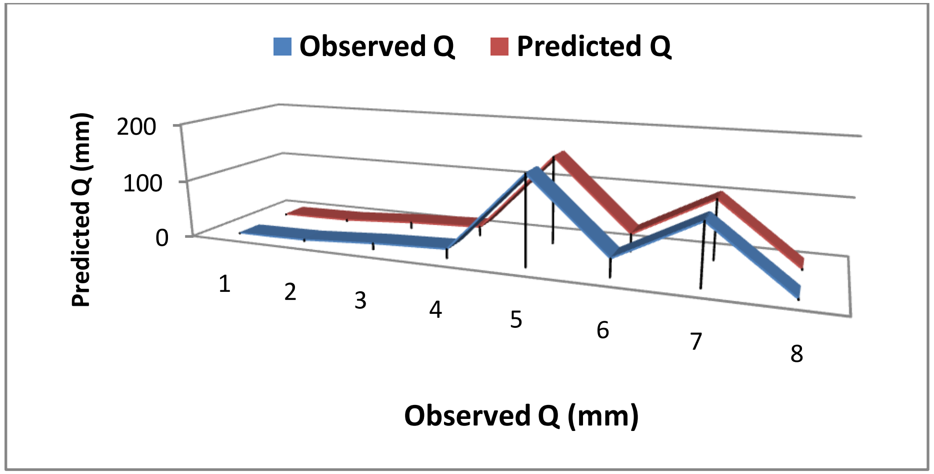

Fig. 5 Observed & predicted runoff(Q) in micro watershed W_5

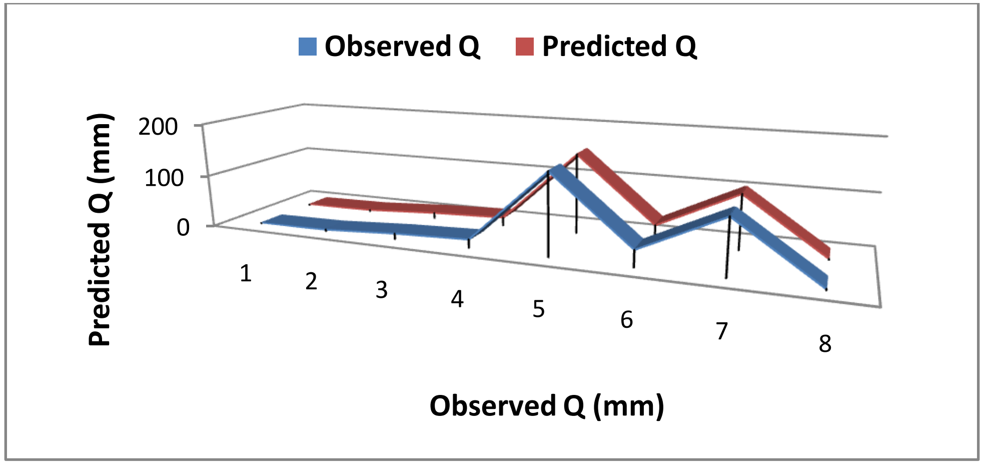

Fig. 6 Observed & predicted runoff(Q) in micro watershed W_6

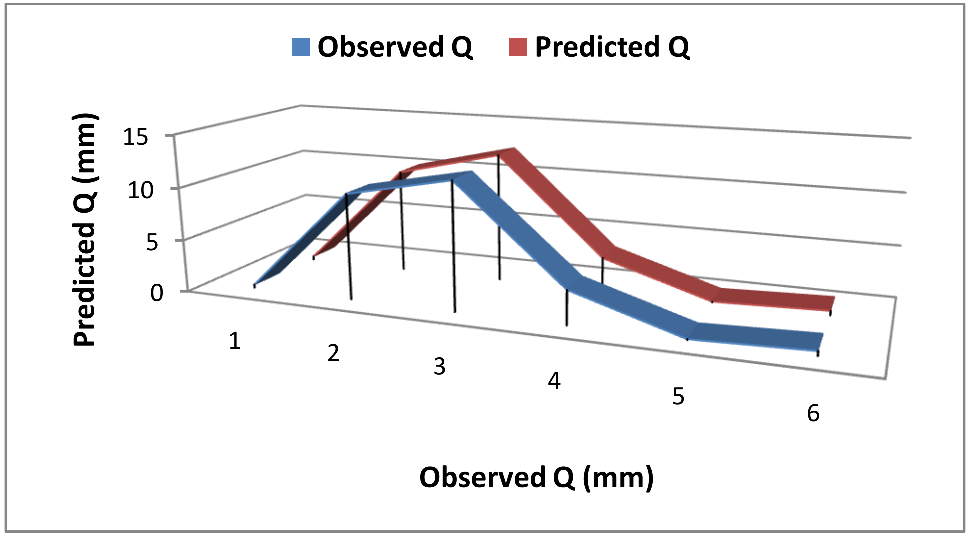

Fig. 7 Observed and predicted runoff(Q) in micro watershed W_7

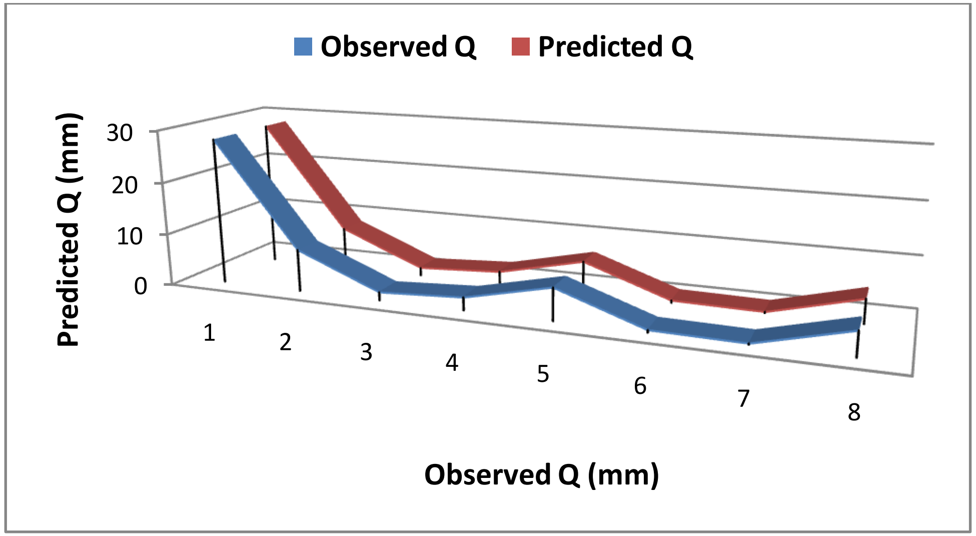

Fig. 8 Observed & predicted runoff(Q) in micro watershed W_8

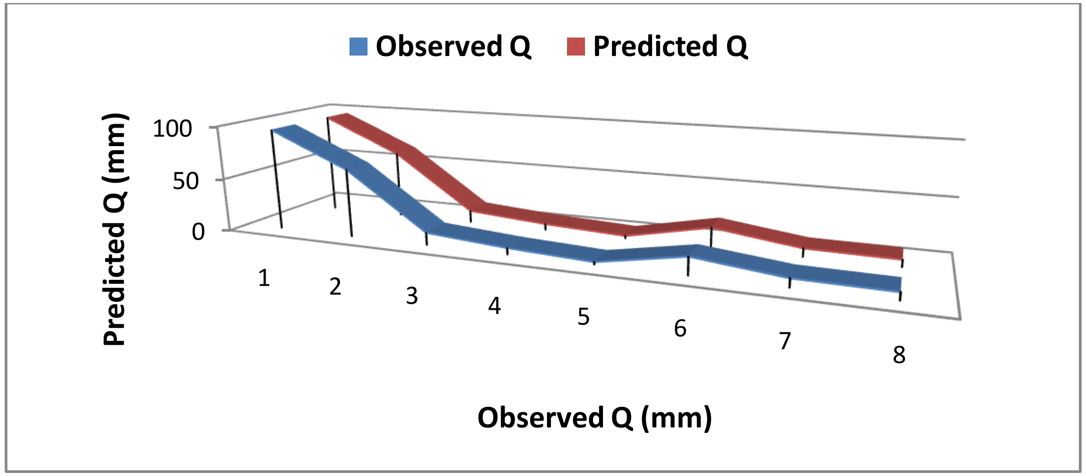

Fig. 9 Observed and predicted runoff(Q) in micro watershed W_{aew}

Graphical trend of observed and predicted runoff during model validation (Figure 10-18)

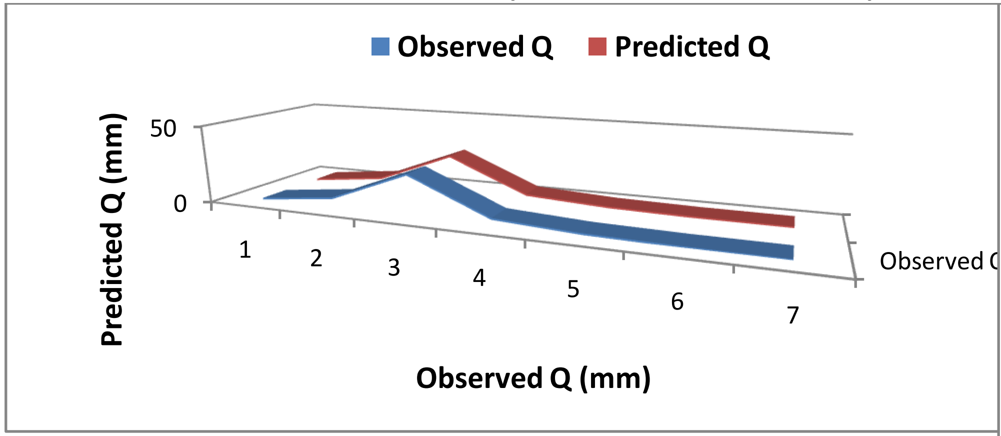

Fig.10 Observed & predicted runoff(Q) in micro watershed W_1

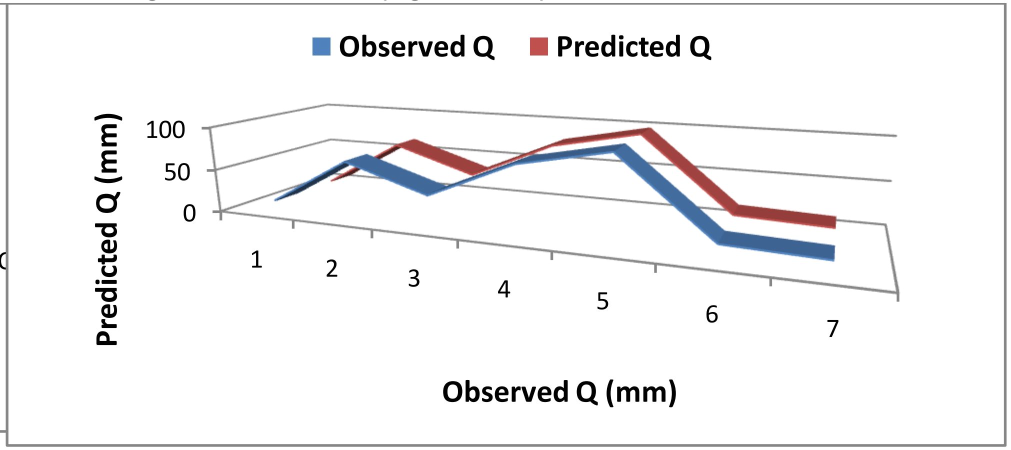

Fig. 11 Observed & predicted runoff(Q) in micro watershed W_2

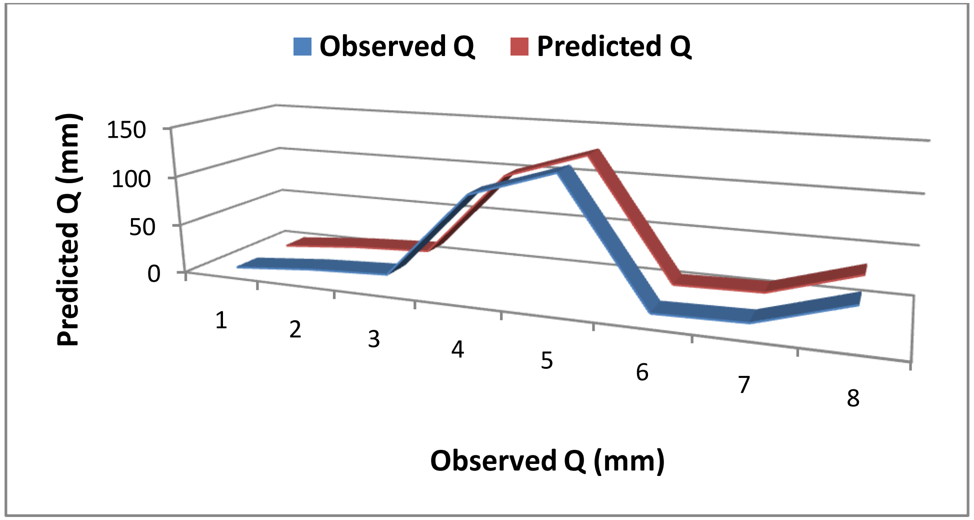

Fig. 12 Observed & predicted runoff(Q) in micro watershed W_3

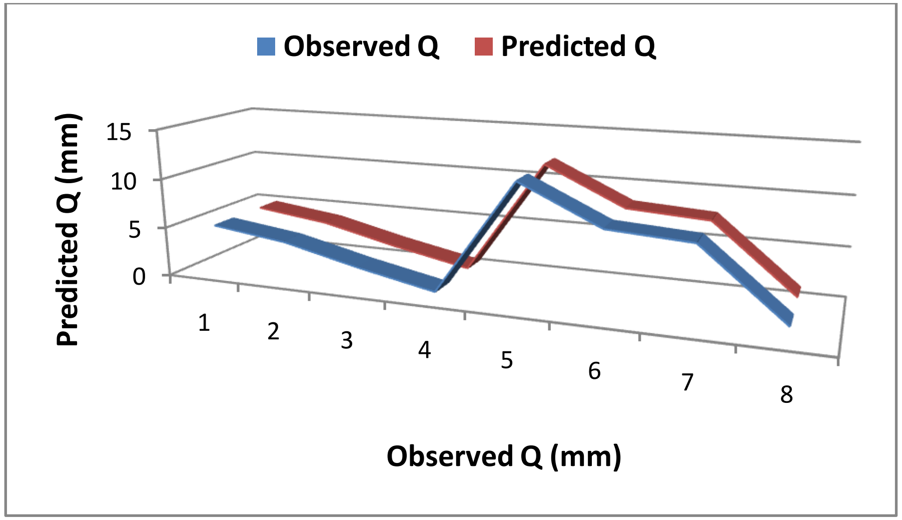

Fig. 13 Observed & predicted runoff(Q) in micro watershed W_4

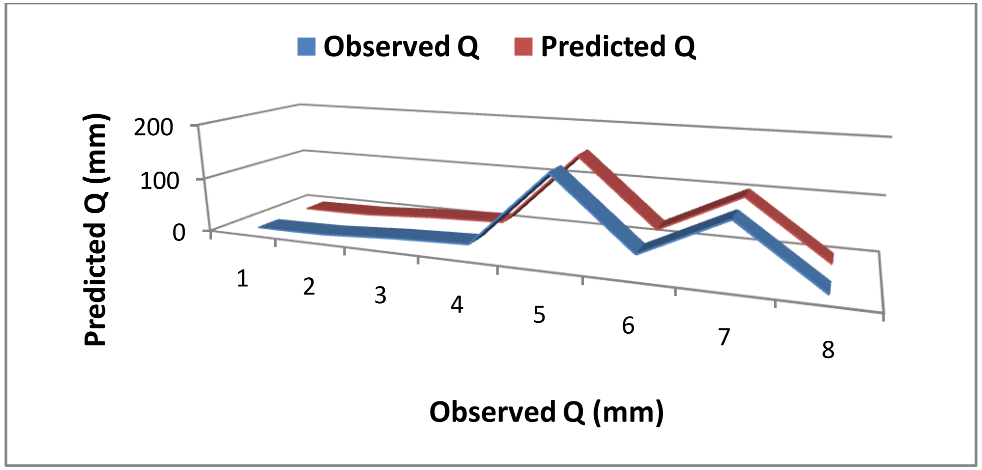

Fig.14 Observed & predicted runoff(Q) in micro watershed W_5

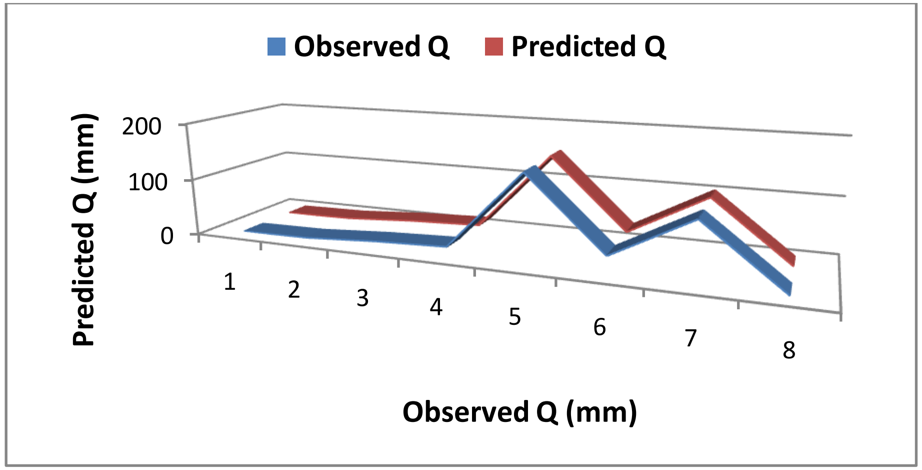

Fig.15 Observed & predicted runoff(Q) in micro watershed W_6

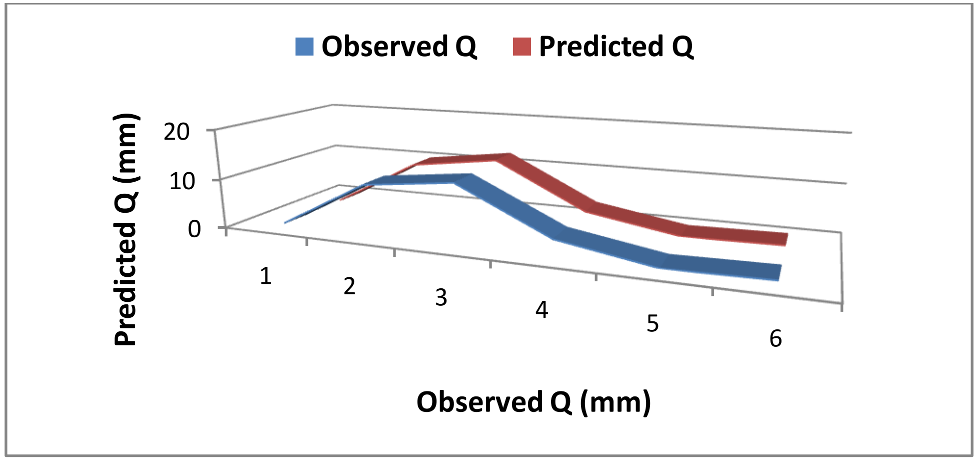

Fig.16 Observed and predicted runoff(Q) in microwatershed W_7

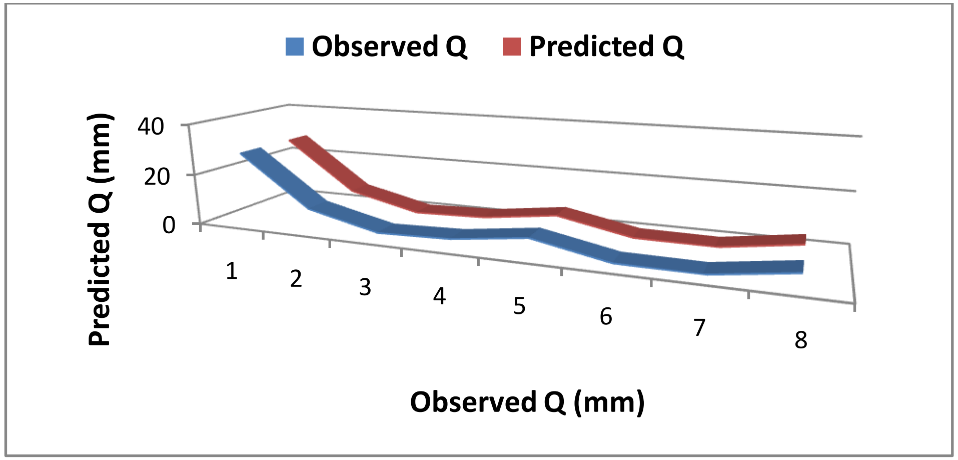

Fig.17 Observed and predicted runoff(Q) in microwatershed W_8

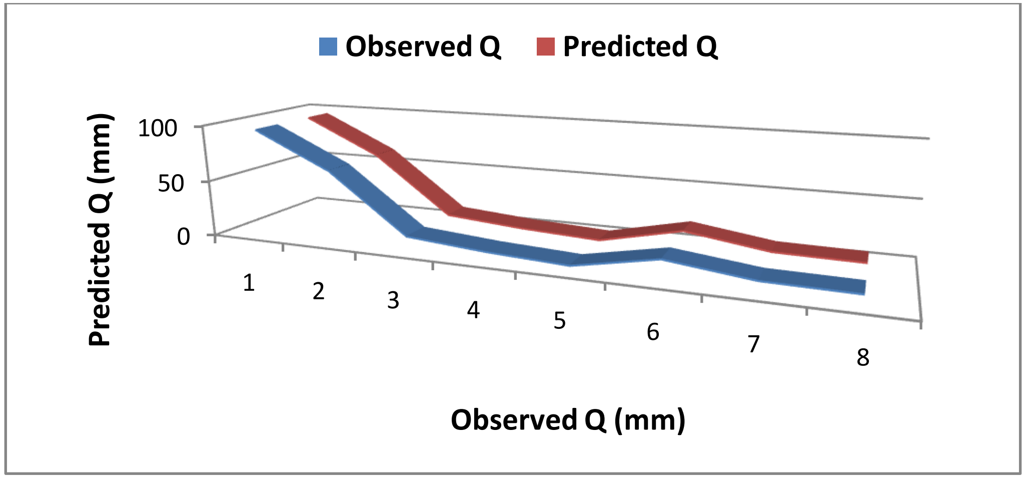

Fig.18 Observed and predicted runoff(Q) in microwatershed W_{aew}