Development of Memorary based System Models for Rainfall- Runoff Process on Sequential Time Scale Basis

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Abstract- The dynamic models based on rainfall-runoff processes of a watershed fluvial system was developed in the present study on sequential time scale basis. The qualitative performance of models were ascertained by estimating the values of absolute prediction error (APE), integral square error (ISE) and the coefficient of efficiency (CE). In the present study the permissible limits for APE, ISE and CE were taken respectively as 30%, 10% and 60%, that is the prediction should satisfy the criteria of the APE less than 30%, ISE less than 10% and CE more than 60%. Two types of memory based runoff prediction models viz., linear and non-linear were developed by using the daily data series of three consecutive years from 1994 to 1996 of active period (June to September) only. Both the models consider the present rainfall, antecedent precipitation index (API), antecedent runoff index (AQI) as input. The values of coefficient of multiple determination (R2) for the linear and non-linear models were found equal to 0.67 and 0.86 respectively, on the basis of which the non-linear memory based model may be considered more appropriate than the linear model for the study area. The Qualitative performance of non-linear model as tabulated in table 4.2 confirm the applicability of the model for all the years (1994-2014) under study.

Keywords: Rainfall, Runoff, Sediment, Rainfall-Runoff Process, Sequential Time Scale, Antecedent precipitation index, Antecedent runoff index

I . INTRODUCTION

The water is one of the most important natural resources available to mankind. It has unique role as a natural resource and deserves special attention of researchers and planners because of its multiple benefits and the problem created by its excess and shortage and quality deterioration. The water on earth, whether as water vapour in the atmosphere, as surface water in the streams, lakes, as salt water in seas and oceans, or as ground water in the interstices of the subsoil, is not at rest, but in a continuous circulatory movement and never ending transformation from one state to another with sun as driving force is called the "hydrologic cycle". It undergoes various complicated process of interception, infiltration, unsaturated flow, saturated flow, evaporation, transpiration, overland flow, channel flow etc. All these process depend on space and time.The hydrologic response of catchment to rainfall, estimates the catchment yield, and runoff data are of vital importance for hydrological analysis for the purpose of water resource planning, flood forecasting, pollution control and many other applications (Shamsudin and Hashim, 2002). Most of the river catchments in India are ungauged and the runoff information is not available for those catchments. Under such circumstances rainfall-runoff model can be developed to simulate the natural hydrological processes to estimate runoff from the catchment. The rainfall-runoff process is most important hydrological process considered during watershed management studies in humid and semiarid areas. It is a complex process as it is influenced by a number of implicit and explicit factors such as precipitation distribution, evaporation, transpiration, abstraction, watershed topography and soil types. The runoff discharges and flow rates at a river sites varies greatly throughout the course of a year, depending on seasonal rainfall, watershed characteristics and many other parameters. These variables greatly influence modeling effort and time and in turn provide opportunities for research endeavours.

Hydrological modeling is a simplified description of hydrological cycle to imitate the natural system. Rainfall-runoff modeling is simplified representation of real world system, and consists of a set of simultaneous equations or logical set of operation with the aim of simulating the end result of hydrological cycle, which is runoff. Many hydrologic models are available; varying in nature, complexity and purpose (shoemaker et al., 1997). Rainfall-runoff modeling is an important tool to deal with various practical problems in water sector such as water resources assessment, design of engineering channels, flood forecasting, predicting population incidents and many other purposes. Water resources development and management in the river basin can be planned by making use of appropriate model. Runoff water is usually the medium involved in the sediment generation and its transporting processes. The rainfall-runoff process is most important hydrological process considered during watershed management studies. In the formulation and operation of soil and water resource management and erosion control programmes, it is necessary to ascertain the probable amount of runoff and sediment yield from a watershed on sequential and integrated time scale basis. Watershed runoff and sediment yield models are yet in the stage of infancy and therefore more serious studies and regress affords are required to develop various mathematical models based on the processes such as rainfall-runoff, runoff-sediment, rainfall-runoff-sediment in watershed system.

Dynamic models are the input-output models which consider the effect of the memory of the system. The hydrologic processes are dynamic in nature where antecedent conditions of input and output affect the present output. Therefore, dynamic models are a better and more appropriate representation of the hydrological process. In most of the studies on hydrological dynamic models (Sharma et al. 1979), Sharma et al. 1993, Ranjan et al. 2010) equal impact was assigned to each of the past successive events, considered affecting the present event. This approach appears to be a gross simplification of the natural process. There is every likelihood that each prior event may not be producing the effect of same magnitude on the present event. That is, the first preceding event may have more effect on the output than the second preceding event and so on. Thus, it can be hypothesized that if independent variables, namely, antecedent precipitation index (API), antecedent runoff index (AQI) are introduced in dynamic models of runoff, then these parameters are expected to account for varying impacts of preceding events on the present output.

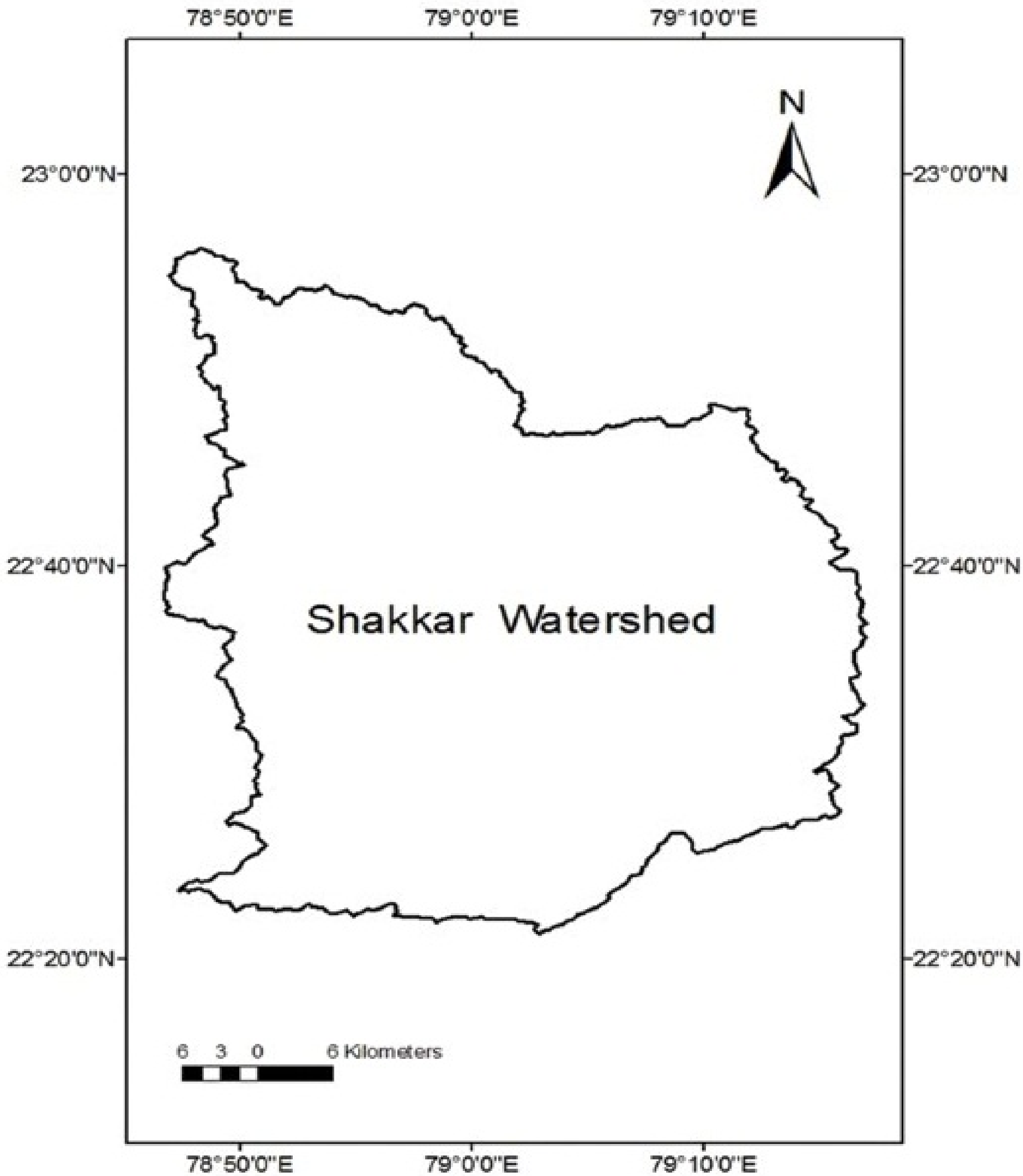
II. MATERIALS AND METHODS

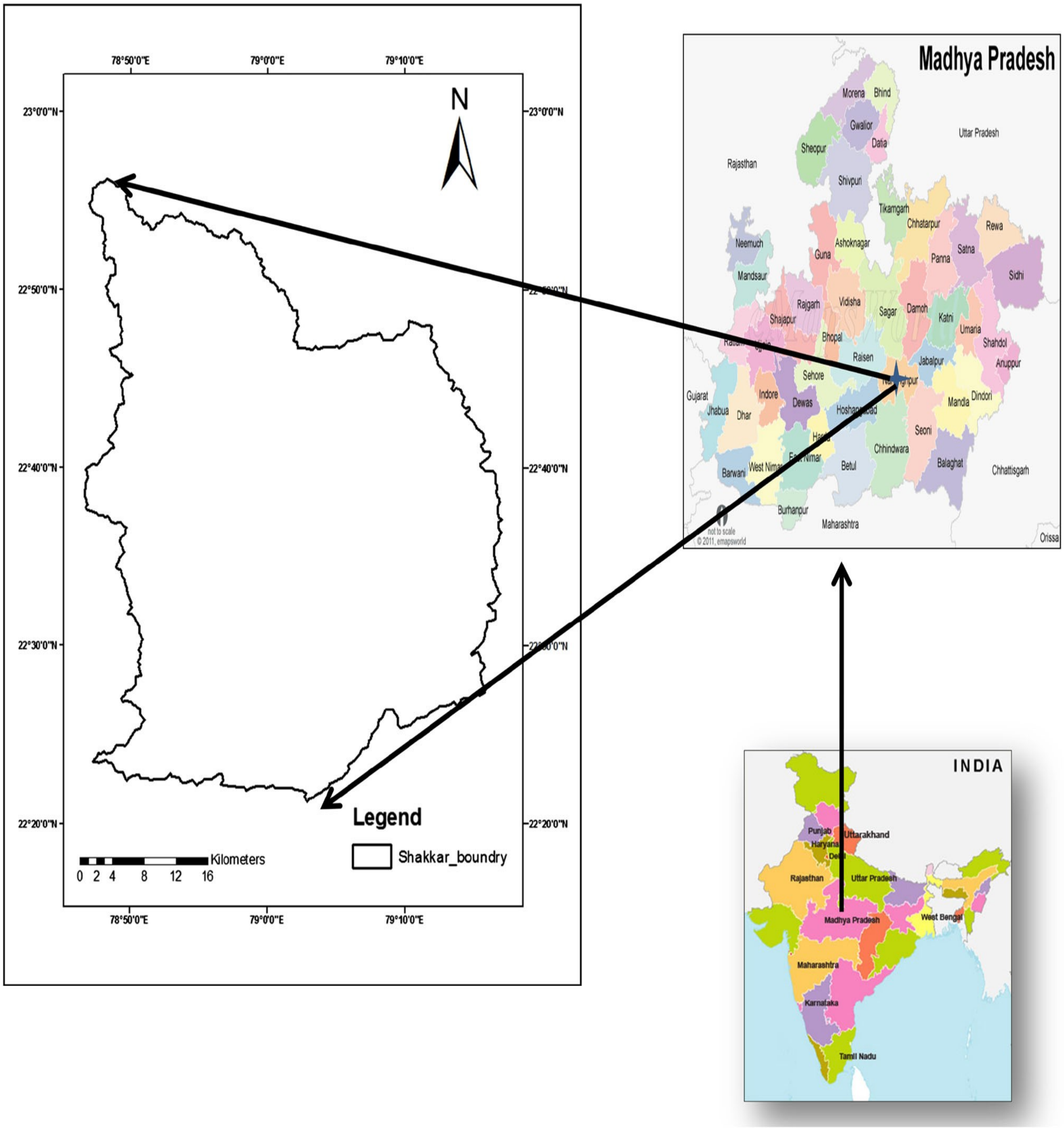
The study was carried out in the Shakkar river watershed, geographically located between 22°20' N to 23°00' N latitude and 78°40' E to 79°20' E longitude. The Shakkar river originates in the Satpura range, east of the Chhindi village Chhindwara district, Madhya Pradesh. The major portion of watershed lies in Narsinghpur district and some part in Chhindwara district. Shakkar river is a left bank tributary of Narmada river. Main town near its confluence with Narmada is Gadarwara. Area is studied upto Gadarwara. The area of the watershed is about 2223 km2 up to the gauge discharge site. Length of the river is 161 km. The maximum and minimum elevations of the watershed are respectively 314 m and 1154 m above MSL (mean sea level).The average annual rainfall of study area is about 1245 mm. The rainfall in the area is due to the southwest monsoon which starts from the middle of June and ends in last of September. The climate condition of the study area in December and January are severely cold, whereas summer month of May and June are intensely hot. The minimum mean air temperature in January is around 8°C while the maximum mean air temperature in the hottest month (May) is around 42.5°C. The relative humidity is low in May (less than 33%) and high in August (more than 87%). Soils are mainly clayey to loamy in texture with calcareous concretions invariably present. They are sticky and in summer, due to shrinkage, develop deep cracks. They generally predominate in montmorillonite and beidellite type of clays .In rest of alluvial areas , mixed clays , black to brown to reddish brown, derived from sandstones and traps is observed which is sandy clay in nature with calcareous concretions. Near the banks of the rivers and at the confluence, light yellow to yellowish brown soils are noticed which were deposited during the recent past. These soils were clayey to silt in nature (Gajbhiye et al.2013).

Table 1.Land use pattern of Shakkar river Watershed

Land Use pattern	**Area (sq. km)**	**Percentage of total area**
Water body	32.456	1.46
Agricultural land	1217.537	54.77
Forest	876.084	39.41
Waste land	96.923	4.36

Fig. 1.Location map of study area





A. Data used

The daily rainfall data of three rain gauge stations namely Gadarwara, Amarwara and Harrai for the period of 20 years that is from 1994 to 2014 were used. The rainfall data was collected from Land Record Department, Collectorate, Narsinghpur and Land Record Department, Collectorate, Chhindwara.

B. Estimation of average rainfall

The recorded daily rainfall data at different stations of watershed were converted into weighted average rainfall data by the Arithmetic mean method.

The average rainfall depth over the watershed was calculated by the following relationship,

$$\overline{P} = \frac{1}{m}(P1 + P2 + ... + Pj + ... + Pm) = \frac{1}{m}\sum_{1}^{m} Pj$$

Where $\overline{P}$ = mean precipitation, P1,P2,….Pm = respective rainfall values in a given

C.Runoff data

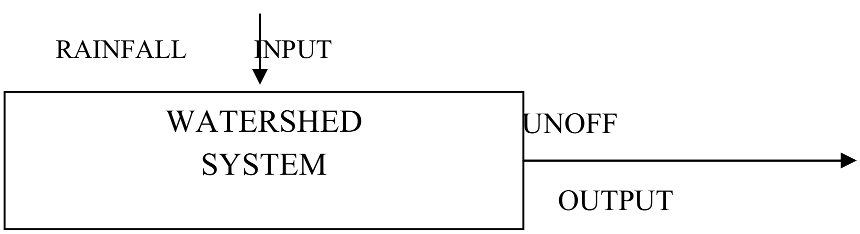
The daily runoff data of Gadarwara site was collected from Central Water Commission, Narmada Division, Paryavas Bhawan, Bhopal. The daily data of runoff in m^3/s were collected from the year 1994 to 2014. These data were converted into millimeter for their use in development of different models.

D.Model development

Under Indian conditions the occurrence of rainfall is confined to the monsoon season of four month, i.e., June to September. Therefore rainfall and runoff data for only these four months was used for the development of models. Runoff producing characteristics of a watershed are greatly affected by the antecedent conditions of input and output which are dependent on previous rainfall and runoff. The antecedent hydrological events of more than 5 days are not likely to have significant effect on the present event (Ojasvi et al.,1993 and Kumar, 1993). In the present study of Shakkar river watershed m values ranging from 2 to 7 were tried to arrive at the appropriate value of m, where m represents the number of successive past events affecting the present event. A significant amount of sediment yield get deposited within the catchment while routing through rills and gullies, and may reach the outlet in addition to the runoff resulted from the subsequent day's event of rainfall and runoff. In almost all earlier research studies in the area of dynamic modeling of runoff on sequential and integrated time scale basis, equal impact was assigned to each preceding event in determining their impact on the present event (Sharma et al.,1979; Kumar, 1993 and Sharma et al., 1993). However it was felt that each prior event may not produce the effect of same magnitude on the present event. That is, the first prior event may have more effect on the current event than the second preceding event and so on. With this hypothesis in mind an attempt was made to introduce the antecedent precipitation index (API) and the antecedent runoff index (AQI) as independent variable in the present study, which is believed to account for varying impact of preceding events on the present event in developing memory based runoff dynamic models.

E. Rainfall-runoff process

The rainfall-runoff process through a watershed system can be described as,



That is, the process may be functionally represented, respectively on sequential time scale basis as,

$$Q_d = f(P_d, Y_1P_1, Y_2P_2, ..., Y_j Pdj, ..., Y_mP_{dm}, ... Y_1Q_{d1}, Y_2Q_{d2}, ..., Y_jQ_{dj}, ..., Y_mQ_{dm}) \qquad ....(1)$$

Where, Q is the present runoff in mm, P is the present rainfall in mm, Q_j and P_j, j= 1,2,3,.....m represents respectively the runoff and rainfall values for the j^{th} event prior to the current event.

That is $\sum_{i=1}^{m} Yj = 1$ ›nts the first event immediately preceding the current event. Y_j is the weighta the j^{th} preceding event, m is an integer also called memory parameter.

The antecedent precipitation index (API) and the antecedent runoff index (AQI) estimated by the following equations,

$API = Y_1P_1 + Y_2P_2 + Y_3P_3 + \ldots\ldots\ldots + Y_jP_j + \ldots\ldots\ldots + Y_mP_m$

$$API = \sum_{i=1}^{m} YjPj \qquad \ldots..(2)$$

$AQI = Y_1Q_1 + Y_2Q_2 + Y_3Q_3 + \ldots\ldots. + Y_jQj + \ldots\ldots + Y_mQ_m$

$$AQI = \sum_{i=1}^{m} YjQj \qquad \ldots.(3)$$

The weight of different preceding events, Yj, j = 1,2,3,…….m was estimated by following equation proposed by Ojasvi et al. (1994),

$$Yj = \frac{\exp[-(j-1)/m]}{\sum_{i=1}^{m} \exp[-(j-1)/m]} \qquad \ldots.(4)$$

The appropriate value of m for the study area was worked out by trial and error the value which gives highest value of coefficient of multiple determination (R^2) was selected for the study area. Now by substituting the antecedent parameters, API and AQI the equations (3.1) and (3.2) can respectively be written in compact form as,

$$Q_d = f\,[P_d, (API)_d, (AQI)_{d]} \qquad \ldots..(5)$$

The above equations indicate that output of runoff is in response to more than one output variables, this relationship can be classified as multiple input and single output (MISO) type models and the multiple regression can be applied to obtain functional relationships between corresponding input and output variables.

An attempt was made to develop both linear and non linear relationships on sequential time scale basis to model rainfall-runoff process in the present study.

F. Linear form

$$Q_d = \alpha_0 + \alpha_1 (P_d) + \alpha_2 (API)_d + \alpha_3 (AQI)_d \qquad \ldots..(6)$$

G. Non-linear form

$$Q_d = \alpha_0 \times (P_d)^{\alpha 1} \times (API)_d^{\alpha 2} \times (AQI)_d^{\alpha 3} \qquad ….(7)$$

where α's are the regression coefficient.

The non-linear equations were linearised for performing further analysis. The non-linear equation linearised by log transformation given below,

$$\ln (Q_d) = \ln \alpha_0 + \alpha_1 \ln (P_d) + \alpha_2 \ln (API)_d + \alpha_3 \ln (AQI)_d \qquad …..(8)$$

The least square technique has been advocated by number of researchers [Schermerhorn and Barton (1968), Zuzel and Cox (1978), Wang and Yung (1986), Stedinger et al. (1988), Wang et al. (1991), Garren (1993), Ojasvi et al. (1994), and Kumar (1995)] for estimation of various regressions and owing to its inherent advantages, it was adopted in the present study also.

H. Parameter Estimation

The determination procedure of various parameters used in the above linear and non-linear models on daily and weekly time scale is described in subsequent sections.

I.Antecedent Precipitation Index and Antecedent Runoff Index

The values of API and AQI for different days were determined respectively by using equations (3.3) and (3.4) Weightage Yj, j = 1,2,3,………m, assigned to the different preceding events affecting the current event were determined by the equation (3.5). The appropriate value of m was determined by trial and error. In the present study m ranging from 2 to 7 have been tried and m=3 has been found to yield highest value of coefficient of multiple determination (R2). Thus the weights assigned to preceding three daily or weekly events prior to the day or week under consideration, as the case may be, came out to be 0.448, 0.321 and 0.230 respectively.

J. Memory Based Runoff Models

In this section the daily runoff prediction models for the study area were developed.

K. Daily runoff models

L. Linear models

Three years active period data were selected for the development of model.. Three different range of three consecutive years, viz., 1994-96, 1997-99 and 1998-00 were tried in the present study. However, the model developed using the data series of the year 1994-96 was found to yield the highest value of coefficient of multiple determination (R2), which was finally selected for further testing and verification for the study area under the present study. The daily runoff prediction linear model obtained through the analysis is expressed as,

$$Q_d = -0.04 + 0.4 (P_d) – 0.16 (API)_d + 0.58 (AQI)_d$$

$$(R^2=0.67) \qquad …..(9)$$

M. Non-linear models

The same sets of three years data, as expressed in 3.5.1.1, were used for development of a non-linear model of the form shown in equation (3.10). However, the data of 1994-96 was again found to yield a better model in terms of higher R2 value. The developed non-linear model is of the form,

$$\ln(Q)_d = -0.2 + 0.27 \ln(P_d) – 0.12 \ln(API)_d + 0.89 \ln(AQI)_d$$

$$(R^2 = 0.86) \qquad …..(10)$$

O. Qualitative Evaluation of Model Performance

The acceptability of a model was judged by the goodness of fit between measured value and the values estimated or generated by a model. For qualitative comparison between measured and estimated or generated values, the following statistical measures have been employed in this study.

P. Absolute prediction error (APE)

Absolute prediction error values are determined by the following equation proposed by the World Meteorological Organization Statistics (1975),

$$APE = \frac{\sum_{i=1}^{n}(Mi - Ei)}{\sum_{i=1}^{n} Mi} \times 100 \qquad \text{……(11)}$$

Where, APE is the absolute prediction error in percentage, and Mi and Ei are measured and estimated values.

Q. Integral square error (ISE)

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

$$ISE = \frac{[\sum_{i=1}^{n}(Mi - Ei)^2]^{1/2}}{\sum_{i=1}^{n} Mi} \times 100 \qquad \text{…..(12)}$$

Where, ISE is the integral square error in percentage, Mi and Ei are measured and estimated values.

R. Coefficient of efficiency (CE)

The coefficient of efficiency for evaluating the model performance has been recommended by many researchers in the field of hydrology [Nash and Sutcliffe, (1970); Mutreja, (1992); Basu, (1993); and Nien et al., (1995)]. The coefficient of efficiency is defined by Nash and Sutcliffe (1970) as the proportion of the initial variance accounted for by the model. The coefficient of efficiency is determined by the following equation,

$$CE = \frac{\sum_{i=1}^{n}[Mi - \overline{M}]^2 - \sum_{i=1}^{n}[Mi - Ei]^2}{\sum_{i=1}^{n}[Mi - \overline{M}]2} \times 100 \qquad \text{……(13)}$$

Where, CE is the coefficient of efficiency in percentage, M and E are measured and estimated value at corresponding time and $\overline{M}$ is the mean of measured values.

III. RESULT AND DISCUSSION

The Shakkar river watershed, comprising an area of 2223 km2 is located in the Narmada catchment, Madhya Pradesh, India. The prediction performance of models was ascertained by verifying with the data of the Shakkar river watershed for all the years individually from 1994-2014. Accurate runoff recording for watershed is a difficult process. With this in view an attempt was made to predict runoff data series on sequential time scale basis for different years, by using developed prediction models in the study. The plausibility of various types of models was verified of various stages for the data series. A period of four month from June to September of each year in case of daily was considered as the active period.

The qualitative performance of different models was checked by estimating the value of absolute prediction error (APE), integral square error (ISE) and the coefficient of efficiency (CE). In the present study the permissible limits for APE, ISE and CE were taken respectively as 30%, 10 % and 60% that means the prediction should satisfy the criteria of APE less than 30%, ISE less than 10% and CE more than 60%.

Testing and verification

Two runoff models, viz., linear and non-linear were developed by using the daily data of active periods only in series during the period of 1994-96. The linear model gave the coefficient of multiple determination (R2) 0.67. Whereas non-linear model gave the coefficient of multiple determination (R2) 0.86. The developed non-linear model was tested on the same data individually for each year from 1994 to 1996. The predicted values of daily runoff for the years 1994 and 1995 were presented in Tables 2. From visual comparison shown in Figs. 4.1 and 4.2 respectively for non-linear model for the year 1994 and 1995, a good degree of closeness between measured and predicted values of daily runoff can be observed. The values of qualitative parameters for the years 1994 and 1995 are shown in Table 4.1 which confirm the plausibility of model for the study area.

Prediction Performance

The non-linear model was applied on the daily data individually for all the years from 1994 to 2014, to establish their applicability for the study area. The model gave fairly accurate prediction of runoff volume for the entire monsoon season (i.e. June-September) in a stretch for all the years. The qualitative performance of non-linear model is also shown in Table 2. From the table 2, it can be observed that in case of non-linear model the values of APE, ISE and CE for all the year are well within the permissible limits adopted in the present study. For better understanding, predicted values of daily runoff using the runoff prediction non-linear model for years 1996, 1998, 2002, 2008, 2010 and 2013 were shown in Table 4.3, 4.4 and 4.5. The graphical comparison of measured and predicted values of daily runoff with time for non-linear model is shown in Figs. 2, 3 and 4 respectively for years 1996, 2002 and 2010. From these figures, a good degree of closeness between the measured and the predicted values can be seen. However, the values of coefficient of multiple determination (R2) for linear and non-linear models were found to be equal to 0.67 and 0.86 respectively; on the basis of prediction performance and R2 value the non-linear model was found more appropriate for the Shakkar river watershed. Hence, the rainfall-runoff process for the watershed was found non-linear.

Table 2 Measured and Predicted values of daily runoff (mm) by runoff prediction non-linear model for year 1994 and 1995

month/date		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1994																																
JUNE	**M**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	3.12	3.12	0.12	0.12	0.13	0.13	0.13	0.15	0.14	0.13	0.13	6.16	9.3	1.71	1.62	4.67	
	P				0.1	0.07	0.14	0.1	0.1	0.14	0.13	0.12	0.08	0.1	0.11	0.15	1.63	1.4	1.62	0.92	0.2	0.29	0.22	0.19	0.07	0.13	0.27	4.3	5.19	4.8	3.15	
JULY	**M**	1.34	7.07	15	6.48	5.24	1.95	0.6	0.34	0.27	0.31	1.23	2.95	5.29	5.28	3.95	4.94	14.1	18.7	14.1	15.7	26	24.6	13.2	11.4	7.43	7.09	6.39	5.56	4.97	4.21	5.34
	P	1.39	5.91	13.6	7.67	8.71	3.2	1.82	1.29	0.73	0.44	0.57	1.06	2.35	4.51	3.3	4.58	11.5	13.6	17	12	25.3	24.1	9.9	11.7	6.03	5.36	5.54	5.47	5.34	2.13	4.45
AUG.	**M**	12.3	11.8	5.79	12.1	15	14.4	20.2	22.2	11.1	7.94	6.1	5.53	11.1	8.09	5.67	4.38	3.76	6.06	15.7	18.8	9.55	7.25	5.8	6.19	7.38	16.5	15.8	8.01	14.9	16.6	14.3
	P	10.1	12.5	4.56	11.9	10.3	9.78	16.3	23.7	10.6	6.98	8.18	6.46	7.16	4.02	4.34	5.76	3.95	2.84	10.9	12.6	7.63	5.42	5.46	8.2	7.77	12.7	12.6	8.93	13.7	15.2	14.8
SEP.	**M**	11.7	17.4	23.7	28.7	23.3	20.1	15.5	8.91	6.62	6.11	7.55	5.65	4.26	3.31	5.79	2.52	2.44	2.4	2.35	2.28	2.19	2.07	1.9	1.82	1.81	1.75	1.67	1.57	1.53	1.5	
	P	12.6	15.3	24.8	24.4	27.6	23.2	11.2	7.24	6.3	5.94	9.01	4.99	4.23	3.51	4.19	3.55	2.03	3.19	2.91	1.42	1.44	1.54	1.62	1.53	1.45	1.4	1.36	1.33	1.27	1.22	
1995																																
JUNE	**M**	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.06	4.06	1.09	0.09	0.09	0.09	0.1	0.09	0.09	1.38	1.11	1.4	3.3	
	P				0.07	0.07	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.12	0.13	0.73	1.58	1.56	1.25	0.33	0.05	0.09	0.18	0.09	0.76	0.68	2.44	
JULY	**M**	2.36	0.31	0.1	0.19	0.17	1.16	1.15	0.1	0.1	1.1	4.91	3.16	4.83	4.72	3.68	2.02	1.69	1.6	3.59	5.8	4.57	5.84	5.8	12.3	10.1	5.06	3.58	5.3	9.1	6.77	3.6
	P	1.47	1.38	1.02	0.64	0.16	0.37	0.44	0.66	0.34	0.74	0.93	2.96	3.67	3.23	3.88	3.29	2.08	2.17	2.41	3.82	3.34	5.03	5.19	13.6	9.01	3.99	3.55	5.59	7.06	2.95	3.28
AUG.	**M**	2.11	0.78	6.41	3.12	5.88	4.23	3.6	3.18	2.03	6.24	4.47	1.63	1.17	0.72	0.73	0.73	0.81	0.92	3.22	5.33	6.22	5.79	5.53	3.23	3.03	2.61	6.89	4.36	2.84	3.53	9.76
	P	2.79	3.39	3.57	2.36	3.89	3.25	3.16	3.01	2.75	4.48	3.96	2.28	1.93	1.57	0.69	0.68	0.87	0.89	1.37	2.6	3.14	2.58	4.24	2.74	2.93	2.51	5.88	2.34	2.18	3.08	6.29
SEP.	**M**	8.69	7.97	7.37	6.2	4.2	3.42	2.82	2.78	0.16	0.64	0.15	0.6	1.47	2.92	5.68	1.63	1.24	1.52	1.41	1.22	1.13	1.14	1.06	0.97	1	0.75	0.75	0.72	0.7	0.74	
	P	6.79	7.66	8.78	7.82	3.25	2.84	2.54	2.37	2.12	1.25	0.8	0.29	0.41	1.1	2.16	3.04	1.75	2.84	1.3	0.93	0.94	1.02	0.93	0.8	0.97	0.98	0.91	0.68	0.62	0.61	

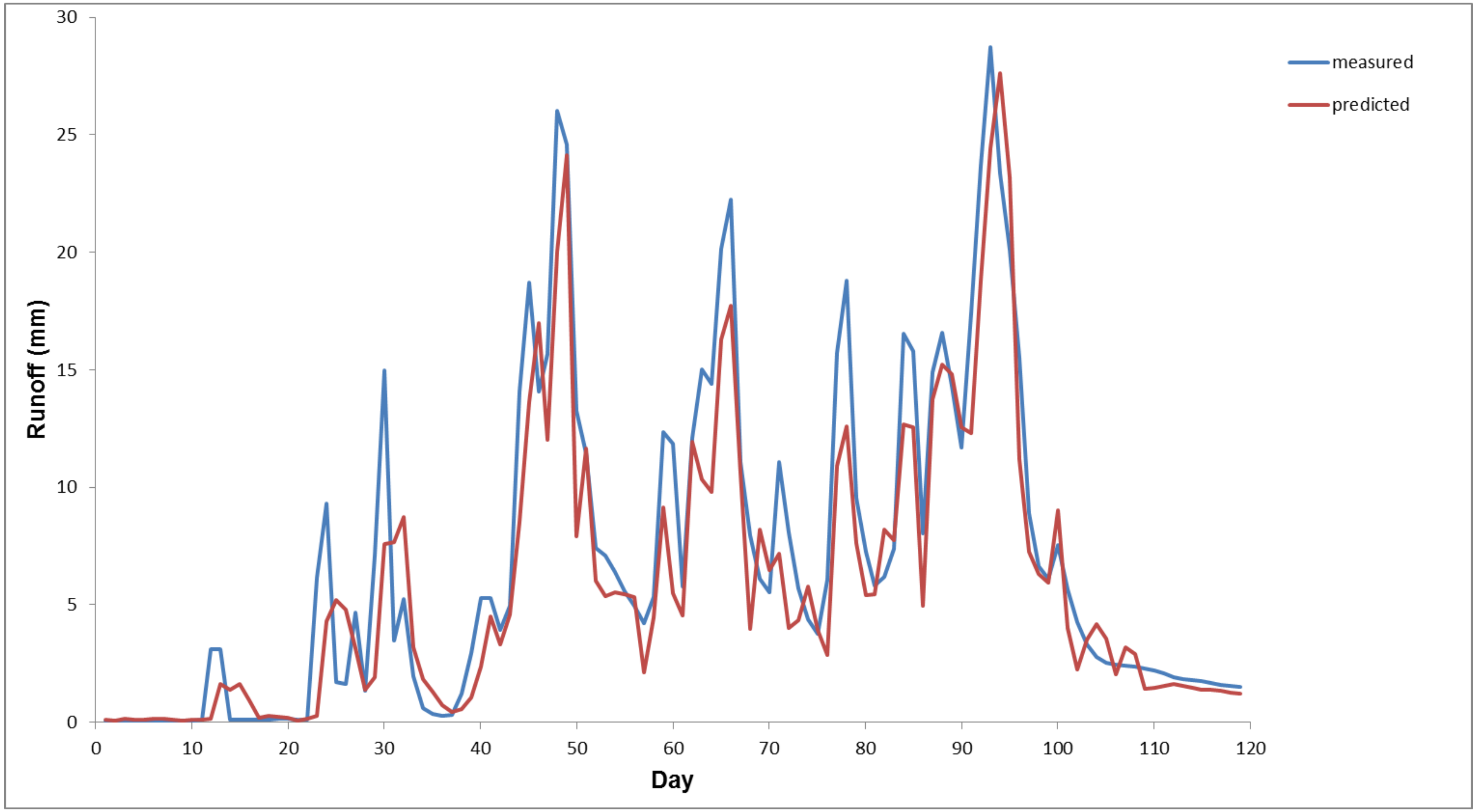


Fig. 2 Comparison of measured and predicted values of runoff for daily runoff prediction non-linear model (DPQNM) for the year 1994

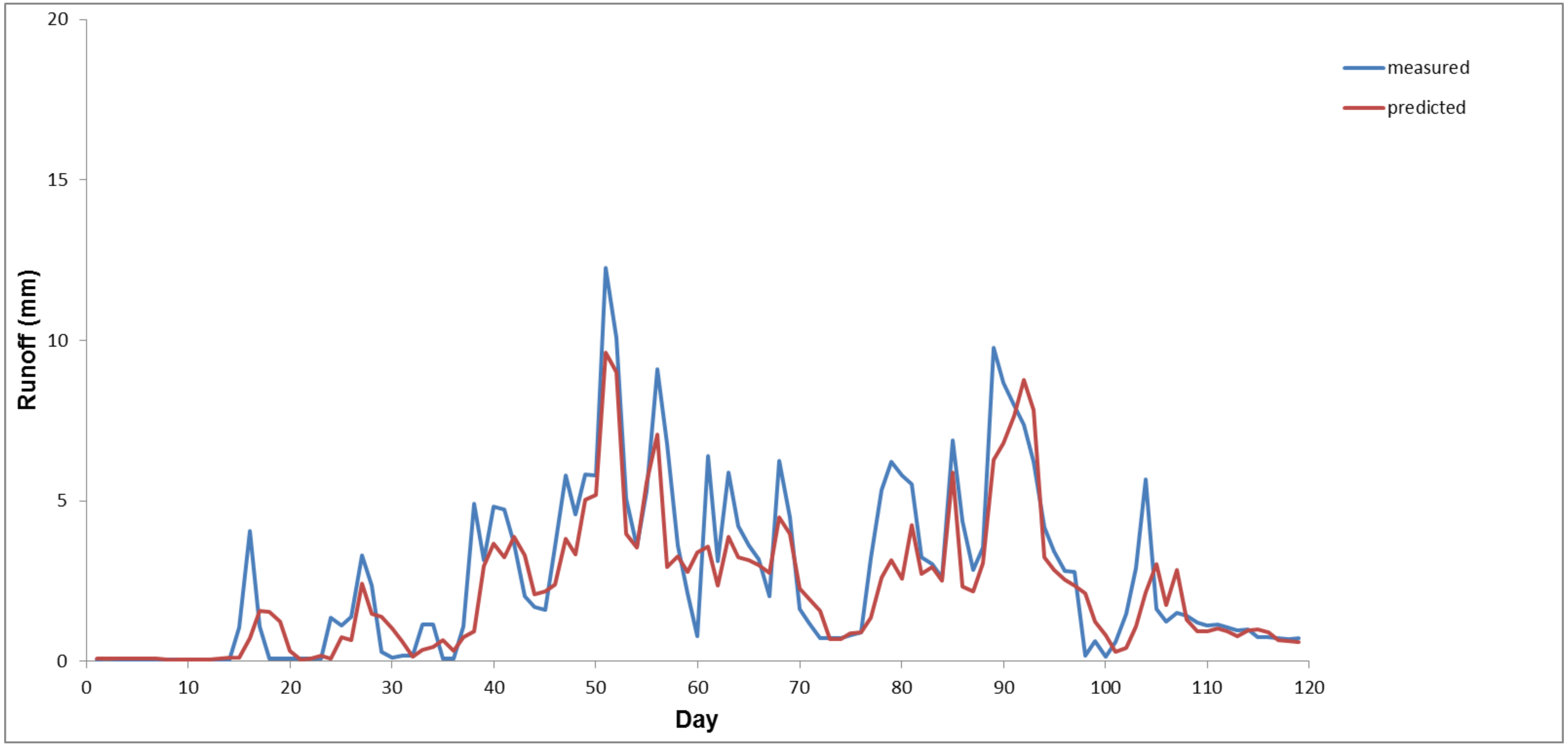


Fig. 3 Comparison of measured and predicted values of runoff for daily runoff prediction non-linear model (DPQNM) for the year 1995.

Table 3 Qualitative comparison of daily runoff prediction non-linear model during year 1994-2014

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014
APE(%)	15.2	16.23	18.41	9.33	13.31	9.49	15.86	11.66	10.15	13.68	11.54	18.83	16.31	16.33	10.31	15.46	10.51	18.79	15.54	16.99
ISE(%)	3.48	4.46	4.35	4.04	3.94	4.21	5.1	5.75	4.9	3.98	5.22	4.74	3.63	5.08	4.19	3.6	3.65	3.52	2.77	4.35
CE(%)	85.16	76.28	70.2	74.49	75.09	80.07	68.97	63.3	82.57	73.69	72.29	71.88	79.76	63.35	79.85	74.82	74.44	81.26	85.86	76.89

Note : (i) Data of the year 2005 were not available at source

Table 4. Measured and Predicted values of daily runoff (mm) by runoff prediction non-linear model for year 1996 and 1998

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1996																															
JUNE																															
M	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	3.01	1.01	1.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
P				0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.36	0.9	0.74	0.79	0.82	0.82	0.81	1.85	1.17	1.22	0.98	0.53	0.26	0.01	0.01	0.01	0.02	0.01	0.01	
JULY																															
M	0.01	0.01	0.02	4.02	4.04	3.06	4.1	2.15	4.14	1.13	4.12	3.15	5.13	4.19	4.34	3.45	2.1	1.92	4.97	6.24	5.08	2.15	1.14	5.59	4.04	4.99	12.6	9.06	4.89	3.61	2.45
P	0.01	0.01	0.01	0.05	0.84	1.73	3.51	2.41	3.95	1.5	3.3	2.87	3.79	3.96	4.12	3.41	2.96	1.81	3.7	4.23	4.36	4.28	1.57	3.58	2.63	4.62	7.8	5.01	3.61	3.65	3.54
AUG.																															
M	2.44	9.79	6.67	4.33	3.35	5.31	3.11	3.22	6.69	4.65	3.14	2.03	1	1.8	1.71	2.12	5.63	4.94	3.59	4.99	5.11	2.95	1.42	1.28	1.09	1.95	1.41	1.02	1.23	2.75	6.02
P	1.72	5.15	5.95	3.17	4.33	5.72	1.15	2.22	5.62	2.41	2.61	2.45	1.85	1.64	2.32	1.69	2.5	3.4	3.17	4.56	5.36	2.12	3.8	2.29	1.49	1.38	1.36	1	1.06	1.23	3.19
SEP.																															
M	4.12	3.88	5.09	2.86	3.3	5.86	7.28	6.06	5.51	2.96	5.05	2.92	1.11	3.27	2.66	3.05	2.7	1.53	2.28	1.09	0.92	1.22	0.79	0.74	0.67	0.65	0.62	0.6	0.58	0.55	
P	1.9	2.54	4.78	2.73	2.24	4.94	5.89	4.79	4.29	3.07	5.74	3.05	2.07	2.93	2.23	2.56	1	1.68	1.56	1.35	1.07	1.02	0.88	0.79	0.72	0.61	0.58	0.55	0.53	1.06	
1998																															
JUNE																															
M	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	1.01	1.01	0.01	0.01	1.01	1.01	0.02	1.02	1.02	0.02	0.02	0.02	1.03	2.03	3.03	5.01	5.44	2.37	
P				0.02	0.02	0.02	0.03	0.03	0.03	0.01	0.02	0.02	0.04	0.36	0.6	0.59	0.36	0.53	0.56	0.74	0.51	0.61	0.47	0.31	0.02	0.86	0.8	3.37	4.38	3.96	
JULY																															
M	2.38	1.12	5.36	7.22	10.5	9.98	6.91	5.86	4.29	2.94	5.52	3.65	8.03	7.37	3.89	3.66	2.24	1.13	1.62	5.89	4.9	2.94	1.7	1.66	1.54	0.49	0.49	0.44	0.4	0.4	1.34
P	2.09	1.73	3.39	4.26	8.03	9.11	6.48	6.49	3.84	3.89	5.13	2.35	6.53	6	3.04	5.91	2.37	1.84	1.35	3.04	2.63	2.32	2.31	2.07	1.48	1.25	0.88	0.62	0.42	0.5	0.47
AUG.																															
M	2.89	5.93	6.92	7.43	3.03	1.23	4.07	3.62	3.58	1.55	1.44	2.9	5.56	6.99	6.27	3.38	1.97	2.39	1.38	1.29	4.29	4.18	3.3	1.53	1.36	3.48	2.42	1.36	3.34	3.19	1.39
P	1	4.95	5.22	6.06	3.04	2.6	4.26	2.65	3.77	2.58	1.76	2.09	4.2	5.46	4.78	2.87	2.66	2.36	1.93	1.2	2.85	3.23	2.95	2.7	1.16	2.93	1.66	2.57	2.36	2.14	2.44
SEP.																															
M	1.63	1.67	1.08	1.59	1.99	3.64	3.17	3.18	2.1	3.09	3.78	2.77	3.75	9.68	7.73	6.75	3.74	1.48	1.46	1.59	2.13	6.11	4.5	3.49	3.49	4.48	0.47	0.44	0.43	0.41	
P	1.45	1.57	1.2	1.28	1.63	1.94	2.68	3.15	2.68	3.01	1.5	3.32	3.89	5.37	6.29	6.11	3.77	2.9	2.14	2.1	1.64	7.92	4.36	3.3	1.92	3.08	2.6	1.23	0.33	0.34	

Table 5 Measured and Predicted values of daily runoff (mm) by runoff prediction non-linear model for year 2002 and 2008

MONTH/DATE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2002																																
JUNE	M	0.02	0.02	0.02	0.02	0.02	0.02	0.14	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	2.02	0.02	1.03	1.03	2.03	1.91	1.97	3.78	2.58	1.93	1.06	0.95	1.72	2.58	
	P				0.02	0.02	0.02	0.05	0.07	0.07	0.06	0.04	0.03	0.04	0.03	0.02	0.04	0.04	0.73	0.81	0.81	1.14	1.33	1.61	2.45	3.15	1.65	1.88	1.56	1.35	1.77	
JULY	M	1.58	0.32	0.28	0.23	0.21	0.2	0.11	0.07	0.05	0.05	0.05	0.04	0.04	0.05	0.04	1.04	0.04	4.04	3.27	3.27	0.97	0.73	0.59	0.45	0.4	0.35	0.29	0.19	0.26	0.24	0.23
	P	1.14	1.07	0.86	0.57	0.32	0.22	0.2	0.16	0.12	0.08	0.06	0.06	0.05	0.05	0.11	0.05	0.45	0.63	2.66	2.38	1.33	1.2	1.02	0.71	0.61	0.41	0.36	0.31	0.25	0.23	0.23
AUG.	M	3.41	3.44	1.08	6.5	3.51	1.84	2.68	3.54	2.41	0.35	0.28	0.3	0.11	0.11	3.22	8.13	9.51	14.8	13.9	14.4	9.75	6.92	10.3	11.3	4.19	5.69	4.11	3.49	8.91	5.44	11.8
	P	0.53	1.5	2.55	3.51	3.84	4.36	3.94	3.47	1.76	1.75	1.04	0.76	0.35	0.17	0.35	2.63	6.61	0.93	13.4	11.3	9.91	10.4	8.98	9.93	7.79	4.78	3.64	4.36	6.84	6.06	9.85
SEPT.	M	5.63	4.95	6.09	6.51	9.74	13.9	11.4	9.66	4	3.56	3.4	3.55	4.24	2.66	2.3	2.8	2.36	2.04	1.92	1.67	1.32	1.75	1.13	1.74	0.95	0.83	0.66	0.63	1.17	0.58	
	P	7.32	7.26	6.43	3.39	8.2	10.8	10.5	8.59	7.55	4.47	5.54	2.48	2.06	2.35	2.62	2.08	1.91	1.83	1.72	1.52	1.55	1.4	1.48	1.08	1.32	1.14	1.04	0.66	0.59	0.73	
2008																																
JUNE	M	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.23	0.2	3.17	2.03	1.03	0.03	0.03	0.03	0.03	0.14	0.03	1.03	3.2	4.23	5.04	5.03	5.04	7.23	
	P				0.13	0.56	0	0	0	0.01	0	0.01	0.01	0.01	0.22	0.14	1.01	1.52	1.51	1.05	0.35	0.04	0.04	0.09	0.13	0.84	2.66	2.68	3.14	5.81	4.45	
JULY	M	5.23	5.11	6.03	4.8	1.7	0.47	0.23	0.14	1.11	3	3.36	6.8	5.56	5.23	2.11	0.03	0.03	0.03	0.03	0.01	0.01	0.11	0.04	0.03	1.03	2.2	4.23	0.23	5.2	8.75	7.48
	P	3.74	6.64	5.3	2.83	2.83	2.38	1.59	0.92	0.31	2.15	2.63	3.21	2.89	3.31	2.82	3.42	2.03	0.47	0.04	0.04	0.02	0.03	0.08	0.09	0.09	0.72	1.13	3.2	3.02	4.9	5.22
AUG.	M	7.16	11	12.6	11	9.52	7.06	5.58	5.35	4.83	4.02	5.96	3.61	3.18	2.53	2.46	1.3	3.96	3.2	2.9	1.85	3.8	0.7	0.7	0.7	0.65	1.65	4.65	6.6	6.6	5.56	3.69
	P	8.61	9.12	9.51	9.33	8.06	9.41	4.39	3.77	3.6	5.73	5.21	5.33	3.73	1.75	1.62	3.51	2.02	1.61	1.82	4.61	1.48	1.79	0.95	2.12	0.69	0.79	2.01	2.56	4.68	2.95	3.82
SEPT.	M	2.16	2.01	2.61	2	3.52	6.06	7.58	5.35	4.83	4.02	3.96	3.61	3.18	2.53	1.46	3.3	3.96	3.9	5.9	6.85	3.8	5.7	4.7	1.7	1.09	0.65	0.65	0.3	0.3	0.26	
	P	2.92	5.34	2.05	1.54	2.25	3.99	5	3.94	3.12	3.18	3.15	3.51	2.71	2.33	2.23	3.83	3	2.55	5.16	5.01	3.46	2.65	3.05	3.58	2.53	1.59	0.84	0.63	0.44	0.35	

Table 6 Measured and Predicted values of daily runoff (mm) by runoff prediction non-linear model for year 2010 and 2013

MONTH/DATE	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2002																														
JUNE M	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0.02	0.02	0.02	0.02	1.02	1.02	0.02	0.04	0.04	0.04	2.05	1.07	2.08	
P			0.82	0.82	0.03	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.06	0.05	0.33	0.53	0.45	0.29	0.05	0.11	0.6	1.71	
JULY M	0.15	1.45	4.75	4.36	1.37	2.7	5.81	5.96	2.74	1.54	1.57	1.6	1.54	1.89	2.14	2.23	2.26	2.37	5.6	3.38	5.31	5	3.2	3.2	7.85	4.68	4.81	4.55	4.38	7.77
P	0.85	1.27	1.48	2.32	3.52	3.81	3.75	3.58	2.5	2.39	2.95	2.21	1.14	1.77	1.1	2.4	1.29	1.88	3.86	2.7	4.69	2.96	2.5	2.4	6.61	3.06	2.07	5.03	2.98	6.06
AUG. M	4.82	9.16	8.28	6.36	5.44	10.9	11.7	7.17	5.45	4.64	3.32	3.19	4.72	9.54	12.7	9.77	5.4	5.7	7.16	8.32	11.7	7.2	5.45	4.83	6.59	4.7	4.8	6.17	8.84	8.83
P	5.91	8.15	7.52	3.48	6.6	10.4	8.25	4.47	4.12	3.91	4.24	5.26	3.31	6.97	7.81	5.67	4.5	8.38	4.49	9.92	9.8	4.1	4.02	7.13	5.14	3.17	7.58	5.59	5.95	6.15
SEPT. M	12.9	9.95	9.28	9.72	4.5	4.35	4.49	4.51	4.26	3.81	4.34	4.3	4.2	4.13	4.74	5.58	4.3	5.44	4.39	4.79	4.38	4.2	3.63	4.01	3.81	2.33	2.13	1.55	1.46	
P	13.9	8.17	7.86	11.5	5.35	3.54	6.44	5.32	3.89	2.24	2.3	2.72	2.92	4.65	5.81	2.77	5.16	4.2	3.96	2.59	2.92	3.16	3.04	2.78	2.75	2.69	2.29	1.89	1.45	
2008																														
JUNE M	0	0	0	0	0	0.01	0.01	0.01	0.01	0.1	0.1	0.1	0.22	1.28	2.21	0.13	0.08	0.03	0.12	0.18	3.41	3.46	4.17	5.22	7.74	8.13	3.11	2.7	2.81	
P			0.17	0.29	0.05	0.03	0.01	0.01	0.01	0.02	0.05	0.17	0.14	0.22	1.28	1.65	0.86	0.76	0.07	0.15	0.2	2.13	4.09	3.66	6.79	5.8	6.07	2.62	2.22	
JULY M	6.92	6.47	5.38	7.47	6.82	6.53	6.05	5.73	5.33	4.76	4.38	5.67	7.97	6.91	8.14	7.7	5.26	7.33	12	9.21	8.48	11.7	13.3	12.4	11.7	13.6	14	15.8	16.1	14.3
P	4.37	5.48	5.02	3.33	6.33	8.5	5.95	6.66	2.87	2.31	6.23	3.66	3.29	6.8	10.1	6.67	6.91	3.13	8.16	8.07	5.34	9.16	11.3	11.3	11.1	13.5	11.5	13.6	15.3	12.5
AUG. M	17.7	16.8	10.9	10.7	10.2	10.1	10.6	15.7	16.4	13.1	13.5	14	13.2	13.4	9.02	5.56	4.88	8.01	10	10.9	14.9	21	22.4	15.9	8.17	6.46	9.08	6.97	5.56	5.87
P	13.4	16.5	7.43	6.77	7.43	10.1	5.77	15.1	13.9	8.91	12	15.6	8.85	12.5	5.99	5.77	7.3	10.9	7.33	8.3	12.1	17.2	16.2	12.8	6.57	6.36	10	4.33	4.27	4.07
SEPT. M	5.21	5.48	5.55	5.04	5.74	4.85	4.1	3.34	3.15	3.05	2.51	2.36	2.33	2.1	2.08	2.1	1.99	1.94	1.88	2.38	3.08	3.56	3.24	2.72	2.4	2.28	2.9	2.41	2.34	
P	3.7	3.62	3.6	3.67	3.59	3.69	3.51	3.23	2.75	2.44	2.26	2.41	2.36	1.68	2.38	1.88	1.42	2.58	1.98	1.71	2.53	2.38	1.8	2.06	2.07	2.09	1.89	2.23	2.28	

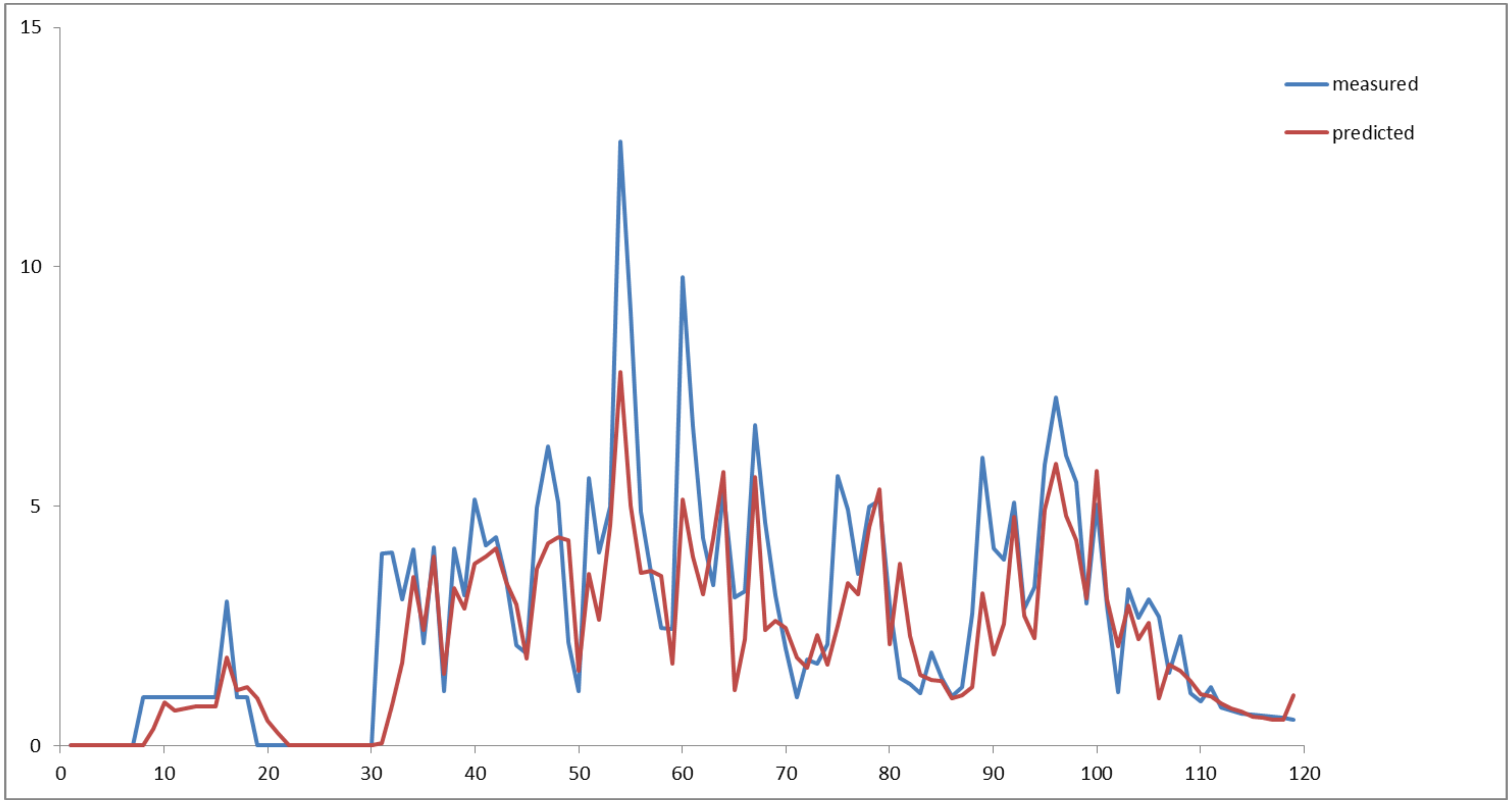


Fig. 4. Comparison of measured and predicted values of runoff for daily runoff prediction non-linear model (DPQNM) for the year 1996

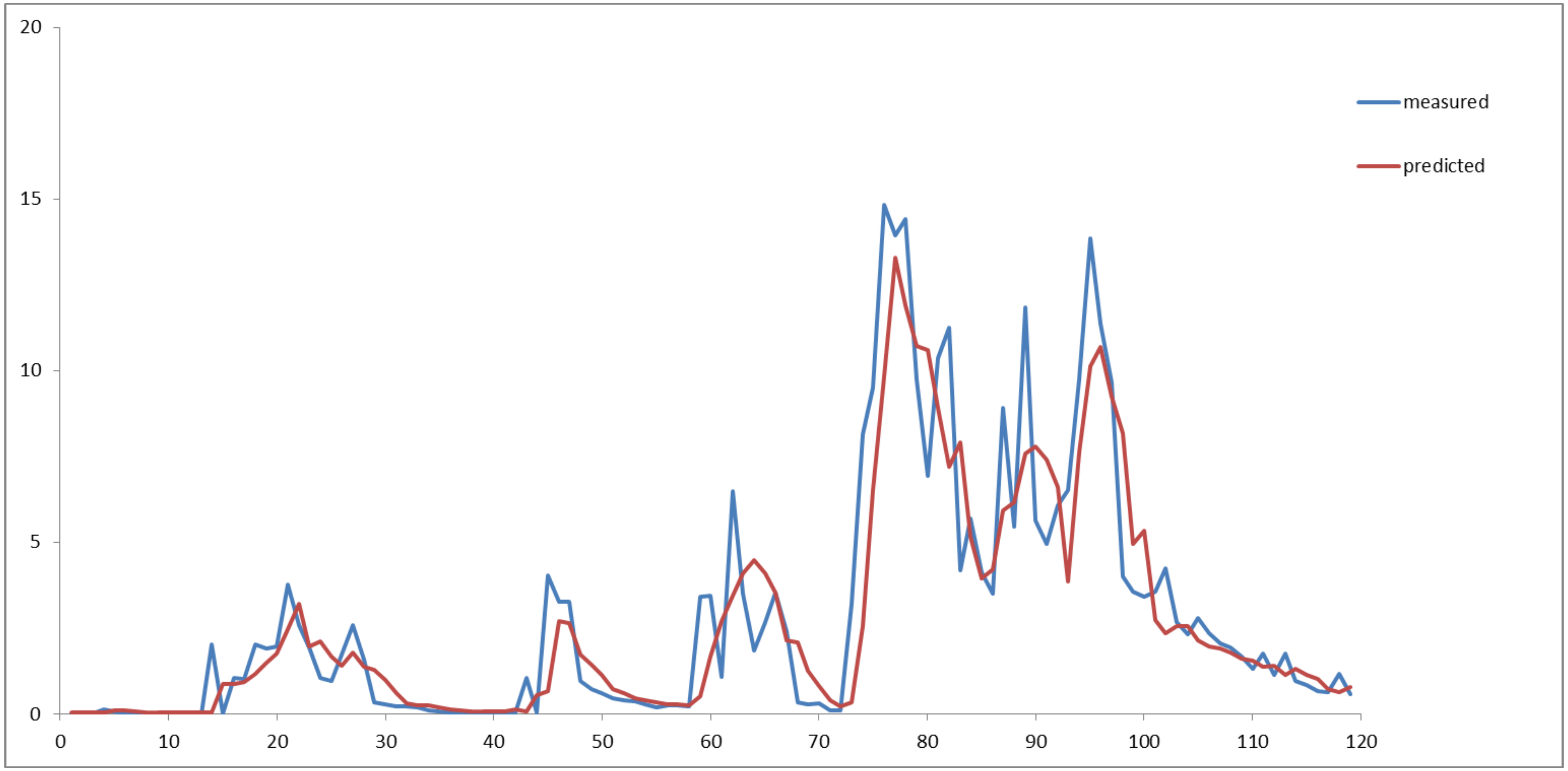


Fig. 5 Comparison of measured and predicted values of runoff for daily runoff prediction non-linear model (DPQNM) for the year 2002

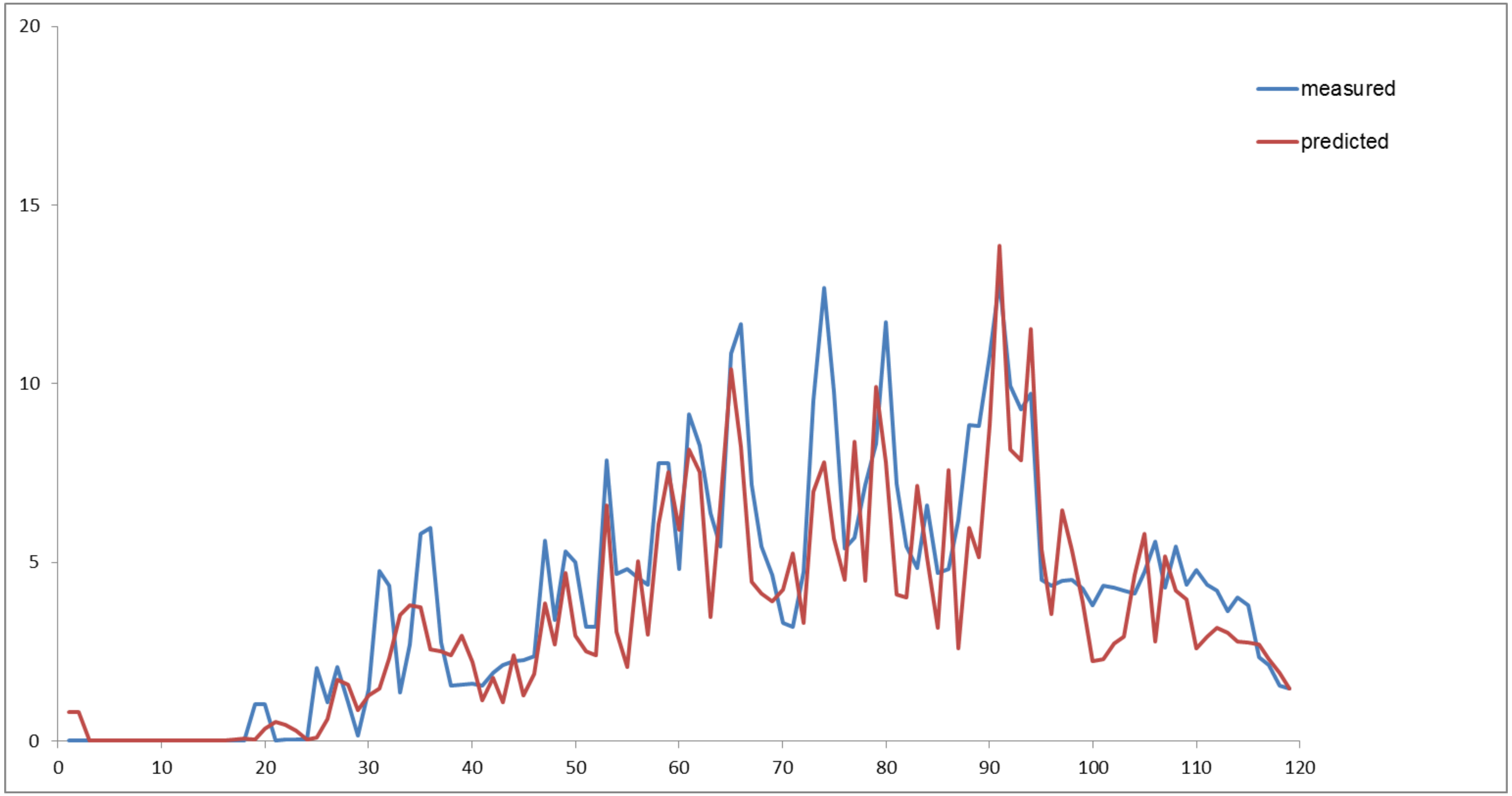


Fig. 6 Comparison of measured and predicted values of runoff for daily runoff prediction non-linear model (DPQNM) for the year 2010

IV.CONCLUSION

The principle objective of this study was to develop and verify the system memory based runoff prediction models on sequential time scale basis as per the hypothesis described. The fluvial system of Shakkar river watershed exhibits a strong memory on the sequential time scale basis. Only past three successive events were found to influence the present event for the Shakkar river watershed of Narmada basin.The first event immediately preceding the current event has been found to have more impact on it in comparison to other preceding event. The weights determined for the three successive antecedent events, affecting the current event, come out to be 44.84%, 32.13% and 23.03% respectively.In case of memory based daily runoff prediction models, on the basis of coefficient of multiple determination (R2) and prediction performance the non-linear memory based runoff prediction model may be considered more appropriate than the linear model for the Shakkar river watershed of Narmada basin.

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