DEVELOPMENNT OF FLOOD FORECASTING MODEL IN BRAHMAPUTRA VALLEY OF INDIA

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ABSTRACT

In India the Himalayan rivers account for maximum flood damage in the country. The problem of flood in the state of Assam is well known and every year it becomes a recurring problem to the entire region. The flood in Assam is mainly from river Brahmaputra which is the biggest river in the Indian Sub-continent. These flood hazards which claim hundreds of human lives and innumerable numbers of cattle and wildlife every year.

The study on flood forecasting and warning plays a significant role in saving human lives and movable properties by informing the people in advance about the likely level of water and its duration at specific places. It also helps in organizing timely rescue and flood fighting measures in order to prevent or minimize the damage to flood protection works like embankments. Flood forecasting is an important non-structural measure of flood prevention. Hydrologists have done so much work on it and are still in search for better flood forecasting technique. Flood prediction currently relies mostly on statistical techniques and historical records of stream behavior.

The main objective of this study is to develop an advance warning system of incoming flood, so that an early warning can be given to the people likely to be affected. The problem investigated in this dissertation work is the development of a flood forecasting model of river Brahmaputra at Sivasagar. For this a detailed analysis has been carried out with a series of locally available data sets. The daily stage data of main river Brahmaputra and its upstream tributaries along with the daily rainfall data of that region have been chosen for use in this dissertation work.

In this study, a discrete, linear time series model has been developed to forecast the flood of river Brahmaputra at Sivasagar for real time flood forecasting. This model can be used as a forecaster at Sivasagar which will help to give early warning to the local community and to the people concerned.

Key words: Discrete time series flood forecasting model

INTRODUCTION

Flood is one of the most damaging natural disasters in this planet that affect many countries in the world year after year. The impact of flooding ranges from the destruction of property, loss of agricultural production and disruption of transport and services to loss of lives. Flood is a natural disaster that results from severe combination of critical meteorological and hydrological conditions which may be grieved by man made causes. To minimize the effects of flooding there are two complementary approaches: (i) flood protection works, including the design and construction of river banks, dams and flood storage areas to protect flood prone areas, and (ii) flood warning. Effective

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flood warning can facilitate evacuation of people, property and livestock, amelioration through temporary flood proofing, early alerting of emergency services and control by adjusting reservoir discharges or preparation of retarding ponds. Flooding cannot be completely avoided, but damages from severe flooding can be reduced if effective flood prevention scheme is implemented. This can be achieved if sufficient information for flood forecasting is acquired both in time and in quality.

DATA

This flood forecasting model has been run with the stage data of river Brahmaputra and its upstream tributaries along with the respective rainfall data of the area. Fig.1 shows the various stage gauge stations and rain gauge stations along with its river system. The river under study is Brahmaputra and the flood forecasting model has been prepared to forecast flood at Sivasagar. There are two main tributaries of river Brahmaputra upstream of Sivasagar as shown in the figure namely Dehing and Desang. Data have collected from four Divisions such as Sivasagar, Dibrugarh, North Lakshimpur and Dhemaji. Sivasagar & Dibrugarh Divisions are in the south bank of river Brahmaputra and North Lakshimpur & Dhemaji in the north bank of river Brahmaputra. These four Divisions have their own daily rain gauge station. These Divisions also collects daily stages of respective rivers during official flood season i.e. from 15th May to 15th Oct. Therefore, four sets of stage data and four sets of rainfall data are used in this study. Out of which two stages of Brahmaputra itself and two from its upstream tributaries are taken into consideration. The period of data used for this study is from 1993 to 2004 i.e. for twelve years daily data during flood period.

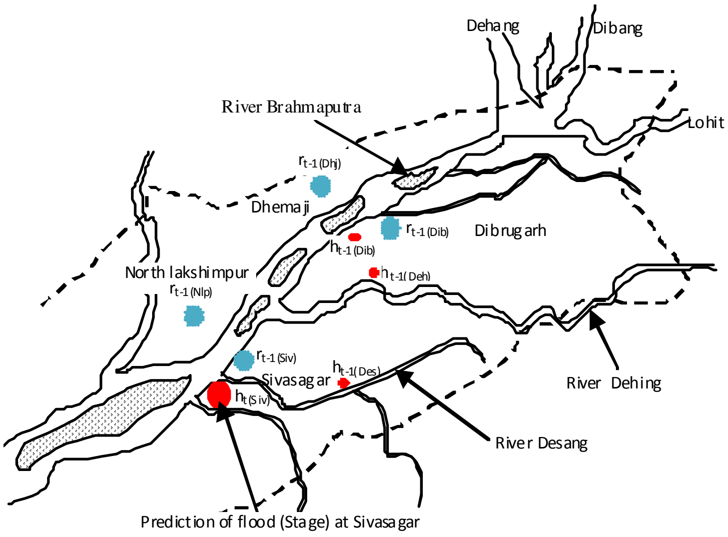

Fig.1 Basin Map

THEORY AND METHODOLOGY

Historic data such as **s**tage or discharge of a river and or rainfall data of that area are required in general for flood forecasting purposes. Tributaries stage or discharge data are also considered for flood forecasting in a multi tributary river system. Different flood forecasting models are formulated depending upon the availability of hydrological and hydro-meteorological data, the basin characteristics, warning time required and the purpose of forecast.

The Brahmaputra is a big river with large numbers of tributaries in India. In this study a linear time series model has been developed for flood forecasting of river Brahmaputra at Sivasagar, Assam. This model is based on the various upstream gauges data of river Brahmaputra and its tributaries along with respective rainfalls of the area. Stage of Brahmaputra, at Sivasagar is influenced by the stage of upstream gauge station of Brahmaputra at Dibrugarh and the stages of its two upstream tributaries namely Dehing and Desang. Stage or discharge of a river is also directly related to the rainfall of the basin of that river. Stage of Brahmaputra at Sivasagar is also dependant on rainfall of the upstream areas and therefore rainfall data of the surrounding areas of Sivasagar are also taken into account.

Model building process

A linear time series model has been developed for flood forecast of river Brahmaputra at Sivasagar. This model is based on the various upstream gauge data of river Brahmaputra and its tributaries along with respective rainfalls of the area. The daily gauge reading and daily respective rainfall readings of (t-1) time are used as input in the model to predict the stage of 't' time. The stage at Sivasagar in 't' time depends on the stages at Sivasagar, Dibrugarh, Dehing at Joangaon, Desang at Nangalamora in (t-1) time and rainfall at Sivasagar, North Lakshimpur, Dibrugarh & Dhemaji in (t-1) time respectively that is stage at Sivasagar in 't' time is the function of stages and rainfall of upstream stations in(t-1) time. The model in general is expressed as:

$$h_t = f(h_{t-1},\ h_{t-1(Dib)},\ h_{t-1(Deh)},\ h_{t-1(Des)},\ r_{t-1(Siv)},\ r_{t-1(Nlp)},\ r_{(t-1)Dib},\ r_{(t-1)Dhg})$$

$$h_t^{Pred} = a_1 h_{t-1} + b_1\, h_{t-1(Dib)} + c_1\, h_{t-1(Deh)} + d_1\, h_{t-1(Des)} + e_1 r_{t-1(Siv)} + f_1 r_{t-1(Nlp)} + g_1 r_{(t-1)Dib} + i_1 r_{(t-1)Dhg}$$

where, $h_t - Stage\ of$ Brahmaputra $at\ Sivasagar\ in\ 't' - time$

$h_{t-1} - Stage\ of$ Brahmaputra $at\ Sivasagar\ in\ (t-1) time$

$h_{t-1(Dib)} - Stage\ of$ Brahmaputra $at\ Dibrugar\ in\ (t-1) time$

$h_{t-1(Deh)} - Stage\ of$ Dehing at Jungaon $in\ (t-1) time$

$h_{t-1(Des)} - Stage\ of$ Desang at Nangalamora $in\ (t-1) time$

$r_{t-1(Siv)} - Rainfall\ of\ Sivasagar\ in\ (t-1) time$

$r_{t-1(Nlp)} - Rainfall\ of$ North Lakshimpur $in\ (t-1) time$

$r_{t-1(Dib)} - Rainfall\ of\ Dibrugar\ in\ (t-1) time$

$r_{t-1(Siv)} - Rainfall\ of$ Dhemaji $in\ (t-1) time$

$h_t^{Pred} - Stage\ of$ Brahmaputra $at\ Sivasagar\ in\ 't' - time$

$a_1, b_1,\ c_1,\ d_1,\ e_1, f_1,\ g_1,\ i_1$ are the parameters which are to be found-out.

The parameters $a_1, b_1,\ c_1,\ d_1,\ e_1, f_1,\ g_1,\ i_1$ are calculated by the method of least squares. The least squares method defines "best" as when the sum, *S*, of squared residuals is a minimum. In this method of calculations '*S'* is considered as the sum of squares of the errors up to n^{th} stages and mathematically it can be expressed as follows:

$$S = e_1^2 + e_2^2 + \dots\dots\dots + e_n^2$$

$$= \sum_1^n e_i^2$$

$$s = \sum_1^n (h_t^{Pred} - h_t^{Obs})^2$$

$$= \sum_1^n (a_1 h_{t-1} + b_1\, h_{t-1(Dib)} + c_1\, h_{t-1(Deh)} + d_1\, h_{t-1(Des)} + e_1 r_{t-1(Siv)} + f_1 r_{t-1(Nlp)} + g_1 r_{t-1(Dib)} + i_1 r_{(t-1)Dhg} - h_t^{Obs})^2$$

'*S'* is minimized when its gradient with respect to each parameter is equal to zero. The elements of the gradient vector are the partial derivatives of *S* with respect to the parameters. On the other hand we can assume that 'S' gets zero so that the least square error has a minimum. If we get the first derivative of 'S', the equation will be as follows:

$$\frac{\partial s}{\partial a_1} = 0 = \sum_1^n 2.\big(a_1 h_{t-1} + b_1\, h_{t-1(Dib)} + c_1\, h_{t-1(Deh)} + d_1\, h_{t-1(Des)} + e_1 r_{t-1(Siv)} + f_1 r_{t-1(Nlp)} + g_1 r_{(t-1)Dib} + i_1 r_{t-1(Dhg)} - h_t^{Obs}\big).\, h_{t-1}$$

$$\therefore\ a_1 \sum_1^n h_{t-1}^2 + b_1 \sum_1^n h_{t-1(Dib)}\, h_{t-1} + c_1 \sum_1^n h_{t-1(Deh)}\, h_{t-1} + d_1 \sum_1^n h_{t-1(Des)}\, h_{t-1} + e_1 \sum_1^n r_{t-1(Siv)}\, h_{t-1} + f_1 \sum_1^n r_{t-1(Nlp)}\, h_{t-1} + g_1 \sum_1^n r_{t-1(Dib)}\, h_{t-1} + i_1 \sum_1^n r_{t-1(Dhg)}\, h_{t-1} = \sum_1^n h_t^{Obs}\, h_{t-1} \quad (1)$$

Similarly, differentiating 'S' with respect to $b_1,\ c_1,\ d_1,\ e_1, f_1,\ g_1,\ i_1$ other 7 equations can be obtained and the co-efficient of the equations can be arranged in the following matrix form to calculate the parameters $a_1, b_1,\ c_1,\ d_1,\ e_1, f_1,\ g_1$ & i_1 of the model.

$$\begin{bmatrix} \sum h_{t-1}h_{t-1} & \sum h_{t-1}h_{t-1(Dib)} & \cdots & \sum h_{t-1}r_{t-1(Dhg)} \\ \sum h_{t-1(Dib)}h_{t-1} & \sum h_{t-1(Dib)}\, h_{t-1(Dib)} & \cdots & \sum h_{t-1(Dib)}r_{t-1(Dhg)} \\ \vdots & \vdots & & \vdots \\ \sum r_{t-1(Dhg)}h_{t-1} & \sum r_{t-1(Dhg)}h_{t-1} & \cdots & \sum r_{t-1(Dhg)}r_{t-1(Dhg)} \end{bmatrix} \begin{bmatrix} a_1 \\ b_1 \\ \vdots \\ i_1 \end{bmatrix} = \begin{bmatrix} \sum h_t^{Obs}h_{t-1} \\ \sum h_t^{Obs}\, h_{t-1(Dib)} \\ \vdots \\ \sum h_t^{Obs}\, r_{t-1(Dhg)} \end{bmatrix}$$

RESULTS AND DISCUSSION

First trial

In this trial, out of 12 years data, 9 years data from 1993 to 2001 have been used to calculate the parameters and 3 years data from 2002 to 2004 have been used for prediction purposes. Following values of the parameters and graphs have been obtained in this trial:

a_1 = 9.78E-01, b_1 = 8.47E-02, c_1 = -7.96E-02, d_1 = 9.32E-03,

e_1 = 4.03E-05, f_1 = 1.38E-03, g_1 = 6.49E-04, i_1 = 8.01E-04

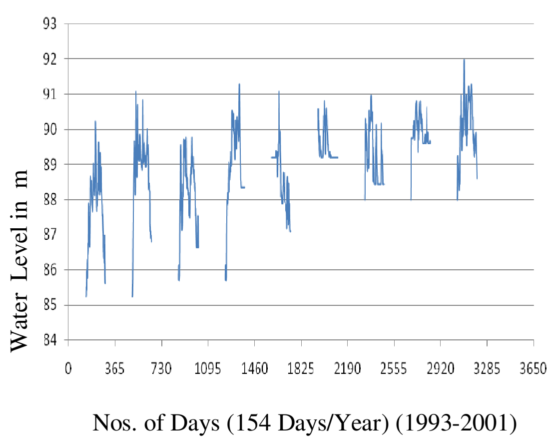

Fig. 2 Observed stages in calibration period

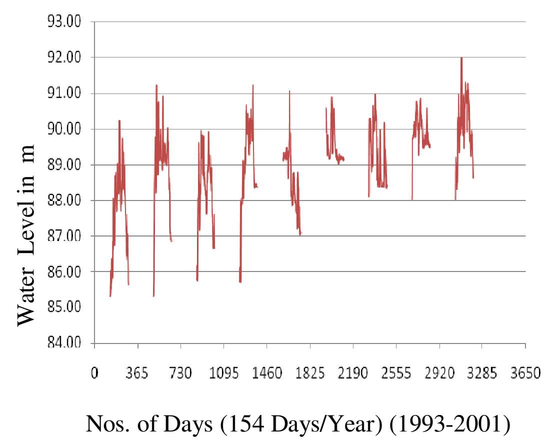

Fig. 3 Predicted stages in calibration period

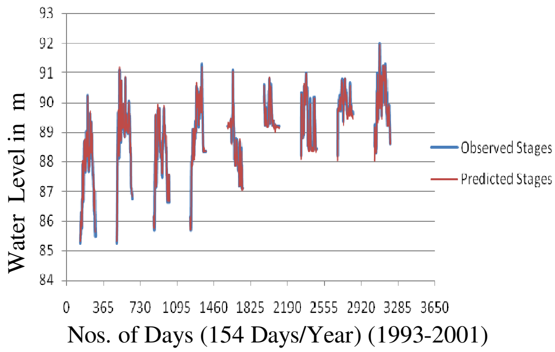

Fig. 4 Observed & Predicted stages in calibration period

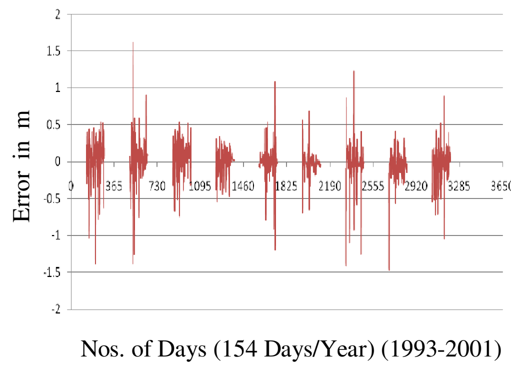

Fig 5 Prediction errors in calibration period

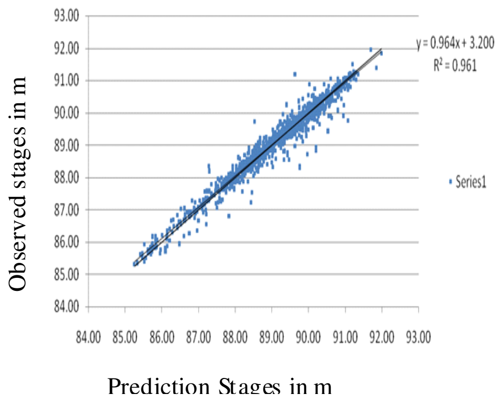

Fig. 6 Observed Vs Predicted Stages

Above results are obtained from the 9 years data set from 1993 to 2001. The value of 'R^2' i.e. coefficient of determination has been calculated as 0.961 as shown in Fig 6 and root mean square error (RMSE) has been calculated as 0.23.

The values of parameters when used to predict the flood for the period of 3 years from 2001 to 2004 then the value of coefficient of determination (R^2) decreases to 0.920 and RMSE increased up to 0.30 which are not so significant.

In the same way second, third and fourth trial have been done. Second trial has been run with average data. Data are not continuous in the first trial and for which calculations are interrupted. Therefore, to eliminate this problem, average data are prepared by simply taking the average of each days stage and rainfall of the calibration period i.e. 1993 to 2001.

In the third trial, the daily gauge reading and daily respective rainfall readings of (t-1) & (t-2) time are used as input into the model to predict the stage of 't' time. The stage at Sivasagar in 't' time is calculated based on the stages at Sivasagar at (t-1) time and Dibrugarh, Dehing, Desang in (t-2) time, similarly rainfall also at Sivasagar & North Lakshimpur at (t-1) time and Dibrugarh & Dhemaji in (t-2) time respectively. This is considered because of the lead time difference. Since lead time of Dibrugarh, Joangaon, Nangalamora, Dhemaji, North Lakshimpur and Sivasagar are not the same. Therefore, t, (t-1) & (t-2) time have been considered and the difference between each time is 24 hours.

Table 1 Comparison of different parameters

Trials	a_1	b_1	c_1	d_1	e_1	f_1	g_1	i_1	k_1
1	9.78E-01	8.47E-02	-7.96E-02	9.32E-03	4.03E-05	1.38E-03	6.49E-04	8.01E-04	-
2	7.91E-01	1.95E-01	-5.11E-02	3.04E-02	1.37E-04	4.12E-03	1.45E-03	4.65E-04	-
3	9.17E-01	4.90E-01	-4.80E-01	3.31E-02	2.73E-03	1.29E-03	2.05E-03	5.55E-04	-
4	9.76E-01	7.96E-02	-5.05E-02	-1.39E-02	1.93E-04	1.52E-03	6.52E-04	8.08E-04	2.71E-06

Table 2 Comparison of different 'R^2' & 'RMSE'

Trials	Calibration period (1993-2001)		Verification period (2002-2004)	
	R^2 Value	RMSE	R^2 Value	RMSE
1	0.961	0.23	0.920	0.30
2	0.982	0.07	0.916	0.34
3	0.887	0.39	0.827	0.48
4	0.961	0.23	0.918	0.30

In the fourth trial (t-1) periods data are considered to predict stage at 't' time, but here one constant term is also taken into consideration which is independent of stage and rainfall.

Various results of these four trial have shown in Table 1 and Table 2 for comparison.

CONCLUSIONS

Among the four trials first and fourth trial have very less differences. The R^2 value is high in the first trial and at the same time RMSE is also low compared to the other trials. Therefore, first trial model will be the suitable model among the four trials for flood prediction of river Brahmaputra at Sivasagar.

Secondly, this is not a physically based model and that is why it can not minimize error to zero. But stochastic type of model can bring the error within an acceptable limit. Since, this model is also stochastic in nature it cannot eliminate error completely and it try to minimize error within an acceptable limit.

RECOMMENDATION

Advanced forecasting techniques are required to be studied and should be used on operational basis for real time flood forecasting if suited well. On the other hand, the network of rain gauges, especially in the mountain region is not adequate as per the WMO suggested norm. The water levels are also measured using conventional methods. Automatic rain gauge network has to set up and recorded for the entire basin with international co-operation.

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