REAL TIME FLOOD FORECASTING
- INDIAN EXPERIENCES

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CAUSES OF FLOODS

- Intense precipitation
- Inadequate capacity within riverbanks to contain high flows, and silting of riverbeds
- Land slides leading to obstruction of flow and change in the river course
- Retardation of flow due to tidal and backwater effects
- Poor natural drainage
- Drainage congestion
- Cyclone
- Heavy rainstorms/cloud bursts
- Snowmelt and glacial outbursts
- Dam break flow.
FLOOD PROBLEMS IN INDIA

- Inundation, drainage congestion due to urbanization and bank erosion.
- Depend on the river system, topography and flow characteristics.
- Being a vast country, the flood problems in India may be visualized on regional basis.
- India may be broadly divided into four zones of flooding:
  - Brahmaputra River Basin
  - Ganga River Basin
  - North-West Rivers Basin
  - Central India and Deccan Rivers Basin
BRAHMAPUTRA RIVER BASIN

• Basins of the rivers Brahmaputra and Barak with their tributaries.
• Covers the States of Assam, Arunachal Pradesh, Meghalaya, Mizoram, northern parts of West Bengal, Manipur, Sikkim, Tripura and Nagaland
• Problems in this region: flood inundation, drainage congestion, erosion, river shifting, sedimentation
GANGA RIVER BASIN

- The Ganga and its many tributaries (the Yamuna, the Sone, the Ghaghra, the Gandak, the Kosi and the Mahananda)
- Covers Uttaranchal, Uttar Pradesh, Bihar, south and central parts of West Bengal, parts of Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh and Delhi.
- Problems of flooding, erosion and drainage congestion, river shifting and meandering
FALSE COLOUR COMPOSITES (NOAA DATA) OF ASSAM AND BIHAR/JHARKHAND STATE.
FLOOD INUNDATED AREA OF ASSAM AND BIHAR/JHARKHAND STATE

AUGUST 05, 2003

FLOOD INUNDATED AREA OF ASSAM AND BIHAR/JHARKHAND STATE
Fig. Details of widening of river Ganga at Daudpur near Danapur as obtained from SOI toposheet (1974-76) and IRS-1C LISS-III data (1996 and 2000)
Flood studies Kao river, NTPC, Kahalgaon, Bihar
NORTH – WEST RIVER BASINS

- Comprises of basins of North-West rivers such as Sutlej, Ravi, Beas, Jhelum and Ghaggar.
- Covers the states of Haryana, Punjab, Himachal Pradesh, Jammu & Kashmir
- In comparison to the two zones, the flood problem in this zone is relatively less.
- The major problem is that of inadequate surface drainage which causes inundation and water logging.
CENTRAL INDIA AND DECCAN RIVERS BASIN

- Narmada, Tapi, Mahanadi, Godavari, Krishna and Cauvery.
- Mostly well defined stable courses.
- Floods in Lower reaches and in the delta area.
- Covers all the southern States namely Andhra Pradesh, Chhattisgarh, Karnataka, Tamil Nadu, Kerala, Orissa, Maharashtra, Gujarat and parts of Madhya Pradesh.
- The Delta areas of the Mahanadi, Godavari and the Krishna rivers on the east coast periodically face flood and drainage problems, in the wake of cyclonic storms.
SPECIAL FLOOD PROBLEMS

- Problem of Tal Areas
- River bank/bed erosion
- Sediment transport by rivers
- Dam Break Floods
- Urban Drainage
- Flash Floods
- Flood due to Snow melt
- Flood in Coastal Areas
Drainage map of Kiul-Harohar basin

Some Rainfall varies from 775 mm to 1344 mm
SCHEMATIC VIEW OF TAL AREAS

GANGA

TAL AREAS

RIVER HAROHAR

VERY MILD SLOPE

RIVER KIUL

SPILL FROM GANGA THROUGH PUNPUN

SPILL FROM GANGA

BACK FLOW FROM GANGA

NORTH FLOWING RAIN FED RIVERS

FATUHA

LAKHISARAI
Fig: A view of Mokama Tal during August, 1999
Fig.: WaterLogged Area Map delineated from remote sensing data

Post Monsoon Waterlogging in Mokama group of tals
FLOOD MANAGEMENT

STRUCTURAL MEASURES

• Multipurpose reservoirs
• Retarding structures which store flood waters
• Channel improvements which increase floods carrying capacity of the river
• Embankments and levees which keep the water away from floods prone areas
• Detention basins which retard and absorb some flood water
• Flood-ways which divert flood flows from one channels to another
• Over all improvement in the drainage system.
• Water Transfer
FLOOD MANAGEMENT...

NON STRUCTURAL MEASURES

• Real Time Flood Forecasting
• Flood Plain Zoning
• Flood Insurance Scheme
• Dam Break Flood Simulation
REAL TIME FLOOD FORECASTING

- The process of estimating the future stages or flows and its time sequence at selected vulnerable points along the river course during floods

- Real time flood forecasting systems formulated for issuing the flood warning in real time in order to prepare the evacuation plan during the flood

- Loss of lives and property etc. can be reduced to a considerable extent by giving reliable advance information about the coming floods.

- The effectiveness of real time flood forecasting systems in reducing flood damage depend upon how accurately the estimation of future stages or flow of incoming flood and its time sequence at selected points along the river predicted

- The rivers of alluvial plain exhibit the meandering, shifting of the course and unstable cross sections due to the problems of sediment transport which complicate the issue of adopting the suitable measures for flood management.
NEEDS FOR REAL TIME FLOOD FORECASTING

• To evacuate the affected people to the safer places,
• To make an intense patrolling of the flood protection works so as to save them from breaches, failures, etc.
• To regulate the floods through the barrages and reservoirs for their safety
• To operate the multi-purpose reservoirs
• To operate the city drains (out falling into the river) to prevent back flow and flooding of the areas drained by them.
REAL TIME FLOOD FORECASTING IN INDIA

• Central Water Commission (CWC) is Nodal Government Agency

• CWC established a network of more than 150 flood forecasting and warning sites in four zones of flooding
METHODOLOGY FOR REAL TIME FLOOD FORECASTING

• Observation and collection of hydrological and meteorological data
• Transmission/Communication of data to the forecasting Centres
• Analysis of data and formulation of forecasts
• Dissemination of forecasts and warning to the Administrative and Engineering Authorities of the States.
METHODS FOR FORMULATING REAL TIME FLOOD FORECASTS

• Statistical Methods
• Stochastic Methods
• Deterministic Methods
• Soft Computing Techniques
STATISTICAL METHODS

- Stage and discharge of the base station
- Stage and discharge of the forecasting station
- Change in stage and discharge of the base station
- Travel time at various stages
- The rainfall (amount, intensity and duration) in the intercepting catchment
- Topography, nature of vegetation, type of soil, land use, density of population, depth of gw table, soil moisture deficiency etc. of the intercepted catchment.
- The atmospheric and climatic conditions; and
- Stage and discharge of any important tributary joining the main stream between the base station and the forecasting station.
FLOOD PROFILE CHART OF RIVER YAMUNA FOR KALANAUR DELHI BEACH

FIG. 1

KOHALAUR

269
268
267
266

MAWI
WATER LEVEL IN MTS

233
232
231
230

DELHI RLY. BRIDGE
WATER LEVEL IN MTS

208
207
206
205
204

KOHALAUR

MAWI

DELHI RLY. BRIDGE

90 KMS

106 KMS
STATISTICAL METHODS...

• Direct correlation between upstream and downstream gauges/discharges

• Correlation between gauges at u/s and d/s with additional parameters.
Direct correlation between upstream and downstream gauges/discharges

- The simplest of all is the correlations between the Nth hours stage of base station and (N+T)th hour stage of forecasting stations; where T is the travel time of flood wave between the base station and forecasting station. Fig.2 shows one such graph which is used for forecasting the river stage in River Brahmini in Orissa.
Direct correlation between upstream and downstream gauges/discharges

• The simplest of all is the correlations between the Nth hours stage of base station and (N+T)th hour stage of forecasting stations; where T is the travel time of flood wave between the base station and forecasting station. Fig.2 shows one such graph which is used for forecasting the river stage in River Brahmini in Orissa.
FIG. 2 CORRELATION DIAGRAM OF RIVER BRAHMANI BETWEEN GAUGE AT PANPOSH TALCHER AND JENAPUR
Direct correlation between upstream and downstream gauges/discharges...

- Direct correlation between the peaks, at forecasting station and base station:
  - The gauge (peak) at the base station and the gage (peak) at the forecasting station for the various intensities of flood are plotted.
  - The travel time at various intensities of flood is also plotted corresponding to peak.
  - Such graphs have been successfully used for river Subernarekha in Orissa. The graph is shown in Fig.3 warning time available is about 24-30 hrs.
Direct correlation between upstream and downstream gauges/discharges...

- Correlation between the change in stage of the base station and change in the stage of forecasting stations during T hours (T = time of travel of flood wave between the base station and forecasting site)(Fig. 4)
- Correlation between the Nth hour and (N+T)th hour stages of the forecasting station with change in stages at the base station during past ‘T’ hours as variable. (Fig. 5 &Fig. 6)
FIG. 4 - CORRELATION GRAPH FOR DIGHAGHAT PATNA

FIG. 5 - CORRELATION GRAPH FOR DALMAU SITE ON RIVER GANJA
Direct correlation between upstream and downstream gauges/discharges...

- For rivers having wide fluctuation in U/S stages and relatively much less fluctuations in lower reaches due to inundation/valley storage in between the two points, tendency effect is considered:

- Correlate Nth and (N+T)th hour stage of the forecasting site in Past ‘T’ hours as variable in the 1st quadrant. Then in the 2nd quadrant, the average gauge of the base station is considered as a variable.

- This type of graph have proved quite useful in Bagmati and Adhwara group of rivers of Bihar in Ganga Basin. One such graph developed for Kamtaul site of River Adhwara is shown in Fig. 7.
Direct correlation between upstream and downstream gauges/discharges...

Poanta – Tajewala Model (For River Yamuna)

- The travel time from Poanta to Tajewala being 2 hours, Poanta gauge in ft. at t hours, Gp(t) is correlated to Tajewala discharge in cusecs, QT(t+2) for rising limb

\[ QT(t+2) = 7.4045 \times 10^5 \ Gp(t)^{4.333} \]

- Another relation has been developed for falling limb when the travel time of 3 hours is found to be more appropriate and the relationship is:

\[ QT(t+3) = 1.819 \times 10^{-6} \times GP(t)^{5.555} \]

- The graphical representation is shown in Fig. 8.
PAONTA GAUGE IN

PAONTA GAUGE IN

EQN: QT(t+2) = 7.4045X10^-5 G_P(t)^4.333

EQN = Q_t (t+3) = G_P 5555 X 1.1919X10^-6

FIG. 8 - PAONTA GAUGE VS. TAJEWALA DISCHARGE (WITH 2 HRS. LAG) RISING LIMB
Direct correlation between upstream and downstream gauges/discharges…

Gauge-Rise Models for various reaches of Yamuna.

• The height of the flood wave at D/S section is related to its height at the U/S section:

\[(GDP - GDO) = a(GUP - GUO) + b\]

• Where GDP and GUP are the peak gauge at the D/S and U/S sections. GDO and GUO are the estimated gauges at the time of recorded peak, had the recession prior to the start of the flood wave continued.

• a & b are constant, to be evaluated on the basis of past flood data. One such equation developed for Kalanur and Delhi reach of the Yamuna is shown in the Fig. 9.
FIG. 9

LINE PLAN SHOWING THE LOCATION OF VARIOUS STATION

EQN: \((G_{DP} - G_{DO}) = 200 (G_{KP} - G_{KO}) - 0.77\)
Direct correlation between upstream and downstream gauges/discharges...

**Discharge-Rise Models**

The discharge rise due to a flood wave at a D/S section is related to that on an U/S section, if the effect of the intermediate catchment contribution is not significant

\[(Q_{DP} – Q_{DO}) = m(Q_{UP} – Q_{QUO}) + n\]

Where \(Q_{DP}\) and \(Q_{UP}\) are the discharges at the D/S and U/S sections \(Q_{DO}\) and \(Q_{QUO}\) are the estimated discharges at the time of recorded peak, had the recession prior to the start of flood wave continued and \(m\) and \(n\) are constant to be evaluated on the basis of past flood data.

On such relation developed for Kalanaur – Mawi reach of Yamuna is shown in Fig. 10.
LINE PLAN SHOWING THE LOCATION OF VARIOUS STATIONS

EQN: \( \frac{Q_{MP} - Q_{MO}}{KP - KO} = 0.7946 \left( \frac{Q - Q_{KO}}{Q_{KP} - Q_{KO}} \right) + 65 \)

FIG. 10-CORRELATION BETWEEN RISE IN DISCHARGE AT KALANAUR AND MAWI
Correlation between gauges at u/s and d/s with additional parameters

Multi tributary model

- A discrete, linear, time-invariant model developed for operational flood forecast of river Brahmaputra at Dibrugarh.

- The model considers the difference of the gauge reading at the forecasting station and the upstream base station in the tributary.

- The forecast of Dibrugarh formulated with the help of observed gauge data on three major upstream tributaries namely Dihang, Debang and Lohit.

$$g_{i(i+T)} = A_i g_{i(i-T)} + \sum_{j=1}^{m} A_{2,i} h_{(i-T+T)}(i+T) + \sum_{j=1}^{m} A_{3,i} h_{(i-T)}(i-T)$$
Correlation between gauges at u/s and d/s with additional parameters…

Rainfall-stage method

- It is the relation between the average rainfall over the catchment and the peak stage.

- The relation may be either a graphical or mathematical and established by using the statistical technique.

- The results can be further improved by incorporating other parameters such as API etc.

- These relations are used on many places with quite good result but the deficiency in this method is that the time of occurrence of the peak or the full shape of hydrograph cannot be forecasted.
REAL TIME FLOOD FORECASTING

Stochastic Methods
BACKGROUND

• The response of a catchment to a given rainfall event is dynamic
• Every flood hydrograph may give different parameter estimates.
• The real time monitoring of the hydrological system is important
• On line updating of the model parameter and structure
• For better forecasts, update the model parameters recursively as the flood develops
METHODOLOGY

• Stochastic time series model
  – Box-Jenkins (1976) models (ARIMA Models)

• Updating algorithm
  – Recursive Least square method
STOCHASTIC TIME SERIES MODELS

- AR (Autoregressive) model
- MA (Moving average) model
- ARMA (Autoregressive Moving average) model
- ARIMA (Autoregressive Integrated Moving average) model
- ARIMAX (Autoregressive Integrated Moving Average with exogenous inputs) models.
ADAPTIVE ALGORITHM
(Recursive Least square method)

• Output from the model is continuously assessed against the actual system output.

• The residual errors between the actual and forecast output used as a feedback information

• Model parameters updated using the previous estimate of the model parameters and a function of the forecast error process.
The updating algorithms are of the general form

$$\theta(k+1) = \theta(k) + k(k+1) \ast e(k+1)$$

where

- $\theta(k+1)$ = Updated parameter vectors at time $(k+1)$
- $\theta(k)$ = Previous estimate
- $k(k+1)$ = Weighting factor
- $e(k+1)$ = Residual error between the observed and the forecast values.

For recursive least square algorithm

$$k(k+1) = P_k h_{k+1}^T [h_{k+1} P_k h_{k+1}^T + 1]^{-1}$$

and

$$e(k+1) = Y_{k+1} - h_{k+1} \theta_k$$
where

\[ Y_k = k \times 1 \text{ observation vector} \]
\[ \theta_k = p \times 1 \text{ parameter vector} \]
\[ \epsilon_k = k \times 1 \text{ identically independently distributed error vector} \]
\[ H_k = k \times p \text{ past observation matrix} \]
\[ P_k = (H_k^T H_k)^{-1} \]
CASE STUDY

- Jamtara gauging site of Ajay river basin, having area of about 2915 km²
- Flood events for 1997 to 1999 considered.
- The flood hydrographs for the year 1997 considered for initial parameter estimation of AR model
- Developed model used to forecast floods for the year 1998 and 1999 using constant parameter and updated parameter for different lead time to forecast.
RESULTS

• For the year 1997, whose flood hydrographs are used for parameter estimation, no (significant) improvement in forecasts are noticed with updated parameters as compared to constant parameters for different lead time to forecast.

• For the year 1998, marginal improvements are observed in the forecasts made with updated parameters as compared to constant parameters for different lead time to forecast.

• For the year 1999, significant improvements are noticed in the forecasts made with updated parameters as compared to constant parameters for different lead time to forecast.
Table 5.1 RMSE for two and three time step ahead forecast for constant and updated parameters for the flood hydrographs of year 1998

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Flood Hydrograph</th>
<th>Two time step ahead forecast (RMSE)</th>
<th>Three time step ahead forecast (RMSE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Constant</td>
<td>Updated</td>
</tr>
<tr>
<td>1</td>
<td>FH4</td>
<td>0.2928</td>
<td>0.2891</td>
</tr>
<tr>
<td>2</td>
<td>FH5</td>
<td>0.2500</td>
<td>0.2377</td>
</tr>
<tr>
<td>3</td>
<td>FH6</td>
<td>0.5633</td>
<td>0.5347</td>
</tr>
</tbody>
</table>
Table 5.2 RMSE for two and three time step ahead forecast for constant and updated parameters for the flood hydrographs of year 1999

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Flood Hydrograph</th>
<th>Two time step ahead forecast (RMSE)</th>
<th>Three time step ahead forecast (RMSE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Constant</td>
<td>Updated</td>
</tr>
<tr>
<td>1</td>
<td>FH7</td>
<td>0.5203</td>
<td>0.4097</td>
</tr>
<tr>
<td>2</td>
<td>FH8</td>
<td>0.1262</td>
<td>0.09887</td>
</tr>
<tr>
<td>3</td>
<td>FH9</td>
<td>0.1837</td>
<td>0.1342</td>
</tr>
</tbody>
</table>
Fig. 5.1: The observed and two time step (6 hours) ahead forecasted stage values of flood hydrograph (FH1, 1997) for constant and updated parameters.
Fig. 5.2: The observed and three time step (9 hours) ahead forecasted stage values of flood hydrograph (FH2, 1997) for constant and updated parameters.
Fig. 5.7: The observed and two time step (6 hours) ahead forecasted stage values of flood hydrograph (FH4, 1998) for constant and updated parameters
Fig. 5.8: The observed and three time step (9 hours) ahead forecasted stage values of flood hydrograph (FH4, 1998) for constant and updated parameters
Fig. 5.13: The observed and two time step (6 hours) ahead forecasted stage values of flood hydrograph (FH7, 1999) for constant and updated parameters
Fig. 5.14: The observed and three time step (9 hours) ahead forecasted stage values of flood hydrograph (FH7, 1999) for constant and updated parameters
CONCLUSIONS

• No significant improvements noticed in the forecasted stage values using updated parameters for the year 1997

• Around 4-5% improvement in the forecasted stage values of year 1998 for two time (six hours) step ahead forecast.

• Improvement is up to 8% for three time step (nine hours) ahead forecast

• Significant improvements have been noticed for the forecasted hydrographs of the year 1999 both for two and three time step ahead forecasts.

• For two time step ahead forecasts the improvement using updated parameters is 20 -22%, whereas for three time step ahead forecasts the improvement is 24-26%.
• Initial estimated parameters required to be updated for more improved forecast and to incorporate the dynamic behavior of catchments as it changes over time.

• Initial parameter estimated for Jamtara gauging site of Ajay river basin are required to be updated (preferably after two years) for more improved forecast (using univariate runoff time series).
DETERMINISTIC METHODS

- Unit Hydrograph based methods (CA < 5000 sq. km)
- Event based Network Model (CA > 5000 sq. km.)
  (UH and Flood Routing)
  - HEC1 F
- Conceptual Rainfall-Runoff Model
  - SSARR model
  - NAM-System 11 FF model
DETERMINISTIC METHODS…

• WMO/UNDP Project for Yamuna Basin up to Delhi
  – HEC1 F
  – SSARR model

• CWC-DHI Collaboration Project for Damodar River Basin
  – NAM-System 11 FF model
REAL TIME FLOOD FORECASTING USING FUZZY LOGIC
OBJECTIVES

• to develop a fuzzy logic based model for flood forecasting
• to apply the developed model on a river gauging site
Fuzzy Logic was initiated in 1965 by Lotif Zadeh.

It is basically a multi-valued logic that allows intermediate values to be defined between conventional boolean logic like true/false, yes/know, black/white.

Human like way of thinking e.g. warm/hot very hot.
WHY FUZZY LOGIC?

- Hydrologic modeling is inherently messy
- The standard approach based on the laws of conservation of mass, momentum and/or energy.
- Non-availability of the physical parameters and approximation involved make these models unreliable and unsuitable
A Fuzzy system consists of:

- Fuzzy input and output variables
- Fuzzy rules
- Fuzzy inference
Operation of Fuzzy Controller

Step 1

Crisp Input

Fuzzification

Fuzzy Input

Rule Evaluation

Fuzzy Output

Defuzzification

Crisp Output
FUZZY SYSTEM FOR FLOOD FORECASTING

Fuzzy Rule Base

Learning Fuzzy Rules

Fuzzy Inference Machine

Data Base (Fuzzy)

Fuzzification

Membership Function

Defuzzification

User Interface

FUZZY DATA/EXACT DATA

EXACT QUERIES/FUZZY QUERIES

FUZZY SYSTEM FOR FLOOD FORECASTING
Example for Flood Forecasting System

Rainfall → Qi → Fuzzy Input

Qi → Rule Inference

Fuzzy Output → Output membership function

Qi+t → Q → t
Fuzzy Logic Based Flood Forecasting System

• **Steps:**
  – identify the problem
  – define the input and output variables
  – define the set of fuzzy rules
  – select the fuzzy inference method
  – experiment and validate the system
FUZZY RULES EXTRACTION

- Experts Knowledge
- Clustering-based method
- Learning rules through training of neural networks
- Learning rules through genetic algorithms
STUDY AREA

NARMADA BASIN
Catchment Area Up to Mandla
(13120 sq. km.)

DATA USED
Rainfall data:
   Jamtara, Dindori and Malankhand
Discharge data:
   Mandla

PERIOD
1989 to 1993
MODEL STRUCTURE

\[ Qt = (Rt-16, Rt-17, Rt-18, Qt-1, Qt-2, Qt-3, Qt-4, Qt-5 \text{ and } Qt-6). \]

In which \( Qt, Qt-1, Qt-2, \ldots \) are observed discharges of Mandla gauging site at \( t, t-1, t-2 \) times etc. and \( Rt-16, Rt-17, \ldots \) are the spatially averaged rainfall values at \( t-16, t-17 \) times etc.
Fuzzy Model for Flood forecasting at Mndala
Comparison of Observed and forecasted discharge (1 hour lead period)
Comparison of Observed and forecasted discharge (6 hour lead period)

- **Computed Discharge**
- **Observed Discharge**

Discharge (cumec)

Time (hours)
# PERFORMANCE OF MODEL FOR DIFFERENT LEAD PERIODS

<table>
<thead>
<tr>
<th>Lead Time</th>
<th>Coefficient of Correlation</th>
<th>Efficiency</th>
<th>RMSE</th>
<th>Average % Error in Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cali</td>
<td>Vali</td>
<td>Cali</td>
<td>Vali</td>
</tr>
<tr>
<td>1</td>
<td>0.993</td>
<td>0.987</td>
<td>98.58</td>
<td>97.23</td>
</tr>
<tr>
<td>2</td>
<td>0.985</td>
<td>0.969</td>
<td>96.93</td>
<td>93.46</td>
</tr>
<tr>
<td>3</td>
<td>0.972</td>
<td>0.939</td>
<td>94.53</td>
<td>87.11</td>
</tr>
<tr>
<td>4</td>
<td>0.956</td>
<td>0.904</td>
<td>91.29</td>
<td>79.34</td>
</tr>
<tr>
<td>5</td>
<td>0.937</td>
<td>0.862</td>
<td>87.76</td>
<td>69.85</td>
</tr>
<tr>
<td>6</td>
<td>0.918</td>
<td>0.828</td>
<td>84.28</td>
<td>62.41</td>
</tr>
<tr>
<td>7</td>
<td>0.897</td>
<td>0.797</td>
<td>80.45</td>
<td>56.26</td>
</tr>
<tr>
<td>8</td>
<td>0.874</td>
<td>0.761</td>
<td>76.37</td>
<td>48.75</td>
</tr>
</tbody>
</table>
CONCLUSIONS

• Fuzzy model is capable to forecast real time floods and the model performs well as indicated by various evaluation criteria

• It provide a well performing and relatively easy solution that may readily be integrated into existing operational flood forecasting systems
REAL TIME FLOOD FORECASTING USING ARTIFICIAL NEURAL NETWORK
Structure Of A Multi-Layer Feed Forward Artificial Neural Network

Input Nodes    Hidden Layer Nodes    Output Nodes
STUDY AREA

Ajay river basin upto Sarath gauging site  $24^\circ 13'$
45” N latitude and $86^\circ 50'$ 43” E longitude
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Period of the Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.08.1977 at 09 hrs. to 13.08.1977 at 20 hrs.</td>
</tr>
<tr>
<td>2</td>
<td>05.08.1978 at 21 hrs. to 06.08.1978 at 02 hrs.</td>
</tr>
<tr>
<td>3</td>
<td>06.08.1979 at 05 hrs. to 16.08.1979 at 16 hrs.</td>
</tr>
<tr>
<td>4</td>
<td>26.08.1980 at 15 hrs. to 26.08.1980 at 07 hrs.</td>
</tr>
<tr>
<td>5</td>
<td>22.08.1982 at 24 hrs. to 23.08.1982 at 06 hrs.</td>
</tr>
</tbody>
</table>
Table 1. Comparative Performance of Various ANN models

<table>
<thead>
<tr>
<th>ANN Forecasting Model</th>
<th>ANN structure</th>
<th>Calibration (Training)</th>
<th>Verification (Testing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANN – 1Hr</td>
<td>(24,8,1)</td>
<td>9.21</td>
<td>0.9993</td>
</tr>
<tr>
<td>ANN – 2Hr</td>
<td>(23,17,1)</td>
<td>21.058</td>
<td>0.9964</td>
</tr>
<tr>
<td>ANN – 3Hr</td>
<td>(22,16,1)</td>
<td>35.319</td>
<td>0.9911</td>
</tr>
<tr>
<td>ANN – 4Hr</td>
<td>(21,16,1)</td>
<td>44.037</td>
<td>0.9881</td>
</tr>
<tr>
<td>ANN – 5Hr</td>
<td>(20,15,1)</td>
<td>51.996</td>
<td>0.9700</td>
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<tr>
<td>ANN – 6Hr</td>
<td>(19,14,1)</td>
<td>75.575</td>
<td>0.9644</td>
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Figure: Scatter Plot of Observed and Forecasted runoff during calibration
Figure : Scatter Plot of Observed and Forecasted runoff during validation

$R^2 = 0.9712$
Hydrology Project-I

- Strengthening HIS in 9 peninsular states with the assistance from the WB

the first concerted effort at this scale for improving HIS in the country
HIS STRUCTURE AT STATE/REGIONAL LEVEL

CWC
IMD
STATE
CGWB

USER

STATE/REG. DATA STORAGE CENTRES
STATE/REG. DATA PROCESS. CENTRES
DIV. DPC
SUB-DIV. DPC
OBSERVATION STATIONS

DATA STORAGE CENTRE
DATA STORAGE CENTRE
DATA STORAGE CENTRE
DATA STORAGE CENTRE

REGION. PROCES. CENTRE
SSW PROCES. CENTRE
SGW PROCES. CENTRE
REGION. PROCES. CENTRE(S)

DIVISIONS
DIVISIONS
REGIONAL/DIVISIONS
UNIT PROCESS. CENTRE

SUB-DIVISIONS
SUB-DIVISIONS
DISTRICT

FIELD OFFICES/STATIONS
FIELD OFFICES/STATIONS
FIELD OBSERV. STATIONS
FIELD OBSERV. STATIONS

INFO. EXCHANGE
STORAGE & DISSEMINA.
FINAL VALID. & PROCESS.
DATA ENTRY & VALID.
DATA COLLECTION
HIS STRUCTURE
(LINKS - NATIONAL & REG. LEVELS)

USER

NDSC CWC

NDSC CGWB

NDPC CWC

NDPC CGWB

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Decision Support System

Using a DSS, a person responsible for the actual project is able to make rational use of the system without an in-depth knowledge of modelling techniques.
Decision Support System

Definition

- Computer based models together with their interactive interfaces are typically called decision support systems (DSSs)
- DSS does not take decisions
- Provides timely information
- Easy comprehension of abstract information
Why a DSS?

- Communicate result to a larger audience
- Open and unbiased working
- Scenario analysis
Decision Support Systems

Information Systems
- Geographic Information Systems
- Interactive Spreadsheets
- Databases
- Internet
- Other Documents

Interaction

Models
- Optimization/Simulation
- Deterministic/Stochastic
- Operation/Management/Planning

Disciplines
... Public Policy, Hydrology, Engineering, Economics, Environment, Ecology, Law, Politics, ...

Actors
... Government, Academic, NGOs, International Institutions, Research, Consultants, General Public, Other Stakeholders...

Decision Making
Modern Spatial Toolkit

- GIS
- GPS / Modern Survey Tools
- Remote Sensing
- Modern Hardware
- Modern Software
- Modern Platforms (www)
- Modern Applications/DSS
- and most important... Skilled Staff with multi-sectoral perspectives

...along with all the old-fashioned insights, knowledge, expertise
A Typical Decision Support System

- GIS
- Database
- Knowledge base
- Hypertext file

Pre-processors

- Optimisation techniques
- Simulation models
- Expert systems

Analytical tools

Post-processors

Interactive user-interface
Visualization/menu system/help & explain
Decision Support System
Real Time Flood Forecasting

• Forecast flood stages and potential inundation areas along a river network
• Provide information needed for early Flood Warning
• Develop real time operational policies to mitigate flood damages

• Study Area: Bhakhra-Beas Reservoir System
Decision Support System (Planning)

- Surface water planning
- Integrated operation of reservoirs
- Conjunctive surface water and ground water planning
- Drought Monitoring, assessment and management
- Water Quality
CONCLUDING REMARKS

• The hydrological information system required to be developed for all the river basins of India.
• Conventional systems of communication are normally used for transmitting the data in real time.
• The automatic systems of data communication like Telemetry system are used in pilot projects on limited scale.
• In the areas of arid and semi-arid, flash floods are usually experienced. As such there is no system for formulating the flash flood forecast in the region.
• Most of the techniques for formulating the real time flood forecast are based on statistical approach. For some pilot projects, network model and multi-parameter hydrological models are used.
CONCLUDING REMARKS…

• The forecasting techniques such as deterministic models, stochastic models, ANN and Fuzzy Logic etc required to be studied and a suitable method may be recommended for field applications based on the performance evaluation criteria and considering the data availability and purpose of the forecast.

• The information about the flood have to be disseminated well in advance to the people likely to be affected so that an emergency evacuation plan may be prepared and properly implemented.

• Development of Decision Support System (DSS) for Bhakhra-Beas Reservoir System would provide useful information in real time for taking necessary flood management measures in the downstream of the reservoir.
THANKS