Dr. P.K. Patwardhan Award 2011

Development of Real-time Intermittent Reservoir inflow Prediction Models and its use in real life

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Genesis of the present work

Prior to IIT B

- Worked in developing Reservoir Operation rule curves
- Found that Reservoir inflow prediction plays major role in implementing the rule curves

After Joining IIT B

- Started Working in reservoir inflow prediction models
- IIT B seed grant (Multi-site synthetic inflow generation using ANN Model)
- DST Workshop (*Application of Advanced Soft Computing Techniques in Geo-Spatial Data Analysis)*
- STTP on Soft computing techniques in Hydrology and Water Resources Engg

MoWR/ KRF Project

- MoWR Sponsored Project (Derivation of operating rules for a multi-purpose reservoir using soft computing techniques)
- Real Time reservoir inflow prediction (3 PhD Scholar)
- Derivation Reservoir Operating Rule (1 PhD Scholar)
- Korean Research foundation R&D project (catchment classification/dimension study to generalize a catchment)

Introduction

- Altogether 100's of prediction models using various techniques are available at national and international levels (as reported in national and international journals),
  - all the models are lying as published papers, there is no reported evidences of models used in the field, in Indian Scenario.

- In the present study the reservoir inflow models are developed using soft computing techniques, namely Artificial Neural Networks, and Genetic Programming, and are converted into graphical user interface (GUI) to use it at field level.

- After developing the GUI, the field engineers at dam site (Present study area is KOYNA RESERVOIR REAL TIME INFLOW PREDICTION) were trained to use the model.
  - After training, the field engineers validated the model and accepted the model before putting it in practical use.

Major Research Gap (in process)

- The dimensions required to model a rainfall-reservoir inflow processes is not studied in detail.
  - Many works on rainfall-runoff is available
    - How many number of input data is required to develop rainfall-inflow? – Dimensions of a model? Input to a model?
    - The problem of time of concentration in rainfall-inflow ?
    - Length of the data to be considered for developing the models?

- The problem of having more number of continuous zero inflow values together with high variation in the data series has not been addressed in artificial intelligence modelling.

Major Research Gap (in data used)

- Scanty literature on the effect of using lumped and distributed data for reservoir inflow prediction on same catchment.

  – Assessment of the effect of different models based on lumped and distributed data set with different input combinations such as time-series, cause effect and combined models on multi-time-step reservoir inflow prediction has not been reported in the literature.

Major Research Gap (in techniques)

- Stochastic models assume normality and stationarity of the variables
  - Extreme or peak inflows are poorly mapped

- Most of the research in application of ANN for Rainfall runoff dealt with
  - Mostly event based study
  - Few works on multi-step-ahead forecasting
  - Very few works on applications for daily continuous and hourly seasonal time-series

- Few application of ANFIS, MT and GP for cause-effect and time series modeling

Koyna Reservoir inflow prediction Methodology Flow Chart

Stage-I

- Daily multi-time-step ahead reservoir inflow prediction- with continuous lumped and distributed data
  - Daily inflow prediction models for Koyna reservoir ARIMA, MLR, ANN, ANFIS and LGP techniques for lumped and distributed (full year continuous 47 years) data.
- Select the best model from both daily lumped and distributed data

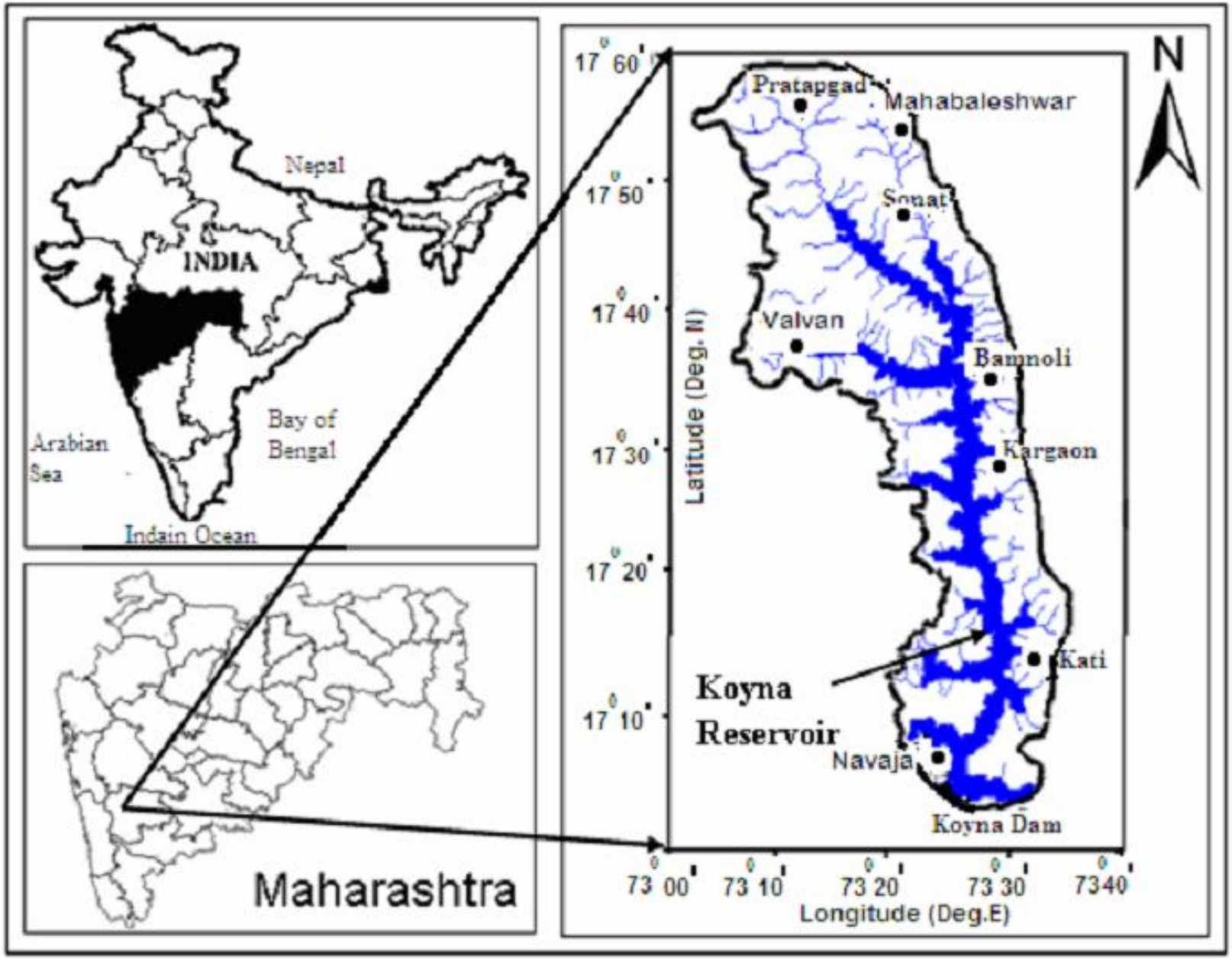
Stage-II

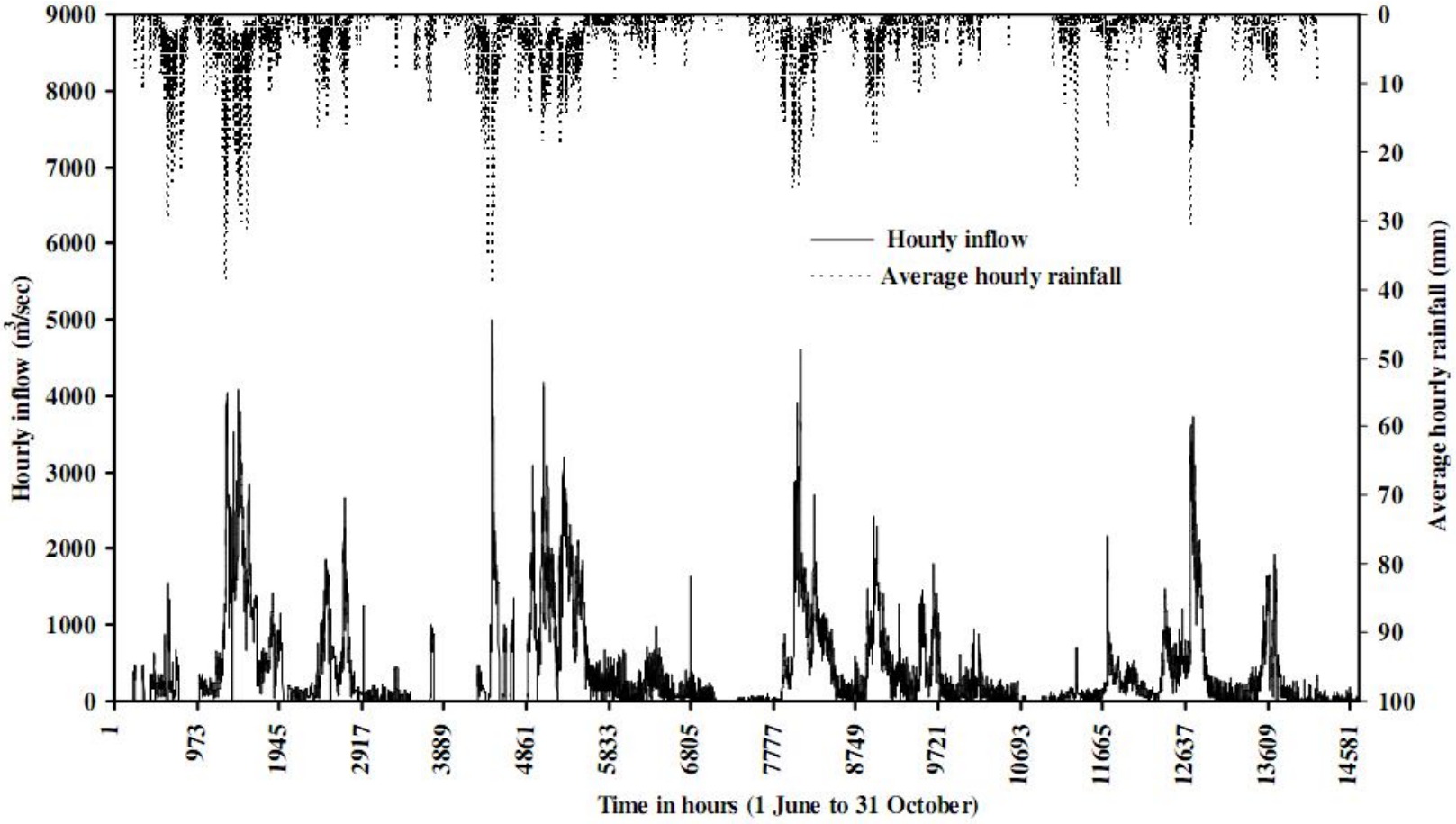
- Development of an IUH for the Koyna reservoir.
- Hourly multi-time step ahead reservoir inflow prediction -With lumped and distributed data
  - Hourly multi-time step reservoir inflow prediction models for Koyna reservoir using MLR, ANN, ANFIS and LGP techniques for lumped and distributed (seasonal 4 years) data.
- Select best model from both hourly lumped and distributed data

Stage-III

To develop and test GUI for both multi-time step daily and hourly reservoir inflow prediction based on best daily and hourly model. Testing data set (2008-2010) for daily data and (2009 -2010) for hourly data. For actual use on dam site

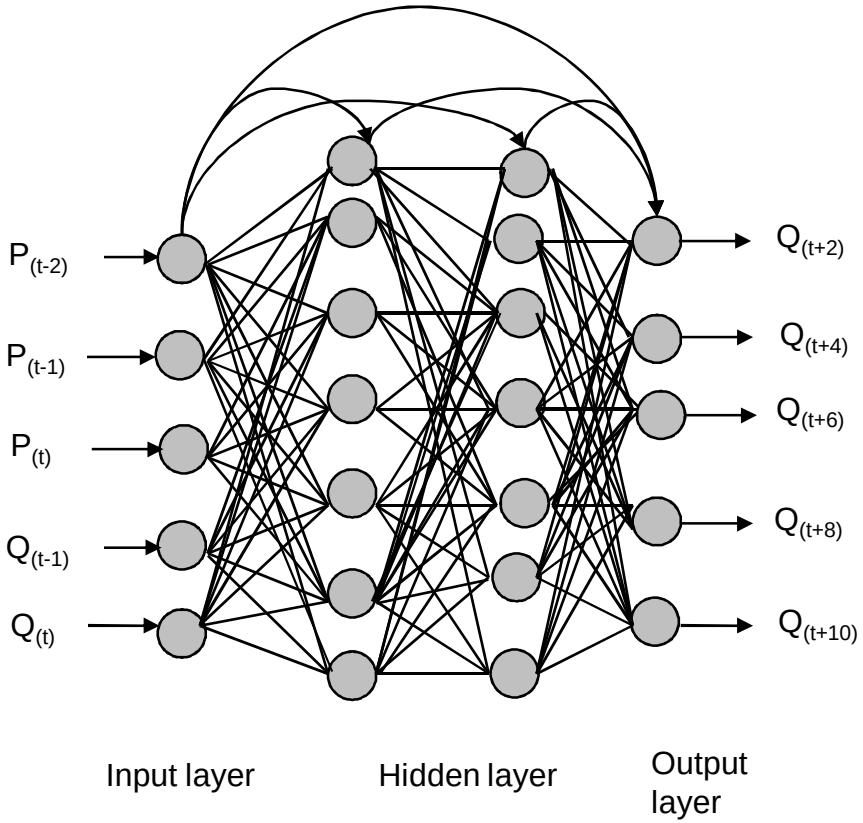
Study Area - Koyna Reservoir





Plot of hourly rainfall and hourly inflow (1 Jun 2005-31 Oct 2008)

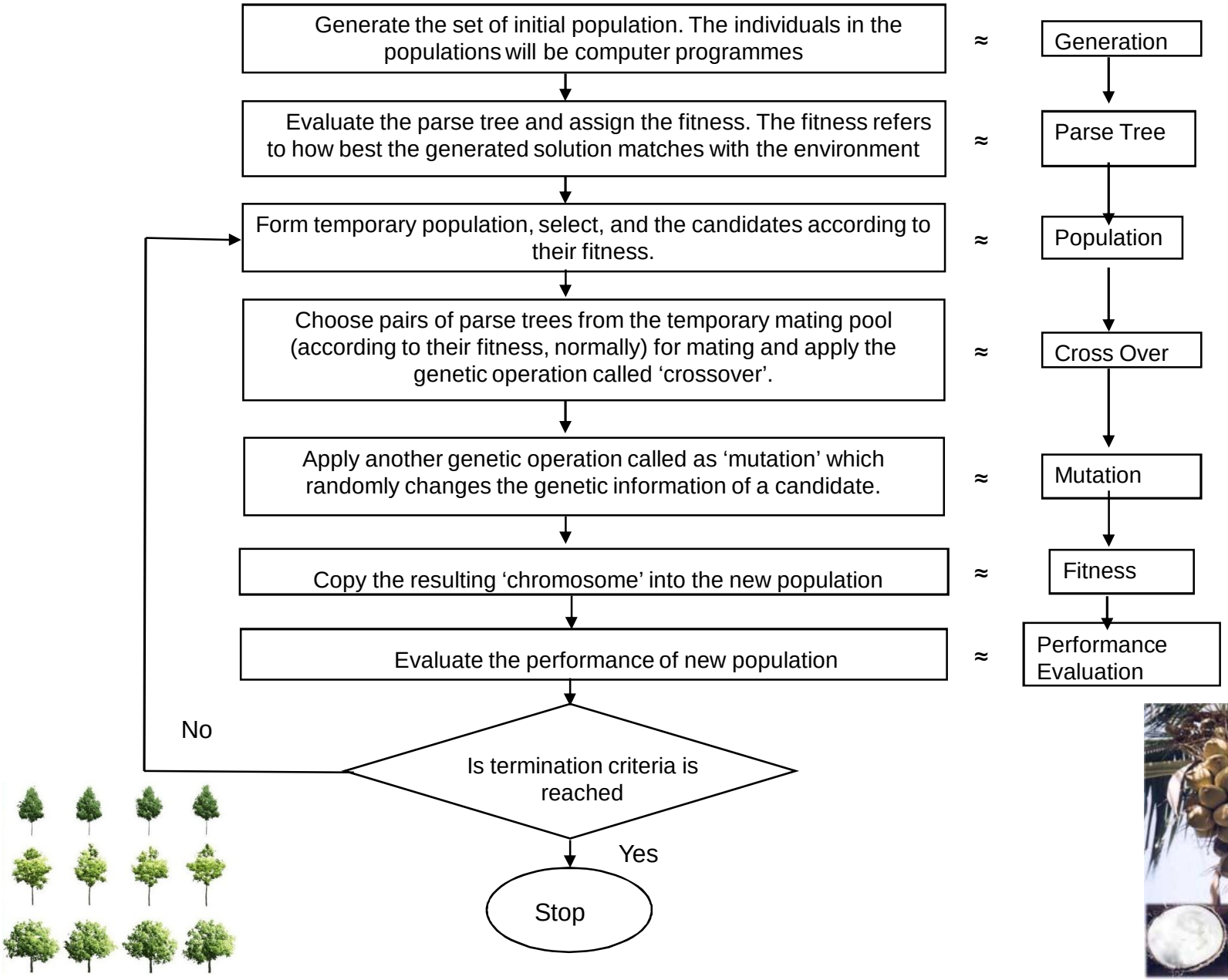
Generalized Feed forward ANN



Connections can jump over one or more layers, allowed to cross the hidden layer, i.e. output layer will get the input from the hidden layer and directly from input layer also

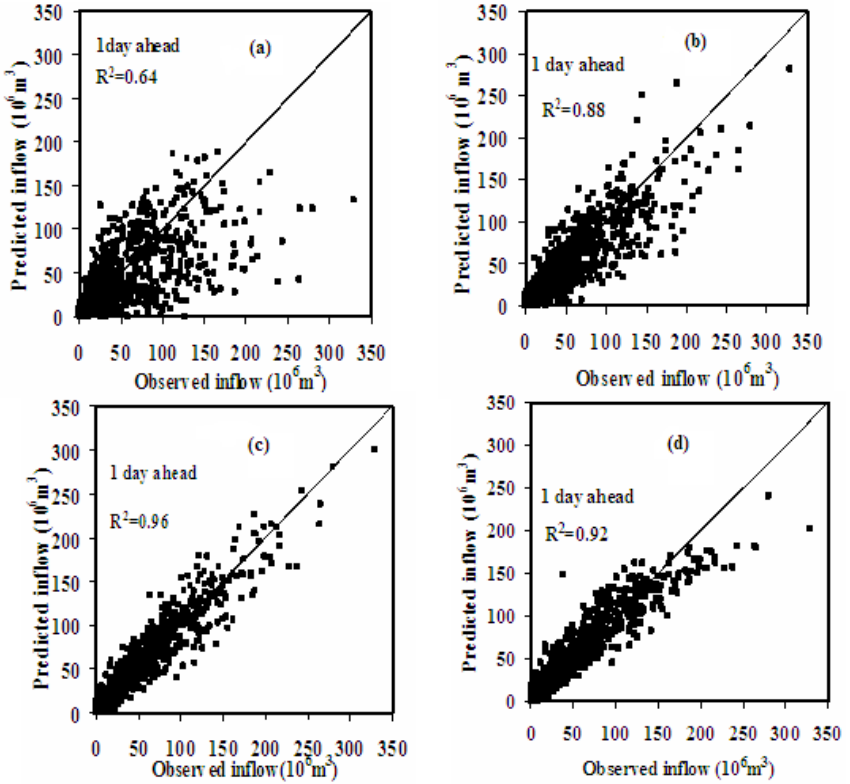
Easy way to explain ANN

Linear Genetic Programming (LGP)



Daily lumped data model performance during training and testing - 1 day lead period – results

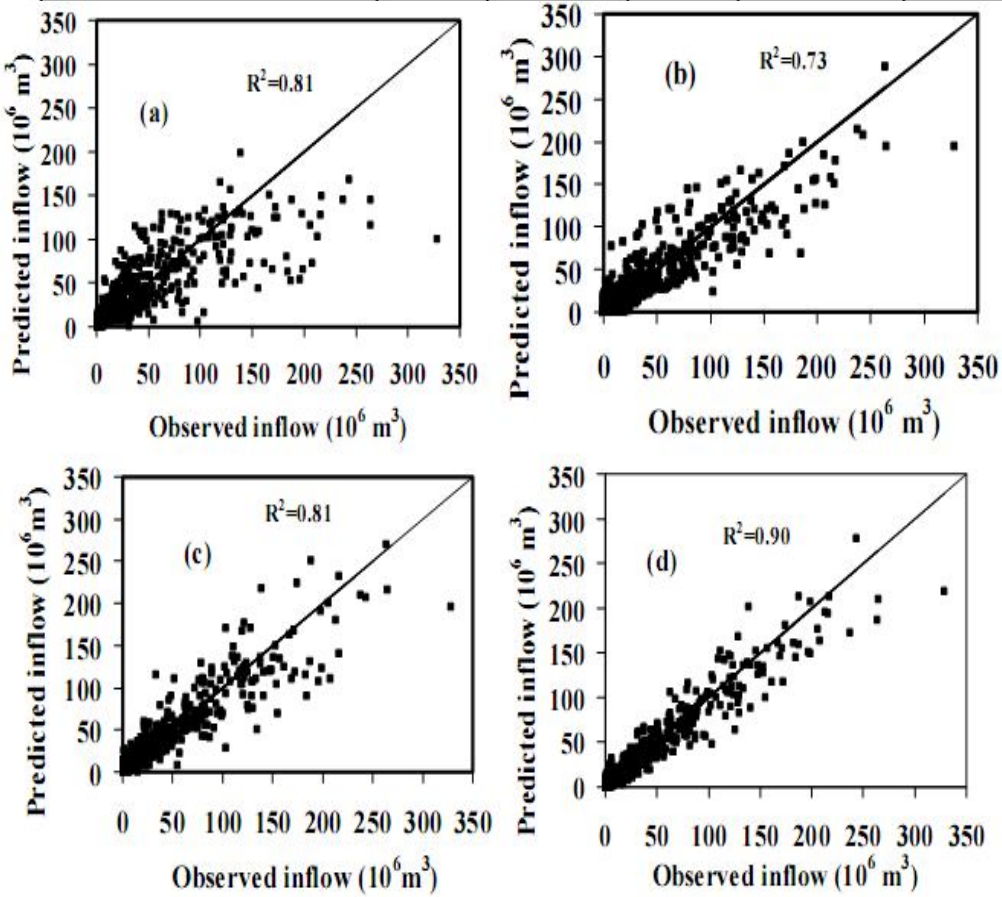
Technique	Training					Testing				
	R	RMSE	E	AIC	BIC	R	RMSE	E	AIC	BIC
MLR	0.84	14.57	0.69	32199.94	32207.33	0.80	14.83	0.66	13891.64	13898.19
TDRNN	0.95	8.37	0.92	25532.96	25540.36	0.94	8.55	0.90	11051.70	11058.24
ANFIS	0.94	7.94	0.91	24899.67	24907.07	0.96	8.07	0.91	10753.42	10759.97
LGP	0.98	6.80	0.93	23043.53	23050.9	0.98	6.95	0.93	9989.05	9995.60



Scatter plot best lumped data model (a) MLR (b) TDRNN (c) ANFIS (d) LGP

Daily distributed data model performance during training and testing - 1 day lead period – results

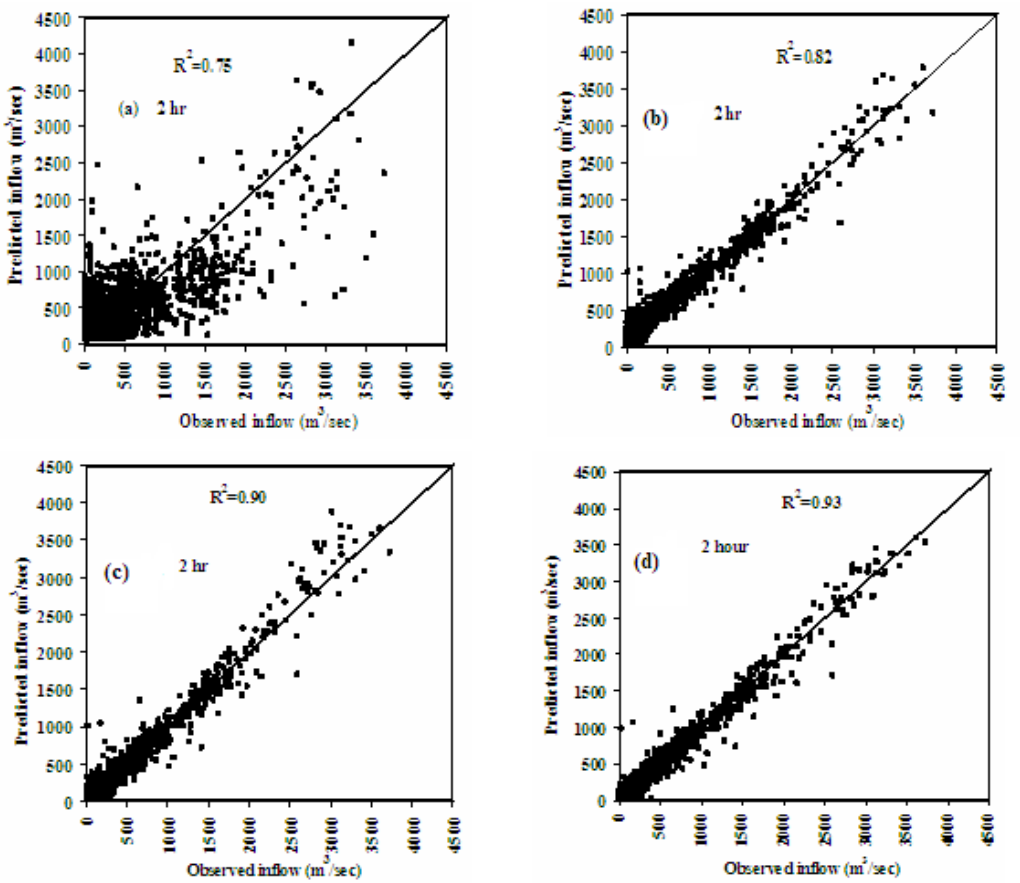
Model Type	Training					Testing				
	R	RMSE	E	AIC	BIC	R	RMSE	E	AIC	BIC
MLR (Model 17)	0.80	16.03	0.67	10642.0	10648.3	0.76	18.07	0.62	4644.36	4649.76
TDRNN (Model 15)	0.90	13.00	0.78	9838.58	9120.45	0.86	12.22	0.84	4114.55	4119.95
ANFIS (Model 16)	0.92	10.34	0.85	8960.64	8966.89	0.90	11.31	0.86	4757.26	4762.66
LGP (Model 16)	**0.94**	**10.22**	**0.87**	**8915.87**	**8922.12**	**0.95**	**10.89**	**0.85**	**3925.23**	**3930.63**



Scatter plots distributed data best model in each case (a) MLR (b) TDRNN (c) ANFIS (d) LGP during testing

Hourly lumped data model performance during training and testing results (2 hr lead period)

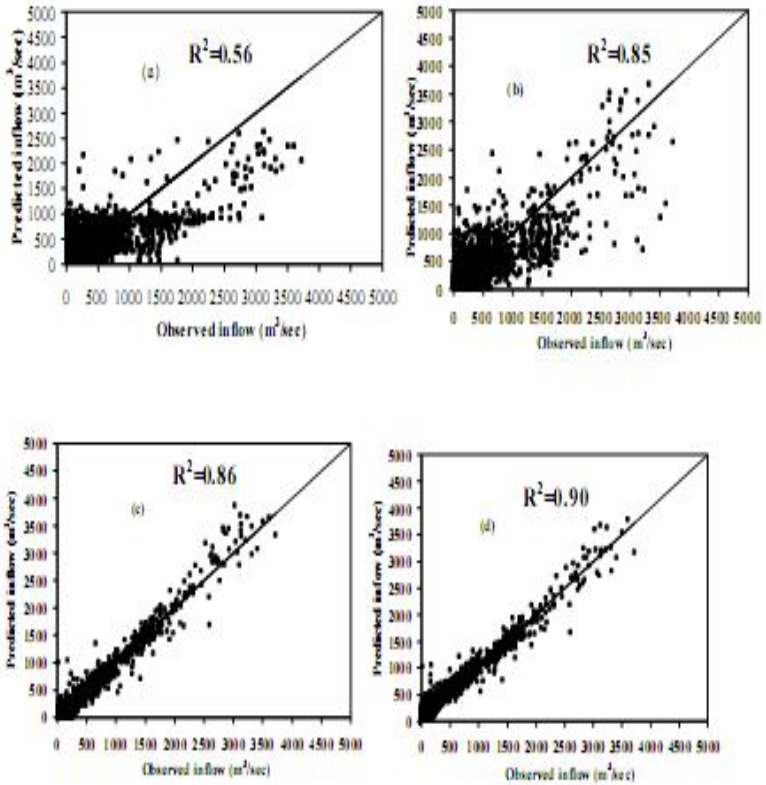
Model	Training				Testing			
	R	RMSE	E	% MF	R	RMSE	E	% MF
HL -MLR Model (4 inputs)	0.82	262.52	0.79	19.45	0.79	270.52	0.75	23.21
HL-ANN Model (5-7-7-5)	0.93	113.08	0.88	12.45	0.91	113.08	0.81	11.39
HL-ANFIS Model (5 inputs)	0.95	79.09	0.90	10.45	0.93	80.43	0.87	9. 54
HL-LGP Model (4 inputs)	0.98	75.76	0.95	-5.47	0.97	77.81	0.93	8.81



Scatter plots of observed and predicted 2 hr ahead inflow (a) MLR (b) ANN (c) ANFIS (d) LGP

Hourly distributed data model performance during training and testing results (2 hr lead period)

Model Type	Training				Testing			
	R	RMSE	E	%MF	R	RMSE	E	% MF
MLR (Model 11)	0.74	286.11	0.68	-10.51	0.73	308.81	0.68	-25.62
GFF (Model 8) (19-7-7-5)	0.95	162.64	0.90	16.56	0.92	263.24	0.85	15.82
ANFIS (Model 11)	0.95	91.98	0.86	14.40	0.93	93.13	0.87	12.90
LGP (Model 8)	0.97	98.64	0.94	8.15	0.95	87.58	0.90	11.54



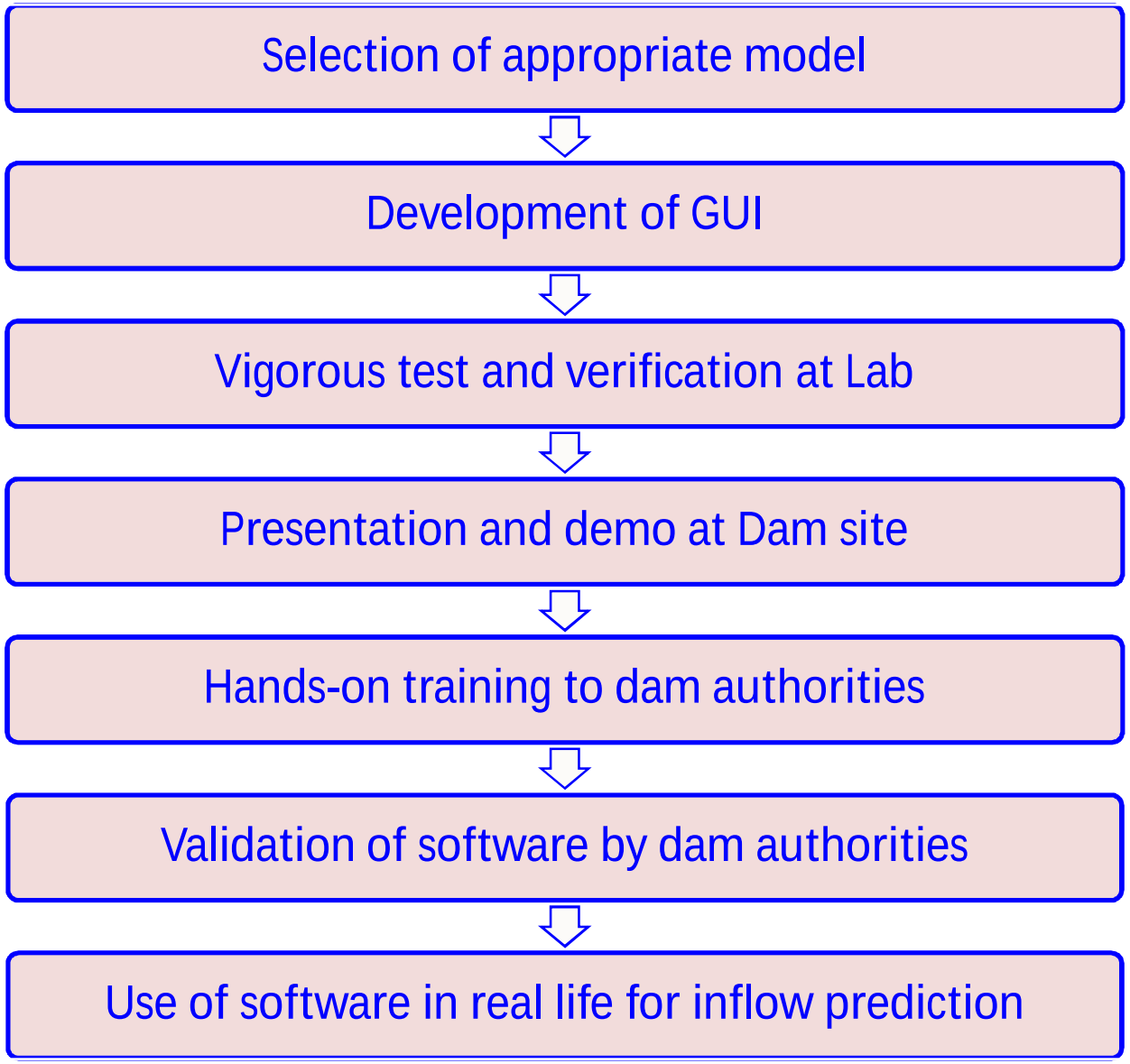
Scatter plots of observed and predicted 2 hr ahead inflow (a) MLR (b) ANN (c) ANFIS (d) LGP

Novelty considered in the model

- Appropriate length of data required to develop a hydrologic prediction model
- Appropriate selection of type of model
  - by statistical performance measures
- Appropriate modifications in the model to predict the peak inflows
- Appropriate methodology to handle longer length of continuous zero values in the time series
  - Data pre processing
- Consideration of time of concentration in the large scale flood retention reservoirs for their inflow prediction
  - Distributed-lumped / multi-time-step-ahead including the time of concentration

Novelty in application of the developed technology to implement in real life for reservoir inflow prediction

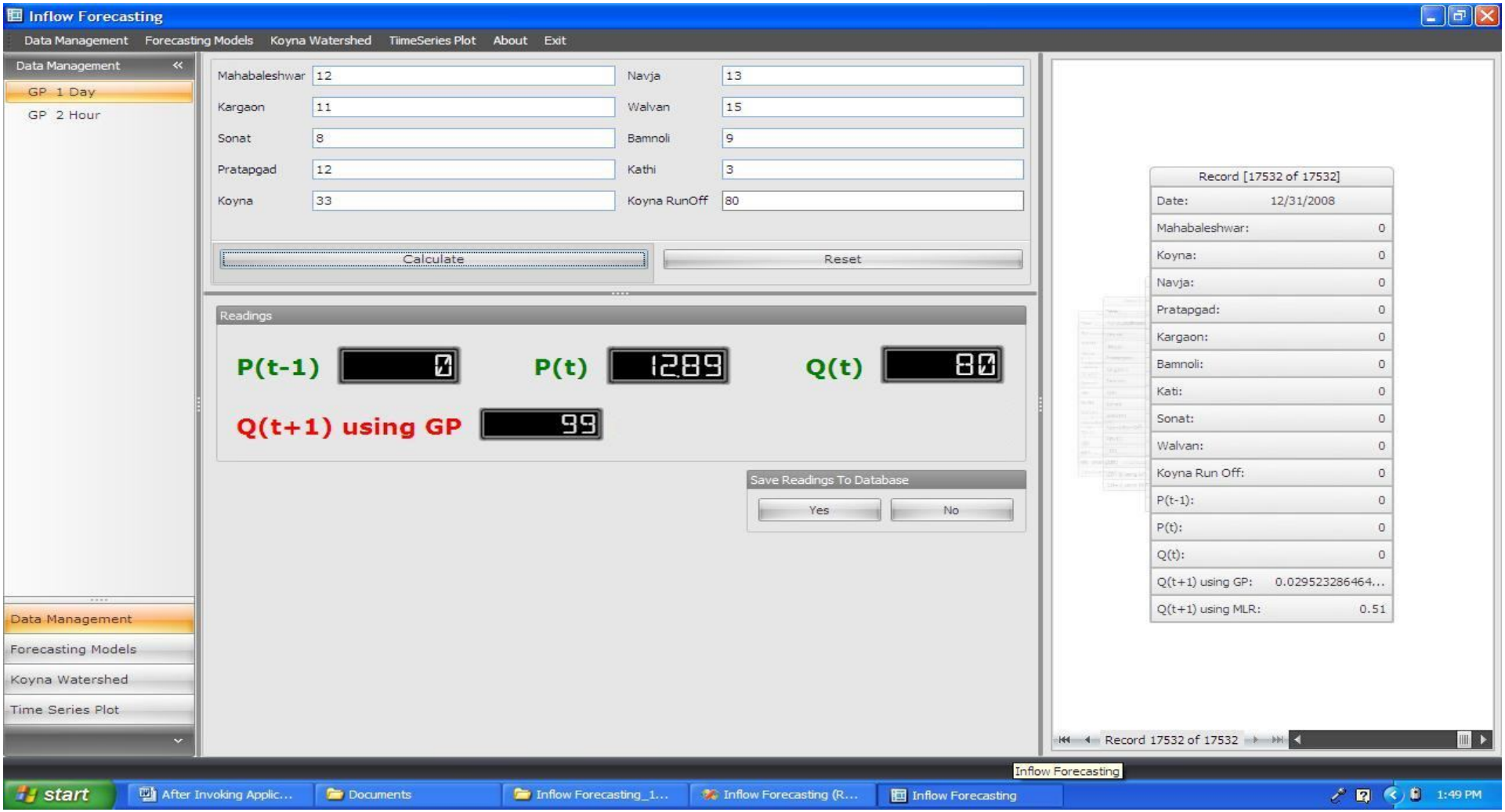
Development of GUI



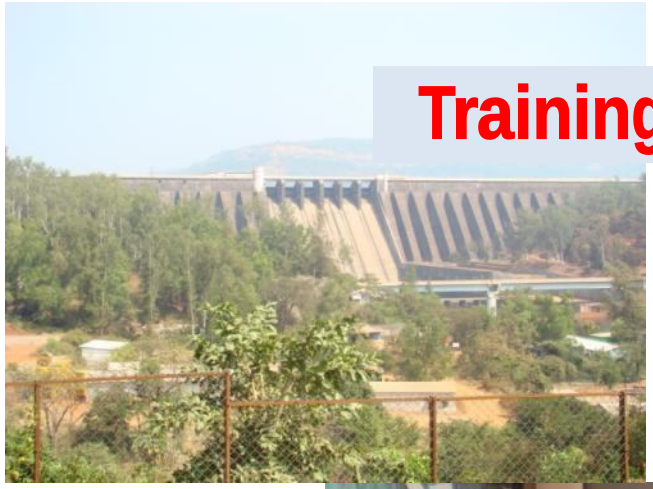
Graphical user interface (GUI)

Splash Screen

Main module of GUI

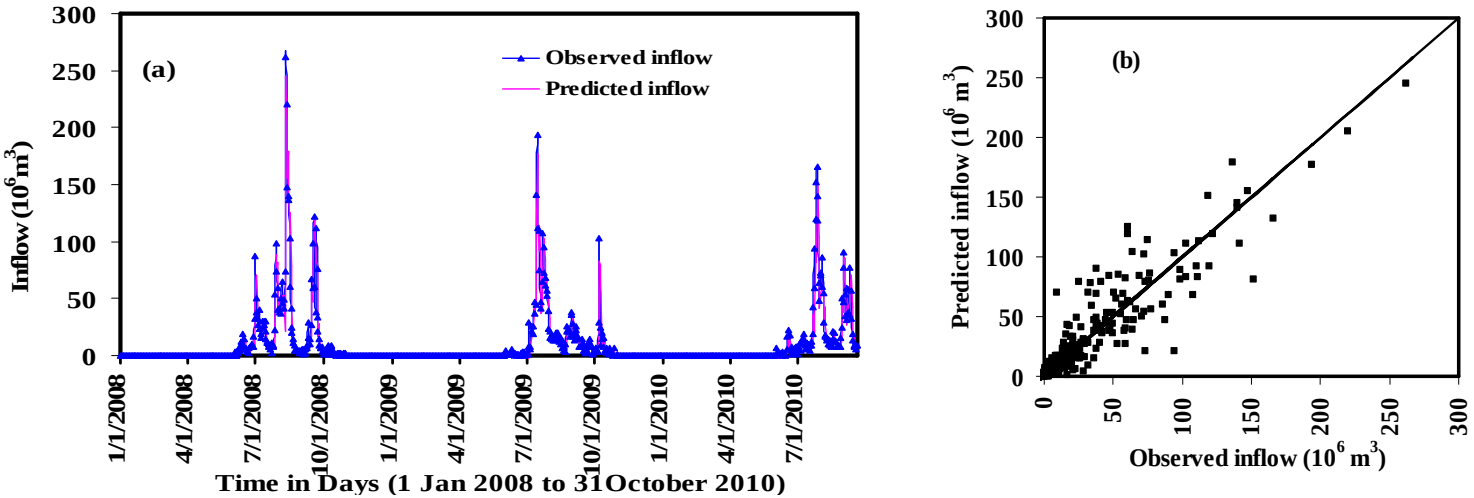


Training Program Photos at Dam office



Statistical performance of daily observed and 1 day ahead predicted inflow during validation and real-time forecasting period (2008-2010)

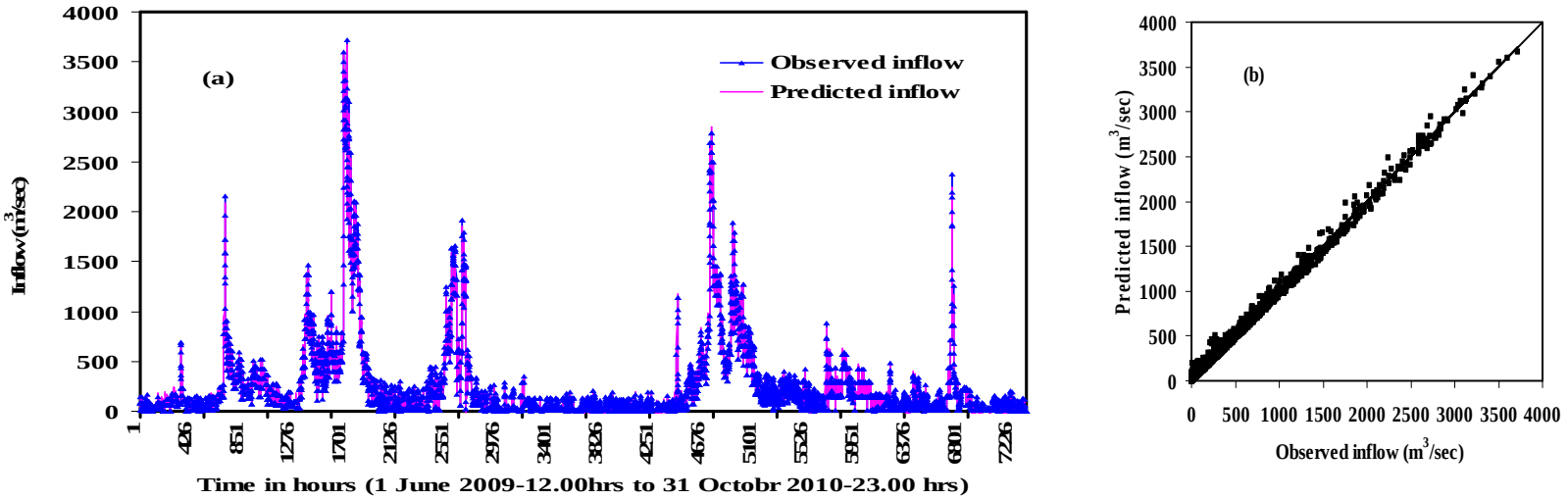
Statistical properties	Observed inflow ($10^6 m^3$)	Predicted inflow ($10^6 m^3$)	% error
Mean	9.49	9.62	1.37
Std. Dev.	24.83	24.18	-2.62
Kurtosis	27.45	25.56	-6.88
Skewness	4.58	4.34	-5.24



(a) Time-series and (b) scatter plot of observed and predicted inflow during validation and daily real-time forecasting period (2008-2010)

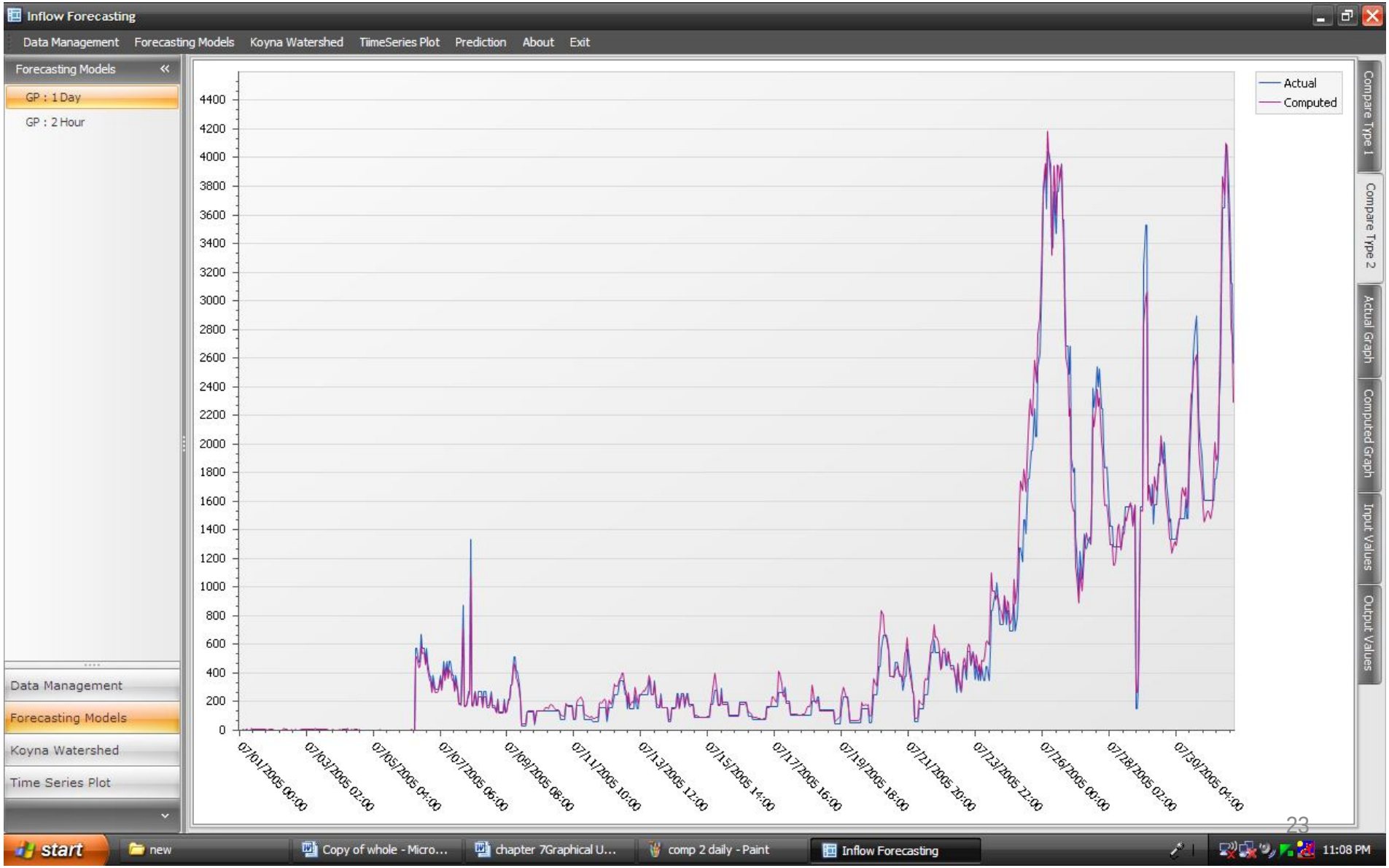
Statistical performance of daily observed and 2 hr ahead predicted inflow during validation and real-time forecasting period (2008-2010)

Statistical Properties	Observed Inflow $m^{3/}/sec$)	Predicted inflow (m^3/sec)	% Error
Mean	205.23	206.30	-0.521
Std Dev	354.39	354.24	0.042
Kurtosis	15.02	15.12	-0.66
Skewness	3.36	3.38	-0.59



(a) Time series and (b) Scatter plot of observed and predicted inflow during validation and hourly real-time forecasting period (2009-2010)

Use of GUI in real life



Letter of Appreciation from the Dam authorities

KOYNA DAM MAINTENANCE DIVISION, KOYNANAGAR

ISO 9001-2000 REGISTERED

Koynanagar, Tal. Patan, Dist. Satara,
Pin-415 207 (Maharashtra State)
☎ 02372/284343 Fax No. :- 02372/284469
E-mail :- eekcd4koyna@sancharnet.in

No. KDMDK/PB1/2758 of 2010
Dated : 30/06/2010

CERTIFICATE

This is to certify that the research scholar Rajendra Baburao Magar who is working under the guidance of Prof. V. Jothiprakash from IIT Bombay has developed Graphical User Interface (GUI) Software for reservoir inflow forecasting of Koyna Reservoir. The software for next time-step inflow forecast has been installed and explained to the officers of Koyna Dam Maintenance Division. The installed software was tested for two years (2008-2010) of daily and hourly data set. The performance of the model is excellent with 'R' values about 0.98 for both the data sets. At present it is being used for real-time Koyna reservoir inflow forecast. I appreciate the work of Rajendra Magar.

Executive Engineer
Koyna Dam maintenance Division
Koyna Nagar

- **Economic benefit**
  - The accurate estimation of inflow is useful for estimating the water releases from the dam for various purposes like power production, irrigation and industrial use. Especially the flood release, which is directly affecting the Sangli City. There is large amount of intangible benefits.
- **Industrial Utility**
  - The present models and GUI can be converted into a adaptive mode models and can be used at any intermittent reservoirs.
- Work in Progress
  - Catchment classifications – to generalise the work
  - Need to apply for patent after this step.

Students Involved

- **Research Scholars:**
  1. Dr. Alka S. Kote,
  2. Dr. R.B. Magar,
  3. Mr R. Arunkumar
  4. Ms. Fathima T. A.
- **M. Tech Students:**
  1. Mr. Sunil Kalkutti,
  2. Ms. Dipali More
- **B.Tech Students:**
  1. Ms. Nilesh Priya,
  2. Mr. Mayank Dobhal,
  3. Mr. Mayank Mehta,
  4. Mr. Nirdesh Kumar,
  5. Ms. Harpreet Kaur
- **Summer Internship Students:**
  1. Tirupan Mandal

Other Awards

- **ISTE-Maharashtra State National Award for Research Work in Engineering and Technology for the year 2011** awarded by *Indian Society for Technical Education*, during the 41st Annual Convention of ISTE held at Fatehgarh Sahib, Punjab on 16th Dec 2011. (for overall work on the Reservoir inflow prediction)

- **The Union Ministry of Water Resources: Department of Irrigation Prize** awarded by *Institution of Engineers (India)* for the paper published in Civil Engineering Division, during the 25th Indian Engineering Congress held at Kochi on 17th Dec. 2010. (for the paper co-authored with Dr. Alka S. Kote, listed as number 5 in the list of publication)

- **Dr. Magar's PhD thesis has been selected for the Excellence in Thesis Work, IIT Bombay, the awarded during the 50th Convocation, 2012.**

Publications

- **Published**
  - ❖ International Journals 10
  - ❖ National Journals 06
  - ❖ International Conferences 07
  - ❖ National Conferences 26
  - ❖ **Total** **49**

- **Submitted**
  - ❖ International Journals 08
  - ❖ National Journals 07
  - ❖ International Conferences 01
  - ❖ National Conferences 02
  - ❖ **Total** **18**

Acknowledgements

- IRCC –IITB – seed grant
- DST- Workshop
- MoWR – R& D Project
- Korean Research Foundation-R&D Project
- Chief Engg, Exec. Engg Koyna Dam Irrigation and Maintenance Division and Kukadi project – for data and support and for using our models today
- Research Scholar : Alka Kote, Magar, Arunkumar, Fathima and others

Thank you