RESERVOIR OPERATIONS USING HYBRID MODELLING - ANN AND FNN

A DISSERTATION
SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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OF

MASTER OF TECHNOLOGY
IN
HYDRAULICS AND WATER RESOURCES ENGINEERING

SUBMITTED BY

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CANDIDATE'S DECLARATION

I, SHIVANI, Roll No. 2K19/HFE/13 of M.Tech **(**Hydraulics and Water Resources Engineering), hereby declare that the project Dissertation titled "**RESERVOIR OPERATIONS USING HYBRID MODELLING- ANN AND FNN**" which is submitted by me to the Department of Hydraulics and Water Resource Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**RESERVOIR OPERATIONS USING HYBRID MODELLING- ANN AND FNN**" which is submitted by SHIVANI, Roll No. 2K19/HFE/13 Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

In this study, an attempt has been made to study reservoir operations using different technologies to check for their efficiency in predicting the water supply release and comparing it with the demands to be met. A hybrid modelling comprising of ANN and FNN has been used. ANN has the ability to predict the output data by assigning weights to the input variables based on its learning ability while FNN has an advantage of making decisions based on the logical inferences of fuzzy rules. The system considered for study purposes in this project is multipurpose reservoir dam across Sutlej river- Bhakra reservoir also known as Govind Sagar Reservoir situated in Una and Bilaspur district of Himachal Pradesh. Combining these two model for reservoir operations of Bhakra reservoir will improve the efficiency of operations of reservoir during critical time period.

From the results it was observed that the improvement in the performance of reservoir operations were significant emphasizing on the use of AI methods such as ANN and FNN. Storage capacity, inflow into the reservoir and Evaporation losses were considered as independent parameters for the modelling the operations of ANN and FNN. These input parameters are tested for randomness and any correlations using the regression analysis method. Linear regression method for prediction of release is also effective but is not suggested because of numerous computations involved, this may result in confusion and chaos. Hence, the hybrid model of ANN and FNN is regarded as the most suited one for reservoir operations. Along with this an attempt has been made to predict the release and compare the same graphically using programming language such as Python. The algorithms of ANN, Random Forest and XGBosst has been used as these operates on the principle of Decision Trees and hence are considered effective for prediction and comparison purpose.

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LIST OF SYMBOLS AND ABBREVIATIONS

WMO	World Meteorological Organization
ARMA	Autoregressive Moving Average
LP	Linear Programming
DP	Dynamic Programming
Th. Ha	Thousand Hectare
CCA	Culturable Command Area
BCB	Beas Construction Board
BBMB	Bhakra Beas Management Board
BMB	Bhakra Management Board
AI	Artificial Intelligence
ANN	Artificial Neural Network
FNN	Fuzzy Neural Network
BCM	Billion Cubic Metre
MCM	Million Cubic Metre
R^2	Coefficient of Determination
MSE	Mean Square Error

CHAPTER 1

INTRODUCTION

1.1. GENERAL

Reservoirs are the important component of water resources system. These are constructed by creating a dam across a stream. The objective of reservoir is to maximize the regional welfare along with regulating the natural flow by storing the surplus amount of water in the wet season and releasing the stored water to meet the demands especially during the dry season. These are also responsible for hydropower generation. The purpose of reservoir is to change the temporal and spatial availability of water. The basic needs that come along its purpose is to store and control floods, hence there are to be carefully designed and monitored. Sufficient storage should be provided to the reservoirs to cater to the needs of growing populations along with serving the functions of flood control, water supply during the normal water requirements and sufficient water availability during the drought periods. It should serve all the seasonal requirements efficiently.

The water stored in the reservoir could be diverted to different places as per the requirements through canals, pipes etc to the meet the demands of irrigation and other beneficial purposes. The head of the water stored could be used for generation of electric power. Reservoir designed for the flood control purposes stores the flood water thereby attenuating the hydrograph peaks. It also becomes imperative in terms of navigation purposes, for recreation and sports facilities and supports habitat for aqua life thereby enhancing the scenic beauty along with promoting afforestation.

The efficient use of water resources requires judicious use of the water components and its proper management. As water is important and a prime natural resource where only 2.7% of water is available as freshwater out of which majority lies in the form of frozen ice in the polar regions, leaving us with mere percentage of water for all the purposes. Hence water conservation and its utilization for various benefits is important.

In the past few years' country has witnessed immense industrialization and urbanization for the economic development. This has resulted in the increase in the quantity and quality of demand of water. To cater to these needs more complicated reservoir operation methods are being implemented which includes the government policies in combination with the efficiently formulated supply system to reduce the conflicts thereby meeting the demands as per the requirements.

The reservoir operations assist in managing the reservoir by specifying the amount of the water to be released from the reservoir storage at any time, depending on the storage availability of reservoir, level of demands and based on the hydrological parameters such as rainfall, total inflow, evaporation rate etc. In multipurpose reservoir, it is required to allocate certain amount of water for release for several purposes.

The conventional method of reservoir operations includes empirical methods and judgement based correct operational decisions. Now with the applications of engineering techniques and with the help of AI, it is possible to solve water resources problems and evaluate the consequences of operating decision in advance by simulation of the river system and reservoir operation on real time basis. The real time study of reservoir operation is done to maximize its benefits and minimize the adverse effects.

1.1.1. CHARACTERISTICS AND REQUIREMENTS OF WATER SUPPLY

The various purposes for which for which a reservoir is used and their functional requirements for these purposes are:

a) Irrigation
Water requirement for irrigation are seasonal and are based on the types of crops, water availability, cropping patterns in the command area. The irrigation demands are consumptive. The demand values are in direct correlation with the rainfall in the command area. These depends on the crops (Kharif and Rabi crops). The irrigation requirement is maximum during winter and summer months and minimum during monsoon period. The annual demand almost remains constant and the variation pattern is observed for different cropping patterns over year over a command area.

b) Hydroelectric power
The hydroelectric power demand varies over season to daily or hourly variations. It is non consumptive demand as water gets utilised at the downstream after passing through the turbines. The availability of water head at the reservoir, its volume and the demand at the downstream is considered for the hydroelectric production.

c) Municipal and industrial water supply
The water demand for both increases due to rapid growth of populations and urbanization. It follows a trend and is mostly constant throughout the year when compared with the irrigational and hydroelectric demands. The seasonal peak demand is observed during summer. Hence the supply system is designed to meet the high reliability.

d) Navigation
Sufficient storage depth is maintained in the reservoir over its entire stretch to allow navigational purposes. The water requirements show seasonal variations. Its also depends on the type and volume of the navigable traffic.

e) Flood Moderation
Flood control is an important function of a reservoir. This is achieved by temporarily storing the flood water and releasing the water in a controlled manner with respect to time and space. Reservoirs are solely not designed for the flood control but are designed for both conservational purposes and flood control purposes. The flood storage capacity varies over years.

When the reservoir is at its full capacity level, then to counter the floods, flood cushioning is created. This is created by releasing the additional water thereby making temporary space for storing the flood water. This is called pre-release or reservoir evacuation. In this scenario, forecast of inflows and other hydrological parameters plays an important role to make the decisions for the reservoir operations without affecting the storage space of reservoir thereby increasing its efficiency.

1.1.2 NECESSITY OF HYDROLOGICAL FORECAST

a) Hydrologic Forecast:

Hydrological forecast is imperative for reservoir operations. Forecast can be classified as short term (up to 2 days), medium term (2-10 days), long terms (beyond 10 days) or seasonal (several months) according to the WMO guides.

b) Forecasts for flood control:

Forecasting is pivotal for flood control. Short term forecasting is used for reservoir operation for controlling flood. This forecasting is done on the upstream side followed by the routing on downstream side. The routing is done by simple hydrologic procedures which are based on conservation of mass whereas the routing of complex models is based on conservation of mass and momentum involving differential equations.

Other method of short-term forecasting is through time series analysis and stochastic modelling. These forecasting were based on the observed historical values or the mean of the historical values. Later, concept of moving average was introduced. Exponential smoothing of errors became less popular after the introduction of more systematic method of smoothing errors thereby making short term forecasting more reliable using Box-Jenkins models and these are effective for immediate future prediction as the variance of forecast function increases with time. Adaptive types are the alternatives to the Box-Jenkins model where model parameters are updated prior to forecasting using the previous estimates and function of prediction error process.

c) Forecast for storage:

Forecasting inflows in the reservoir is necessary in order to utilise water available in excess or restrict the supplies during the low inflow periods to make the reservoir operations more efficient. These forecasts may be seasonal or long term. As most of the inflow is received during monsoon period hence it becomes easier to plan the supplies for the forth coming rabi season. The challenge arises during the Kharif season especially when the monsoon fails or is short lived. In such scenario, inflow into the reservoir decreases and demand increases. Thus, optimization models are important to predict such case scenarios and take actions accordingly. One such example is using Time series model. Time Series model such as ARMA models could be used for long term forecasting based on seasonal or monthly basis. Time series model could be used for monthly stream flow forecasting.

1.2 PRINCIPLES OF RESERVOIR OPERATIONS

Operation of reservoirs are carried out through sets of rules and guidelines for storing and releasing water to serve its purpose.

The continuity equation (water or mass balance equations of a reservoir) forms the basis of reservoir operations. These are expressed as under:

$$\boxed{S_t = S_{t-1}+I_t+\bar{I}_t+P_t-Ev_t-O_t-O'_t} \quad (1.1)$$

for all t……..

Where

S_t = reservoir storage at the end of time t
S_{t-1} = reservoir storage at the beginning of time t
I_t = inflow into the reservoir during time t
$\bar{I}_t$ = local inflow to the reservoir from surrounding area in time t
P_t = precipitation volume in the reservoir in time t
Ev_t = evaporation losses from the reservoir in time t
O_t = total outflow (release) from the reservoir in time t
O'_t = release (mandatory release) to natural channel from reservoir in time t

1.3 OPERATIONAL MATHEMATICAL TECHNIQUES

The popular operational mathematical approach used are simulation and optimization.

1.3.1 SIMULATION

It is the simple and versatile method of evaluation. It can be deterministic or stochastic. If randomness is involved in the system in terms of inflow or other parameters, then is a stochastic model. If no randomness is involved, then it is called deterministic. Stochastic models are best suited for reservoir operations. For instance, A reservoir can have conditions of being half full, full or empty, whereas precipitation received is a random parameter, hence the demands are also random. As randomness is associated with this, thus Stochastic simulation is the best suited model for reservoir operations.

Simulation is time and event sequenced. Hence a fixed time interval is selected and the state of the system (i.e., flow, demands, storage volumes) are assessed in the successive time intervals. Care should be taken to increment by small amount so as not to lose data. Hence time interval should be selected with utmost care.

1.3.2 OPTIMIZATION

Optimization is choosing the best solution out of the given number of possible alternatives. Optimization methods find out a set of decision variables such that the objective function is optimised.

1.4 OBJECTIVE OF STUDY

Bhakra reservoir is the biggest artificial lake that has been planned pre-independence period and has been completed post-independence. Majority of study has been carried out on this reservoir but still it catches hold the eyes of researcher to for further analysis and improvement. An attempt has been made to understand the reservoir operations of the reservoir and compare its results with different methodologies available for the best possible result. This will enhance the working efficiency of the reservoir.

This objective of reservoir operations is achieved by modelling the datasets using Linear regression (statistical regression analysis), by using the concept of hybrid modelling of Artificial Neural Network (ANN) and Fuzzy Neural Network (FNN).

Major focus is upon hybrid modelling as is incorporates the advantage of both the models to derive single operation.

1.5 STUDY AREA

1.5.1 CASE STUDY OF BHAKRA DAM RESERVOIR

Two important factors for the construction of this reservoir were for irrigation and power generation purposes. This integrated complex structure requires efficient management for its operations to meet the demands of irrigation and power generation. The efficient usage and its achievement in attaining the targets have been studied in the successive chapters via formulations through software. A case study of Bhakra Dam Reservoir has been studied in this paper. Fig 1.1 shows the location of reservoir basin considered for the case study.

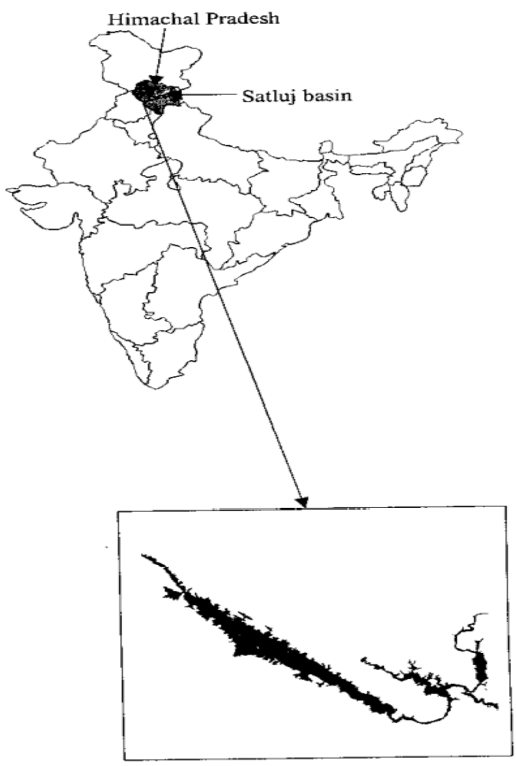

Fig1.1 Representation of the reservoir basin

1.5.2 SYSTEM DESCRIPTION

The Bhakra reservoir is also known as Govind Sagar Reservoir. The Bhakra system is one of the largest projects of India. Bhakra dam is a 225.55m high concrete gravity dam constructed in 1963, on the river Sutlej in Bilaspur district, Himachal Pradesh. The river Sutlej is the largest tributary of river Indus, begins in Tibet and enter the Indo-Gangetic plains near Bhakra. The important purpose served by Bhakra dam is controlling floods, meeting irrigational demands and efficient hydropower generation. The Govind Sagar reservoir is like a huge lake on the upstream side of the dam. The widespread area covers 168.35km^2 of land at fill reservoir level of 515.11m. The total catchment area at upstream of Bhakra is 56,980km^2. The water head of the reservoir is as high as 12.87km above Slapper village near Kasol. The dead storage and live storage of is about 2431.81Mm^3 and 7436.03Mm^3 respectively. In a dependable year the total runoff is around 13,723Mm^3. Furthermore, salient features of the dam are mentioned in Table 1.1.

The reservoir receives its inflows mainly from rainfall and melting of snow. Around (40-60) % is received for annually into the reservoir from monsoon season whereas (5-10) % is received as inflow post monsoon period. Long duration of sedimentation affects the life span of dam. As Sutlej ricer transports heavy sediments, it affects the functioning and storing efficiency of the reservoir. The area around the reservoir is prone to landslides, which adds up to the sedimentation in the reservoir. However, the detailed characteristics of the reservoir are discussed in Table 1.2.

Table 1.1 Characteristic of Bhakra Dam

Total cost of the project	Rs. 245.28 crore
Type of Dam	Straight Gravity Concrete Dam
Height above the deepest foundation	225.55 metres (740 feet)
Height above the river bed	167.64 metres (550 feet)
Length at top	518.16 metres (1700 feet)
Width at top	9.14 metres (30 feet)
Length at bottom	99.06 metres (325 feet)
Width at base	190.5 metres (625 feet)
Elevation at top of dam above mean sea level	518.16 metres (1700 feet)

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

Table 1.2 Characteristics of Bhakra Dam Reservoir

Catchment area	56876 sq. Kilometres
Normal reservoir level	EL. 513.58 metres (EL. 1680 ft.)
Dead storage level	EL. 445.62 metres
New area irrigated	60 lakh acres
Area of reservoir	162.48 sq. Kilometres (62.78 sq. miles)
Length of reservoir	96.56 kilometres
Live storage capacity at EL. 1685 ft.	7189.33 million cum (5.80 MAF)
Gross storage capacity at EL. 1685 ft.	9621.14 million cum (7.80 MAF)
Dead storage capacity	2431.81 million cum (1.97 MAF)

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

1.5.3 IRRIGATION DEMANDS

The main objective of commissioning of Bhakra dam was for irrigation purposes, to irrigate area of 1.42 million hectares in addition to 2.43 million hectares. The area covered under this are Punjab, Haryana and Rajasthan. The crops grown during Kharif season in these areas are bajra, cotton, maize, rice, jowar, sugarcane, oilseeds, pulses and fodder. While the crops sown during Rabi season (winter) are wheat, gram, oilseeds, barley, potatoes and fodder.

The irrigation requirements have been changing of late due to advancement in the cropping systems. The high yielding crops requires more water, thereby increasing the demand from the reservoir.

The irrigation water required during maturing of Kharif crops is more. Also, more amount of water is needed for preparation and sowing of Rabi crops too. The water requirements vary from moths to season, as more amount of water is needed during the months from September to November and from May to June. However, during the monsoon period, majority of the demands are met by the rain.

Summarizing the command area benefits of the Bhakra Project in Table 1.3:

Table 1.3 Bhakra Project: Irrigation Benefits (All in m ha)

Gross Commanded Area	2.68
Culturable (Cultivable) Commanded Area	2.37
Annual Irrigation (Proposed)	1.46

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

From Table 1.3, it is observed that many parts of Punjab have been irrigated by the Bhakra dam where the annual irrigation is 3.602Vm acres or 1.46 m ha. This has in turn increased the yield of the crops.

As per 1988 BBMB report, the given below in Table 1.4 is the state wise CCA

Table 1.4 State wise Cultivable Command Area of Bhakra Project

State	CCA (Million ha)	% Of Bhakra CCA in state
Rajasthan	0.372	16%
Haryana	1.160	49%
Punjab	0.840	35%
Total	2.373	

Source: BBMB report 1988

The Gross irrigated area (GIA) as a percentage of Gross cropped area (GCA) for the India in average is 40% but this percentage rises much above the average value to 91% for Punjab and 85% for Haryana alone. Due to this, the project has been proved boon in this area and helped in bringing the poverty curve to the lowest.

1.5.3.1 Developments at the Project

With the completion of the dam, a rapid surge in the irrigation was observed. The dam met the irrigational and power demands.

Table 1.5 shows the development of irrigation from the Bhakra project from inception to 1963-64.

Table 1.5: Development of Irrigation from the Bhakra-Nangal Project

Year	Area Irrigated		Year	Area Irrigated	
	Acres	Ha		Acres	Ha
1951-52	16170	6547	1958-59	1712020	693126
1952-53	46320	18753	1959-60	1818000	736032
1953-54	46320	18753	1960-61	1700000	688259
1954-55	868890	351777	1961-62	1909000	772874
1955-56	1033411	418385	1962-63	2321000	939676
1957-58	1303000	527530	1963-64	2480000	1004049

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

On comparing the project report from table 1.3, it was observed that the total annual irrigation was 1.46 m ha which indicates that about 68% of the planned irrigation had been achieved in 1963-64. Thus, over the years irrigation from the project have significantly increased.

Bhakra commands the districts of Punjab, Rajasthan and Haryana. The Bhakra command is divided into 3 zones namely- I, II and III

Zone I- Area near the hill that receives ample rainfall during monsoon and winter. these are north of Sutlej and areas of south of Patiala.

Zone II- Areas on both sides of sutlej which receives libreal supplies from inundation canals.

Zone III- These are the dry and arid tracts of Hissar and Rohtak. the rainfall is less and spring level is low. It is the critical zone.

As most of the areas of Punjab fall under zone I and zone II, while 15% of the area fell under zone III as shown in the Table 1.6, hence Punjab had limited benefits from the Bhakra system. However, Haryana and Rajasthan have been largely benefitted from the reservoir system. In Haryana most of the areas are under zone III as discussed in Table 1.7 while all the areas fall under zone III in Rajasthan.

Table 1.6 Zone-wise Bhakra Gross Command Area in Punjab (Acres)

Zone I	1304390	57%
Zone II	666870	29%
Zone III	334733	15%

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

Table 1.7 Zone-wise Bhakra Gross Command Area in Haryana (Acres)

Zone I	460720	14%
Zone II	0	0%
Zone III	2772793	86%

Source: Unravelling Bhakra-report study by Manthan Adhyayan Kendra

1.5.4 EVAPORATION RATE

In this study, the evaporation rate is taken from the period of 21 years. The negative sign denotes that the evaporation has taken place and is more than the precipitation that might have happened during that time whereas the positive results show that the net evaporation is less that the rainfall received hence minimizing the effect of evaporation.

Evaporation and transpiration are seasonal dependent and during low temperatures with low wind speed, the evaporation noted is low. However, evaporation increases with increase in temperature, wind velocity with low cloud cover. Maximum rate of evaporation is observed from May-June.

1.5.5 HYDROELECTRIC POWER

In earlier days of proposal of the dam, hydroelectric power generation was not its objective. 1939-42 Project Report incorporated hydroelectric power development for the first time, as an integral part of the project. Majorly in 1951 Project Report, a multipurpose scheme focused on the primary objective of incorporating irrigation and hydropower generation as its important components. In 1955, BCB installed 4 units at the powerhouse but in 1960, the need of 5unit was felt at Bhakra and was installed. Similarly, the need for installing more units i.e., sixth and seventh units were felt in 1962 and 1965.

Earlier, at all India level, the total hydroelectricity generated throughout the country was about 25% only but now, as reported by BBMB, 50% of the hydropower in the northern region of India is provided by the Bhakra-Nangal Dam project along with generating huge revenue. As a result, by 1976, it was possible to provide 100% electrification in areas of Punjab and Haryana.

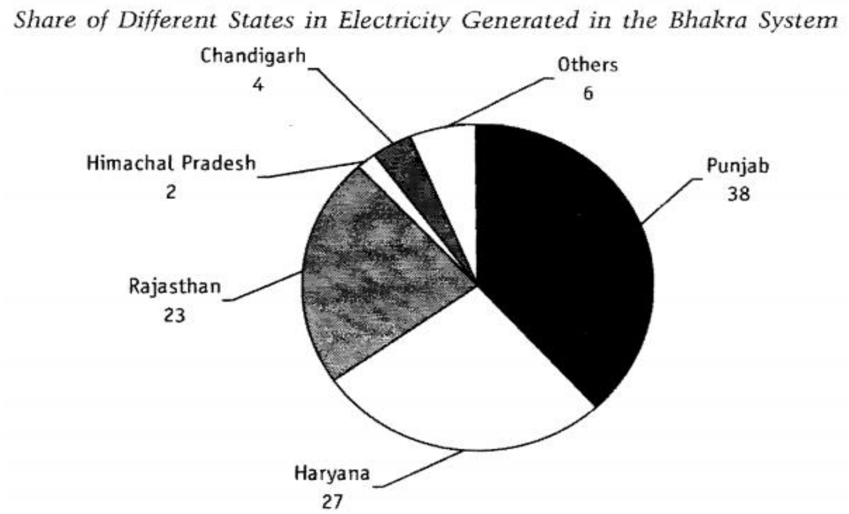

Fig 1.2 Percentage share of total electricity generated in the Bhakra System

Source: Indirect Economic Impacts of Dams, Ramesh Bhatia-45524

From Fig 1.2, it is observed that the electricity generated through the Bhakra dam is widely used across various states among which the highest utilisation is by Punjab.

1.5.6 STANDARD OPERATING POLICY

BMB (Bhakra Management Board) looks after the operating policies and regulation of water supplies from the reservoir. 1 June to 31 May is considered water year, which is divided into two periods namely 'filling period' and 'depletion period'. 1 June to 20 September is the 'filling period' as water in the form of inflow into the reservoir is available due to snowmelt and rainwater which fills up the reservoir. 21 September to 31 May is the 'depletion period' when the water is released from the reservoir to meet the demands of irrigation and power. For the depletion period, generally water power studies are conducted for the available stored volume of water.

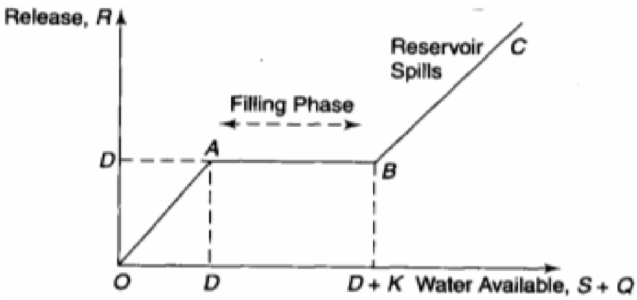

Fig 1.3 Graphical representation of Standard Operating Policies

Source: NPTEL

This policy is used not used for deriving optimal solutions but rather used for planning purposes. From the fig 1.3, it is observed that when the total inflow is less than the demand, then the release is made to fulfil the demand but when the demand is less than inflow, then water is released to fulfil the demand and the surplus water is used for storing in the dam. this storage of water is the filling phase. once the filling phase reach its saturation, then the surplus water is released from the spillway as reservoir spills.

1.5.6 FLOOD CONTROL BENEFITS OF THE BHAKRA DAM

These dams were not designed initially for the flood moderation but these have sufficiently contributed towards absorbing peak flood inflows. It has solved problems of recurring flood in the Sutlej River which could be inferred from Table 1.8. Here, release was decided based on the previous flood pattern and the storage allocation of reservoir was increased to accommodate floods.

Table 1.8 Impacts of flood control

YEAR	BHAKRA DAM	
	Peak Flood Inflow (Cumecs)	Max Released (Cumecs)
1978	10719	3887
1988	9004	4209
1992	6625	1542
1994	6364	1695
1995	8977	1658
1998	5244	1330

SOURCE: Indirect Economic Impacts of Dams, Ramesh Bhatia-45524

CHAPTER 2

LITERATURE REVIEW

Nachimuthu Karunanithi et al. (1994) observed that the conventional analytical model failed to analyse stream flow data and the flow process because they are based on the natural phenomena that influence the flow. **S. K. Jain et al. (1999**) adopted ANN method for the inflow prediction and operation of reservoir. ANN works similar to the biological neuron system in terms of recognition, prediction, analysis etc. **V. Chandramouli & Raman (1996)** trained neural network using back propagation techniques to check for the relation between the trained and target data. They achieved success in implementing the results. **V. Chandramouli & Raman (2001)** proposed the use of dynamic programming algorithm as an extension to the ANN model which altogether is used as dynamic-programming based neural network for the optimal operation of multi-reservoir but this time by using a feedforward approach by learning from back- propagation algorithms. They used three variable dynamic programming algorithms with three decision variables. **V. Chandramouli et al. (2002)** considered a case study of water sharing between two reservoirs for deriving operating rules of multi reservoir system using dynamic programming-based neural network (DPN model) but this time considered four decision variables and three state variables for analysing the water sharing between the two reservoirs to obtain the maximum benefit.

D. K. Srivastava & Taymoor (2009) observed that with the complexity of multi-reservoir, more nested ANN models were adopted for the analysing, prediction purposes. One such case study was done by them on Mula river using the nested model which comprises of linear programming (LP), dynamic programming (DP), ANN, hedging rules (HRs) and simulation. The dynamic programming (DP) based optimization were used due to the non-linearity associated with the models but this suffers from the curse of dimensionality. Due to this, hybrid models were adopted for diminishing the short comings of the model and enhance its performance. So, with the ANN model, combination of DPN model and radial basis function model (RBN) were used for the evaluation of reservoir using the results of DP model. **Matteo Giuliani et al. (2016)** observed that the use of DP and Stochastic dynamic programming (SDP) along with ANN as a hybrid model gained momentum for formulating reservoir policies but lately it was observed that SDP too suffers from the curse of dimensionality. Along with this for formulating the real-world problems, SDP suffers from curse of modelling and curse of multiple objectives, these added to the computational complexities. However, this problem was tackled by using policy search-based method. One such method proposed was DPS (direct policy search). This is simulation based and is advantageous over the DP family. Hence, when DPS coupled with multi-objective evolutionary algorithms were able to estimate a Pareto front in a single run of the algorithm. This simulation-based approach of EMODPS (evolutionary multi-objective direct policy search) were used for operating policies of water reservoir.

Samuel O. Russell & Paul (1996) observed that the computations were made simpler by the use of ANN model in combination with the other analytical models but operators tried avoiding its usage because of the complex optimization of these models and were looking for a model that could logically explain these functions. Thus, fuzzy logic seemed a way to explain these. **Bijaya P. Shrestha et al. (1996)** used fuzzy rule-based model for deriving the operation rules for a multi-purpose reservoir. They observed that the fuzzy rule model operates on logical 'if-then' conditions where 'if' is for fuzzy explanatory variables and 'then' is for fuzzy consequences. **Suharyanto et al. (1997)** believed that the reservoir operation by using fuzzy rule-based (FRB) model can be extended by using SDP for formulating the optimal operating policies. Even though the results were reliable but this optimization technique were regarded to be 'long-term-consequence'. **A. Tilmant et al. (2002)** compared the classical formulations of both the methods and developed a fuzzy explicit SDP (FSDP) approach to fill the gap between the two classical approaches. **Seyed Jamshid Mousavi et al. (2004)** used this FSDP (fuzzy-state stochastic dynamic programming) for the study purpose of reservoir system and observed that the model considers the uncertainties and imprecision of hydrological variables. **Sangeeta Kumari and P. P. Mujumdar (2015)** formulated FSDP in two phases where in the first phase the fuzzy dynamic programming model allocates the available water to the crops and in the second phase stochastic dynamic programming model optimizing impact of allocations. **Sangeeta Kumari and P. P. Mujumdar (2016)** observed that apart from the fuzziness included in the model, the water allocation model was integrated with the real time operation model for the short-term real time operation where soil moisture and reservoir storage were the fuzzy state variables. **Sangeeta Kumari and P. P. Mujumdar (2017)** then compared the different fuzzy set-based models to evaluate their best performance. These included comparisons of FSDP, SDP and COP (conceptual operating policy). This was done to analyse the failure of FSDP (fuzzy reliability), ease of recovery from failure (fuzzy resiliency) and to analyse the consequences (fuzzy vulnerability) for obtaining the realistic solutions despite considering the uncertainties.

Sh. Momtahen & A. B. Dariane (2007) observed that as these SDP models were flexible but were restricted to separable objective functions and constraints. Hence, direct search approach method of optimization was proposed by using the Genetic Algorithms. These were capable of overcoming the short comes of SDP models. The direct search approach optimizes the objective functions for the use in simulation models. **Paulo Chaves & Toshiharu Kojiri (2007)** observed that GA optimizes complex systems with high number of decision variables but these could not be generalised for future operational rules. Hence, they introduced a new approach of optimization namely stochastic fuzzy neural network (SFNN) which operational decisions are the fuzzy states variables which are trained by the GA model for operational purposes. **Parisa-Sadat Ashofteh et al. (2015)** observed that the multi-objective problems were not addressed in the reservoirs and other water resources. Hence, they addressed this issue using GA parameters along with the GP (genetic programming). These combinations were able to solve the reservoir operational problems by incorporating the climate change parameter under different conditions. **Li-Chiu Chang and Fi-John Chang (2001)** stated that these GA have significantly contributed in management of water resources and formulation of operating rules for reservoir. However, they designed an intelligent control model which takes into account both the functions of GA and network-based fuzzy system collectively known as ANFIS (adaptive-network based fuzzy inference system). **Fi-John Chang and Ya-Ting Chang (2005)** used GA for searching the reservoir operating histogram pattern to be used for training of ANFIS to be used as a prediction model. ANFIS works as a multilayer feedforward network for learning the algorithms and is advantageous in extracting rules from the numerical data.

Paulo Chaves & Toshiharu Kojiri (2007) observed that the hybrid models were mostly based on the ANN and fuzzy logic in order to deal with the fuzzification of inputs to make it easier for human understanding. Thus, an attempt was made to combine it with physical equations and concepts. **Paresh Chandra Deka and V. Chandramouli (2009)** used this hybrid modelling to increase the robustness of this model in formulating the reservoir operational policies. **Shripad Dharmadhikary et al. (2001)** analysed command area and the areas irrigated by Bhakra and found them to be misleading due to messy calculations involved in the reservoir releases. **B. S. Minhas et al. (2016)** observed that reservoir operations failed to address the issue of flood control also compromising with meeting the irrigation demand thereby the efficiency of utilisation being reduced.

INFERENCE DRAWN:

Reservoir operations for a reservoir needs to be modelled for meeting the irrigational demands without compromising with the flood control operations. This could be attempted by using the hybrid modelling.

CHAPTER 3

METHODOLOGY

3.1 DATA USED

Data is collected from the website of "UK Centre for Ecology and Hydrology" and from "Bhakra Beas Management Board".

Monthly data from the year 1989 to 2009 is collected for the Bhakra Dam reservoir [1].
Data includes: Reservoir storage, Inflow and Evaporation loss, Water Level, Releases and Demand.

3.1.1 System Considered- BHAKRA RESERVOIR

The system considered for study purposes in this project is multipurpose reservoir dam across Sutlej river- Bhakra reservoir also known as Govind Sagar Reservoir. It is situated in Una and Bilaspur district of Himachal Pradesh with coordinates of latitude 31°N and longitude 76°E. It stretches to over a length of 56km and breadth of 3km. The average rainfall received in Bilaspur district is 1258mm.

3.2 RESERVOIR OPERATION FUNCTIONS- TOOLS USED

Reservoir operation is a complex situation which has to be configured considering all the uncertainties and imprecisions. The tools used for studying the case scenario has been listed below.

To start with, the data was collected from open-source site and following operations were performed on them.

1) **Linear Regression**

At first Linear Regression modelling was used for checking the relationship amongst the data. In this process, the randomness of data is checked. It is done to ensure that the data is not following any pattern and it is random.

However, this could be used at the onset to check the correlation amongst the data and autocorrelation. With inclusion of large no. data comes the problem of overfitting, hence this basic model of operation is avoided in the long run.

While performing the operations of computation of release, then it would be checked against the inequality eq^n.

$$R_t \leq S_t + I_t - E_t$$

Where, R_t = Release during the time period t

S_t = Storage during the time period t
I_t = Inflow during the time period t
E_t= Evaporation during the time period t

21 years of historic data from 1989-2009 has been collected and is used for computations. Following are the steps used for regression analysis:

(i) To begin with, before predicting the output value or carrying out any computations, the elements of the data sets have to be tested to prove their suitability to carry out the computations.

To find the strength of predictors it is important to find any correlation among the variables to be used for predicting the output. This is done by finding the correlation in Excel using regression analysis. From this Pearson's rank could be determined giving the information about the strength of input parameters.

(ii) After knowing the strength of independent parameters, it is important to know if the elements of the variables are strong enough to explain the variance of the output data due to the changes in the input data. This explains the capability of variables in determining goodness of fit of model and is found out by using R^2.

R^2 values can be lower or higher but focus should be that the model with higher R^2 should be selected as minimum noise are observed then. However, sometimes a model with low R^2 can also be used because there may be a possibility that the output is governed by several parameters out of which the predominant ones are considered for computational purposes. Hence, it is important to study the behaviour of independent parameters to be used.

(iii) Following this, the randomness of variables is checked by means of residual plots. This tells us if the variables follow any particular pattern or not.

(iv) Once the randomness is observed through scattered plots, autocorrelation for the elements is determined to make sure that the variables are not affected by its lagged values.

After the independent variables satisfies the above conditions, it is then considered for modelling.

2) STANDARD OPERATING POLICY

Standard operating policy aims to best meet the demand in each period based on the water availability in that period. It is one time operation policy.

Equations considered for computations are:

$$R_t = D_t \ if \ S_t + Q_t - E_t \geq D_t$$
$$= S_t + Q_t - E_t \ \ otherwise$$

$$O_t = (S_t + Q_t - E_t - D_t) - K \ if \ positive$$
$$= 0 \ otherwise$$

- $S_{t+1} = S_t + Q_t - E_t - R_t - O_t \ with \ R_t \ and \ O_t \ determined \ as \ above$

Where, S_t = Storage at the beginning of the period t
Q_t = Inflow during period t
D_t = Demand during period t
E_t = Evaporation loss during period t
R_t = Release during period t
O_t = Spill (overflow) during period t

3) Artificial Neural Network (ANN model)

ANN models are widely used in reservoir operations of single purpose or multipurpose reservoir systems. It is a computational tool that is based on biological process of human brain. It approximates the non-linear relationship between input and output variable to reduce the noise while training the data set.

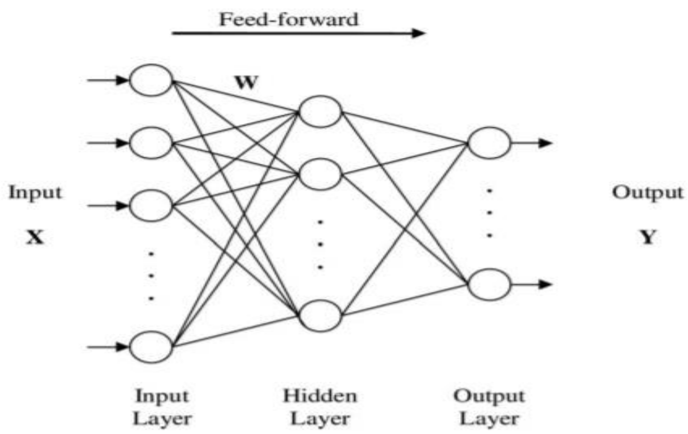

Fig 3.1 Schematic diagram of three-layered feed forward ANN

As ANN associates' large input with the outputs, hence it is able to solve problems by developing memory which are capable of associating these variables as demonstrated in Fig 3.1.

Three stages namely 'training, validation and testing' are used for creating a model in ANN.

TRAINING DATA: Uses set of examples to fit the parameters by assigning connection weights and is used for learning the model. The learning operations of predictions are performed on this set of data. It comprises of 2/3rd of data to be used for the training purposes.

VALIDATION DATA: It is used for predicting the responses for the observations by providing unbiased evaluation of model. This dataset is used for fine tuning the performance of the neural network.

TESTING DATA: Used for final evaluation and generalisation of errors if any. This dataset is used for determining the accuracy of the model and errors if any.

Generally, a feed forward multilayer perceptron architecture (MLP) is adopted for computational purposes. It consists of an input layer with no. of input variables, hidden layers and an output layer. Weights are assigned to the inputs, which are then passed to the internal nodes in the hidden layer, which in turn develops functions for outputs. The quality of simulation result depends on the algorithm and the software used. In feedforward networking, the model interacts with the environment to recognize the pattern to learn from it.

As optimal release is related to storage, inflow and rate of evaporation. Hence for training and testing purposes, the input is taken as monthly storage of the reservoir, inflow into the reservoir and evaporation loss from the reservoir. The output obtained is the predicted water supply released from the reservoir. This obtained result is then compared with the given release value to set up an efficient working system

a) Artificial neural networking could be modelled using number of software but the software used for the study of Bhakra reservoir are MATLAB (NN ToolBox) and through Programming in PYTHON.

3.2.2.1 ANN modelling using MATLAB

Neural networks can learn a pattern easily and performs a function by assigning weights to the neurons. This makes them suitable for prediction and modelling.

While performing the operations, the data sets are divided into training datasets, testing datasets and validation datasets.

Here in this study, out of 252 datasets which includes monthly data storage, inflow, demand, evaporation losses and releases. So,21 years data consists of 252 moths whose data has been used.

ARCHITECTURE OF ANN

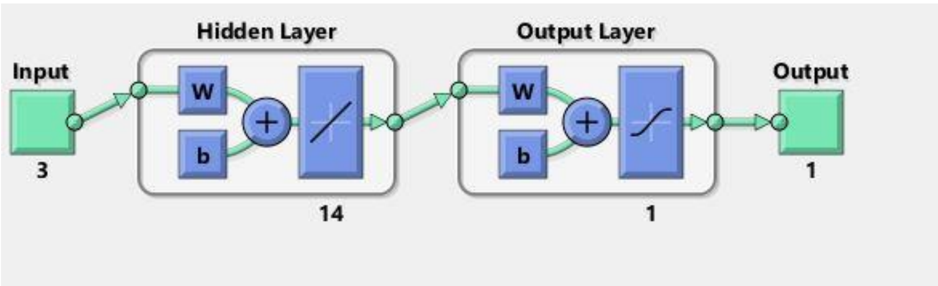

Fig 3.2 Architecture of ANN

57 connection weights used for ANN modelling.

Out of 252 datasets,180 dataset is used for training purposes and remaining 72 datasets are used for testing. For cross validation a different tool box on MATLAB is used which considers 70% of the given data for training and remaining 15% each for testing and validation. The results are computed on MATLAB software using the concept of ANN.

Attempts have been made to predict the demand and release.

In first case scenario, demand is predicted for 24 months and in the second case scenario, release is computed.

<u>IRRIGATION DEFICIT (z): </u>It is a way of maximising the water use efficiency. To achieve maximum water efficiency for higher yield crops, is has to be minimized. After prediction of

24 months demand value, irrigation deficit is computed. Greater deficit is observed if the reservoir is not filled completely.

$$z = \sum (D_t - R_t)^2$$

Where D_t = Demand at time period t and R_t = Release at time period t.

4) Fuzzy Neural Network (FNN) model

It is a combination of artificial neural network and fuzzy logic. It is a hybrid approach of solving the complex problems by approximation techniques. It consists of three layers, namely fuzzy input layer (fuzzification), hidden layer which contains logical fuzzy rules and fuzzy output layer (defuzzification). These models are much easier to understand due to their human like inference. In this 'if', 'then', 'and/or' rules are applied to understand the system more logically to arrive to a conclusion.

The software used for FNN is MATLAB with tool box 'fuzzy'.

In this software, a range of values is provided for each input and output layer followed by setting up logical fuzzy rules. Here, a combination of 8 set of rules as mentioned in Table 3.1 have been used for the reservoir operations and for determining the release value from the reservoir based on the different conditions of inflow and storage.

Table 3.1 Logical fuzzy rules

IF Inflow is **LOW and** Storage is **LOW** then Release is **LOW**
IF Inflow is **LOW and** Storage is **MEDIUM** then Release is **LOW**
IF Inflow is **LOW and** Storage is **MEDIUM** then Release is **MEDIUM**
IF Inflow is **LOW and** Storage is **HIGH** then Release is **LOW**
IF Inflow is **LOW and** Storage is **HIGH** then Release is **MEDIUM**
IF Inflow is **MEDIUM and** Storage is **HIGH** then Release is **LOW**
IF Inflow is **MEDIUM and** Storage is **HIGH** then Release is **MEDIUM**
IF Inflow is **HIGH and** Storage is **LOW** then Release is **HIGH**

This methodology has been adopted for the modelling of reservoir operations for Bhakra dam reservoir.

SUMMING UP THE PROCEDURES INVOLVED FOR COMPUTATIONS ARE:

1. Defining rules of 'standard operating policy'.
2. Computations based on SOP for determining the reservoir spills.
3. Maximising the irrigation benefits by predictive analysis by using the concept of ANN and FNN.
4. Comparing the variations of the graphs obtained.

CHAPTER 4

4. RESULTS AND DISCUSSIONS

4.1. Linear Regression

Linear Regression was carried out for the data set to check for the linear dependence of variables for the prediction analysis. The overall idea is to check if the sets of independent variables are competent enough for the prediction of independent variable (i.e., output).

Three major uses of Regression analysis include:

i. determining strength of predictors
ii. forecasting an effect
iii. trend forecasting

For the present study purposes, Regression analysis is used for the prediction of values using the set of independent variables such as Storage, Inflow and Evaporation. Release from the reservoir is predicted through this statistical approach.

To understand this effectively, the scatter plots are plotted to show the linear variation of individual independent parameters with the dependent variables.

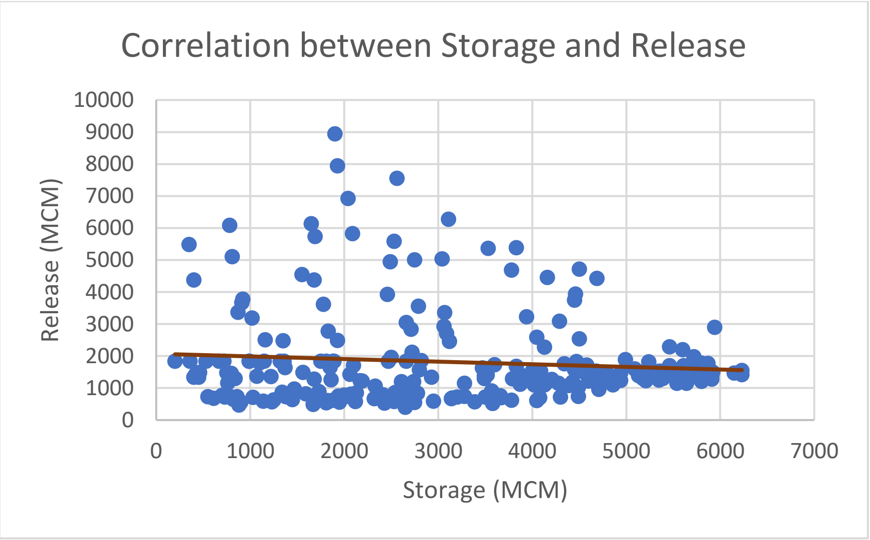

Fig 4.1.1 Scatter plot of Storage and Release

From the Fig 4.1.1, it was inferred that Storage and Release are negatively correlated. As the slope is downward, it indicates that the Release from the reservoir decreases on increasing storage capacity of reservoir.

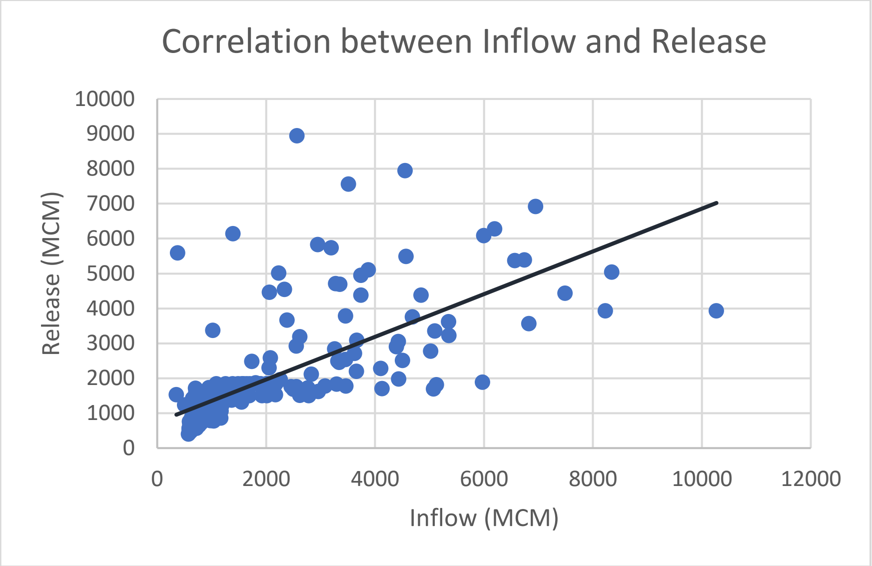

Fig 4.1.2 Scatter plot of Inflow and Release

From the Fig 4.1.2, it could be observed that Release is positively correlated with Inflow with the slope linearly increasing in the positive direction which means that Release from the reservoir increases with increase in the Inflow received in the reservoir. This is proved graphically using FNN model later in this study. The positive steep increasing slope shows the highest correlation amongst the two parameters.

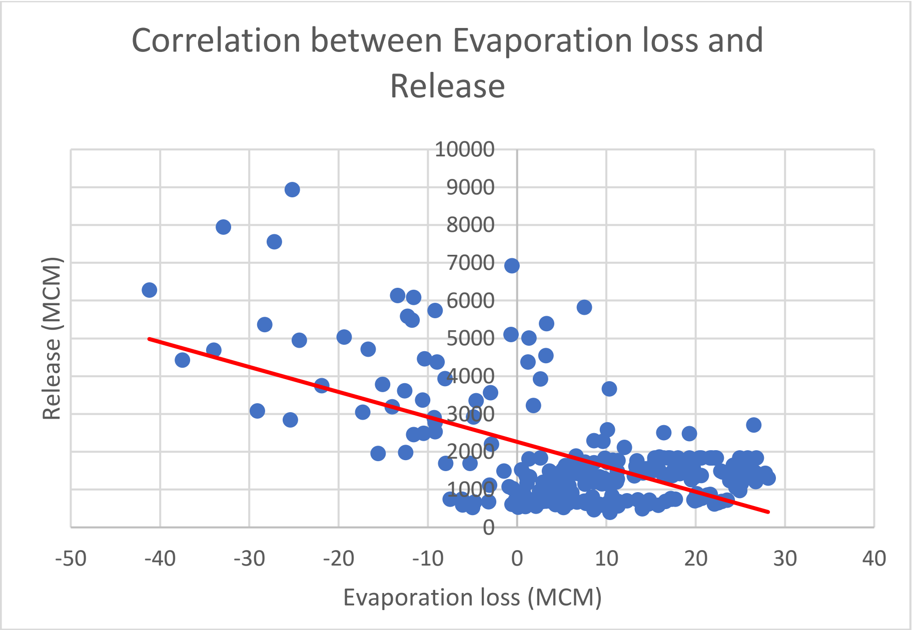

Fig 4.1.3 Scatter plot of Evaporation Loss and Release

From the Fig 4.1.3, it was noted that there exists a negative correlation between Evaporation loss and Release as explained graphically where the slope varies linearly in a downward direction with shows its negative correlation with the Release from reservoir. It can be inferred that with increasing evaporation losses as observed during summers, the release from the reservoir will be less. This is during this time the demand increases as compared to supply creating stress on the reservoir operations.

R^2 :

R^2 is a statistical measure that indicates the percentage of variance in the dependent variable which is explained by independent variable(s) in a regression model. It is goodness-of-fit measure for the regression model.

As correlation explains the strength of association, R^2 explains the extent variance of a variable on the variance of other. Low R^2 do show the correlation between the independent variables and the dependent variable but fails to explain much about the variability in the dependent variable. It measures the scatter of data around the regression line.

Hence, an effort has been made to compute R^2 using the graphical plot. Two cases have been considered to find this value. With case (1) where R^2 is formulated for the given data and its value is compared with case (2) where R^2 is computed for the given independent variables such as Storage, Inflow and Evaporation loss and predicted output value of Release.

Table 4.1.1 Comparison of R^2

Regression Statistics for the given data	
Multiple R	0.774459675
R Square	0.699787788
Adjusted R Square	0.694946512
Standard Error	935.912963
Observations	252

Regression Statistics for the predicted data	
Multiple R	0.982890095
R Square	0.96607294
Adjusted R Square	0.965662532
Standard Error	224.8463952
Observations	252

From the Table 4.1.1, it is observed that the R^2 for the set of given data with the given release data is 0.699 which means 69.9% of the variations of release are explained by the changes in the input variables (Storage, Inflow and Evaporation Loss) while observing the R^2 of the predicted data, which is 0.966 states that 96.6% of the variations on predicted release from the reservoir could be explained by the changes in the input variables (Storage, Inflow and Evaporation Loss).

As the variations explained by the given model is low, which indicates the need for revision of the reservoir operations of the Bhakra dam for achieving higher efficiency. This could be done by predicting the release of the reservoir using ANN model. However, to check this, an effort has been made to predict the release in the Excel model and check for its R^2 value which came out to be 0.966 i.e., 96.6% variations are explained. This indicates that by revising the reservoir operations model for the reservoir we can make an attempt in improving its efficiency because if R^2 is closer to 1, the better the regression line fits the data.

Limitations of R^2:

1. R^2 tells us about the variations of the dependent variables based on the changes in the input independent variable but it does not tell us about if the model is good or bad. It only tells us about the reliability of data. Hence, there can be times, when the R^2 may be low but the model performs better.

So, one should not limit their research till finding R^2 rather an attempt should be made to test the model for its overall performance.

2. R^2 in linear regression model: Graphical representation of R^2 was a hassle while plotting it on a graph. This requires, plotting individual scatter plot against the dependent

variable and then finding its equation and R^2 pertaining to its corresponding trendline and later computing all the R^2 value to get the R^2 value of regression analysis.

This becomes a hassle and creates confusion. To avoid this, we can rely upon the numerical value of R^2 obtained through the computations in Excel modelling or can plot the graph using algorithm of Python which will be discussed further in this report.

Explanation of low R^2 of the given data:

These have greater amounts of unexplainable variations. Hence, R^2 value can be low. For example, taking the case of this research paper, the R^2 came out to be 0.699 which is low but still the data is used for predictions, comparisons and study purposes. This is because there are many other factors that govern the reservoir operations such as the topography, climate conditions, population growth, industrialisation, global warming etc. out of which the major proportions of modelling of reservoir operations are explained by the independent variables considered such as Storage capacity, Inflow and Evaporation loss.

Residuals and Residual Plots:

The residual plots are plotted to check the unbiased relationship of a model for the prediction purposes. At times model with higher R^2 with low noise relationship may follow certain pattern which results into over and under prediction. Unbiased models have residuals with are randomly scattered around 0.

Non-random residual patterns indicate bad fit despite higher R^2. Hence it is necessary to always check the residual plot to check the unbiased nature of model. This non-randomness of residual pattern is due to the model missing significant independent variables.

For the purpose of determining the unbiased relationship, residuals plot have been plotted for the study of Bhakra Reservoir.

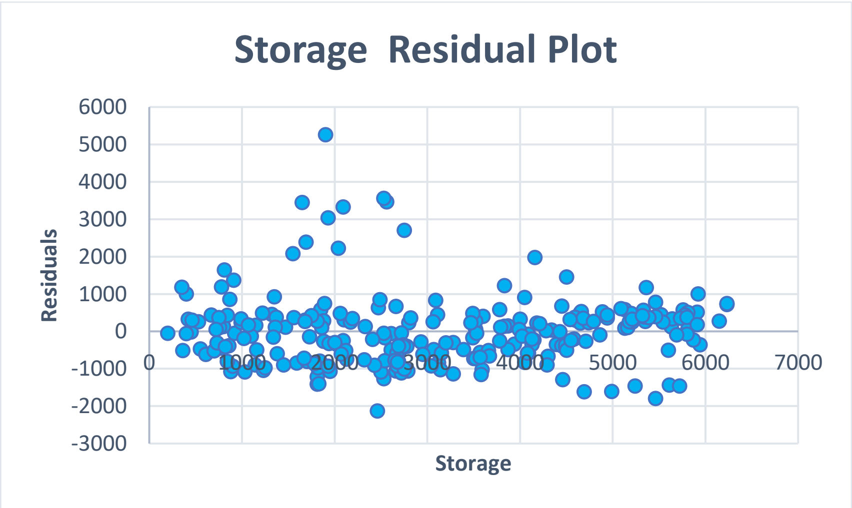

Fig 4.1.4 Residuals plot of storage

From the graphical Fig. 4.1.4, it can be observed that the residuals are randomly scattered and does not follow any particular order. This tells us about the unbiased nature of the Storage input used for computation purposes.

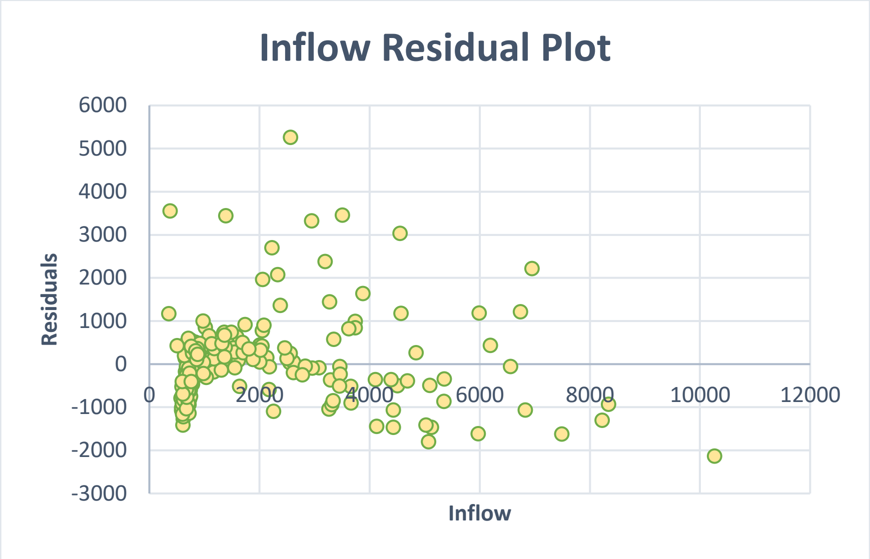

Fig 4.1.5 Residuals plot of Inflow

From the graphical Fig 4.1.5, it can be concluded that the independent variable inflow is unbiased as its residuals plot does not follow any pattern.

Fig 4.1.6 Residuals plot of Evaporation Loss

From the graphical Fig 4.1.6, no patter has been observed which shows the randomness of the scattered residuals.

As no pattern has been observed in the residuals plot of all the three independent variables- Storage, Inflow and Evaporation loss, hence these variables can be effectively used for prediction of dependent variable- Release from reservoir.

<u>ACF of Residuals:</u>

Though the input data have been tested for is its randomness, yet it is not ready for the modelling purpose. It is important to check the correlation among themselves. This means that the data should be free from any influence of its previous values i.e., lagged values.

Autocorrelation represent the degree of similarity between the given data and its lagged version. Correlation is for two different variables while Autocorrelation is for checking the similarity between its own values of a particular variable.

ACF plot is designed to check if the elements of a variable are positively correlated or negatively correlated or are independent.

ACF varies from -1 to +1. The autocorrelation with lag 0 is always 1. Hence it is not considered for plotting purpose. -1 indicates negative autocorrelation while +1 is for positive autocorrelation.

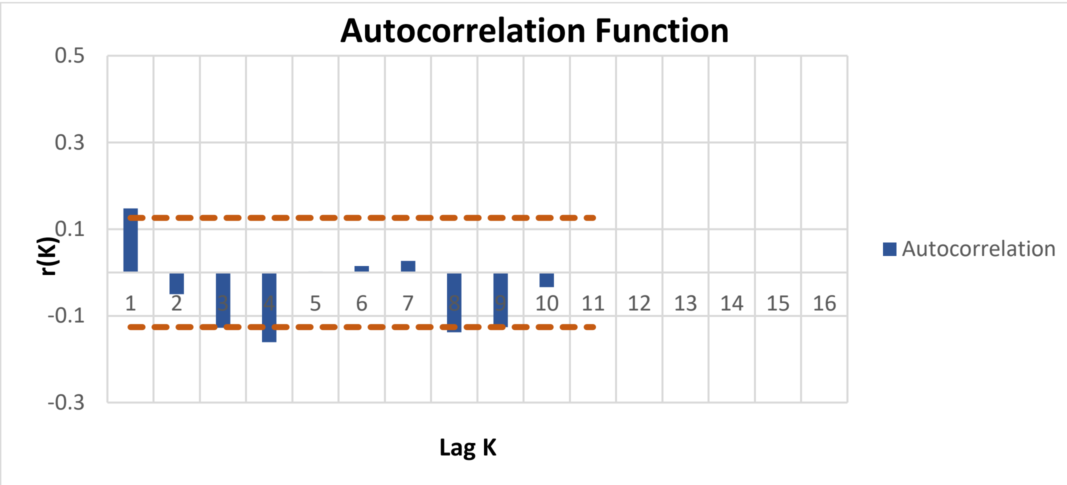

Fig 4.1.7 ACF of residuals

From the graphical Fig 4.1.7, it is observed that the spikes are not highly correlated. Significant negative correlation was observed for lag 4 which vanishes with subsequent lag. Since the variables does not have much of significant correlation, Hence the data can be considered for modelling purposes.

As the input variables are of random nature free from any correlation or any other effect which have been tested above. Hence the input independent variables are used for modelling purposes.

4.2 Modelling Using ANN in MATLAB software

Case-I: Prediction of release

ANN is used because it learns the data and operates in layers using assigned weights to predict the data. For this study purpose, a total of 252 data sets are tested for its suitability is predicting the output data- Release. All 252 data sets are tested for obtaining the results.

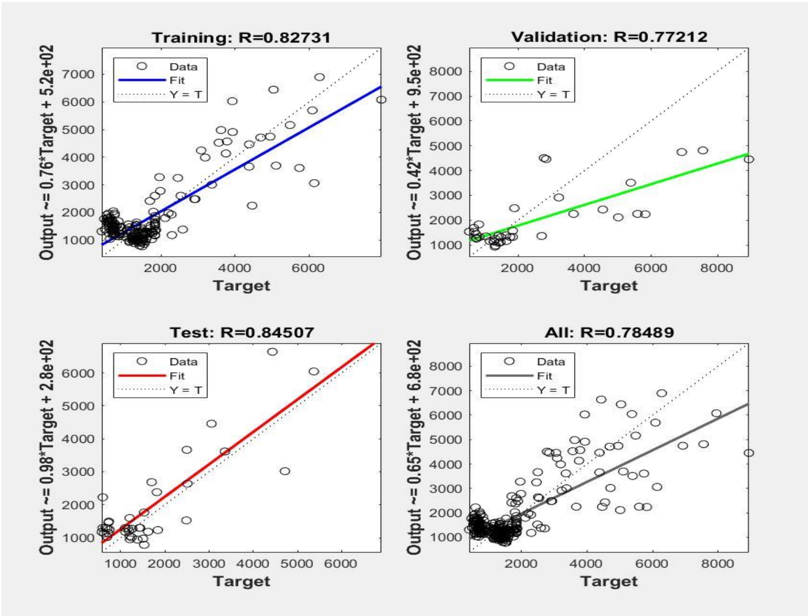

Fig 4.2.1 Graphical representation of R^2 for testing data on ANN

The Graph from Fig 4.2.1 shows the R^2 values by itself dividing its data for training, testing and validation. The R^2 obtained shows good fitness of data. It reduces the noise that was previously observed in the linear regression thereby achieving higher goodness of fit. Hence the data can be further used for training and validation purposes.

<u>Training Data using ANN in MATLAB:</u>

Training a data is used for fitting the parameter and is used for model evaluation. Ideally it is used for prediction of data.

From the sets of 252 data, 180 data sets are used for training purposes and remaining 72 data sets used for testing purposes.

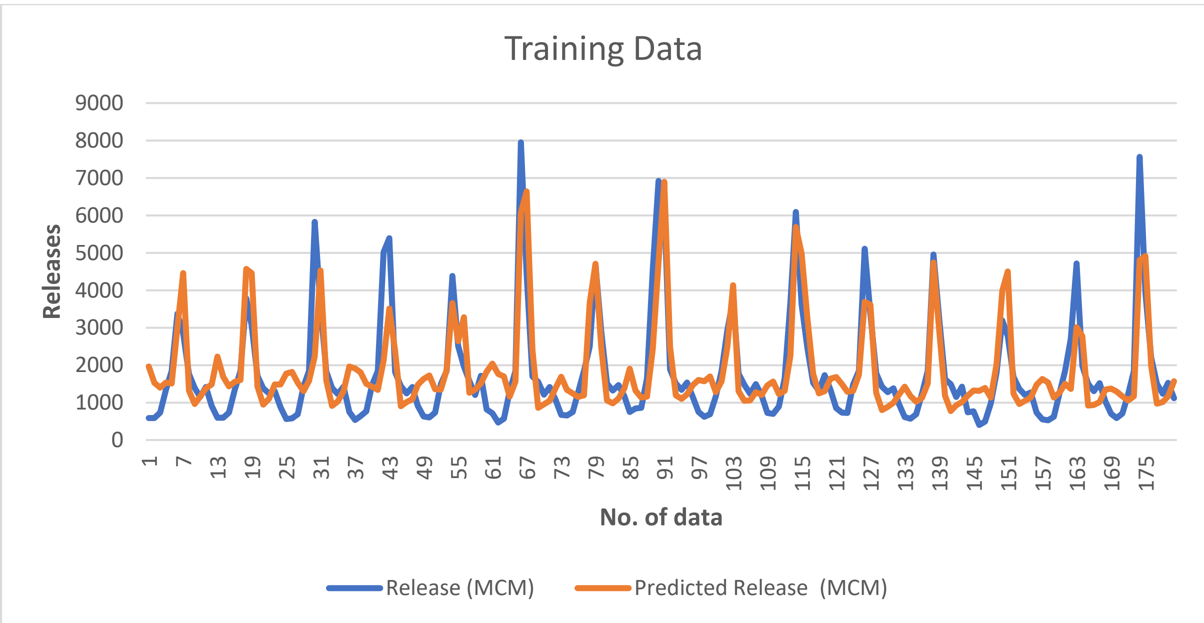

Fig 4.2.2 Comparison of the predicted release with the given release data (training)

From the graphical Fig 4.2.2, it can be observed that 182 data sets are used for prediction of releases. These predicted release values are then compared with the given release data for a period from 1989-2009 monthly.

From the Fig 4.2.2, it is observed that there had been variations of releases which are not in par with the predicted releases. For example, the release from the reservoir was less initially but gradually increases further for data from 1 to 7(Jan to July). However, from the predicted data of release, it can be observed that there was a moderate decrease in the demand for the month of Jan (data no. 1) hence, the release was less from the reservoir for Jan and Feb (data 1 to 2). As for the data 3 (month of March-April) there was moderate supply of water due to the fact that most of the harvest is already done and farmers does not require much water for irrigation purposes. Also due to the climatic conditions near Bhakra reservoir, not much supply of water is needed. But with the onset of summers for the month May-July (data no. 5 to 7) a sharp rise can be observed. This is due the Kharif season (May end to June) and hot summer weather, the demand increases and the high peak shows the higher release from the reservoir. The curve gradually decreases after attaining peak in June. This is due to the onset of monsoon where most of the demands are met by the rain water. The curve of predicted release again increases during the Rabi season due to higher demand for agricultural and irrigational purposes but the operational release shows sharp decline indicating shortage of water of inefficient functioning of reservoir. Hence the prediction of releases using ANN will help in improving higher efficiency of operations by supplying adequate amount of water throughout the seasons.

Testing Data using ANN in MATLAB:

The remaining 72 data out of 252 data sets are used for testing purposes. It is performed for assessing the performance of the data.

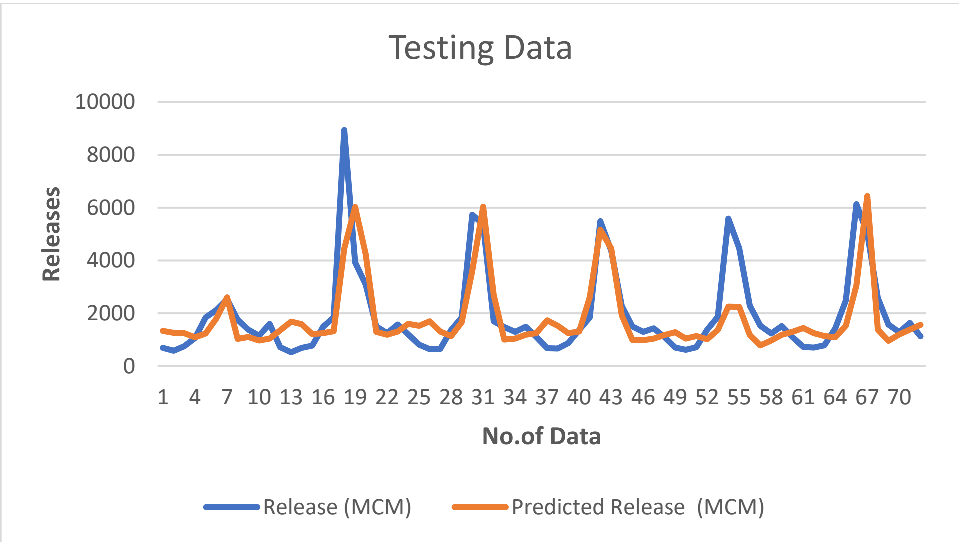

Fig 4.2.3 Comparison of the predicted release with the given release data (testing)

From the graphical Fig 4.2.3, it can be observed that the model behaves in a similar fashion as in Fig 4.2.2 thus performing well. At certain places it can be noted that the release varies in contrast with the predicted release. Heavy release is observed during monsoon period and low release when the demand is less. Thus, the model can be considered for prediction purposes.

Cross validation of Dataset in ANN using MATLAB:

This is be performed by using the Neural Network Start (‘nnstart’) tool in MATLAB. The advantage of using this tool is that it set asides few data among the given datasets for validation and testing purposes and keeps 70% of the data for training purpose but the only drawback is that it does not predicts the results but rather displays the R^2 and MSE values.

In this case, out of 252 data samples, 176 sample (70% of data) is used for training and 38 samples each (15% each of remaining data) is used for validation and testing purposes.

	Samples	MSE	R^2
Training	176	5666.58	0.87
Validation	38	6612.88	0.85
Testing	38	5490.09	0.89

Table 4.1.2 MSE for training

From Table 4.1.2, R^2 is in the range of 0.87-0.89.

Comparison of Residuals:

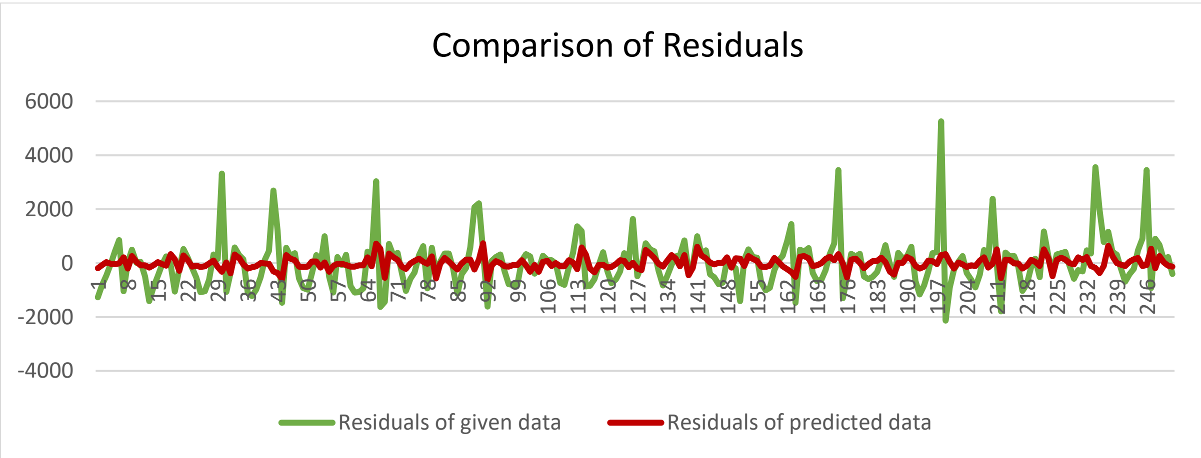

Fig 4.2.4 Comparison of Residuals of given release and predicted release

On comparing the residuals of the two data sets in graphical Fig 4.2.4, it is observed that the residuals of the predicted data using ANN are more stable an compared to the given release data indicating moderate operations of reservoir can be achieved on observing the data obtained from ANN.

CASE-II: Prediction of Demand

For Bhakra reservoir, Filling Period is from “21 May- 20 September” and Depletion Period is from “21 September- 20 May”. As the inflow varies, an attempt has been made to predict demand which have been graphically represented in Fig 4.2.5.

Based on the predicted demand computations, irrigation deficit (z) for a particular year 2000, Z was observed to be 3.06 million Acre Feet. This indicates that the reservoir has sufficient storage for allocating unexpected inflows. This indicates proper management in allocating storage for flood without compromising with meeting the demands.

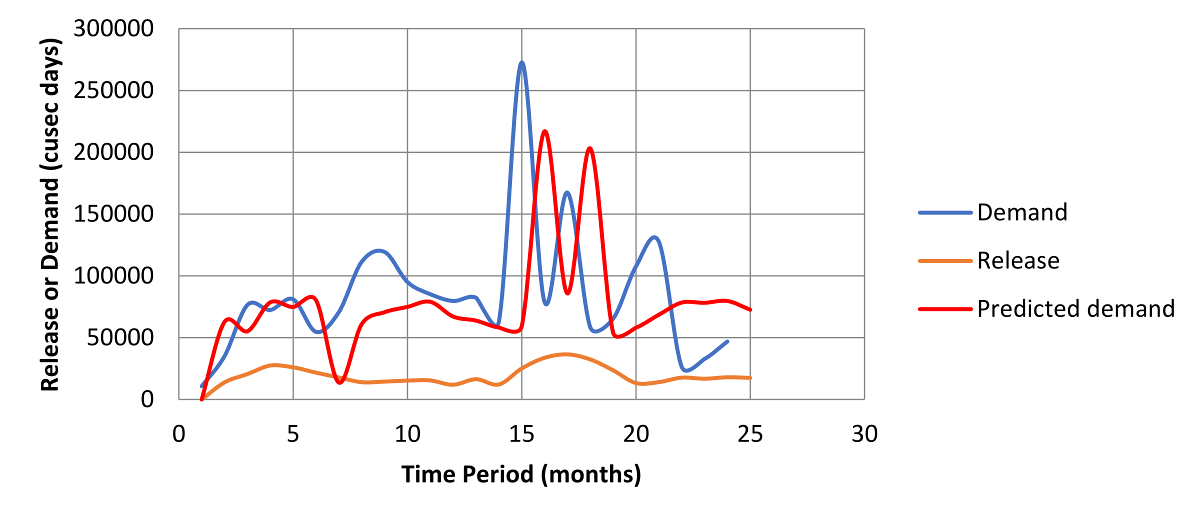

Fig 4.2.5 Variation of demand with the predicted demand

4.3 Prediction of Release graphically using Python Algorithms

As observed in above cases a lot has to be done in terms of modelling and computations but this can be minimized by using a programming language. The programming language used here is Python.

This programming tools predicts the data (release from a reservoir) and plots it against the regression line of the given input data. In this case, the code used here reduces the noise while plotting R^2 (goodness of fit of model) and based on the least variations from the regression lines the best model can be adopted.

The drawback of such programming method is that it requires lot of coding and person with experience can perform it efficiently. This is adopted because least calculations are involved as all the computations can be given as a command to the code which displays the final output.

<u>ANN:</u>

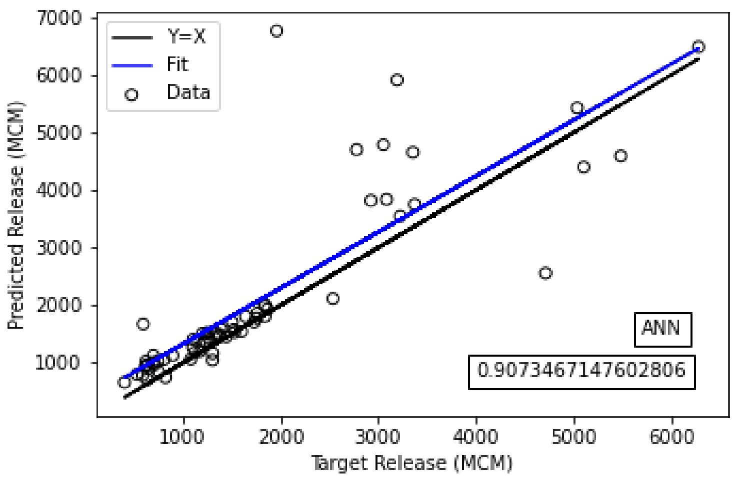

Fig 4.3.1 Graphical representation of R^2 after prediction using ANN modelling in Python

From the Fig 4.3.1, it can be noted that the variation of 90% predictions made can be explained by the changes in the input variables. This model has good fit of parameters.

4.4 Modelling using FNN in MATLAB software

The release of water supply could also be decided based on the logical inferences rather by referring to the values of the given data or predicted data.

These results are easier for human understanding without involving much of technical skills. However, with the advent of programming in this set up, the prediction of values as result could also be obtained. Knowledge in fuzzy system is transparent to the user.

Based on the logical fuzzy rules set up for the compilations, following observations were made:

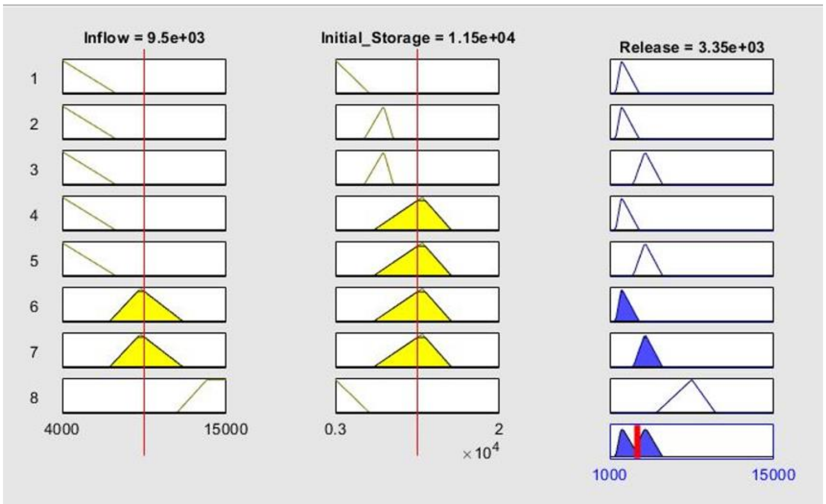

Fig 4.4.1 FNN rules operations

From the Fig 4.4.1, it can be seen that adjusting the amount of inflow and storage, the amount of release can be decided. There are 8 different sets of rules which govern the reservoir operations.

For operation, a set of range are defined for each parameter and upon selecting a value from the given range of input, output release can be obtained. For example, from Fig 4.4.1, considering rule 1, if the inflow is low and storage is low, then the release from the reservoir is low as shown by the graphical representation. Now considering Rule 4 from the Fig 4.4.1, if the inflow is low, storage is moderate, then the release will be low. Similarly for Rule 8, if the inflow is high, storage is low, then the release will be medium. These logical rules help in making reservoir operations efficient due to their quick decision making.

The only drawback of using FNN was the split observed in the release graph for last rule no. 8 for high inflow. This creates a confusion while assessing the results in understanding the split approach of the FNN model.

Coupling ANN with FNN also helps in handling hydrological failures thereby reducing the occurrence of a disaster. But if ANN and FNN are combined and used for reservoir operations, then based on the inflow values and prediction of releases from ANN could be used to graphically represent the release from the reservoir which in turn could notify us of increased inflow on timely basis and help in reducing the effects of flood.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1. CONCLUSION

From results it can be concluded that reservoir operations are dependent on multiple factors of which three important set of parameters were used namely total available storage capacity, Inflow received by the reservoir and the evaporation losses incurred. Based on these input variables, release from the reservoir was predicted and later with the given release, demand was predicted. Prediction of releases using ANN was compared with the given release data and it was observed that the predicted release had an edge over the given release. This implies that if the reservoir operations are done using AI method such as ANN, the results and efficiency of functioning of reservoir operations will be higher. For the study of Bhakra reservoir, the predictions of release values have been made and these values were then later used in FNN for decision making. Based on these computations, following conclusion are drawn:

1. The predictions of variables help in short term forecasting of future releases and demands.
2. The irrigation deficit based on the predicted values could be estimated which provides information on storage for allocation of floods. (Z= 3.06 million Acre Feet)
3. FNN rules efficiently predicts the release from the reservoir.

5.2. FUTURE SCOPE

The modelling for reservoir operations were done considering the input parameters such as available storage capacity, Inflow from reservoir and Evaporation losses for finding out the reservoir releases. This modelling can be improved by incorporating parameters such as various demand at the downstream side, climate affect etc. The more the parameters the more will be the variations of release explained.

Reservoir is affected due to water availability on both the upstream and downstream sides of dam. So, different conditions of water level can be considered for the computation purposes.

Natural disasters such as cloud burst, increased melting of snow, heavy downpour etc. can also be considered for reservoir operations so as to minimize its effect on the people and surrounding area.

APPENDICES

APPENDIX I

Table A1.1 Monthly Reservoir Level (m)- Gobind Sagar Bhakra Reservoir [2]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	TOTAL (BCM)
1989	484.22	477.17	462.44	455.66	460.13	463.97	486.02	499.42	501.61	498.91	493.01	485.02	6.229
1990	476.86	468.28	457.76	454.68	457.4	464.75	485.46	501.09	501.7	498.18	492.81	485.86	6.229
1991	478.33	469.71	458.86	454.99	468.42	479.88	486.75	500.37	504.98	501.23	495.78	486.05	6.229
1992	476.92	469.88	460.86	462.75	470.84	486.3	495.45	505.71	509.03	506.42	501.17	493.47	6.229
1993	485.59	477.02	463.86	455.99	450.45	454.95	468.99	484.5	487.34	486.87	481.89	475.95	6.229
1994	469.08	466.7	467.05	466.05	468.4	480.1	503.32	509.41	512.06	510.62	506.81	500.24	6.229
1995	494.15	486.12	479.55	475.94	484.2	478.64	495.62	510.65	509.82	508.13	504.1	498.48	6.229
1996	491.52	487.14	484.81	477.8	474.19	479.83	490.06	504.47	505.46	502.08	497.31	491.51	6.229
1997	484.82	476.09	463.97	462.52	466.25	489.65	500.68	510.21	512	508.69	505.65	500.54	6.229
1998	493.39	486.27	476.38	471.88	465.81	463.71	478.49	491.84	499.56	499.54	495.76	490.19	6.229
1999	482.51	473.31	462.72	463.18	462.44	464.09	491.35	511.06	512.06	511.78	509.29	503.88	6.229
2000	499.26	494.17	487.53	482.98	479.73	486.12	498.43	510.36	511.84	510.01	507.24	502.35	6.229
2001	496.24	487.77	477.16	474.61	469.04	467.78	479.79	497.53	505.19	504.12	500.44	495.14	6.229
2002	488.64	485.58	479.69	479.53	478.87	491.59	502.46	510.53	511.15	510.92	508.08	502.36	6.229
2003	496.32	490.33	482.17	483.13	479.82	486.86	502.13	509.79	510.59	507.3	503.69	497.89	6.229
2004	492.13	482.46	480.41	484.54	487.84	488.37	502.46	511.06	511.74	509.41	506.54	501.08	6.229
2005	495.62	487.97	481.11	475.95	478.12	479.93	485.83	501.02	502.82	498.79	495.17	488.53	6.229
2006	481.98	474.33	464.38	470.89	473.02	477.48	495.26	508.91	508.86	507.07	504.47	499.02	6.229
2007	492.01	484.44	472.72	468.69	468.3	454.55	477.34	499.91	507.3	508.51	507.95	504.76	6.229
2008	499.52	497.15	492.56	494.95	491.69	489.12	502.19	510.81	510.18	507.51	504.86	501.96	6.229
2009	497.5	490.95	488.02	484.34	475.84	479.63	493.64	505.17	504.18	499.56	497.06	490.53	6.229

Table A1.2 Monthly Reservoir Storage of Bhakra Dam Reservoir (BCM) [2]

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total (BCM)**
1989	2.53	1.84	0.79	0.45	0.67	0.87	2.71	4.34	4.65	4.28	3.52	2.61	6.229
1990	1.81	1.14	0.55	0.4	0.53	0.92	2.66	4.58	4.66	4.18	3.49	2.7	6.229
1991	1.95	1.23	0.61	0.42	1.15	2.09	2.79	4.47	5.13	4.6	3.87	2.72	6.229
1992	1.81	1.25	0.7	0.8	1.32	2.75	3.83	5.24	5.76	5.35	4.59	3.57	6.229
1993	2.67	1.82	0.86	0.46	0.2	0.4	1.16	2.5	2.8	2.61	2.1	1.59	6.229
1994	1.03	0.88	0.9	0.84	0.99	1.93	4.69	5.61	6.23	5.8	5.34	4.39	6.229
1995	3.59	2.67	2.02	1.68	2.47	1.93	3.78	5.94	5.81	5.54	4.94	4.15	6.229
1996	3.28	2.78	2.54	1.85	1.55	2.04	3.11	4.99	5.13	4.65	4	3.28	6.229
1997	2.54	1.7	0.84	0.76	0.99	3.06	4.45	5.87	6.15	5.63	5.16	4.43	6.229
1998	3.5	2.69	1.73	1.37	0.91	0.78	1.78	3.12	4.09	4.09	3.6	2.93	6.229
1999	2.13	1.38	0.73	0.75	0.72	0.81	3.07	5.8	6.23	5.91	5.52	4.71	6.229
2000	4.05	3.39	2.53	2.17	1.88	2.49	3.94	5.69	5.92	5.64	5.2	4.49	6.229

2001	3.66	2.65	1.67	1.47	1.1	1.02	1.83	3.83	4.89	4.74	4.21	3.52	6.229
2002	2.75	2.43	1.88	1.86	1.81	3.09	4.5	5.72	5.81	5.78	5.33	4.49	6.229
2003	3.67	2.95	2.09	2.19	1.89	2.56	4.46	5.6	5.73	5.21	4.68	3.87	6.229
2004	3.15	2.12	1.94	2.33	2.66	2.72	4.5	5.8	5.91	5.54	5.09	4.3	6.229
2005	3.58	2.68	2	1.56	1.75	1.9	2.46	4.29	4.55	3.99	3.52	2.74	6.229
2006	2.07	1.45	0.82	1.22	1.36	1.69	3.53	5.46	5.46	5.18	4.79	4.02	6.229
2007	3.14	2.32	1.34	1.07	0.36	0.35	1.68	4.13	5.21	5.39	5.32	4.86	6.229
2008	4.08	3.78	3.2	3.49	2.82	2.53	4.16	5.46	5.36	4.94	4.54	4.13	6.229
2009	3.57	2.74	2.41	2.06	1.35	1.65	3.04	4.05	4.45	3.79	3.47	2.69	6.229

Table A1.3 Data representing Inflow into the reservoir (MCM)[1]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	613.89	640.2	785	1005.6	1256.7	1017.8	3259.5	2550.9	1174.4	753.5	698.4	665.4
1990	610.5	637.8	747.1	1119.8	1775.6	3460	4429.2	2767.4	1129.7	725.4	658.7	629.8
1991	586.2	600	694	1204	2134	2946.5	6826.4	3292.1	1105.8	731.4	649.7	614.4
1992	616.8	624.6	751.2	1396.4	2006.7	2228.7	6742.1	5125.5	1257.8	812.8	718.6	654.8
1993	618.9	628	707.9	1275.5	2179.3	3737.7	4505.2	2256.8	1666.6	793.6	703.1	640.4
1994	613.1	611.4	721.8	859.8	1903	4551	7489	4126.3	1349.6	859.7	749.6	692.8
1995	666.2	680.7	800.8	1120	1585.5	3314.4	3351	4389.6	2616.9	963.8	813.5	742.8
1996	719.8	771.6	1165.3	1399.8	2333.1	6949	6195.1	5972.5	1617.4	983.7	831.3	744.9
1997	703.1	672.8	732.2	979	1385.4	2555.5	4685.1	3464	1328	966.1	798	717.2
1998	674.2	681.4	817.3	1530.9	2380.6	5992.6	5348.5	3340.6	2174.1	1551.3	949.1	829.8
1999	751.4	745.9	766	977.4	2008.6	3877.4	5096.3	3083.4	1360.6	827.8	717.2	659.9
2000	629.3	624.2	676.3	1166.7	1554.1	3739.6	5354.3	2960	976.3	755.1	668.3	622.5
2001	592.4	575.1	629.1	764.7	1306	2618.4	5022.2	2501.3	833.2	696.3	637.5	601
2002	585.5	595.3	706.4	1055.9	1703.8	3621.8	3274.5	4430.4	1691.7	870.4	747.3	686.5
2003	652	653.1	738.9	1186.8	1485.5	3507.7	8225	3659.2	1922.7	888.9	772.7	715.4
2004	690.6	683.6	704.1	1173.9	1084	2831.2	3456.2	2462	867.5	866.1	710.7	636.1
2005	604.2	623.4	1037.3	1180.4	2045	2567	10267.8	3662.7	2779.3	984.8	835.4	753.9
2006	714	710.3	768.3	920.6	1882.6	3192.4	6562.5	5073.3	1374.9	908.5	783.1	718.4
2007	672.7	680.7	790.2	1365.2	1641.6	4568.6	4843.8	4104.7	2014.9	871.9	760.5	711.8
2008	674.5	675.3	806.4	1132	1809.1	376.06	2059.04	2053.68	352.04	502.54	842.57	732
2009	612	598.3	981.5	1319.08	1735.37	1391.58	8342.3	2078.63	1368.4	861.26	879.3	759.7

Table A1.4 Evaporation (MCM)[1]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	5.1	-9.2	-19.8	-19.5	-20.4	10.6	25.4	-13.4	-16.9	-7.6	-4.1	-6.1
1990	6.1	-9.1	-19.9	-19.9	-22.3	15.1	17.3	-10.1	-17.4	-10.3	-1.1	-5.4
1991	-2.1	-5.3	-16.6	-27.8	-21.8	-7.5	3	-9.8	-16.4	-11.1	-4.3	6.2
1992	-0.1	-5.7	-17.2	-23	-26.8	-1.3	-3.3	-1.3	-14.1	-7.9	-8.2	-0.7
1993	-1.7	-4.3	-20.2	-26.5	-20.6	-1.2	-16.4	15.6	-18.5	-11.1	-8.6	-3.3
1994	-1.9	-8.6	-10.9	-28.1	-21.6	32.9	37.5	8	-14.4	-8.6	-6	0.9
1995	4.8	-10.2	-17.7	-25.3	-22.2	10.5	34	9.3	-15.3	-9.4	-6.2	-1.1
1996	7.5	-10.6	-21.3	-25.7	-3.2	0.6	41.2	-6.6	-7.1	-9.2	-7.6	-3.4
1997	-3.6	-9.2	-11.3	-25.1	-18	4.9	21.9	-11.3	-5.3	-5.3	1.5	-4.9
1998	-1.7	-3.7	-20.1	-24.2	-10.3	11.6	12.6	11.6	-0.5	-11	-7.6	-1.4
1999	-4.3	-13.5	-23.5	-24	-19.3	0.7	4.6	-10.7	-18.2	-11.2	-7.3	-2.5
2000	0.6	-11.3	-22.9	-23.8	-15.4	24.4	-1.8	-13.3	-19.6	-10.2	-7.8	-4.7

2001	-4.4	-10.4	-14	-24.9	-6.4	14	9.2	-19.1	-13.1	-9.2	-8.1	-0.7
2002	-0.9	-5.2	-22.1	-19.5	-17.1	-26.5	16.7	12.5	-15.9	-9.7	-7.8	0.5
2003	-3.2	-9.7	-19.9	-26.7	-25.8	27.2	8.1	2.9	-15	-9.2	-5.1	3.1
2004	-7.5	-15.8	-17.3	-24.5	-16.4	-12	9.2	-15.4	-1	-9.5	-7.3	0.2
2005	5	-2.8	-20.7	-22.8	-24.9	25.2	-2.6	29.1	-14.7	-9.7	-7.1	-2.9
2006	-8.4	-7.7	-22.5	-27.2	-16.9	9.2	28.3	5.3	-11.2	-8.1	-3.6	-5.8
2007	3.2	-6.7	-21.6	-24.9	-2.6	11.8	9	-9.6	-17.5	-9.7	-6.6	-3.2
2008	-3.8	-14.7	-14.8	-20.6	-15.9	12.3	10.4	-8.6	-17.8	-10.2	-5.8	-3.6
2009	-1.5	-12.3	-20.4	-26.8	-19.3	13.4	19.4	-10.1	-19.7	-9.6	-5.4	-4.1

Table A1.5 Release from the Dam (MCM)[1]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	583.6	589.3	730.2	1338.8	1839.6	3373.8	2845.2	1763	1390	1151.4	1417.4	914.7
1990	594.2	597.7	731.1	1337.9	1839.9	3785.4	3053.6	1718.9	1378.5	1242.1	1304.6	878
1991	564.4	576.9	687.6	1436.1	1840	5826.1	3564	1836.6	1388.4	1226.4	1421.1	752.1
1992	539	636	768.3	1466.6	1839.8	5012.9	5391.1	1817.5	1444.5	1248.9	1416.8	910.2
1993	631.8	608.6	736.2	1489.4	1840	4381.7	2509.2	1961.1	1574.9	1202.6	1712.9	821.6
1994	715	471	567.1	1306.6	1839.9	7951.4	4432.6	1700.7	1551.1	1208.6	1417.5	1081.8
1995	671.4	658.6	746.2	1278.5	1839.9	2495.3	4692.4	2905.1	1508.3	1324.3	1470.2	1176.2
1996	747.3	841.7	860	1648.9	4548	6924.5	6282.5	1889.6	1511.4	1341.6	1532	1155.5
1997	753.6	617.2	693.6	1165.2	1840	2926.8	3754.6	1773.9	1476.9	1238.3	1492.3	1190.4
1998	724	694.8	895.4	1644.3	3669.4	6088.8	3621.9	2457.3	1529.1	1317.6	1730.8	1343.8
1999	852.7	731.4	726.7	1481.6	1839.9	5107.5	3356.7	1781.3	1426.6	1281.8	1378.1	964.8
2000	614.3	570.5	689.5	1237.2	1840	4951.4	3226.8	1620.9	1497.6	1151.4	1422.1	744.1
2001	764	402.3	495.5	976.5	1797	3194.3	2779.2	1683.1	1367.6	1202	1272	732.7
2002	552.9	530.9	625.2	1261.6	1839.9	2708.9	4715.7	1982.9	1500.7	1303.8	1521.7	1027.6
2003	698.7	590.8	707.8	1217.9	1839.9	7558.9	3935.9	2204.2	1504.8	1234	1529.5	1121.2
2004	696.1	586.6	749.8	1064.2	1840.1	2117	2537.3	1756.6	1379.3	1157.4	1602.4	721.3
2005	527	693	778.3	1496.1	1839.8	8942.3	3928.7	3087	1502.5	1247.7	1576.1	1201.6
2006	808.4	640	654.7	1366.8	1839.9	5738.1	5370.1	1699.2	1485.6	1300.9	1491	1100.8
2007	677.9	672.8	874.7	1376.9	1839.9	5486.2	4382.3	2283.9	1500.8	1298.4	1434.1	1105.1
2008	699.2	625.1	720.4	1377.7	1867.1	5593.4	4463.7	2296.7	1532.8	1239.6	1520.5	1101.4
2009	733.38	703.84	789.26	1436.8	2486.17	6138.03	5039.4	2589.34	1578.2	1289.4	1634.9	1123.4

APPENDIX II

Python Code for Running ANN model

```
# ANN CODING FOR RESERVOIR OPERATIONS USING PYTHON
# Importing libraries and packages
import numpy as np
import pandas as pd
from sklearn.metrics import r2_score
from sklearn.metrics import mean_absolute_error
from sklearn.metrics import mean_squared_error
import matplotlib.pyplot as plt

# Importing the dataset
dataset = pd.read_excel('dataset_reservoir.xlsx')
X = dataset.iloc[1:,3:6].values.astype('float64')
y = dataset.iloc[1:,2:3].values.astype('float64')

#Feature scaling
from sklearn.preprocessing import StandardScaler
sc_X = StandardScaler()
sc_y = StandardScaler()
X = sc_X.fit_transform(X)
y = sc_y.fit_transform(y)

# Splitting the dataset into training and test set
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(X,y, test_size=0.25, random_state=0)

# Import the keras libraries and packages
import keras
from tensorflow.keras import Sequential
from tensorflow.keras.layers import Dense

#Initialising the ANN
regressors = Sequential()

# Adding the input layer and the first hidden layer
regressors.add(Dense(units = 40,activation="relu", input_dim=3, kernel_initializer="random_uniform"))
# Here units denote number of nodes, input dim is the number of inputs we are giving
# There are different activation functions that we use such as relu, linear, sigmoid etc.
regressors.add(Dense(units = 30,activation="relu", input_dim=3, kernel_initializer="random_uniform"))
# Second layer
regressors.add(Dense(units = 1, activation="linear", kernel_initializer="random_uniform"))

#Compiling the ANN
regressors.compile(optimizer = 'adam', loss = 'mean_squared_error', metrics = ['mean_squared_error'])
# You caan change the value of r2 by changing the activation function used, number of epochs,
# number of units in each hidden layer, which are the nodes
# we have to work upon two r2 values
regressors.fit(X_train, y_train, batch_size=3, epochs=300)
y_pred = regressors.predict(X_test)
```

```
y_predxx = regressors.predict(X_train)
y_test = sc_y.inverse_transform(y_test)
y_train = sc_y.inverse_transform(y_train)
y_pred = sc_y.inverse_transform(y_pred)
y_predxx = sc_y.inverse_transform(y_predxx)
print (r2_score(y_test, y_pred))
# The value of this r2 should be higher too along with the below r2 value
print (mean_absolute_error(y_test, y_pred))
print (mean_squared_error(y_test, y_pred))
print (r2_score(y_train, y_predxx))
# Increasaing this alone without inicresaing the previous r2 value means overfitting of data
print (mean_absolute_error(y_train, y_predxx))
print (mean_squared_error(y_train, y_predxx))

from sklearn.linear_model import LinearRegression
regressorx = LinearRegression()
regressorx.fit(y_test, y_pred)
print (regressorx.coef_)
print (regressorx.intercept_)
plt.scatter(y_test, y_pred, facecolor = 'none', edgecolors='black', label ='Data')
plt.plot(y_test, y_test, color ='black', label ='Y=X')
plt.plot(y_test, regressorx.predict(y_test), color = 'blue', label='Fit')
plt.legend(fancybox=True, loc='upper left')
plt.text(4000, 750, r2_score(y_train, y_predxx), bbox=dict(facecolor='none'))
plt.text(5700, 1500, 'ANN', bbox=dict(facecolor='none'))
plt.xlabel('Target Release (MCM)')
plt.ylabel('Predicted Release (MCM)')
```

APPENDIX III

Table A5 New Irrigation from Bhakra Canals (Th.Ha)

S.No.	Year	(Th.Ha)
1	1967-68	1671
2	1968-69	1622
3	1969-70	1768
4	1970-71	1648
5	1971-72	1671
6	1972-73	1755
7	1973-74	1863
8	1974-75	1757
9	1975-76	1986
10	1976-77	1922
11	1977-78	1890
12	1978-79	1985
13	1979-80	2102
14	1980-81	2188
15	1981-82	2305
16	1982-83	2352
17	1983-84	2377
18	1984-85	2205

S.No.	Year	(Th.Ha)
19	1985-86	2576
20	1986-87	2523
21	1987-88	2670
22	1988-89	2552
23	1989-90	2574
24	1990-91	2657
25	1991-92	2759
26	1992-93	2653
27	1993-94	2882
28	1994-95	2818
29	1995-96	2880
30	1996-97	2881
31	1997-98	3375
32	1998-99	3679
33	1999-2000	3636
34	2000-01	3646
35	2001-02	3678
36	2002-03	3506

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