CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Conceptualisation and implementation is an essential part in any research study. Review of the concepts used in earlier research provides a link with past approaches and gives perspective to improve, modify and adopt the conceptual frame work. Soft-Computing is a collection of techniques spanning many fields that fall under various categories in computational intelligence. Soft-Computing has three main branches namely Fuzzy Logic, Evolutionary Computation, and Neural Networks. Soft computing technique attempts to integrate several different computing paradigms like Artificial Neural networks (ANN), Fuzzy Logic (FL) and Genetic Algorithm (GA). When utilized together, the strength of each technique can be exploited in a comprehensive manner for the creation of ‘smart’ systems.

The review of earlier research related to hydrological process model, simulation and optimisation models in water resources are presented in this chapter.

2.2 HYDROLOGICAL PROCESS MODEL

Hydrology is closely involved with life on the globe in some manner. It’s understanding is important for addressing needs of water supply and food production. Modern hydrology is often concerned with water resources potential estimation and conservation from the sources. The largest user of water is agricultural sector. Efficient water management is extremely
essential in dry areas. Crop production involves supply of water to farms, management of irrigation water, drainage of excess water. Hydrologic and hydraulic concepts are used to determine the time history of water available, canal networks, soil moisture characteristics, location of ground water table, climate and movement of surface and sub-surface water with respect to space and time. The comprehensive hydrological process may be represented with modern computer models. Some of the latest application tools (models) in hydrological process literature are presented as follows.

Merz and Bloschl (2004) developed a lumped conceptual rainfall-runoff model with daily time step. This model considered the soil moisture state with limits of soil storage capacity and potential evaporation. The parameters are calibrated using an automated procedure, which consists of five objective functions namely coefficient of efficiency, error in volume of runoff and the other three are penalty functions which control the deviation between the observed and computed runoff by applying weights to each parameters. The results of regional parameters are similar to some extent and gives coefficient of determination as 0.2 to 0.27. By using multiple regressions with catchment attributes, the parameter estimates can improve the model efficiency. The study concluded that, catchment attributes are not very representative of the real physical controls on the water balance dynamics. Spatial proximity is useful controls on the runoff regime with dynamic catchment characteristics for regionalising the catchment parameters.

Jeníček (2007), used different methods for runoff computation in different land use areas with HEC-HMS model with SCS-CN method. The author had observed that application of SCS-CN method in HEC-HMS appears to be suitable model for this kind of studies based on land use pattern and for estimating the surface water flow from the catchment. The result from the model as runoff was compared with actual runoff and the parameters were
calibrated to minimize the deviation. The author concluded that this method helps to understand the behaviour of the catchment with respect to response to the precipitation.

Elhakeem and Papanicolaou (2009), have experimented in the field to estimate runoff curve number via direct rainfall simulator measurement. The effect of variables like intensity of rainfall, soil type, soil moisture condition, tillage practice and residue cover on CN was studied in six geographical regions. The rainfall simulator was used to simulate definite rainfall intensity at in-situ field condition. The results showed that, the estimation of CN closely agreed during summer than in the other seasons. The initial abstraction is found to vary non-linearly with maximum retention.

Kafle (2010), used the hydrological model HEC-HMS within the Geographical Information System (GIS) environment. A basin scale rainfall-runoff model of Bagmati basin in Nepal was simulated using the hydrologic model. The model developed is a combination with the GIS extension HEC-Geo-HMS. The Curve numbers were assigned based on the soil properties and land use. The peak flow of the derived hydrograph was used as an input in hydraulic model to derive flood maps showing inundation area extent. The authors conclude that the spatially based hydrological model delivered the distribution and availability of water resources in the form of maps and geographical representation of any basin.

Manoharan and Murugappan (2012), have developed a rainfall runoff model to estimate the runoff using GIS and Remote Sensing techniques with several important properties of watershed namely, soil permeability, landuse and antecedent soil moisture conditions. The model was applied to Perumal tank (artificial pond) catchment, Tamilnadu State. The daily rainfall data from 1980 to 2009 is used in the GIS based SCS-CN method to estimate runoff. The result shows that, the mean runoff coefficient
varies in the order of 0.338, 0.483, 0.157 and 0.220 for South-West monsoon, North-East monsoon, winter season and summer season respectively. It is also inferred that the proportion of runoff generated was highest during North-East monsoon and the proportion of run-off generation during South-West monsoon was found to be nearly one-third of the total runoff. It is concluded that the GIS and Remote sensing techniques along with SCS Curve Number technique is effective tool in estimation of small watershed. The development of regional mathematical relationship may help the planner in estimation of inflow into the tank system for the water resources management.

2.3 DATABASE MANAGEMENT SYSTEM

A problem common with most of the water resources systems is the extensive formulation necessary to describe the system as well as the large amount of data required to describe inputs and outputs of the system. In general it is difficult to describe the system and its inputs and outputs in terms of the complex relationships between the system and its subsystems. Management of data can be achieved through an appropriate digital database management system.

Data acquisition and management includes collection of field data, standardisation of data collection forms, methods of collection, measurement and observation as well as establishment of a systematic data acquisition network. Processing of raw data is done through quality control, editing, and analysis; check for consistency and missing data, time-series, regression and correlation analysis etc.

Storage and retrieval of data using a database management system (DBMS) and dissemination of information to users in terms of computer listings, CD-ROMs, pen drives, memory card and memory chip etc. Data may also be presented in analogue form such as graph, map and drawing for
better understanding. The database management process components are shown in Figure 2.1.

![Diagram of database management system](image)

**Figure 2.1 Database Management system data storage and retrieval**

Rajasekaram and Nandalal (2005) developed reservoir water management system for conflict resolution using Decision Support System (DSS). The DSS models supported by the data base management system in order to store and manage the water resources data sets. The database consists
of tables to store system data, parameters, alternatives, and simulation results. In addition, a script of dialogue held during the course of consultation is saved continuously in a temporary table, for reference at a later stage. The system data consists of reservoir characteristics relationship among elevation, water surface area, and storage; full supply level; minimum supply level; spill and sluice capacities, etc., lower plant characteristics power generating capacity, minimum draw-down level, power plant efficiency, etc., irrigation system characteristics irrigation command area, crop pattern and crop calendar, irrigation water supply efficiency, etc. and pertinent time-series data on reservoir inflow and evaporation. The set of system parameters stored in the database includes the watershed runoff coefficient, irrigation efficiencies, power plant efficiencies, etc. These parameters are calibrated and verified when new time series data is available for operation.

Ramani Bai et al (2012) have developed an integrated database information management system for assessing impact of climate change. The impacts of climate change studies in the area of sea-level rise, floods, ecosystems, water related phenomena in the earth system. The model consists of spatial data base for three countries namely India, Singapore and Malaysia along with simple software that provides the users to make querying, updating, reporting and data-acquiring capabilities and techniques. The web-based data information system provides also the flood prediction and water quality analysis as inbuilt functions.

2.4 SIMULATION

Simulation techniques in hydrology started about 1960 with research at Stanford University (Stanford Watershed Model). After preliminary research had indicated that it was feasible to simulate hydrologic processes and compute stream flow from rainfall data. This requires antecedent conditions created by previous storms to correctly simulate the
runoff in a particular storm. The program should be physically based and calibrated with the observed flows to allow the hydrologist to extrapolate beyond the range of observed data.

Simulation models may be physical or mathematical. With modern computer simulation it is routine to compute on a one-hour interval which more accurately deals with infiltration and hydrograph characteristics for small watersheds.

The limitation in a simulation model is that, it may not be able to generate an optimal solution to a problem directly. However, by making numerous runs of a model with alternative decision policies, one can detect an optimal or near optimal solution. The concepts inherent in the simulation approach are easier to understand and communicate.

Real time reservoir operation was modeled for power generation using Real-time Hydro Operations Model (RHOM) which was developed from earlier developed HYDROPS software (Livingstone et al 1999).

2.4.1  Reservoir Operation Simulation Studies

Simulation is a powerful tool available for establishing an optimum design for complex systems. It is the process of mimicking the essence of reality without ever attaining that reality itself. Simulation model can be extremely useful in tracing changes in system performances through varying time and rules of operation. Reservoir operations are simulated for single purpose single reservoir (Ahmad and Simonovic 2000). Ahmed and Simonovic used system dynamics concepts to arrive at operation rules for flood management., multipurpose single reservoir (Vedula and Mohan 1990) and multipurpose multi-reservoir systems (Goor et al 2010).
Vedula and Mohan (1990) developed a real time multipurpose reservoir operation policy for Bhadra reservoir using stochastic dynamic programming. The main focus was to optimize the release for hydropower without affecting the previous releases for irrigation. Two policies were developed depending on the power capacity of the bed turbine. The results of monthly power production are shown to be better for both the policies compared to the existing operation.

Labadie (2004) reviewed the state-of-the-art techniques used in multi-reservoir operations. Different approaches like Linear Programming (LP), Non-linear Programming (NLP), Differential Dynamic Programming (DDP), discrete, explicit, implicit, stochastic dynamic programming. Chance constrained programming (Ouarda and Labadie 2001), multi-objective optimization, goal programming are elaborated for overcoming difficulties in reservoir system optimization. Also, heuristic and meta-heuristic approaches to reservoir optimization are discussed for developing reservoir operating policies. It is suggested that the heuristic approaches need to be linked with “trusted simulation models” for reliable predictions. The difficulties of implicit stochastic dynamic optimization models may be overcome through applications of fuzzy-rule based systems and artificial neural networks.

Ramesh et al (2009) developed optimization model for daily operation scheduling of Irrigation Canal. This paper reviewed that Zero-One Mixed Linear Integer Programming model is applied to a field problem in order to derive the daily operation scheduling of canal of the Harihar branch canal which is sub-system of Bhadra irrigation system in Karnataka state. Optimization model is carried out for Karif season during the year 2002 with prioritization of different lateral canal. The author concluded that this modified Mixed Integer programming model resulted efficient operation policy which can be adopted to any other similar system.
Goor et al (2010) used the stochastic dual dynamic programming (SDDP) algorithm to solve for economic allocation policies, reservoir releases for different hydrological scenarios in the Nile basin. A saving of about 2.5 billion m$^3$ is envisaged by co-ordinated release operation of reservoirs and reduced evaporation losses in Lake Nasser. The regulation storage capacity of reservoirs located in Ethiopia would also increase the irrigation release by 5.5 percent in Sudan. This paper also reveals that constructing new large structures in the upper part of the basin shows significant impacts on the operating strategies of the reservoir releases.

Binoy (1992) has attempted to simulate the release from Periyar valley irrigation project consisting of Idamalyar reservoir and Periyar barrage. The simulation model proposed evaluates the performance with respect to meeting the irrigation, industrial and low-flow augmentation demand. The model uses monthly time step for a period of 10 years. Operating policy for the release from Periyar barrage are worked out based on demand and water available in the reservoir.

Manickavel (1994) has simulated the releases from Krishnagiri reservoir project using C++. The components simulated in this study include the paddy main field, nursery area, and catchment area of tanks falling outside and within the command area. The model was used to study the variations in yield for different storage levels of reservoir.

Performance evaluation based model for the operation of multi-purpose multi-reservoir system for Narmada River system was developed by Joshi and Gupta (2010). System performance index was used to measure the overall performance of the system with respect to reliability of water supply both with respect to time and volume, power generation, revenue income and spill-prevention. The algorithm developed was linked to the simulation model to obtain global optimization.
Chavez-Morales et al (1992) have developed a simulation model for planning and management of an irrigation district. Conjunctive use of water from a single multipurpose reservoir and ground water from the aquifer was considered. The simulation results reveal that the annual profit, monthly schedule of reservoir releases and aquifer withdrawals which satisfy the water requirements of the cropped area and hydropower generated by reservoir releases may be obtained.

2.5 ARTIFICIAL NEURAL NETWORK

Artificial Neural Networks (ANN) are able to mimic the functioning of human brains and are able to extract the relationship between inputs and outputs of a process without directly specifying the physical process that underlies the system. The application of ANN in hydrology in general and in areas of rainfall-runoff modelling, stream flow and water quality modelling, hydrologic time series, reservoir operations in particular, are well documented (ASCE Task Committee on Application of Artificial Neural Networks in Hydrology 2000 a and 2000 b).

Artificial Neural Network consists of nodes; they (artificial neurons) are arranged in layers. First layer of neural network is known as input layer. Final layer of neural network is known as output layer. The layers between these are called as hidden layers and they, depending upon type and size of networks nodes, are connected with varying weights (connection strength). The schematics representation of typical Feed forward three layers ANN is shown in Figure 2.2. These weights are altered as the network is being trained to learn a particular kind of task. The ANN development is based on the following rules:

(i) Information processing occurs at many single elements called nodes, also referred to as units, cells, or neurons.
Signals are passed between nodes through connection links.

Each connection link has an associated weight that represents its connection strength.

Each node typically applies a nonlinear transformation called an activation function to its net input to determine its output signal.

A neural network is characterized by its architecture that represents the pattern of connection between nodes, its method or determining the connection weights, and the activation function. A typical ANN consists of a number of nodes that are organized according to a particular arrangement. One way of classifying neural networks is by the number of layers such as three layers, four layers and Multi-layer (Most Back propagation Networks).

ANN’s can also be categorized based on the direction of information flow and processing elements. In a feed–forward network, the nodes are generally arranged in layers, starting from a first input layer and
ending at the final output layer. There can be several hidden layers, which
each layer having one or more nodes. A typical configuration of three layers
ANN is shown in Figure 2.2. Information passes from the input to output side.
The nodes in one layer are connected to those in the next, but not to those in
the same layer. Thus the output of a node in a layer is only dependent on the
inputs it receives from previous layers and the corresponding weights.

In most networks, the input (first) layer receives the input variables
for the problem at hand. This consists of all quantities that can influence the
output. The input layer is thus transparent and is a means of providing
information to the network. The last or output layer consists of values
predicted by the network and thus the represents model output. The number of
hidden layers and the number of nodes in each hidden layer are usually
determined by a trial and error procedure. The nodes within neighbouring
layers of the network are fully connected by links. A synaptic weight is
assigned to each link to represent the relative connection strength of two
nodes at both ends in predicting the input-output relationship.

Jain et al (1999) developed ANNs independently, for reservoir
inflow prediction and operation. A Feed-forward, error back propagation
network was adopted under a supervised learning mode. The results of ANN
models are compared with ARIMA time series model for inflow prediction
and with dynamic programming for reservoir operation policies. The results
of inter comparison indicate that the ANN is a powerful tool for input-output
mapping and can be effectively used for reservoir inflow forecasting and
operation.

Neelakantan and Pundarikanthan (2000) made an attempt to
develop simulation-optimization model using neural network for the Chennai
city water supply problem. The method suggested adopted in this study is a
baseline procedure and is flexible to adopt in many optimization problems.
The results indicate that the neural network-based simulation-optimization model performs satisfactorily, as compared to the conventional simulation-optimization model. Generating the examplars requires the conventional simulation model, and a sufficient number of examplars is needed to train the neural network. This training process requires considerable time. The author concluded that the reservoir operation problems with more reservoirs and complicated operations can be handled with this method. However, depending on the problem, in place of a back-propagation neural network model, a regression equation or any other suitable neural network model or other similar nonlinear programming models such as genetic algorithm model can also be attempted.

Keskin and Terzi (2006) developed feed-forward ANN models to estimate daily pan evaporation from measured meteorological data. The back-propagation algorithm is utilized for training the ANN to estimate the evaporation of Lake Egirdir in Turkey. The ANN results are compared with Penman-Monteith method. The comparison shows that there is better agreement between the ANN estimations and measurements of daily pan evaporation.

Rajurkar et al (2003) presented the application of ANN technique for modeling the daily flows during monsoon flood events over a large size catchment of Narmada river in Madhya Pradesh. The feed forward back propagation ANN is employed for each of the subdivision scenario with different input combinations. The ANN model is very flexible as it learns the unknown relationship between the input and output data through a process of training, without a prior knowledge of the catchment characteristics. He can be concluded that the ANN model can be successfully applied for modeling of the daily flows over a large size catchment having highly non-linear rainfall-runoff relationship.
2.6 RESERVOIR RELEASE OPTIMISATION

Mohammadi and Marino (1984) have developed an operation model for the real-time operation of a single multipurpose reservoir using a combined linear programming and dynamic programming model. This has been applied for three scenarios namely Water and energy maximization, Water and energy maximization with flood control consideration and Water and energy maximization for peak demand months. It is inferred that the model provides the reservoir operator with different choices for annual optimization. The model is applied to Folsom reservoir of the California project and the result obtained is optimal monthly release policy of a reservoir.

Nagesh Kumar and Janga Reddy (2007) used the metaheuristic approach of elitist-mutation particle swarm optimization (EMPSO) to obtain operating policies of releases for irrigation and hydropower generation. The results were compared with the Genetic Algorithm optimization method. The proposed approaches were tested both for a hypothetical and a real reservoir system. The EMPSO results were shown to be better than both the standard PSO Particle Swarm Optimization and the Genetic Algorithm outputs.

Dynamic operations have been used in engineering practice for large, economically important, reservoirs for many years. To date, practical constraints (e.g. real-time watershed conditions are not observed or modeled) have prevented or limited the scope of dynamic operations for many smaller reservoirs. Optimization provides still greater flexibility in reservoir operations, replacing rule curves and including dynamic rule curves. With optimization, detailed information on current watershed conditions is used in models to forecast future water supplies. The detailed consequences of
reservoir operation have been seen and the overall benefit from the reservoir operations is maximized.

2.7 GENETIC ALGORITHM

Genetic algorithms were formally introduced in the United States in 1970s by John Holland at University of Michigan. In particular, genetic algorithms work very well on mixed (continuous and discrete), combinatorial problems. They are less susceptible to getting ’stuck’ at local optima than gradient search methods. The three most important aspects of using genetic algorithms are: (i) definition of the Objective Function, (ii) definition and implementation of the genetic representation and (iii) definition and implementation of the genetic operators.

Genetic Algorithms are heuristic search algorithms that work with a collection of possible designs. The designs in the population are evolved using an evolutionary process modelled after natural selection. Each design in the population is represented using a “string” (also called a “chromosome”) of decision variables specific to the problem at hand. The string is usually coded in binary form for ease of operation. Based on the idea of “natural selection” better designs are created by using various GA operators on the chromosomes. Genetic Algorithms combine survival of the fittest among string structures with a structured but randomized gene exchange to form search algorithms with some of innovative flair human search (Goldberg 1989). It is computationally simple and powerful in their search without restrictive assumptions about search spaces. In a simple GA, five basic aspects should be considered: the representation or coding of problem, the initialization of population, the definition of evaluation function, the definition of genetic operators, and the determination of parameters.
Genetic Algorithms are being successfully used for water resources problems because they are capable of finding globally optimal or near-optimal solutions to discrete, non-convex, and discontinuous problems (Shanthi and Jothiprakash, 2005). GA is different from traditional optimizations in the following ways (Kalyanmoy 2001). (i) It works with a coding of the parameter set, not the parameters themselves; (ii) It searches from a population of points and not a single point. (iii) It uses information of a fitness function, not derivatives or other auxiliary knowledge; (iv) It uses probabilistic transition rules, not deterministic rules and (v) It is very likely that the expected GA solution will be a global solution. The important terms in GA are Chromosomes, Population, Mutation, Cross-over and Fitness function. One of the important advantages of using GA is that the general implementation is independent of the simulation code and the form of objective function. The link of the GA based optimization code to flow and a transport simulation code is very straightforward. Since there is no need for the derivative information, the objective function can be highly nonlinear.

Mohan (2004), developed a combined simulation-optimization approach for optimal operation of multi-purpose multi-reservoir systems using soft computing techniques. ANN was used to develop a decision system and GA was used to develop the required optimization model. A feed-forward network is adopted for forecasting inflow from catchment. The study concluded that ANN is quick, flexible and suitable for forecasting the inflows. GA model was found to be suitable for single and multi-reservoir operation, and in low inflow periods GA performs better than the LP model.

Nagesh Kumar et al (2006) developed a Genetic Algorithm model for optimizing the relative yield from all the crops in the irrigated area in a single purpose reservoir system in Karnataka. The following parameters were considered in the model: reservoir inflow, rainfall, intra-seasonal competing
demand for water among multiple crops, the soil moisture dynamics, soils characteristics, and crop response. This model is generic and can applied for optimizing the available water resources to derive maximum benefits.

Mathur and Nikam (2009), developed a methodology for deriving reservoir operating rules through Genetic Algorithm (GA). One of the advantages of GA is that it identifies alternative near optimal solutions. The objective function was to minimize the squared deviation of monthly irrigation deficit along with the squared deviation in the target storage. The reservoir chosen for the application of the GA model was the Upper Wardha reservoir in Wardha river basin. The results of the Optimization model indicated that the irrigation release is equal to irrigation demand. Also, minimum storages are observed in start of monsoon i.e. at the end of water year and maximum storage is observed when the monsoon reaches to its peak.

2.8 VAIGAI RESERVOIR RELEASE SIMULATION

A number of studies are available for the release policies from the Vaigai reservoir. These studies focused on the release apportionment among the different zones of Vaigai basin. The zones are divided based on the control structure like regulators. The storage in Vaigai is divided into the Vaigai credit and Periyar credit. This leads to complexities in release operations and has attracted many a research study in this system. Some of these studies are mentioned below.

Jothiprakash et al (2012) developed a simulation model using ANN to generate inflows. The releases were computed using the simulation for 42 years data. The ANN model was trained using supervised learning back propagation algorithm. For the year 1994-95 (average flow year) the model releases were observed to be close to the actual releases. They conclude that
the ANN model can be used gainfully to predict the inflows for the reservoir operations.

WAPCOS (1996) developed a simulation model to optimize the available water resources, both surface water and ground water, in the Vaigai basin in different spheres of demand. The ratio of resources allocated by them is 1:3:4:: (water allocated for) Zone III: Zone IV: Zone V respectively.

PWD (1996) developed a simulation model THANNI (The Holistic Analysis of Natural Network Information) Model for optimal allocation of water for various uses in Vaigai basin. It takes the results from Monthly Runoff Simulation (MRS) model (developed by TAHAL consultants) such as water requirement, estimating the water potential both surface and ground water. The ratio of resources allocation is 2:3:7:: (water allocated for) Zone III: Zone IV: Zone V respectively.

CWR (2001) developed a simulation model VASIM (Vaigai Simulation) for allocation of water for various uses in Vaigai basin. Conjunctive use of surface and ground water are considered in this study. Various policies were developed and its working condition is checked for Zones III, IV and V. The two scenario simulation results are surface water only, and surface water and ground water conjunctively. The ratio of resources allocated by them is arrived at 6:4:9:: (water allocated for) Zone III: Zone IV: Zone V respectively.

2.9 SUMMARY

Various literature related to objectives of the study were reviewed to frame the methodology. The growing body of the literature indicates that
Many soft computing techniques have been used to study the reservoir operating policy and optimum release from reservoirs.

Most of the literature reviewed on hydrological modeling indicates that HEC-HMS along with GIS database has been widely used. In case of reservoir simulation, several studies are carried out based on the hedging rule, standard operating policy with help of numerous software. The reservoir inflow simulation is widely attempted through ANN. Also, the reservoir optimisation has been addressed through the evolutionary algorithms such as GP (Goal Programming), Fuzzy Logic, GA (Genetic Algorithm), and ACO (Ant Colony Optimization). The advantages of using soft computing techniques include numerous facilities for data preparation, easy exchange of data in standard form, rich worldwide experience, continuous development, and are relatively user friendly. The application of the computational intelligence techniques in the field of water resources in general and reservoir operation in particular is growing.

However, these computing techniques based simulation-optimization models have their own limitations. The sensitivity of rainfall in the ayacut (command area) is not yet fully analyzed and remains as one important topic in the reservoir operation. Therefore, there is a need to develop a combined simulation-optimization approach using Neuro-Fuzzy along with evolutionary algorithm for solving complex intractable problems. This approach is adopted for addressing the reservoir release in Vagai system. The details of the study area and the salient features of the Vaigai reservoir are presented in the next chapter.