CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The world’s reservoirs are currently filled up with sediments at a rate of approximately 1% per year (Yoon 1992). This implies that within about 50 years, the world’s water storage in reservoirs will be half of the current storage, which will have large economical and environmental consequences, especially in semi-arid environments where many reservoirs have been built for irrigation, water supply, flood control and production of electricity. Therefore, it is of utmost importance to predict sediment yield at the basin scale and understand which factors determine the sedimentation rate of reservoirs. This knowledge will allow estimating the probable lifespan of a reservoir and moreover to take proper measures against reservoir sedimentation.

Reservoir sedimentation results from soil erosion, sediment transport and sediment trapping by the reservoir. It is affected by the climate and hydrology of the catchment, water and sediment chemistry, vegetation cover and land use including man-made erosion. Altogether, reservoir sedimentation is associated with a loss of reservoir capacity and often with loss of fertile soils.

Many Indian reservoirs have lost their storage capacities because of sedimentation. It has been reported (CWC 2001) that the rate of sedimentation
in some of the Indian reservoirs is higher than the design rate assumed at the planning stage. Many of these reservoirs are losing capacity at the rate of 0.2–1.0% annually (CWC 2001). The rates of sedimentation in some of the major reservoirs of India have been reported along with the name of river and catchment area of each reservoir in Table 1.1.

### Table 1.1 Rate of Sedimentation in Indian Reservoirs

<table>
<thead>
<tr>
<th>Name of Reservoir</th>
<th>Name of River</th>
<th>Catchment area (km²)</th>
<th>Initial storage capacity ($10^6$ m³)</th>
<th>Average sedimentation rate (ha m/100 km²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linganamakki</td>
<td>Sharavathi</td>
<td>2176</td>
<td>4435.35</td>
<td>24.00</td>
</tr>
<tr>
<td>Ramganga</td>
<td>Ramganga</td>
<td>3,134</td>
<td>2,449.60</td>
<td>22.94</td>
</tr>
<tr>
<td>Pong</td>
<td>Beas</td>
<td>12,562</td>
<td>8,578.99</td>
<td>21.10</td>
</tr>
<tr>
<td>Malaprabha</td>
<td>Malaprabha</td>
<td>2,176</td>
<td>1,064.04</td>
<td>19.00</td>
</tr>
<tr>
<td>Konar</td>
<td>Konar</td>
<td>997</td>
<td>281.23</td>
<td>17.50</td>
</tr>
<tr>
<td>Idukki</td>
<td>Periyar</td>
<td>649</td>
<td>1,998.57</td>
<td>15.92</td>
</tr>
<tr>
<td>Gandhisagar</td>
<td>Chambal</td>
<td>23,025</td>
<td>7,740.00</td>
<td>8.96</td>
</tr>
<tr>
<td>Aliyar</td>
<td>Aliyar</td>
<td>195</td>
<td>109.40</td>
<td>8.48</td>
</tr>
<tr>
<td>Ukai</td>
<td>Tapi</td>
<td>62,224</td>
<td>8,510.00</td>
<td>8.13</td>
</tr>
<tr>
<td>Hirakud</td>
<td>Mahanadi</td>
<td>83,395</td>
<td>8,105.00</td>
<td>6.35</td>
</tr>
<tr>
<td>Bhakra</td>
<td>Satluj</td>
<td>56,980</td>
<td>9,868.00</td>
<td>6.10</td>
</tr>
<tr>
<td>Jayakwadi</td>
<td>Godavari</td>
<td>21,774</td>
<td>2,909.04</td>
<td>4.78</td>
</tr>
<tr>
<td>Matatila</td>
<td>Matatila</td>
<td>20,720</td>
<td>1,132.70</td>
<td>4.69</td>
</tr>
<tr>
<td>Sriram Sagar</td>
<td>Godavari</td>
<td>91,751</td>
<td>3,171.94</td>
<td>2.80</td>
</tr>
</tbody>
</table>

The estimation of reservoir sedimentation has been the subject of several empirical studies since the 1950s. However, this prediction has never been an easy task due to complicated simultaneous processes involved such as
sediment transport, erosion and deposition. In recent years, the artificial neural network (ANN) technique has shown excellent performance in regression, especially when used for pattern recognition and function estimation (ASCE Task Committee on Application of the Artificial Neural Networks in Hydrology 2000a,b). It is a highly nonlinear tool that can capture complex interactions among the input and output variables without any prior knowledge about the nature of these interactions. In comparison to conventional methods, ANNs can tolerate imprecise or incomplete data, approximate information and presence of outliers and are well suited to this problem.

Sedimentation of a reservoir which ultimately determines its useful life is a complicated phenomenon and depends on a number of variables of which reliable information is generally not available (Swamee 2001). Of these variables, the inflow rates of water and sediments are probably the two most important factors. Both of these vary with time (Arnold et al 1990). Sedimentation is controlled by the future discharges of water and the sediments in a river, and there is no way of predicting these factors reliably (McKeogh 1981). If there is a sufficient length of past records of these parameters, empirical approach can be used to generate future data. This in turn needs to develop and use new technologies like computer aided modeling, remote sensing, geographical information system (GIS) etc and advanced models like spatially distributed approaches, Artificial Neural Network (ANN), etc in their assessment.

1.2 PROCESS OF SEDIMENTATION

Sediment is the material which is derived from rock, volcanic or organic matter (Gregory 1997). This is transported by water from the place of origin to the place of sediment deposition. Sedimentation is defined as the process whereby the detached particles generated by erosion are deposited on
land or into water bodies, such as lakes, reservoirs (Bhardwaj 2002). The process of sedimentation is shown in Figure 1.1. It is well known that a volume called the dead storage is allocated in every reservoir for the accommodation of the sediment that will accumulate over a specified period known as the economic life. After this, dead storage is completely filled up with the sediment, the useful life of reservoir tends to decrease if it is not provided with proper removal mechanisms such as dredging and flushing (Blanton et al 1981, Bowonder et al 1987).

**Figure 1.1 Process of Sedimentation**

### 1.3 HYDROLOGIC PROCESSES

The rainfall and runoff process is a complex process (Ven Te Chow 1964) involving interception, infiltration, percolation, evapotranspiration, surface and subsurface runoff etc. The physiographic factors which influence the surface runoff are surface slope, soil cover, land use, hydraulic roughness and climatic factors such as rainfall, temperature, evaporation etc. The rainfall-runoff models are thus, based on relation between these physiographic and climatic factors (Brown 1943).

In the absence of any measurements, soil erosion in watershed is estimated based on rainfall, slope, land use and soil type (Brandt 2000).
Physiographic factors such as surface slope, soil texture, land use, climatic factors like rainfall, temperature, runoff etc., influence the soil erosion and sediment yield process.

Rainfall, runoff and consequent soil erosion are all temporally and spatially distributed processes. A better estimation of these hydrological processes like runoff and sediment yield is feasible by considering the watershed as small pieces of land units and applying the hydrologic model for the process being investigated for each land unit, which is known as spatially distributed approach. Even though good results are obtained, it is a laborious and time consuming approach, hence new methods need to be developed to overcome this difficulty.

1.4 NEED FOR RUNOFF AND SEDIMENT YIELD MODELLING

Runoff and sediment yield of a watershed are important processes in the assessment of droughts, floods and degradation of soil cover from slopes. The sediment brought from upstream catchment through runoff result in loss of capacity of reservoir. Thus there is an interaction between the runoff and sediment yield in a watershed. For a sustainable development through water resources planning and management, timely and accurate estimation of runoff and sediment yield through appropriate modeling are essential.

1.5 METHODS OF RUNOFF AND SEDIMENT YIELD MODELLING

Hydrological models used for runoff and sediment yield estimation may be classified as (i) empirical, (ii) conceptual and (iii) distributed models. Empirical models are developed by building a relationship between two or more hydrologic parameters with the long observed field data. The conceptual
models are based on physics of the problem that consider some of the predominant processes on a watershed (Chao and Ahmed 1985). But the distributed models are based on incorporating the spatial and temporal variability of physiographic and climatic factors.

1.5.1 Conventional Methods

Conventional methods employ the empirical and conceptual lumped models. The empirical lumped runoff models include, rational formula, Dicken’s formula, Ryves formula, Englis formula etc., and for soil erosion and sediment yield include Ellison equation, Musgrave equation, Soil Erosion Prediction Equation (SYPE), Universal Soil Loss Equation (USLE), etc.,

Conceptual lumped runoff models include Stanford Watershed Model (SWM), Hydrologic Simulation Program Fortran (HSPF), Water Yield Model (WYM), Soil Conservation Services Curve Number (SCS CN), etc., Soil erosion and sediment yield models include Soil and Water Resources for Rural Basin (SWRRB), Soil Water Assessment Tool (SWAT), Erosion Productivity Impact calculator (EPIC). Apart from these, stochastic methods such as regression models, time series models etc., that use various statistical analysis are employed in forecasting rainfall, runoff, stream flow etc., These are relatively simple and easy to use and provide reasonable results, but they lack in accounting the spatial distribution.

1.5.2 Modern Methods

The modern methods include physically based distributed approaches that use remotely sensed data, geographic information systems, digital elevation models etc., and neural network models. Physically based models involve (Freeze and Harlan 1969) solution of a system of partial differential equations that represent the flow processes within the watershed.
Physically based models are applicable to ungauged watersheds in theory, but almost they require historical data for model calibration purposes. Some of the distributed runoff models are Precipitation Runoff Modelling System (PRMS), System Hydrologic Europeon (SHE), Watershed Modelling System (WMS) etc., and sediment yield models include European Soil Erosion Model (EUROSEM), Water Erosion Prediction Project (WEPP) etc.

Reasonably good results of runoff and sediment yield have been obtained using the models based on conventional and modern methods that adopt spatially distributed approach. But these methods require data on hydrometeorological variables and data processing, which makes the efforts cumbersome. Artificial Neural Network (ANN), were found to satisfy most of the requirements of hydrological modeling.

ANN may be treated as a universal approximator (ASCE 2000a,b). The ability to learn and generalize knowledge from sufficient data pairs makes it possible for ANNs to solve large scale complex problems such as pattern recognition, nonlinear modelling, classification and others, all of which find application in hydrology. An attractive feature of an ANN is its ability to extract the most appropriate relation between the inputs and outputs of a process and generate an appropriate model, without the physics of the processes being explicitly provided to them.

1.5.3 Nonlinear Models

Hydrological processes are complex and non-linear and are spatially and temporally variable and hence the tools used for modelling should also be non-linear (ASCE 2000). This is inherent in ANN which uses a non-linear transfer function to map the inputs and outputs and provide for temporal variability of climatic attributes. ANNs are similar to regression based models in hydrology except that they do not require explicit specification of any mathematical form. ANNs are more versatile because of
the freedom available with the choice of number of hidden layers and the nodes associated with each of these layers. ANNs are found to be best suited for hydrological modelling especially runoff modelling in which the underlying processes are not well understood (ASCE 2000a,b)

1.5.4 Linear Models

A common assumption in many time series techniques is that the data are stationary. A stationary process has the property that the mean, variance and autocorrelation structure do not change over time. Time series models such as Autoregressive (AR), Moving Average (MA), Autoregressive Moving Average (ARMA), Autoregressive Integrated Moving Average (ARIMA) models have been applied in temporal hydrologic predictions of rainfall, runoff, stream flow, sediment flow etc. (Hsu et al 1995).