Chapter 1

INTRODUCTION

1.1 Background

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Because of its several inherent qualities as well as the relative ease and flexibility with which it can be tapped, it has become most reliable and very important source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Foster *et al.*, 2000; Zektser, 2000; Bocanegra *et al.*, 2005). It is estimated that groundwater provides about 50% of the current global domestic water supply, 40% of the industrial supply, and 20% of water use in irrigated agriculture (World Water Assessment Program, 2003). However, the aquifer depletion due to over-exploitation and the growing pollution of groundwater are threatening our sustainable water supply and ecosystems (Shah *et al.*, 2000; Zektser, 2000; Sophocleous, 2005; Biswas *et al.*, 2009). Hence, the key concern is how to maintain a long-term sustainable yield from aquifers (e.g., Hiscock *et al.*, 2002; Alley and Leake, 2004) in the face of impending climate change and socio-economic changes.

India receives an annual precipitation of about 4000 km^3 out of which total average annual flow per year for the Indian rivers is estimated as 1953 km^3. The total annual replenishable groundwater resources are assessed as 432 km^3. The annual utilizable surface water and groundwater resources of India are estimated as 690 km^3 and 396 km^3 per year, respectively (Kumar *et al.*, 2005). Total water requirement of the country for various activities around the year 2050 has been assessed to be 1450 km^3/year (Gupta and Deshpande, 2004). This is significantly more than the current estimate of utilizable water resource potential (1086 km^3/year) through conventional development strategies. Therefore, when compared with the availability of 500 km^3/year at present, the water availability around 2050 needs to be almost trebled. For adequate living standards as in western and industrialized countries, a renewable water supply of at least 2000 m^3 per person per year is necessary. If only 1000-2000 m^3 is available, the country is water stressed, while below 500 m^3 per person per year it is water scarce (Bouwer, 2000). With the population of India expected to stabilize around 1640 million by the year 2050, the gross per capita water availability will decline from 1820 m^3/year in 2001 to as low as 1140 m^3/yr in 2050 (Gupta and Deshpande, 2004).

In India, demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization and economic development (Kumar *et al.,* 2005; Mall *et al.,* 2006). It is projected that most irrigated areas in India would require more water around 2025 and global net irrigation requirements would increase relative to the situation without climate change by 3.5–5% by 2025, and 6–8% by 2075 (Doll and Siebert, 2001). In India, roughly 52% of irrigation consumption across the country is extracted from groundwater, and therefore it can be an alarming situation with a decline in groundwater and an increase in irrigation requirements due to climate change. The conditions may deteriorate in terms of severity of droughts in some parts of the country and enhanced intensity of floods in other parts of the country (Gosain *et al.,* 2006). However, there will be a general overall reduction in the quantity of the available runoff. The river basins of Mahi, Pennar, Sabarmati and Tapti will also face water shortage conditions, whereas the river basins of Cauvery, Ganga, Narmada and Krishna will experience seasonal or regular water-stressed conditions. On the other hand, the river basins of Godavari, Brahmani and Mahanadi will not have water shortages but are predicted to face severe flood conditions in the future (Gosain *et al.,* 2006).

In spite of favorable national scenario on the availability of groundwater, there are several areas of the country that face water scarcity due to intensive groundwater exploitation (CGWB, 2006). The experiences in the field of water management in India have shown that unbalanced use and mismanagement of water resources have either lowered groundwater levels or caused waterlogging and salinity in different parts of the country (Jha *et al.,* 2001). Particularly in the canal-dominated regions of North India, there has been increase in groundwater levels due to seepage from the canals leading to the problems of waterlogging and salinity in many canal commands of the country. Excessive groundwater exploitation on the other hand has led to alarming decrease in groundwater levels in several parts of the country such as Tamil Nadu, Gujarat, Rajasthan, Punjab and Haryana (CGWB, 2006). In recent studies, the analysis of GRACE satellite data revealed that the groundwater reserves in the states of Rajasthan, Punjab and Haryana are being depleted at a rate of 17.7 ± 4.5 km^3/yr (Rodell *et al.*, 2009). It was also found that between August 2002 to December 2008, the above mentioned north-western states of India lost 109 km^3 of groundwater which is double the capacity of India's largest reservoir Wainganga and almost triple the capacity of 'Lake Mead', the largest man-made reservoir in the United States (Rodell *et al.*, 2009). Thus, depletion of groundwater resources has increased the cost of pumping, caused seawater intrusion in coastal areas and has raised questions about sustainable groundwater supply as well as environmental sustainability. Therefore, efficient and judicious utilization of surface and groundwater resources is essential as part of sustainable land and water management strategies.

The state of Orissa is no exception and it has its own share of water problem with diverse situation in different parts like the recurrence of drought in western parts, pockets of saline water in the coastal tract and acute water scarcity in many other parts. The state receives most of its rainfall (annual rainfall of 1470 mm) from the southwest monsoon between mid-June to early October. Due to the confinement of the rainfall within four to five months, there is surplus water during rainy seasons and water scarcity during non-rainy seasons. The uneven annual distribution of rainfall also leads to either drought or flood situations quite frequently. Because of uneven nature of rainfall and its capricious distribution, there is an increasing dependence on groundwater resources for meeting the growing water demand of agriculture, industrial and domestic sectors. About 3 million people in the western part of Orissa are facing acute drinking water crisis due to large-scale deforestation, unplanned irrigation and poor management of natural resources (Rejani *et al.*, 2003). Moreover, the overexploitation of groundwater has resulted in declining groundwater levels in several areas and seawater intrusion in coastal areas (Panda *et al.*, 2007; Rejani *et al.*, 2008). Now, Orissa is passing through a phase of rapid industrialization where many mineral-based industries have either come up or are envisaged. Water being the primary infrastructure need, there is already a sign of conflict arising out of use of water by agriculture and mineral-based industries in the state (Pati *et al.*, 2009). This is progressively adding to the stress on the state's groundwater system. More than 80% of the geographical area of Orissa is underlain by hard rocks and the remaining area by semi-consolidated and unconsolidated subsurface formations. In hard-rock terrains, groundwater is mainly confined to weathered residuum and fractured zones, with limited to moderate groundwater potential. The coastal alluvial tract has extensive aquifers with good groundwater potential, but salinity hazards restrict their development in the areas adjoining the coast (CGWB, 2006).

The groundwater simulation models have emerged as the tool of choice among water resources researchers and planners for addressing questions about the impacts of groundwater development (Anderson and Woessner, 1992; Rushton, 2003). These models are useful in simulating groundwater flow scenarios under different management options, thereby taking corrective measures for the efficient utilization of water resources by conjunctive use of surface water and groundwater. The simulation approach attempts to replicate real world complexity by integrating components of the physical hydrogeologic system, climatic effects, and anthropogenic stresses, thereby providing insight not only into changes within the aquifer but also on their interaction with overlying surface water systems (Zume and Tarhule, 2008). Recently, groundwater simulation models are being widely used in different parts of the world including India. However, basin-wide groundwater modeling studies in India are in its infancy due to the lack of adequate field data, financial resources, infrastructure and proper technical knowledge.

As the physically based groundwater simulation models are very data intensive, labour consuming and time consuming, the application of empirical models which require relatively less data and less modeling effort can be useful (Coppola *et al.*, 2005; Daliakopoulos *et al.*, 2005; Uddameri, 2007). Artificial Neural Network (ANN) technique is one of such models, which are treated as universal approximators and are very much suited to dynamic nonlinear system modeling (ASCE, 2000a). Unlike physically based numerical models, ANNs do not require explicit characterization and quantification of physical properties and conditions of the system under investigation. ANNs learn the system's behavior from representative data. The ability to learn and generalize from sufficient data pairs makes it possible for ANNs to solve large-scale complex problems (ASCE, 2000a; Haykin, 1999) including water management problems (ASCE, 2000b; Maier and Dandy, 2000).

Considering the above water problems in India in general and Orissa in particular, the present study was undertaken with an overall objective of efficient management of groundwater resources in a river island 'Kathajodi-Surua Inter-basin' (study area) located in the Mahanadi delta of Orissa, eastern India. In this study, hydrologic and hydrogeologic investigations of the study area have been done followed by the development of a groundwater-flow simulation model and the development of neural network models for groundwater-level forecasting. Finally, a simulation-optimization model has been developed for optimal groundwater utilization in the study area. To date, the study area has not been scientifically investigated as far as water management is concerned.

1.2 Objectives

The specific objectives of the present study are as follows:

(i) To investigate hydrologic and hydrogeologic conditions in the Kathajodi-Surua Inter-basin.

(ii) To develop a groundwater-flow model for the river basin and simulate salient groundwater management scenarios using Visual MODFLOW.

(iii) To evaluate artificial neural network models for the prediction of groundwater levels over the basin.

(iv) To develop a simulation-optimization model for optimal land and water utilization in the basin.