Chapter 1

Introduction

In the recent decade, there has been an increased interest in the development of soft computing models for hydraulic and water resource engineering problems that do not have a general established empirical model. This thesis is focused on the investigation of the soft computing techniques and the development of a data-driven hybrid model with an empirical application for estimating local scour depth at bridge abutment. This chapter introduces the background and motivation for this research work. The aims, objectives and the contributions of this thesis are also summarized. Finally, an overview of the remainder of the thesis is provided.

1.1. Motivation

Soft computing (SC) refers to a collection of computational techniques in computer science, artificial intelligence, machine learning and some engineering disciplines, which attempts to study, model, and analyze very complex solutions. Its aim, unlike conventional hard computing, is to exploit the tolerance for imprecision, uncertainty, approximate reasoning and partial truth in order to achieve tractability, robustness, low solution cost and close resemblance with human like decision-making (Pal, 2001). The constituents of soft computing are: fuzzy logic (FL), artificial neural network (ANN), genetic algorithm (GA), genetic programming (GP), genetic expression programming (GEP), evolutionary strategies and evolutionary programming, support vector machines, rough sets, swarm optimization, wavelets, simulated annealing, memetic algorithms, ant colony optimization and tabu search. These techniques are complementary rather than competitive. One SC technique can be combined with other technique (called hybrid system) resulting in more versatile and efficient model by integrating the benefits of both. Neuro-fuzzy and neuro-genetic models are the examples of hybrid models.

In recent years, SC methods have become popular and are considered as efficient alternatives for prediction problems in a wide variety of applications including hydraulic engineering problems. The attraction of researchers to apply different SC
methods to estimate scour depth around different types of obstruction is due to their capability to handle imprecision, uncertainty and extracting hidden relationships between data, when no proper general mathematical relationship is available.

Scour is the erosion caused by flowing action of water. Scouring process can be classified into three groups: general scour, contraction scour and local scour (Cheremisinoff et al., 1987). General scour involves the removal of material from the bed and banks across all or most of the width of a channel. This type of scouring occurs irrespective of any human imposed structure. Contraction scour results from the acceleration of the flow due to contraction of channel. With a decrease in flow area, there is an increase in average flow velocity and bed shear stress. Because of the increase in velocity and shear stress, more bed material is transported through the contracted region. Local scour occurs around obstructions like abutments, piers, spurs and embankments is caused by the acceleration of the flow induced by these obstructions and the formation of vortices at their bases (Fig. 1.1). The vortex system and the down flow are the principal causes of the local scour (Kwan et al., 1994). The vortex removes bed material from the base of the obstruction. When the sediment transported from the base of the obstruction is higher than the amount of incoming sediment, a scour hole develops. As the depth of the scour increases, the strength of the vortices is reduced. On the other hand, there are vertical vortices downstream of the structure called wake vortices which lift up sediment from the bed. The intensity of wake vortices diminishes rapidly as the distance downstream of the structure increases. Generally, depths of local scour are much larger than general or contraction scour depths, often by a factor of ten (Federal Highway Administration, 2001). Based on the manner of sediment transport by the approaching flow, local scour was classified into two categories, namely, clear-water scour and live-bed scour (Chabert et al., 1956). Clear-water scour takes place in the absence of sediment transport by the approaching flow into the scour hole. On the other hand, live-bed scour occurs when the scour hole is continuously fed with sediment by the approaching flow.
Failure of bridges due to local scour at their foundation is a common occurrence and each year a large amount is spent to repair or replace bridges whose foundations have been under-cut by the scouring action of stream flow (Melville et al., 1988; Jeng et al., 2005). Bridge foundation consists of abutments and piers. Probably the number of existing bridge abutments is much more than the numbers of bridge piers as most of the bridges are of single span. According to a report of Transportation Research Board, more than 1,000 bridges collapsed in the United States in 30 years, and about 60% failures were related to the bridge foundations scour (Shirhole et al., 1991). In another study by Lagasse et al. (1997), it was estimated that the annual cost for scour-related bridge failures in United States was $30 million. According to Kandasamy and Melville (1998), 6 of 10 bridge failures that occurred in New Zealand during Cyclone Bola were related to abutment scour. According to another study by the Department of Scientific and Industrial Research (DSIR) of New Zealand (Macky, 1990), it is mentioned that almost 50% of total expenditure was made to repair and maintain bridge damage, out of which 70% was spent to repair abutment scour. Thus, scour around bridge abutment is a severe hazard to the performance of bridges. Although, considerable investigations on pier scour have been carried out and reliable design
It is essential to understand the scour in the design of foundations of structures as well as scour protection work. Without a detailed understanding of scour, failures are more likely to occur. The depth of scour is an important parameter for determining the minimum depth of foundations as it reduces the lateral capacity of the foundation. Experimental investigations have been conducted to understand the complex process of scour and to determine a method for predicting scour depth but no general formula has been developed yet that can be applied to all abutment conditions to determine the extent of scour that will develop. Although, numerous empirical formulae have been presented to estimate equilibrium scour depth at bridge abutment (Froehlich, 1989; Melville, 1997; Kandasamy and Melville, 1998; Melville and Coleman, 2003; Dey and Barbhuiya, 2005), each varies significantly, highlighting the fact that there is a lack of knowledge in predicting scour depth and that a more universal solution would be beneficial.

From the available literature it is revealed that various SC methodologies have been applied for scour depth estimation around different types of hydraulic structures like bridge piers, spillway and culvert outlet and yield reasonably accurate results than empirical equations. However, application of SC methods and hybrid models for prediction of scour depth at bridge abutment is lacking of attention from the researchers and only a few numbers of studies were carried out in the recent years. Towards this perspective, the present study is primarily focused on investigating the potential use of various standalone and hybrid SC methodologies for local scour depth prediction at abutment in clear-water condition for safe and cost-effective design of bridges. Further, it is also aimed at improving the generalization performance of the developed hybrid model and carrying out sensitivity analysis to find the influencing parameters causing scour at bridge abutments.

1.2 Objectives

The aim of the research presented in this thesis is to review the theory of SC methodologies and to apply various standalone and hybrid SC techniques for the estimation of local scour depth at different types of abutments in clear-water condition. In order to achieve this aim, the following objectives are identified:
(i) To study SC methodologies and to apply SC methods as standalone and hybrid variants for the estimation of scour depth around different types of bridge abutments.

(ii) To develop a hybrid data-driven scour depth estimation model at bridge abutments and to compare the performance of the developed model with the traditional empirical equations and a hybrid variant.

(iii) To improve the generalization performance of the developed hybrid scour depth estimation model.

(iv) To perform sensitivity analyses to identify the influencing parameters causing scour at abutments.

1.3 Methodology

- **Literature Survey**: SC techniques with an application to scour depth estimation around different type of obstructions are extensively studied and reviewed.

- **Data Collection**: The dataset used in the present work is the laboratory measurements compiled from published literature and are numeric in nature. It consists of laboratory data for three different types of abutment viz. vertical, semi-circular and 45° wing-wall abutments.

- **Model Development**: Model development consists of two phases:

  (i) *Construction of SC models*: ANNs viz. Multilayer perceptron (MLP) and radial basis function (RBF) networks are implemented in MATLAB 7.9 environment and are applied for estimation of scour depth around vertical, semi-circular and 45° wing-wall abutments using the dataset compiled from published literature. Further, GEP model is developed and a new equation for each type of abutment is generated with GEP to estimate scour at abutment. Best fit model is selected along with the associated parameters.

  (ii) *Construction of Hybrid Model*: The predictive accuracy of the best fit ANN model is improved using GA for optimal weight initialization. Further, the generalization performance of the hybrid GA-ANN is enhanced by employing validation techniques and then compared with an existing hybrid variant viz. adaptive neuro-fuzzy inference system (ANFIS) over the same datasets.
Performance Evaluation: The predictive accuracy of the ANN models (MLP and RBF), GEP and hybrid models are analysed with respect to mean absolute error, root mean square error and coefficient of determination between the target and predicted values. To compare the performance, same dataset has been used to evaluate the SC models as well as the empirical equations. The generalization performance of the developed hybrid GA-ANN model is enhanced by employing validation technique.

Sensitivity Analysis: Sensitivity analysis is carried out to identify the influencing parameter on scour depth around different type of abutments.

1.4 Research Contributions
This thesis investigated the applicability of SC techniques for estimation of scour depth at different types of bridge abutments using laboratory data compiled from published literature. Consequently, the thesis explored the effectiveness of a variety of SC and hybrid methodologies. The main contribution of this thesis is the development of a data-driven hybrid GA-ANN model for prediction of scour depth at bridge abutment. The developed hybrid GA-ANN model outperforms the hybrid variant i.e. ANFIS. Further, the generalization performance of the hybrid GA-ANN model is enhanced.

1.5 Overview of the Thesis
This thesis continues with the following chapters:

Chapter 2 - Literature Review: This chapter includes a detailed review of the literature on previous related work for estimation of scour depth around different types of hydraulic structures. A review of empirical formulae, SC methodologies and hybrid techniques employed previously in hydraulic engineering domain to predict scour depth at different types of obstructions has been carried out in terms methods/techniques adopted, types of obstruction, parameters/variables used and the types of statistical error measures. A summary of the reviewed literature has been presented in this chapter. The work carried out in this chapter has been published as a journal paper (Fujail et al., 2011).
Chapter 3 - Soft Computing Methodologies: The special focus of this chapter is on the study of SC methodologies with an emphasis on data-driven models (ANNs) and evolutionary methods. This chapter presents the preliminary theoretical aspects, the training and testing algorithms and the various issues in ANN modeling. A discussion on evolutionary methods employed for prediction of scour depth in the present study has been provided.

Chapter 4 - Methodology: This chapter presents the methodology for prediction of scour depth around vertical, semicircular and 45° wing-wall abutments. The chapter mainly focuses on enumerating the sources of data collection, data pre-processing, methodology for development of the SC models including discussion on selection of input and output variables, data normalization, training and testing procedure and the performance metrics employed to measure the predictive accuracies of the developed models.

Chapter 5 - ANN and Evolutionary Methods for Estimation of Scour Depth at Bridge Abutment: This chapter provides an overview of the ANNs architecture and GEP parameters for estimation of scour depth at different types of abutments. A brief introduction to different weight initialization methods, used for determining the optimal initial weights of neural networks to increase the rate of convergence of networks is provided. A discussion on different transfer functions and the algorithmic parameters for the learning algorithm have also been presented. Different methods of centre selection for RBF are described in this chapter. Experiments have been carried out in Matlab 7.9 environment with an objective to identify the best fit model amongst ANN (i.e., MLP, RBF) and GEP models and empirical formulae to predict scour depth around vertical, semicircular and 45° wing-wall abutments. This chapter and parts thereof have been published as journal and conference papers (Begum et al., 2011, 2012, 2013; Fujail et al., 2013).

Chapter 6 - A Hybrid Computational Model for Scour Depth Prediction at Abutment: The performance of the best fit ANN model i.e., ANN-MLP model for the prediction of scour depth presented in chapter 5 is further enhanced by applying GA for the optimal weight initialization. This chapter presents the experimental results and performance analysis of hybrid GA-ANN model and its comparison with
ANFIS to estimate scour at abutments. A part of this chapter is published in conference proceeding (Fujail et al., 2014).

**Chapter 7 - Improving Generalization Performance of the Hybrid GA-MLP Model:** This chapter discusses various validation techniques for improving the generalization performance of hybrid GA-MLP. Experimental results with different validation techniques are presented in this chapter.

**Chapter 8 - Conclusions and Future Work:** This chapter presents the summary and conclusions drawn from the present work. Some further works arising from the work presented in this thesis are put forward.