Applied Ocean Research 30 (2008) 273–286

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Longshore sediment transport estimation using a fuzzy inference system

R. Bakhtyar [a,b,*], A. Ghaheri [b], A. Yeganeh-Bakhtiary [b], T.E. Baldock [c]

[a] Institut des sciences et technologies de l'environnement, Ecole polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland

[b] Civil Engineering Department, Iran University of Science and Technology, Tehran, Iran

[c] School of Engineering, University of Queensland, Brisbane, Australia

ARTICLE INFO

Article history:
Received 28 May 2008
Received in revised form
7 October 2008
Accepted 12 December 2008
Available online 13 January 2009

Keywords:
ANFIS
Beach
Breaking wave
Membership functions
Wave characteristics

ABSTRACT

Accurate prediction of longshore sediment transport in the nearshore zone is essential for control of shoreline erosion and beach evolution. In this paper, a hybrid Adaptive-Network-Based Fuzzy Inference System (ANFIS), Fuzzy Inference System (FIS), CERC, Walton–Bruno (WB) and Van Rijn (VR) formulae are used to predict and model longshore sediment transport in the surf zone. The architecture of ANFIS consisted of three inputs (breaking wave height), (breaking angle), (wave period) and one output (longshore sediment transport rate). For statistical comparison of predicted and measured sediment transport, bias, root mean square error and scatter index are used. The longshore sediment transport rate (LSTR) and wave characteristics at a 4 km-long beach on the central west coast of India are used as case studies. The CERC, WB and VR methods are also applied to the same data. Results indicate that the errors of the ANFIS model in predicting wave parameters are less than those of the empirical formulas. The scatter index of the CERC, WB and VR methods in predicting LSTR is 51.9%, 27.9% and 22.5%, respectively, while the scatter index of the ANFIS model in the prediction of LSTR is 17.32%. A comparison of results reveals that the ANFIS model provides higher accuracy and reliability for LSTR estimation than the other techniques.

1. Introduction

An important task for coastal engineers is to predict the sediment transport rates in coastal regions; with correct estimation of this transport rate, it is possible to predict beach morphology changes and the influence of coastal structures on the coast line. Littoral sediment transport is caused by the interaction of winds, waves, currents, tides, sediments and other phenomena in the littoral zone. Considerable attention has been committed to the complex issue of nearshore processes, since the sediment transport in this region is of fundamental importance as a boundary condition for beach evolution. Due to the many phenomena affecting sediment transport in the nearshore zone and the difficulties encountered in field measurements, there still is much to be investigated about the hydrodynamics and sediment transport of this zone. A schematic illustration of the nearshore region is shown in Fig. 1.

Both longshore and cross-shore sediment transport rates are significant in surf and swash zones. Less attention has been paid on the longshore part of the sediment transport occurring in the nearshore, which is difficult to measure. Nearshore sediment transport can result in a local rearrangement of sand into bars and troughs, or into a series of rhythmic embayment cut into the beach. At other times there are extensive longshore displacements of sediments, possibly moving hundreds of thousands of cubic meters of sand along the coast each year. This paper focuses on the latter issue and investigates model performance for the prediction of the longshore sediment transport. Many different formulations are available for estimating longshore sediment transport on beaches. A large number of empirical formulas or parametric models has been proposed for predicting the longshore sediment transport rate (LSTR) as a function of the breaking wave characteristics and beach slope [1]. Other more complex models calculate sediment transport directly from wave and current conditions and evaluate the spatial variations in transport to determine morphological change [2].

Bijker's [3] sediment transport formula is one of the earliest formulas developed for waves and currents in combination. It is based on a transport formula for rivers proposed by Kalinske–Frijlink [4]. Bailard and Inman [5] derived a formula for LSTR based on the energetics approach by Bagnold [6]. The gross longshore transport is mainly computed with the CERC formula [7] in engineering applications. The LSTR was also calculated using the breaker height, surf zone width and average longshore current velocity in the surf zone [8]. Van Rijn [9] derived a formula

* Corresponding author at: Institut des sciences et technologies de l'environnement, Ecole polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland. Tel.: +41 (21) 693 8086.

E-mail address: roham.bakhtyar@gmail.com (R. Bakhtyar).

0141-1187/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apor.2008.12.001

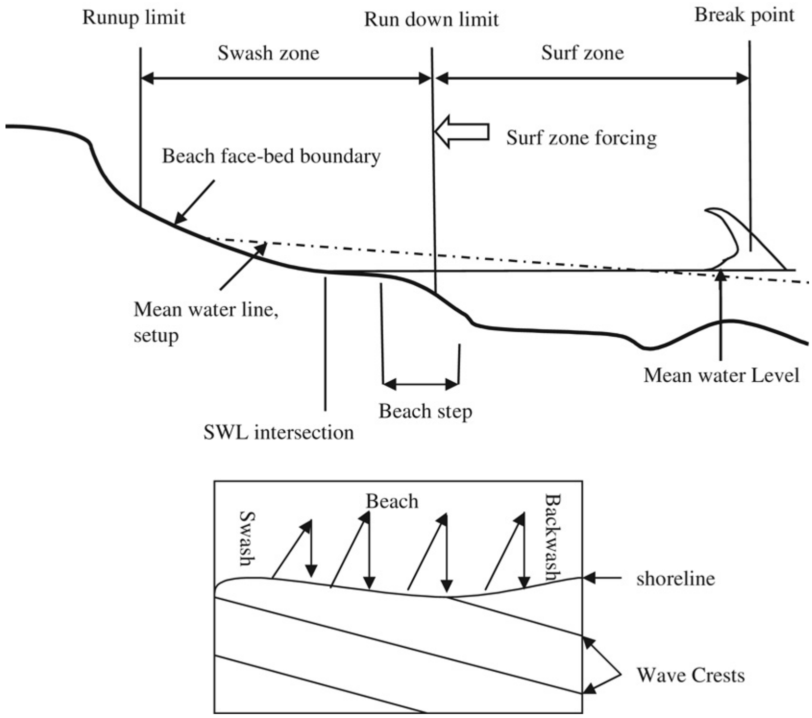

Fig. 1. Schematic illustrations of the nearshore.

for LSTR based on the theory for the sediment transport rate in rivers. Watanabe [10] proposed a formula for the total load based on the power model concept. The Watanabe formula and its coefficient values have been calibrated and verified for a variety of laboratory and field data sets. Nevertheless, it has not yet been recognized whether the value of the non-dimensional coefficient in the formula is a constant or it depends on the wave and sediment conditions. Wang [11] evaluated available formulas for predicting the LSTR as a function of the cross-shore distance. Bayram et al. [12] studied the cross-shore distribution of longshore sediment transport and evaluate the predictive capability of well-known sediment transport formulae, based upon the field data sets. They point out there is no well-established transport formula that takes into account all the different factors that control longshore sediment transport in the surf and swash zones. Kumar et al. [13] compared measurement and estimation of LSTR for the central west coast of India field data. The sediment transport models described include some aspects of a detailed deterministic approach and have a certain validity range. The brief literature review shows that classical modeling techniques cannot accurately determine the LSTR. The main shortcoming of these empirical formulas is that they give a wide range of different predictions, and consequently, their reliability under changing wave conditions or wave climate is somewhat uncertain. Alternatively, the longshore sediment transport can be modeled using soft computing techniques such as the artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) approaches.

A fuzzy rule-based technique has been used for modeling complex non-linear systems. Fuzzy rules have the simple linguistic form of "IF-THEN" propositions. The fuzzy modeling or fuzzy identification, first explored systematically by Takagi and Sugeno [14], has found numerous practical applications in control, prediction and inference. Fuzzy and neural network methods have been individually used in different applications; examples are the studies of Stuber et al. [15] for flood forecast, studies of Azmathullah et al. [16] for estimating the scour below spillways, daily flow forecasting of Singh and Deo [17] and Singh et al. [18], and the studies of Ruchi Kalra et al. [19] for estimating wave heights using a fuzzy rule base.

The ANFIS technique is used for predicting the desired output parameters of a system when enough experimental data is provided. Because they allow the modeling of physical phenomena in complex systems without requiring explicit mathematical representations, this technique is particularly useful in the engineering applications where classical approaches fail or they are too complicated to be used. In order to use this system, first the ANFIS should be trained with a series of historical or primary data. The training should be well performed and the data for training should include as much data as possible that are involved in the application of the model. The model validity is evaluated using input/output testing data which have not been used for training.

The application of ANFIS as a modeling tool in coastal engineering is rather new. Recently, ANFIS has been used in water resources problems such as reservoir operation [20], modeling hydrological time series [21], wave prediction studies [22], predicting scour depth of piles [23], prediction of runup [24], and other related fields. To date, there has been no study on the application of ANFIS in predicting longshore sediment transport using wave characteristics as the input data. In addition, there has been no study testing an ANFIS model against empirical models for the prediction of sediment transport.

In this paper, we determine the accuracy of CERC, VR and WB formulae for estimation of temporally varying LSTR in the surf zone. FIS, which is based on expertise expressed in terms of "IF-THEN" rules, is used here as a framework to map state variables of the sediment transport, breaking wave height, breaking angle and wave period, to the LSTR. We also use ANN to find the best FIS membership function parameters. A hybrid Adaptive Networks FIS which is a combination of ANN and FIS, is implemented to predict and modeling LSTR. These models were applied to the beach at Arge near Karwar on the west coast of India [13]. The paper is organized as follows. Section 2 briefly reviews the CERC, VR and WB formulas for calculating longshore sediment transport. In Section 3, the principles of the FIS and ANFIS models are described. A presentation of study area and available field data