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AERATION EFFICIENCY ESTIMATION IN STEPPED CASCADE AERATORS USING NEURAL NETWORK APPROACH

ABSTRACT

The oxygen concentration in surface waters is a prime indicator of the water quality for human use as well as for the aquatic biota. The physical process of oxygen transfer or oxygen absorption from the atmosphere acts to replenish the used oxygen. This process is termed re-aeration or aeration. Aeration enhancement by macro-roughness is well-known in water treatment, and one form is the aeration cascade. The macro-roughness of the steps significantly reduces flow velocities and leads to flow aeration along the stepped cascade. This paper seeks the performance of artificial neural networks (ANNs) for the estimation of aeration efficiency in stepped cascade aerators. Consequently, it is demonstrated that an ANN model could be employed successfully in modeling aeration efficiency in stepped cascade aerators.

Keywords: Neural Networks, Stepped Cascade, Aeration Efficiency, Oxygen Transfer, Oxygen Concentration

SİNİR AĞI YAKLAŞIMI KULLANARAK BASAMAKLI KASKAT HAVALANDIRICILARDA HAVALANDIRMA VERİMİNİN TAHMİNİ

ÖZET

Yüzey sularındaki oksijen konsantrasyonu suda yaşayan canlılar için olduğu kadar insani kullanım içinde su kalitesinin başlıca göstergesidir. Atmosferden oksijen transferi veya oksijen absorpsiyonunun fiziksek yöntemi, kullanılmış oksijeni tekrar kazanmak için harekete geçmektir. Bu yöntem havalandırma olarak isimlendirilir. Makro pürüzlülük yardımıyla havalandırmanın arttırılması, su arıtımında iyi bir şekilde bilinir ve bunun bir tipi havalandırma kaskatlarıdır. Basamakların makro pürüzlülüğü, akım hızını önemli bir derecede azaltır ve basamaklı kaskat boyunca akım havalanmasına yol açar. Bu makale, basamaklı kaskat havalandırıcılarda havalandırma veriminin tahmini için kullanılabilecek yapay sinir ağlarının performansını araştırmaktadır. Sonuç olarak, basamaklı kaskat havalandırıcılarda havalandırma veriminin modellenmesinde yapay sinir ağı modelinin başarılı bir şekilde kullanılabileceği görülmüştür.

Anahtar Kelimeler: Sinir Ağları, Basamaklı Kaskat, Havalandırma Verimi, Oksijen Transferi, Oksijen Konsantrasyonu

1. INTRODUCTION (GİRİŞ)

Stepped cascade flows are characterized by the strong turbulent mixing, the large residence time and the substantial air bubble entrainment. Air bubble entrainment is caused by turbulence fluctuations acting next to the air-water free surface. Through this interface, air is continuously tapped and released. Air entrainment occurs when the turbulent kinetic energy is large enough to overcome both surface tension and gravity effects. The turbulent velocity normal to the free surface must overcome the surface tension pressure, and be greater than the bubble rise velocity component for the bubbles to be carried away (Chanson, 2002).

Stepped flows can be classified into skimming flow, transition flow, and nappe flow. For narrow steps or larger discharges such as the design discharge the water skims over the step corners and recirculating zones develop in triangular niches formed by the step faces and the pseudo-bottom, as shown in Fig. 1a. In skimming flow the water flows as a coherent stream over the pseudo-bottom formed by the step corners. For a range of intermediate discharges, a transition flow regime takes place. The dominant feature is stagnation on the horizontal step face associated with significant splashing and a chaotic appearance (Figure 1b). For nappe flow the steps act as a series of overfalls with the water plunging from one step to another (Figure 1c). Generally speaking nappe flow is found for low discharges and wide steps (Chanson, 2002).

Water can trap a lot of air when passing through steps and then increasing oxygen content in water body, so stepped cascades can be used as highly effective aerators in streams, rivers, constructed channels, fish hatcheries, water treatment plants, etc. Chanson and Toombes (2002) conducted gas-liquid interface measurements in stepped cascade. Local void fractions, bubble count rates, bubble size distributions and gas-liquid interface areas were measured simultaneously in the air-water flow region using resistivity probes. However, they stated that future work is needed to compare aeration efficiencies estimated with detailed interfacial area data and based upon dissolved gas measurements.

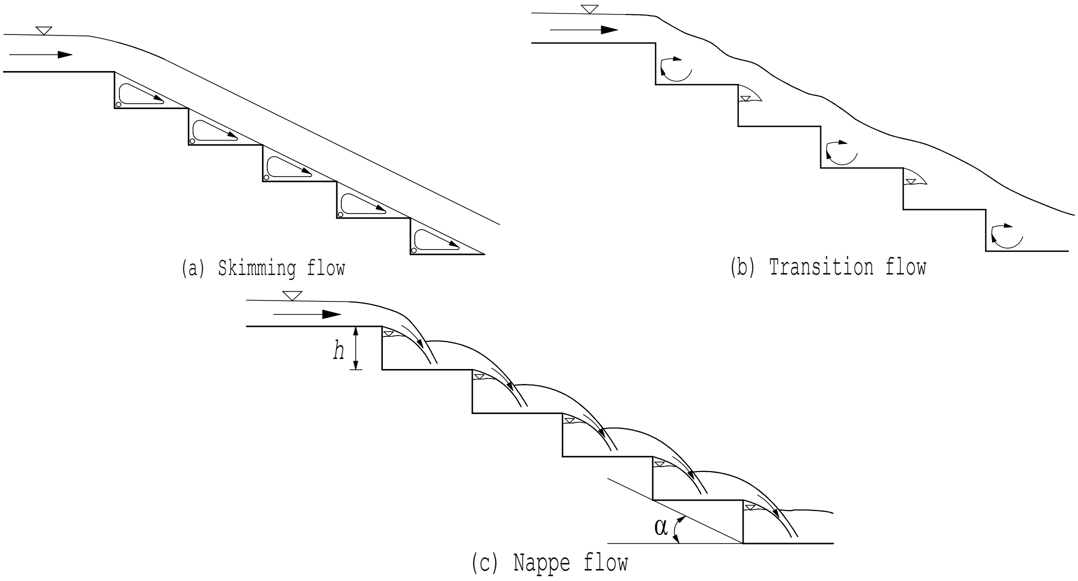


Figure 1. Flow regimes above stepped cascades:
a) skimming flow, b) transition flow, c) nappe flow
(Şekil 1. Basamaklı kaskat üzerinde oluşabilecek akım rejimleri
a) sıçramalı akım, b) geçiş akımı, c) nap akımı

Recently, Baylar and Emiroglu (2003, 2004, 2005), Emiroglu and Baylar (2003, 2006), Baylar et al. (2006, 2007a-d) and Kisi et al. (2007) did some detailed studies on the aeration efficiency of stepped cascades. In the present paper, an artificial neural network (ANN) model is established for the estimation of aeration efficiency in stepped cascade aerators. Among machine learning techniques, ANN is the one that is widely used in various areas of water-related research (Govindaraju, 2000; Kisi, 2004 a, b).

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

It is important to predict aeration efficiency in stepped cascades because they are used in most water treatment applications for re-oxygenation. This research will investigate whether artificial neural networks (ANNs) can be used to predict aeration efficiency in stepped cascades.

3. OXYGEN TRANSFER (OKSİJEN TRANSFERİ)

The rate of oxygen mass transfer, i.e. from the gas (air bubbles) to the liquid phase (water) is governed by the terms described below.

$$\frac{dC}{dt} = K_L \frac{A}{V}(C_s - C) \tag{1}$$

where C = Dissolved oxygen (DO) concentration; K_L= liquid film coefficient for oxygen; A= surface area associated with the volume V, over which transfer occurs; C_s = saturation concentration; and t= time.

The term A/V is often called the specific surface area, a, or surface area per unit volume. Equation (1) does not consider sources and sinks of oxygen in the water body because their rates are relatively slow compared to the oxygen transfer that occurs at most hydraulic structures due to the increase in free-surface turbulence and the large quantity of air that is normally entrained into the flow.

The predictive relations assume that C_s is constant and determined by the water-atmosphere partitioning. If that assumption is made, C_s is constant with respect to time, and the oxygen transfer efficiency (aeration efficiency), E may be defined as (Gulliver et al. 1990):

$$E = \frac{C_d - C_u}{C_s - C_u} = 1 - \frac{1}{r} \tag{2}$$

where u and d= subscripts indicating upstream and downstream locations, respectively; and r= oxygen deficit ratio $\left[(C_s - C_u)/(C_s - C_d)\right]$.

A transfer efficiency value of 1.0 means that the full transfer up to the saturation value has occurred at the structure. No transfer would correspond to E= 0.0. The saturation concentration in distilled, deionized water may be obtained from charts or equations. This is an approximation because the saturation DO concentration for natural waters is often different from that of distilled, deionized water due to the salinity affects.

Comparative evaluations of oxygen uptake at hydraulic structures require that aeration efficiency is corrected to a reference temperature. To provide a uniform basis for comparison of measurement results, the aeration efficiency is often normalized to a 20°C standard. Gulliver et al. (1990) proposed the following equation to describe the influence of temperature

$$1 - E_{20} = (1 - E)^{1/f} \tag{3}$$

where E= transfer efficiency at actual water temperature; E_{20}= transfer efficiency for 20°C; and f= exponent described by

$$f= 1.0 + 2.1 \times 10^{-2} (T - 20) + 8.26 \times 10^{-5} (T - 20)^2 \quad (4)$$

where T= water temperature. In this study, the aeration efficiency was normalized to 20°C using Eq. (3).

4. EXPERIMENTAL (DENEYSEL)

4.1. Experimental Arrangement (Deneysel Düzenleme)

The data used in this study were taken from studies conducted by Baylar and Emiroglu (2003) and Baylar et al. (2006) on a large model of a stepped cascade. Schematic representation of the experimental setup used in these studies is shown on Figure 2. All experiments were conducted in a prismatic rectangular channel with 0.30 m wide and 0.50 m deep. The side walls were made of transparent methacrylate to follow flow regime. Tap water was used throughout the present experiments. The water was changed for each experiment. The water in the tank was deoxygenated by sodium sulfite method. During the experiments, dissolved oxygen measurements upstream and downstream of the stepped cascade were taken using oxygen meters at the locations identified in Figure 2.

All experimental runs were carried out in unit discharges ranging between 16.67 and 166.67 L/s.m. The slopes of stepped channel were varied as 14.48°, 18.74°, 22.55°, 30.00°, 40.00°, and 50.00°. For all slopes tested, steps with equal to 5, 10, and 15 cm were used. For all stepped cascades tested, the range of parameters such as channel slope (α), step height (h), channel length (L) and total number of steps (N) are given Table 1.

Table 1. Geometries of stepped cascades
(Tablo 1. Basamaklı kaskatların geometrileri)

α (deg.)	h (m)	L (m)	N	α (deg.)	h (m)	L (m)	N
14.48	0.05	5.00	25	30.00	0.05	5.00	50
14.48	0.10	5.00	12	30.00	0.10	5.00	25
14.48	0.15	5.00	8	30.00	0.15	5.00	16
18.74	0.05	3.89	25	40.00	0.05	3.89	50
18.74	0.10	3.89	12	40.00	0.10	3.89	25
18.74	0.15	3.89	8	40.00	0.15	3.89	16
22.55	0.05	3.26	25	50.00	0.05	3.26	50
22.55	0.10	3.26	12	50.00	0.10	3.26	25
22.55	0.15	3.26	8	50.00	0.15	3.26	16

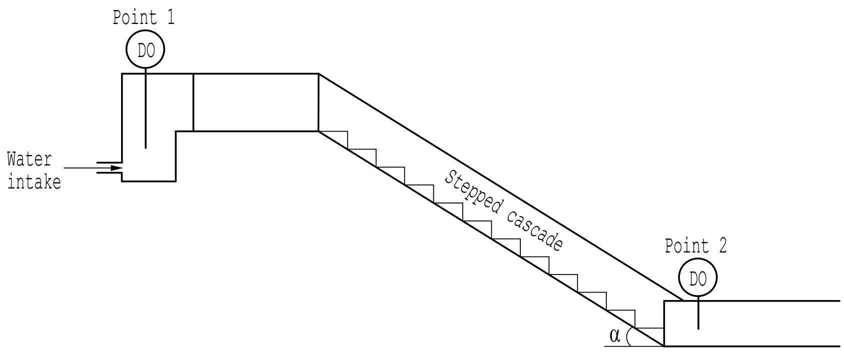


Figure 2. Experimental arrangement for stepped cascade model
(Şekil 2. Basamaklı kaskat modeli için deneysel düzenleme)

4.2. Experimental Results (Deneysel Sonuçlar)

The experimental results for aeration efficiency in stepped cascade aerators are given in Table 2.

Table 2. Data of stepped cascades
(Tablo 2. Basamaklı kaskatlardan elde edilen deneysel sonuçlar)

α (deg)	h (m)	q (m^2/s x 10^{-3})	E_{20} (-)	Flow Regime	α (deg)	h (m)	q (m^2/s x 10^{-3})	E_{20} (-)	Flow Regime
14.48	0.05	16.67	0.60	Nappe	30.00	0.05	16.67	0.81	Nappe
14.48	0.05	33.33	0.58	Transition	30.00	0.05	33.33	0.82	Skimming
14.48	0.05	50.00	0.55	Skimming	30.00	0.05	50.00	0.74	Skimming
14.48	0.05	66.67	0.45	Skimming	30.00	0.05	66.67	0.70	Skimming
14.48	0.05	100.00	0.30	Skimming	30.00	0.05	100.00	0.62	Skimming
14.48	0.05	133.33	0.26	Skimming	30.00	0.05	133.33	0.59	Skimming
14.48	0.05	166.67	0.23	Skimming	30.00	0.05	166.67	0.57	Skimming
14.48	0.10	16.67	0.55	Nappe	30.00	0.10	16.67	0.80	Nappe
14.48	0.10	33.33	0.54	Nappe	30.00	0.10	33.33	0.79	Nappe
14.48	0.10	50.00	0.54	Nappe	30.00	0.10	50.00	0.77	Nappe
14.48	0.10	66.67	0.52	Transition	30.00	0.10	66.67	0.75	Transition
14.48	0.10	100.00	0.44	Transition	30.00	0.10	100.00	0.72	Skimming
14.48	0.10	133.33	0.41	Skimming	30.00	0.10	133.33	0.67	Skimming
14.48	0.10	166.67	0.34	Skimming	30.00	0.10	166.67	0.60	Skimming
14.48	0.15	16.67	0.49	Nappe	30.00	0.15	16.67	0.78	Nappe
14.48	0.15	33.33	0.50	Nappe	30.00	0.15	33.33	0.76	Nappe
14.48	0.15	50.00	0.48	Nappe	30.00	0.15	50.00	0.75	Nappe
14.48	0.15	66.67	0.46	Nappe	30.00	0.15	66.67	0.75	Nappe
14.48	0.15	100.00	0.43	Nappe	30.00	0.15	100.00	0.73	Nappe
14.48	0.15	133.33	0.40	Transition	30.00	0.15	133.33	0.72	Transition
14.48	0.15	166.67	0.40	Transition	30.00	0.15	166.67	0.71	Skimming
18.74	0.05	16.67	0.60	Nappe	40.00	0.05	16.67	0.74	Transition
18.74	0.05	33.33	0.57	Transition	40.00	0.05	33.33	0.75	Skimming
18.74	0.05	50.00	0.52	Skimming	40.00	0.05	50.00	0.72	Skimming
18.74	0.05	66.67	0.44	Skimming	40.00	0.05	66.67	0.70	Skimming
18.74	0.05	100.00	0.28	Skimming	40.00	0.05	100.00	0.63	Skimming
18.74	0.05	133.33	0.22	Skimming	40.00	0.05	133.33	0.59	Skimming
18.74	0.05	166.67	0.16	Skimming	40.00	0.05	166.67	0.56	Skimming
18.74	0.10	16.67	0.58	Nappe	40.00	0.10	16.67	0.74	Nappe
18.74	0.10	33.33	0.58	Nappe	40.00	0.10	33.33	0.76	Nappe
18.74	0.10	50.00	0.55	Nappe	40.00	0.10	50.00	0.77	Transition
18.74	0.10	66.67	0.55	Transition	40.00	0.10	66.67	0.76	Transition
18.74	0.10	100.00	0.47	Transition	40.00	0.10	100.00	0.70	Skimming
18.74	0.10	133.33	0.41	Skimming	40.00	0.10	133.33	0.66	Skimming
18.74	0.10	166.67	0.37	Skimming	40.00	0.10	166.67	0.63	Skimming
18.74	0.15	16.67	0.57	Nappe	40.00	0.15	16.67	0.76	Nappe
18.74	0.15	33.33	0.58	Nappe	40.00	0.15	33.33	0.76	Nappe
18.74	0.15	50.00	0.53	Nappe	40.00	0.15	50.00	0.77	Nappe
18.74	0.15	66.67	0.52	Nappe	40.00	0.15	66.67	0.76	Nappe
18.74	0.15	100.00	0.47	Nappe	40.00	0.15	100.00	0.71	Transition
18.74	0.15	133.33	0.43	Transition	40.00	0.15	133.33	0.69	Transition
18.74	0.15	166.67	0.39	Transition	40.00	0.15	166.67	0.68	Skimming
22.55	0.05	16.67	0.68	Nappe	50.00	0.05	16.67	0.79	Transition
22.55	0.05	33.33	0.61	Transition	50.00	0.05	33.33	0.77	Skimming
22.55	0.05	50.00	0.53	Skimming	50.00	0.05	50.00	0.75	Skimming
22.55	0.05	66.67	0.42	Skimming	50.00	0.05	66.67	0.74	Skimming
22.55	0.05	100.00	0.32	Skimming	50.00	0.05	100.00	0.72	Skimming
22.55	0.05	133.33	0.29	Skimming	50.00	0.05	133.33	0.66	Skimming
22.55	0.05	166.67	0.24	Skimming	50.00	0.05	166.67	0.64	Skimming
22.55	0.10	16.67	0.62	Nappe	50.00	0.10	16.67	0.77	Nappe
22.55	0.10	33.33	0.59	Nappe	50.00	0.10	33.33	0.74	Transition
22.55	0.10	50.00	0.57	Nappe	50.00	0.10	50.00	0.74	Transition
22.55	0.10	66.67	0.55	Transition	50.00	0.10	66.67	0.73	Transition
22.55	0.10	100.00	0.46	Skimming	50.00	0.10	100.00	0.71	Skimming
22.55	0.10	133.33	0.39	Skimming	50.00	0.10	133.33	0.68	Skimming
22.55	0.10	166.67	0.30	Skimming	50.00	0.10	166.67	0.65	Skimming
22.55	0.15	16.67	0.56	Nappe	50.00	0.15	16.67	0.77	Nappe
22.55	0.15	33.33	0.56	Nappe	50.00	0.15	33.33	0.75	Nappe
22.55	0.15	50.00	0.53	Nappe	50.00	0.15	50.00	0.74	Nappe
22.55	0.15	66.67	0.52	Nappe	50.00	0.15	66.67	0.74	Transition
22.55	0.15	100.00	0.51	Nappe	50.00	0.15	100.00	0.72	Transition
22.55	0.15	133.33	0.47	Transition	50.00	0.15	133.33	0.70	Skimming
22.55	0.15	166.67	0.41	Transition	50.00	0.15	166.67	0.69	Skimming

5. NEURAL NETWORKS (SİNİR AĞLARI)

5.1. Neural Networks Modeling (Sinir Ağları Modeli)

Artificial neural networks (ANNs) are based on the present understanding of biological nervous system, though much of the biological detail is neglected. ANNs are massively parallel systems composed of many processing elements connected by links of variable weights. Of the many ANN paradigms, the multi-layer backpropagation network (MLP) is by far the most popular (Lippman, 1987). The network consists of layers of parallel processing elements, called neurons, with each layer being fully connected to the proceeding layer by interconnection fully connected to the proceeding layer by interconnection strengths, or weights, W. Figure 3 illustrates a three-layer neural network consisting of layers i, j, and k, with the interconnection weights W_{ij} and W_{jk} between layers of neurons. Initial estimated weight values are progressively corrected during a training process that compares predicted outputs to known outputs, and backpropagates any errors (from right to left in Figure 3) to determine the appropriate weight adjustments necessary to minimize the errors.

The Levenberg-Marquardt (LM) training algorithm was used here for adjusting the weights. The adaptive learning rates were used for the purpose of faster training speed and solving local minima problem. For each epoch, if performance decreases toward the goal, then the learning rate is increased by the factor learning increment. If performance increases, the learning rate is adjusted by the factor learning decrement. The numbers of hidden layer neurons were found using simple trial-error method.

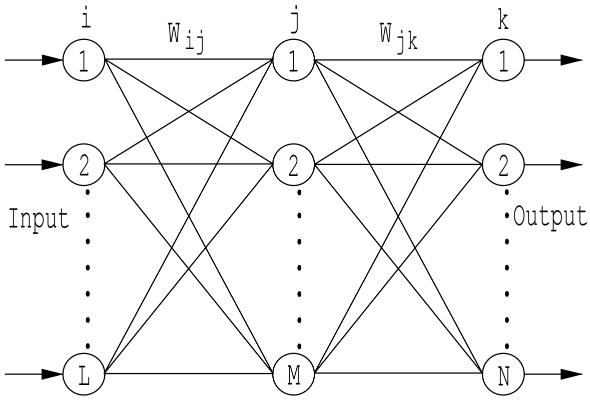


Figure 3. A three-layer neural network structure
(Şekil 3. Üç tabakalı sinir ağı yapısı)

5.2. The Levenberg-Marquardt Algorithm (Levenberg-Marquardt Algoritması)

While back propagation with gradient descent technique is a steepest descent algorithm, the Levenberg-Marquardt algorithm is an approximation to Newton's method (Marquardt, 1963). If we have a function $V(\underline{x})$ which we want to minimize with respect to the parameter vector $\underline{x}$, then Newton's method would be

$$\Delta\underline{x} = -\left[\nabla^2 V(\underline{x})\right]^{-1}\nabla V(\underline{x}) \qquad (5)$$

where $\nabla^2 V(\underline{x})$ is the Hessian matrix and $\nabla V(\underline{x})$ is the gradient. If we assume that $V(\underline{x})$ is a sum of squares function

$$V(\underline{x}) = \sum_{i=1}^{N} e_i^2(x) \tag{6}$$

then it can be shown that

$$\nabla V(\underline{x}) = J^T(\underline{x})\,\underline{e}(\underline{x}) \tag{7}$$

$$\nabla^2 V(\underline{x}) = J^T(\underline{x})\ J(\underline{x}) + S\ (\underline{x}) \tag{8}$$

where J(x) is the Jacobean matrix and

$$S(\underline{x}) = \sum_{i=1}^{N} e_i \nabla^2 e_i(\underline{x}) \tag{9}$$

For the Gauss-Newton method it is assumed that $S(\underline{x}) \approx 0$, and the update (4) becomes

$$\Delta\underline{x} = [J^T(\underline{x})\ J(\underline{x})]^{-1}\ J^T(\underline{x})\ \underline{e}(\underline{x}) \tag{10}$$

The Marquardt-Levenberg modification to the Gauss-Newton method is

$$\Delta\underline{x} = [J^T(\underline{x})\ J(\underline{x}) + \mu I]^{-1} J^T(\underline{x})\underline{e}(\underline{x}) \tag{11}$$

The parameter μ is multiplied by some factor (β) whenever a step would result in an increased $V(\underline{x})$. When a step reduces $V(\underline{x})$, μ is divided by β. When μ is large the algorithm becomes steepest descent (with step 1/μ), while for small μ the algorithm becomes Gauss-Newton. The Marquardt-Levenberg algorithm can be considered a trust-region modification to Gauss-Newton. The key step in this algorithm is the computation of the Jacobean matrix. For the neural network-mapping problem the terms in the Jacobean matrix can be computed by a simple modification to the back propagation algorithm (Hagan and Menhaj, 1994).

6. APPLICATION AND RESULTS (UYGULAMA VE SONUÇLAR)

A program code including neural networks toolbox was written in MATLAB language for the ANN simulation. Different ANN architectures were tried using this code and the appropriate model structure was determined.

A difficult task with ANN involves choosing parameters such as the number of hidden nodes, the learning rate, and the initial weights. Determining an appropriate architecture of a neural network for a particular problem is an important issue, since the network topology directly affects its computational complexity and its generalization capability. The optimum network geometry is obtained utilizing a trial-and-error approach in which ANN are trained with one hidden layer. It should be noted that one hidden layer could approximate any continuous function, provided that sufficient connection weights are used (Hornik et al. 1989). Here, the hidden layer node number of ANN model were determined after trying various network structures since there is no theory yet to tell how many hidden units are needed to approximate any given function. In the training stage, the adaptive learning rate and the same initial weight were used for each ANN networks. The sigmoid activation function was used for the hidden and output nodes.

The parameters considered in the study are unit discharge (q), step height (h), channel slope (α), channel length (L), total number of steps (N), flow regime information and aeration efficiency at the 20^0C (E_{20}). The parameters, q, h, α, L, N and flow regime information were used as inputs to the ANN for the estimation of E_{20}. Of the 126 experimental data sets, the 106 data were used to train the ANN and the remaining data were used for validation. The remaining 20 data sets were randomly selected among the whole data. The model results were evaluated using the absolute relative error (ARE) and determination coefficient (R^2) statistics.

Before applying the ANN to the data, the training input and output values were normalized using the equation

$$a\frac{x_i - x_{min}}{x_{max} - x_{min}} + b \tag{12}$$

where x_{min} and x_{max} denote the minimum and maximum of the stage and discharge data. Different values can be assigned for the scaling factors a and b. There are no fixed rules as to which standardization approach should be used in particular circumstances (Dawson and Wilby, 1998). The a and b were taken as 0.6 and 0.2 herein, respectively.

The ARE statistics of the ANN model are given in Table 3. In the sixth column, the numbers 1, 2 and 3 indicates the flow regimes, nappe, transition and skimming, respectively. In the eighth column, the ANN (6, 10, 1) denotes an ANN model comprising 6 input, 10 hidden and 1 output layer neurons. It can be obviously seen from Table 3 that the ANN approximates measured E_{20} values with a quite high accuracy. The mean ARE for the E_{20} computed values with ANN is as low as 0.6%.

Table 3. The ARE statistics for the computed E_{20} using ANN model - training period
(Tablo 3. Yapay sinir ağı modeli kullanarak hesaplanılmış E_{20} için mutlak rölatif hata istatistikleri – eğitim periyodu)

q (m^2/s x 10^{-3})	h (m)	α (deg.)	L (m)	N	Flow Regime Information	E_{20} Measured	E_{20} Computed (ANN (6,10,1))	ARE (%)
16.67	0.05	14.48	5.00	25	1	0.60	0.60	0.13
33.33	0.05	14.48	5.00	25	2	0.58	0.58	0.36
50.00	0.05	14.48	5.00	25	3	0.55	0.55	0.00
66.67	0.05	14.48	5.00	25	3	0.45	0.45	0.22
133.33	0.05	14.48	5.00	25	3	0.26	0.26	0.81
166.67	0.05	14.48	5.00	25	3	0.23	0.23	1.13
16.67	0.05	30.00	5.00	50	1	0.81	0.81	0.06
33.33	0.05	30.00	5.00	50	3	0.82	0.82	0.18
50.00	0.05	30.00	5.00	50	3	0.74	0.74	0.15
100.00	0.05	30.00	5.00	50	3	0.62	0.62	0.21
133.33	0.05	30.00	5.00	50	3	0.59	0.59	0.12
166.67	0.05	30.00	5.00	50	3	0.57	0.57	0.23
16.67	0.05	18.74	3.89	25	1	0.60	0.60	0.15
33.33	0.05	18.74	3.89	25	2	0.57	0.57	0.53
50.00	0.05	18.74	3.89	25	3	0.52	0.52	0.92
100.00	0.05	18.74	3.89	25	3	0.28	0.28	0.32
133.33	0.05	18.74	3.89	25	3	0.22	0.21	2.41
166.67	0.05	18.74	3.89	25	3	0.16	0.16	2.31
16.67	0.05	40.00	3.89	50	2	0.74	0.74	0.30
33.33	0.05	40.00	3.89	50	3	0.75	0.75	0.56
50.00	0.05	40.00	3.89	50	3	0.72	0.72	0.08
66.67	0.05	40.00	3.89	50	3	0.70	0.70	0.46
133.33	0.05	40.00	3.89	50	3	0.59	0.61	2.59
166.67	0.05	40.00	3.89	50	3	0.56	0.55	1.80
16.67	0.05	22.55	3.26	25	1	0.68	0.68	0.34
33.33	0.05	22.55	3.26	25	2	0.61	0.61	0.02
50.00	0.05	22.55	3.26	25	3	0.53	0.52	1.62
66.67	0.05	22.55	3.26	25	3	0.42	0.43	1.67
100.00	0.05	22.55	3.26	25	3	0.32	0.32	0.50
166.67	0.05	22.55	3.26	25	3	0.24	0.24	0.17
16.67	0.05	50.00	3.26	50	2	0.79	0.79	0.46

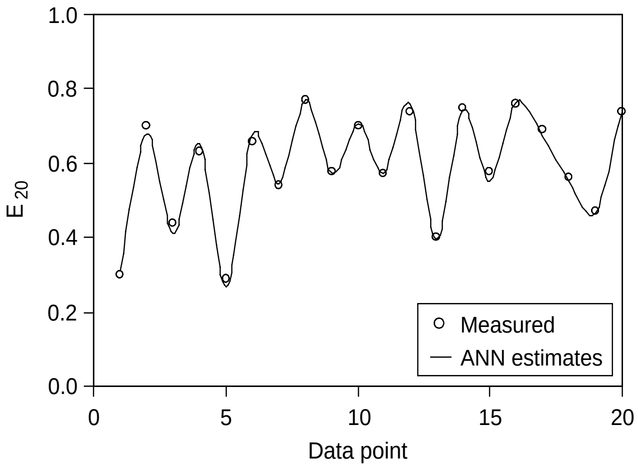
33.33	0.05	50.00	3.26	50	3	0.77	0.77	0.29
50.00	0.05	50.00	3.26	50	3	0.75	0.76	0.85
66.67	0.05	50.00	3.26	50	3	0.74	0.74	0.20
100.00	0.05	50.00	3.26	50	3	0.72	0.71	1.18
166.67	0.05	50.00	3.26	50	3	0.64	0.64	0.30
16.67	0.10	14.48	5.00	12	1	0.55	0.55	0.00
50.00	0.10	14.48	5.00	12	1	0.54	0.54	0.09
66.67	0.10	14.48	5.00	12	2	0.52	0.52	0.60
100.00	0.10	14.48	5.00	12	2	0.44	0.44	0.98
133.33	0.10	14.48	5.00	12	3	0.41	0.41	0.00
166.67	0.10	14.48	5.00	12	3	0.34	0.34	0.35
16.67	0.10	30.00	5.00	25	1	0.80	0.80	0.21
33.33	0.10	30.00	5.00	25	1	0.79	0.79	0.43
66.67	0.10	30.00	5.00	25	2	0.75	0.75	0.44
100.00	0.10	30.00	5.00	25	3	0.72	0.72	0.08
133.33	0.10	30.00	5.00	25	3	0.67	0.67	0.73
166.67	0.10	30.00	5.00	25	3	0.60	0.60	0.63
16.67	0.10	18.74	3.89	12	1	0.58	0.59	1.34
50.00	0.10	18.74	3.89	12	1	0.55	0.55	0.44
66.67	0.10	18.74	3.89	12	2	0.55	0.55	0.27
100.00	0.10	18.74	3.89	12	2	0.47	0.46	1.53
133.33	0.10	18.74	3.89	12	3	0.41	0.41	0.22
166.67	0.10	18.74	3.89	12	3	0.37	0.37	0.86
16.67	0.10	40.00	3.89	25	1	0.74	0.74	0.18
33.33	0.10	40.00	3.89	25	1	0.76	0.76	0.41
50.00	0.10	40.00	3.89	25	2	0.77	0.77	0.60
66.67	0.10	40.00	3.89	25	2	0.76	0.76	0.55
133.33	0.10	40.00	3.89	25	3	0.66	0.66	0.06
166.67	0.10	40.00	3.89	25	3	0.63	0.63	0.10
16.67	0.10	22.55	3.26	12	1	0.62	0.61	1.61
33.33	0.10	22.55	3.26	12	1	0.59	0.60	1.14
66.67	0.10	22.55	3.26	12	2	0.55	0.55	0.44
100.00	0.10	22.55	3.26	12	3	0.46	0.46	0.59
133.33	0.10	22.55	3.26	12	3	0.39	0.38	2.67
166.67	0.10	22.55	3.26	12	3	0.30	0.31	3.60
16.67	0.10	50.00	3.26	25	1	0.77	0.77	0.32
50.00	0.10	50.00	3.26	25	2	0.74	0.74	0.50
66.67	0.10	50.00	3.26	25	2	0.73	0.73	0.66
100.00	0.10	50.00	3.26	25	3	0.71	0.71	0.04
133.33	0.10	50.00	3.26	25	3	0.68	0.68	0.47
166.67	0.10	50.00	3.26	25	3	0.65	0.65	0.55
16.67	0.15	14.48	5.00	8	1	0.49	0.50	1.04
33.33	0.15	14.48	5.00	8	1	0.50	0.49	1.30
50.00	0.15	14.48	5.00	8	1	0.48	0.48	0.25
66.67	0.15	14.48	5.00	8	1	0.46	0.46	0.11
100.00	0.15	14.48	5.00	8	1	0.43	0.43	0.14
166.67	0.15	14.48	5.00	8	2	0.40	0.40	0.05
16.67	0.15	30.00	5.00	16	1	0.78	0.78	0.37
33.33	0.15	30.00	5.00	16	1	0.76	0.76	0.21
50.00	0.15	30.00	5.00	16	1	0.75	0.75	0.01
100.00	0.15	30.00	5.00	16	1	0.73	0.73	0.18
133.33	0.15	30.00	5.00	16	2	0.72	0.72	0.11
166.67	0.15	30.00	5.00	16	3	0.71	0.71	0.03
16.67	0.15	18.74	3.89	8	1	0.57	0.56	1.26
50.00	0.15	18.74	3.89	8	1	0.53	0.54	1.15
66.67	0.15	18.74	3.89	8	1	0.52	0.51	1.15
100.00	0.15	18.74	3.89	8	1	0.47	0.47	0.47
133.33	0.15	18.74	3.89	8	2	0.43	0.43	0.02
166.67	0.15	18.74	3.89	8	2	0.39	0.39	0.28

16.67	0.15	40.00	3.89	16	1	0.76	0.76	0.38
50.00	0.15	40.00	3.89	16	1	0.77	0.77	0.49
66.67	0.15	40.00	3.89	16	1	0.76	0.76	0.41
100.00	0.15	40.00	3.89	16	2	0.71	0.71	0.15
166.67	0.15	40.00	3.89	16	3	0.68	0.68	0.40
16.67	0.15	22.55	3.26	8	1	0.56	0.56	0.50
50.00	0.15	22.55	3.26	8	1	0.53	0.53	0.89
66.67	0.15	22.55	3.26	8	1	0.52	0.52	0.67
100.00	0.15	22.55	3.26	8	1	0.51	0.51	0.12
166.67	0.15	22.55	3.26	8	2	0.41	0.41	0.44
16.67	0.15	50.00	3.26	16	1	0.77	0.77	0.55
33.33	0.15	50.00	3.26	16	1	0.75	0.75	0.27
66.67	0.15	50.00	3.26	16	2	0.74	0.74	0.05
100.00	0.15	50.00	3.26	16	2	0.72	0.72	0.14
133.33	0.15	50.00	3.26	16	3	0.70	0.70	0.19
166.67	0.15	50.00	3.26	16	3	0.69	0.69	0.42

The ARE statistics of the ANN model in test period are given in Table 4. Here also the ANN estimates are very close to the corresponding measured E_{20} values. The mean ARE for the E_{20} estimates with ANN is as low as 2.3%. The ANN estimates are compared with the measured E_{20} values in Figure 4 in the form of hydrograph and scatter plots. As can be seen from these graphs, the ANN estimates catch the measured values with a high accuracy. The coefficients of the fit line equation, 1.0256 and 0.0179, are quite close to the 1 and 0, respectively, with a high R^2 value of 0.9912.

Table 4. The ARE statistics for the estimated E_{20} using ANN model - test period
(Tablo 4. Yapay sinir ağı modeli kullanarak tahmin edilmiş E_{20} için mutlak rölatif hata istatistikleri - test periyodu)

q ($m^2/s \times 10^{-3}$)	h (m)	α (deg.)	L (m)	N	Flow Regime Information	E_{20} Measured	E_{20} Estimated (ANN (6,10,1))	ARE (%)
100.00	0.05	14.48	5.00	25	3	0.30	0.31	3.13
66.67	0.05	30.00	5.00	50	3	0.70	0.68	2.64
66.67	0.05	18.74	3.89	25	3	0.44	0.41	6.50
100.00	0.05	40.00	3.89	50	3	0.63	0.65	3.68
133.33	0.05	22.55	3.26	25	3	0.29	0.27	6.93
133.33	0.05	50.00	3.26	50	3	0.66	0.68	2.76
33.33	0.10	14.48	5.00	12	1	0.54	0.55	1.44
50.00	0.10	30.00	5.00	25	1	0.77	0.77	0.21
33.33	0.10	18.74	3.89	12	1	0.58	0.57	0.98
100.00	0.10	40.00	3.89	25	3	0.70	0.70	0.67
50.00	0.10	22.55	3.26	12	1	0.57	0.57	0.65
33.33	0.10	50.00	3.26	25	2	0.74	0.76	2.66
133.33	0.15	14.48	5.00	8	2	0.40	0.39	1.38
66.67	0.15	30.00	5.00	16	1	0.75	0.74	1.01
33.33	0.15	18.74	3.89	8	1	0.58	0.55	4.83
33.33	0.15	40.00	3.89	16	1	0.76	0.77	0.78
133.33	0.15	40.00	3.89	16	2	0.69	0.67	2.64
33.33	0.15	22.55	3.26	8	1	0.56	0.55	1.50
133.33	0.15	22.55	3.26	8	2	0.47	0.47	0.85
50.00	0.15	50.00	3.26	16	1	0.74	0.74	0.45



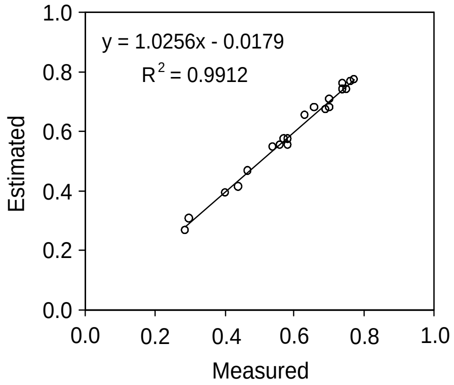


Figure 4. The plotting of ANN estimates and measured E_{20} values in test period
(Şekil 4. Test periyodu için yapay sinir ağı tahminleri ve ölçülmüş E_{20} değerlerinin çizimi)

6. CONCLUSIONS (SONUÇLAR)

A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships. Neural network is widely used in different fields of science and practice. However, its applications to the hydraulic systems are very limited. In this study, a three layer neural network approach was used in estimation of aeration efficiency of stepped cascade aerators. The results indicated that this method provided aeration efficiency estimates with a quite high accuracy. Therefore, the neural network can be used to estimate aeration efficiency in stepped cascade aerators and it can also be recommended to be used in many hydraulic and environmental engineering systems.

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