POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.gov.tr/politeknik

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Benzer S. ve Benzer R., "Modelling nitrate prediction of groundwater and surface water using artificial neural networks", ***Politeknik Dergisi***, 21(2): 321-325, (2018).

Erişim linki (To link to this article): http://dergipark.gov.tr/politeknik/archive

DOI: 10.2339/politeknik.385434

Modelling Nitrate Prediction of Groundwater and Surface Water Using Artificial Neural Networks

Araştırma Makalesi / Research Article

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(Geliş/Received : 27.02.2017 ; Kabul/Accepted : 13.04.2017)

ABSTRACT

This study aims to estimate the changes in the amount of nitrate in Yeşilırmak Watershed using surface water and underground water of the nitrate content determined by General Directorate of State Hydraulic Works using Artificial Neural Networks (ANNs). This study was conducted in 2010 at 30 stations (9 groundwater, 18 surface water and 3 closed water source) in Yeşilırmak Watershed. Nitrate ranged from 0.341 to 77.700 mg/L, with an average value of 17.870 mg/L. In this study, changes in the amount of nitrate in Amasya using groundwater and surface water in the basin of the nitrate content determined by the Provincial Directorate of Agriculture modeling was presented with an approach based on Artificial Neural Networks (ANNs) and predict the nitrate value for the year of 2020 and 2030. Thus, the nitrate levels of water samples obtained from 30 stations water supplies found to be under the limits of Turkish and international codex of drinking water intended for human consumption.

Yapay Sinir Ağları Kullanılarak Yer Altı ve Yüzey Sularındaki Nitrat Tahmininin Modellenmesi

ÖZ

Bu çalışmada, Devlet Su İşleri Genel Müdürlüğü tarafından Yeşilırmak Havzasında (Amasya) belirlenen istasyonlardaki Nitrat değişim miktarının yüzey ve yeraltı sularının Yapay Sinir Ağları (YSA) kullanılarak tahmin edilmesi amaçlanmıştır. Çalışma 2010 yılları arasında Yeşilırmak Havzasındaki 30 istasyonda (9 yer altı suları, 18 yüzey suları ve 3 kapalı su kaynağı) ölçülen veriler ile yürütülmüştür. Nitrat miktarı 0,341 ila 77,700 mg l-1 arasında olup ortalama nitrat miktarı 17.870 mg l-1'dir. İl Tarım Müdürlüğü tarafından belirlenen havzadaki yeraltı suyu ve yüzey suyundaki nitrat içeriği kullanılarak Amasya'da nitrat miktarındaki değişiklikler Yapay Sinir Ağları (ANNs) temelli bir yaklaşımla sunulmuş ve 2020 ve 2030 yıllarına ait nitrat değerleri tahmin etmiştir. Yapılan modellemede, 30 istasyondaki su kaynağından elde edilen su numunelerinin nitrat seviyeleri, insan tüketimine yönelik Uluslararası ve Türk sınırların altında bulunmuştur.

Anahtar Kelimeler: Yapay sinir ağları, nitrat, Amasya, yüzey suları, yeraltı suları

1. INTRODUCTION

Groundwater and surface water pollution caused by nitrate is one of the serious ecological and agricultural problems in today's world. There have been a lot of droughts recently, and groundwater for agriculture has been overused; therefore, water supply in rural and urban areas has become a crucial issue in water resources management of water-scarce regions.

Nitrate can be found in surface and groundwater naturally and anthropogenically. Among the major sources of nitrate in surface and groundwater are decayed vegetable and animal wastes, certain solid wastes, household wastes, industrial waste waters, fertilizers used in agriculture, and sewage waters from waste water treatment facilities [1-3].

Overall, nitrate levels in drinking water coming from surface water are about 10 mg/l in most countries. For example, in some European countries, the percentage of the population exposed to nitrate levels in drinking water above 50 mg l^{-1} varied from 0.5% to 10 % (nearly 10 million people) [4-5].

In 2005, it was reported that 30% of the EU's groundwater bodies were at risk of not achieving good status by 2015. The situation, nonetheless, shows a considerable variation all over Europe. Such states as Belgium, the United Kingdom and the Czech Republic, predicted that approximately 60% of their groundwater bodies were at stake [6].

European Union countries are taking action to protect and assess many problems of underground waters. The project "Technical Assistance for the Implementation of Nitrates Directive in Turkey" is one of the three components of the Programme "Implementation of Nitrates Directive in Turkey", targeting to "reduce the nutrient input impact on the water resources, soil and atmosphere by controlling pollution caused by the agricultural sources in Turkey's water and soil resources, and to implement the Nitrates Directive in Turkey" [7].

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Nitrate in waters has been observed in many studies through depth-specific sampling [8-12].

Estimating the nitrate concentration using cost-effective technologies is necessary. Black-box models like artificial neural networks (ANNs) attracts attention when estimating the nitrate concentration using easily measurable water quality parameters such as temperature, electrical conductivity (EC), groundwater level, pH, etc. In this regard, ANNs do not entail previous information about the structure and relationships possible to exist between significant variables. In addition, the learning abilities of the ANNs have enabled them to be adaptive to the changes in the system [13].

There are a number of studies into the prediction and modelling of nitrate in various water reservoirs, such as Şengörür and Öz [14] in Mahmudiye Stream; Garcet et al. [15], Yesilnacar et al. [16] in Harran Plain, O'Shea and Wade [17] in Kennet Catchment, Kunkel et al. [18] in Weser Basin, Peña-Haro et al. [19] in Castilla-La Mancha Region, İleri et al. [20] in Uluabat Lake, Aguilera et al. [21] in coastal waters in a Spanish tourist area, Palani et al. [22] in Singapore coastal waters, Singh et al. [23] in Gomti River (India).

This study aims to estimate the changes in the amount of nitrate in Yeşilırmak Watershed using surface water and underground water of the nitrate content determined by General Directorate of State Hydraulic Works using Artificial Neural Networks (ANNs).

2. MATERIAL and METHOD

2.1. Study Region and Data

The Yeşilırmak watershed is bordered by the Amasya and Tokat provinces and parts of Samsun, Çorum and Yozgat provinces (Figure 1). The watershed covers an area of about 36,000 km^2, while the total area of the five provinces is nearly 51,000 km^2. The total area of the provinces is actually the basis of present GIS, and corresponds to approximately 7% of the total area of Turkey. The total population of the watershed provinces is about 4 million [24].

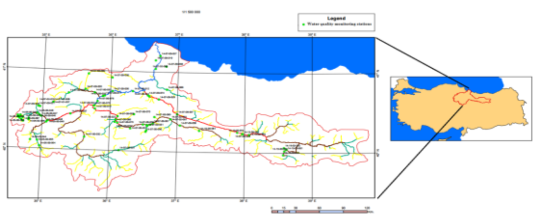

Figure 1. Location map of the Yeşilırmak Watershed with Stations [25]

The General Directorate of State Hydraulic Works (DSİ), is a legal entity, and is the primary executive state agency responsible for planning, management, development, and operation of overall national water resources. This study was conducted by DSİ in 2010 at 30 stations (9 groundwater, 18 surface water and 3 closed water source) in Yeşilırmak Watershed. Nitrate analysis was performed by DSİ, and the results were evaluated by ANNs approach.

2.1. Study Region and Data

ANNs refer to an information processing system which replicates the response of a human brain by imitating the operations and connectivity of biological neurons. As a mathematical interpretation, the ANNs result is defined as a complex nonlinear function with many parameters set to mimic the measured output in a known set of data [26].

Among the features and advantages of ANNs are nonlinearity, parallelism, implemented ease of local information processing, fault tolerance, to be learned that can be system, generalization, customization, hardware acceleration, analysis and design simplicity [27].

The transfer function, mostly used a sigmoid or a logistic function, gives values in the range of [0,1] and can be described as (normalization):

$$V_N = 0.8\,x \left(\frac{V_R - V_{min}}{V_{max} - V_{min}}\right) + 0.1 \qquad (1)$$

V_R : *data to be normalized*

V_{min} : *minimum value*

V_{min} : *maximum value*

Mean Squared Error (MSE) was used as a criteria. MSE was used as convergence criteria during the training of the network. SSE is described by equations 2, respectively.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_{it} - Y_i)^2 \qquad (2)$$

Where Yi is the actual observation value, Yit is the prediction value, and n is the number of total observations.

This study used the sigmoid activation function. ANNs can work with a small data set; and ANNs seem better than other methods because it has such significant features as generalization, learning from data, working with unlimited number of variables and no need for any information about the problem in advance.

3. RESULTS and DISCUSSION

The maximum allowable concentration of nitrate in drinking water is 50 mg/L according to the TS 266 [28], the WHO (2) guidelines and the EU directive [29]. The maximum allowable concentration of nitrate in underground water is stations was determined as 25 mg l-1 according to the TS 266 [28]. Nitrate was well above the maximum admissible concentration and it ranged from 0.341 to 77.7 mg l-1, with an average value of 17.87 mg l-1. The excessive nitrate concentration in the study area is triggered by excessive and uncontrolled irrigation [16].

Within the scope of the Regulation on the Protection of Waters against Nitrate Pollution from Agricultural Sources, the Provincial Directorates of Agriculture have been conducting nitrate analyzes for certain months (January-March-June-September-December) of the year at surface and underground measuring stations. In this context, the results of nitrate analysis in 2010 using the data taken for 30 stations (9 surface, 18 groundwater and 3 closed) from Amasya Provincial Directorate of Agriculture are given in Table 1.

Underground water stations have stations that exceed the limit nitrate values. Boğazköy, Hayrettin, İncekulak and İlyas stations' values are above 25 mg l-1. The critical value at the Ayten Çöl Farm is very close to 50 mg l-1. It is above 50 mg l-1 in the Tuzsuz Village station.

The structure of the ANNs proposed for Modelling Nitrate Prediction is as follows: The neuron number of the input layer is 3, the number of hidden layer is 1, and the number of output layer neuron is 1 (Figure 2).

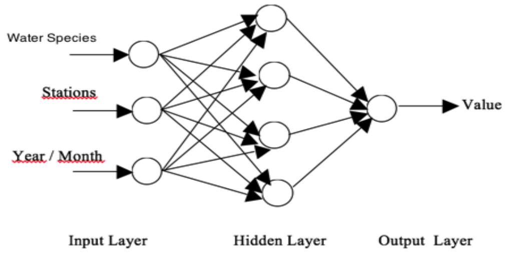

Figure 2. ANNs layers

The data of nitrate was further divided into 70% for training and 30 % for testing the data. Out of the 70 % for training, 30 % was used for just training the model.

Before being put as input into the ANNs, the inputs were normalized according to the normalization function defined in MATLAB, wherein the mean was subtracted and the value divided by the variance of the data.

The data used in the neural network approach is taken from the Provincial Directorate of Agriculture. The results of the data on Amasya are illustrated in Figure 3-

Table 1. Nitrate analyzes results for surface and groundwater stations in 2010 (Amasya/Turkey).

Station Name	Station ID	Water source	Nitrate values (mg / L)				
		Surface /Underground	Jan	Mar	Jun	Sep	Nov
Yeşilırmak entrance	1	Surface	8.66	4.69	5.74	5.93	14.1
Yeşilırmak exit	2	Surface	12.4	8.38	12.2	9.86	10.2
Terkasan entrance	3	Surface	8.56	8.03	6.41	4.45	8.54
Tersakan -Yeşilırmak	4	Surface	12.2	5.89	4.88	4.99	2.83
Çekerek steram	5	Surface	10.3	9.76	12.3	13.3	11.5
Çekerek steram-Yeşilırmak	6	Surface	11.9	11	13.2	11.7	12.9
Çorum Stream	7	Surface	13.4	14.2	21.4	10.8	10.6
Doğantepe Pond	8	Surface	12.3	11.2	8.13	6.79	3.09
Uluköy Pond	9	Surface	1.87	1.02	0.341	0.74	0.38
Yassıçal	10	Underground	12	15.2	7.5	6.04	7.38
Tuzsuz	11	Underground	68.1	59.4	62.9	71.1	77.7
Yerkozlu	12	Underground	Closed Station				
Boğazköy	13	Underground		30.4	41.4	17.3	22.2
Büyük Kızılca	14	Underground	4.76	25.8	22.8	7.21	35.2
Ezinepazar	15	Underground	12.5	1.71	11.3	17.6	16.1
Saluca	16	Underground	Closed Station				
Merbes	17	Underground	Closed Station				
Kendir Factory	18	Underground	32	32.7	31.2	26.1	31.1
Şarlayık	19	Underground	16.5	16.7	15.4	15.9	15.8
Esençay	20	Underground	1.02	0.974	1.04	1.18	1.18
Uzunoba	21	Underground	40.7	41.1	26.3	41.1	40.7
Hayrettin	22	Underground	25.6	30.1	27.6	26.9	26.2
Ayten ÇÖL Farm	23	Underground	48.9	44.3	39	36.9	37.3
İncekulak	24	Underground	24.2	21	20.7	26.0	27.8
Hasanbeyli	25	Underground	3.84	3.61	3.57	20.2	12.8
İlyas	26	Underground	26.7	26.2	24.5	26.2	27.1
Taşova	27	Underground	8.07	7.06	9.43	8.02	13.9
Eslemez	28	Underground	20.7	21.7	21	22.3	21.6
Gümüşhacıköy	29	Underground	16.2	7.48	13.9	22.8	23.8
Gümüş	30	Underground	7.45	13	10.9	7.13	5.42

4. The MSE value for the YSA model calculated with Amasya nitrate data was calculated to be 220.45 and 13.57 respectively. The MSE value was also found to be smaller than the observed data and the performance was better.

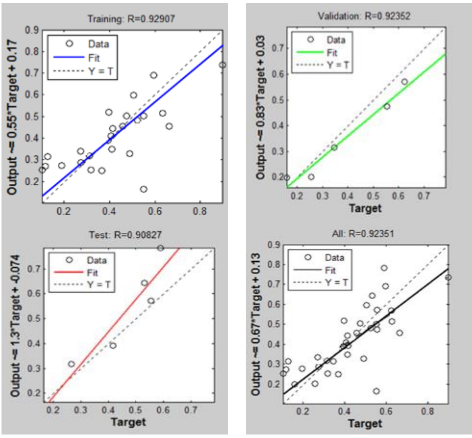

Figure 3. Results (training, validation, test and all) by ANNs

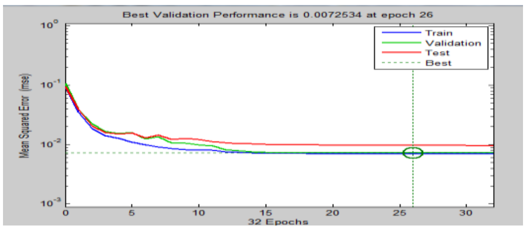

Figure 4. Performance related to learning, validation and test data

Table 2. Nitrate analysis predict year for 2020 and 2030.

	Nitrate Values			
	Min	Max	Average	ANNs
2010	0.341	77.70	17.87	15.636
Nitrate analysis Predict Year (2020 and 2030)				
2020	16.99			
2030	17.75			

Finally, long-term estimation of the nitrate value rates in line with the levels of education over the period between 2020 and 2030 is calculated by the model; and these results are shown in Table 2.

This study illustrates the usefulness of ANNs for the evaluation of complex data in water-quality assessment, and pollution sources, for effective water-quality management. In order to prevent nitrate pollution, it is necessary to monitor the nitrate values in this area and to obtain the required nitrates.

The designed, trained, validated neural network model is powerful enough to predict nitrate. It would be better to compare the data obtained with the longer-term data by increasing the number of stations and the estimation methods (ANNs, ARIMA Model and Multi-Layer Perceptron (MLP) Model for time series forecasting). Thus, with the proposed ANNs application in the current study, surface water and groundwater resources can be managed in a more cost-effective and easy way.

In this study, we described the application of Artificial Neural Networks to the task of nitrate values prediction. We described the theory behind ANNs and our Neural Network model.

ACKNOWLEDGEMENT

Authors are thankful to anonymous reviewers whose suggestions have greatly improved of this article. This work was presented at the National Ecology Symposium in Sinop on 6-9 May 2015.

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