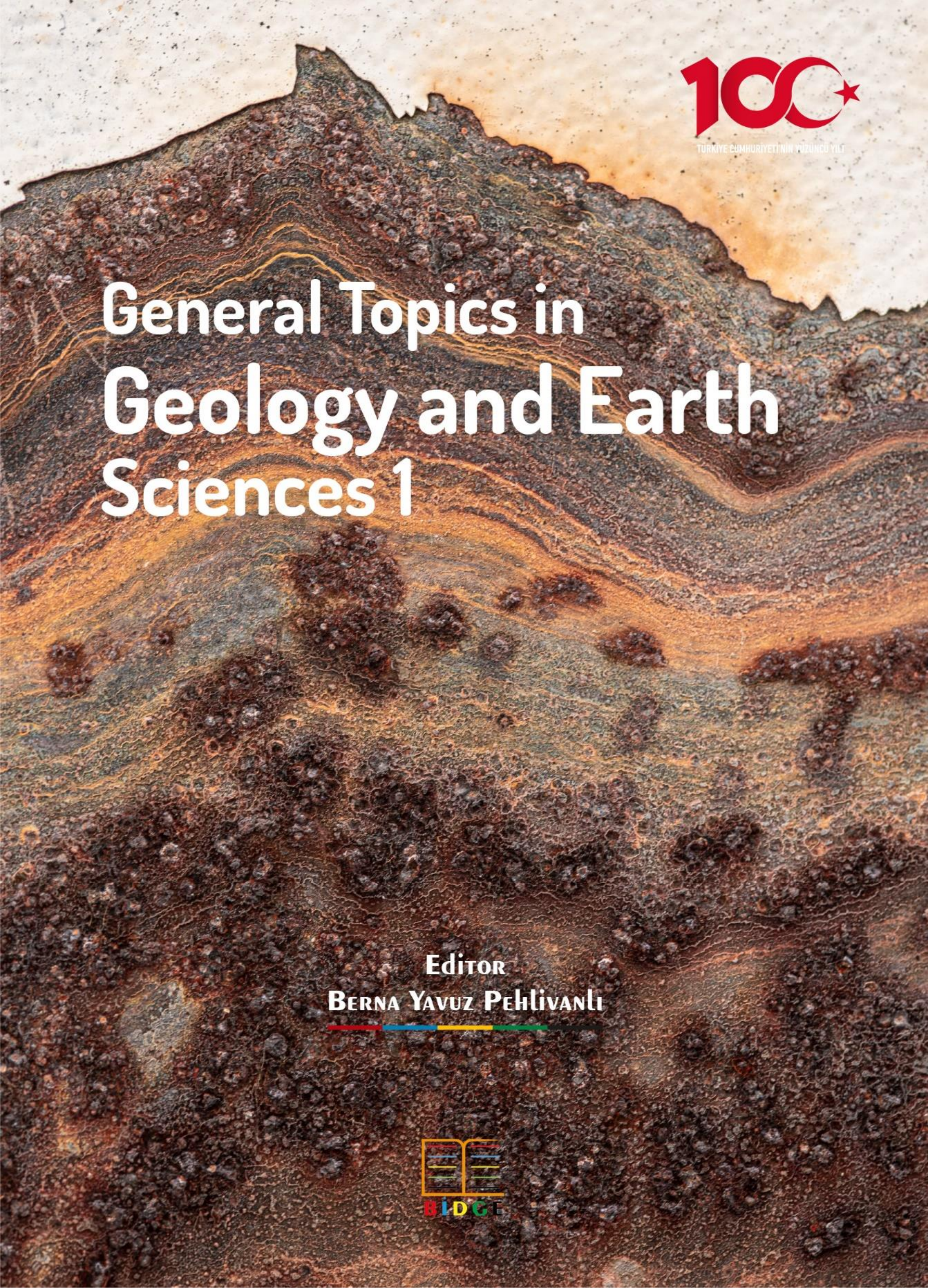

# General Topics in Geology and Earth Sciences 1

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Berna Yavuz Pehlivanlı

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# CHAPTER VI

# Prediction of Capillary Water Absorption (CWA) Values for Pyroclastic Rocks Using Gene Expression Programming (GEP)

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**İsmail İNCE**[2]

## Introduction

Natural stones are materials commonly used for structures constructed for defence, beliefs and residential purposes from the past to the present day. From the moment natural stones are quarried, they are exposed to atmospheric processes and deterioration processes begin. The presence of water within the building stone

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triggers and accelerates deterioration processes (İnce, 2021). Water within the building stone enters through transportation with the effect of capillary water absorption forces acting on water from rain and/or groundwater. A variety of features (low kinematics, index-mechanical properties, structural and textural properties etc) of the rock control the capillary water absorption of building stones (Tomašićet et al., 2011; Ozcelik and Ozguven, 2014; Sengun et al., 2014; Çobanoğlu, 2015; Bao and Wang, 2017; Pötzl et al., 2018; Unal and Altunok, 2019). Determining the capillary water absorption (CWA) value of building stones may be listed among important information for determining locations where the stone can be used and about deterioration processes. Several researchers examined simple regression correlations between CWA with index-strength and textural features of building stones (Vazquez et al., 2010; Stück et al., 2011; Dinçer et al., 2012; Sengun et al., 2014; İnce, 2021). Some researchers predicted the CWA values of building stones using artificial neural network (ANN), fuzzy and support vector regression (Çobanoğlu, 2015; İnce et al., 2021; Zhao et al., 2023; Miao et al., 2023; Yu and Wei, 2023; Ding, 2023; Qian et al., 2023). Gene expression programming (GEP) was proposed by Ferreira (2001) and is a prediction method commonly used in several disciplines (geology, environmental and civil engineering, biology) in recent times (İnce et al., 2019). In this study, the CWA values were predicted with GEP using index values for pyroclastic rocks.

## Material and Method

For this study, 21 pyroclastic rock samples were collected from quarries in different regions of Anatolia. To prepare cube samples for use in the experimental stage, building stone blocks with dimensions of 30 × 30 × 30 cm were obtained from the quarries. For detection of the features of the building stones, cube samples with edge length 70 mm were prepared from these blocks.

The prepared samples had P-wave velocity, dry density, porosity and CWA tests performed. For determination of the P-wave velocity of the building stones, the standards recommended in

ASTM E494 (2010) were noted. The dry density and porosity values of the samples were identified by paying attention to methods recommended in TS EN-1936 (2010). The CWA values of the building stones were examined on the basis of the TS EN-1925 (2000) standard. From the moment the base of the cube samples contacted water, the water absorption amounts per unit area ($g/m^2$) were measured at the time intervals recommended in the standard (1, 3, 5, 10, 15, 30, 60, 480 and 1440 minutes). Measurements ended when the variation between two sequential measurements was less than 1%. Later, graphs of the square root of time ($t^{1/2}$) against water absorption amount per unit area ($g/m^2$) were drawn and the CWA value was determined for each sample from the slopes of the graphs.

## Genetic Expression Programming (GEP) Approach

The GEP approach was developed by Ferreira in 2001. GEP was developed using the main principles of two programs (genetic algorithm and genetic programming). According to Ferreira (2001), in the GEP application, individuals code linear sequences of a genome with fixed dimensions. Later, non-linear clusters with different shapes and dimensions are defined and these are called expression trees (ETs). The gene chromosomes in GEP generally comprise two sections forming the head and tail. These entities are known as ET's, which are the expression of a chromosome. GEP chromosomes generally comprise more than one gene with equal length and each gene is divided into two sections of head and tail. The ETs for the GEP model developed to predict the CWA values of pyroclastic rocks are shown in Figure 1.

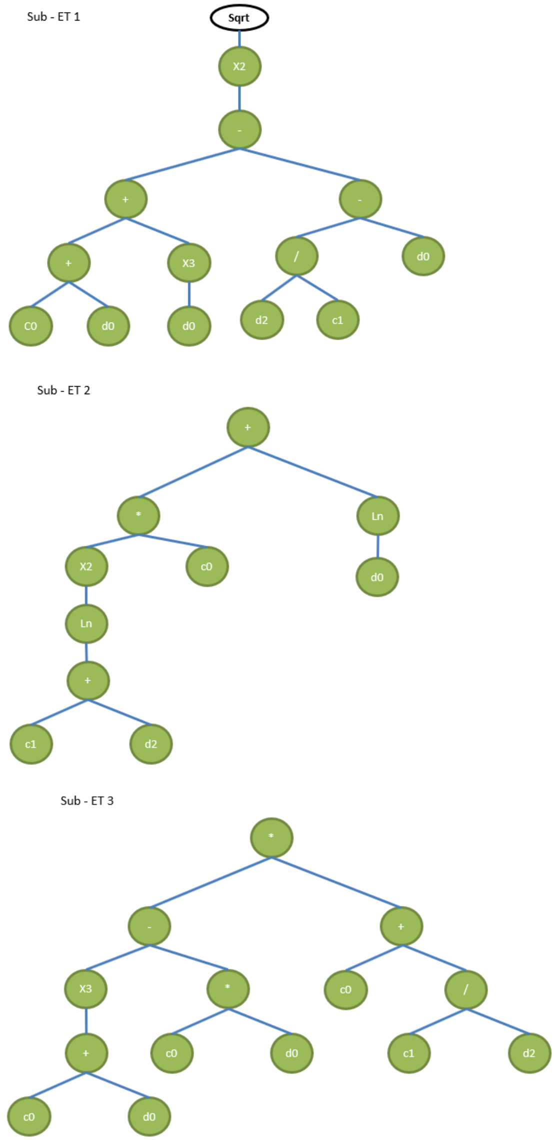


*Figure 1. Expression Tree of GEP Model*

In this GEP model, the number of genes and head length were 3 and 8, respectively (Table 1). During this process, multiplication is used as connective process. During training and confirmation of the GEP model, Vp, $\rho_d$ and n values were defined as input variables, while the CWA value was defined as the output variable (Table 1). In this study, 50 pyroclastic rock samples were used. To predict the CWA values of pyroclastic rocks with the GEP method, the Gene X pro Tools 4.0 software was used. The parameters chosen for the GEP model to predict the CWA value of building stones are given in Table 1. The constants for the developed model are presented in Table 2.

*Table 1. Parameters of GEP Approach Models*

| Parameter definition | GEP |
|---|---|
| Function set | +, -, *, /, Sqrt, ln, $x^2$, $x^3$ |
| Chromosomes | 30 |
| Head size | 8 |
| Number of genes | 3 |
| Linking function | Multiplication |
| Mutation rate | 0.044 |
| Inversion rate | 0.1 |
| One-point recombination rate | 0.3 |
| Two-point recombination rate | 0.3 |
| Gene recombination rate | 0.1 |
| Gene transposition rate | 0.1 |

*Table 2. The Input, Output Quantities and Constants Used in GEP Model*

| Input variables | | Constants | |
|---|---|---|---|
| d0 | $\rho_d$ - g/cm$^3$ | G1c0 | -8.398773 |
| d1 | $n$ - % | G1c1 | 0.580963 |
| d2 | Vp- km/s | G2c0 | -0.256531 |
| | | G2c1 | -0.226379 |
| Output variable | | G3c0 | -4.597229 |
| CWA | g/m$^2$s$^{0.5}$ | G3c1 | -8.837983 |

## Results and Discussion

## Some Indexes Properties of Building Stones

The statistical data related to P-wave velocity, porosity, dry density and CWA values among the index features of pyroclastic rocks used in the study are given in Table 3. The porosity values for the pyroclastic rocks used in the study varied over a broad interval of 12.13-38.30, while dry density values varied from 1.16 $g/cm^3$ to 2.19 $g/cm^3$. According to the NBG (1985) classification, these samples are defined as very low-density rocks with high and very high porosity.

The highest P-wave velocity value for the pyroclastic rocks was 4.00 km/s, with lowest P-wave velocity of 0.70 km/s. According to the CWA classification of Snethlage (2005), samples were included in the low and high absorption rock classes. The CWA values of the samples used in the study vary in a very wide range from 5.32 to 533.29 $g/m^2s^{0.5}$.

*Table 3. Properties of Pyroclastic Rocks Used in The Study*

| Rock Properties | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| Vp - km/s | 0.70 | 4.00 | 2.44 | 0.80 |
| n - % | 12.13 | 38.30 | 22.41 | 7.60 |
| $\rho_d$ – $g/cm^3$ | 1.16 | 2.19 | 1.76 | 0.26 |
| CWA- ($g/m^2s^{0.5}$ | 5.32 | 533.29 | 145.74 | 124.43 |

## Prediction of Capillary Water Absorption Values of Pyroclastic Rocks

In this study, a prediction model using the GEP program for CWA values of 21 pyroclastic rocks collected from Anatolia was developed. In the model, 75% of the sample cluster (16 samples) was allocated for training, while 25% of the dataset (5 samples) was used to test the developed model. Three parameters of mean squared error (MSE), root mean squared error (RMSE) and correlation coefficient ($R^2$) were used to check the reliability of the developed equation (Equations 1-3).

$$MSE = \sum_{t=1}^{n}(o_i)^2, \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(t_i - o_i)^2}, \quad (2)$$

$$R^2 = \frac{(n\sum t_i o_i - \sum t_i \sum o_i)^2}{(n\sum t_i^2 - (\sum t_i)^2)(n\sum o_i^2 - (\sum o_i)^2)}. \quad (3)$$

Where *n* is total data number, *o* is calculated value and *t* is experimental value.

The statistical parameters for the training and test sets for the GEP model developed to predict the CWA values of pyroclastic rocks are given in Table 4. For the training set of the GEP model, the MSE, RMSE and $R^2$ values were 679.23, 26.06 and 0.96, respectively (Figure 2a). For the test set of the GEP model, the MSE values was 1108.29, the RMSE value was 33.29 and the $R^2$ value was 0.91 (Figure 2b).

*Table 4. The CWA Statistical Values of GEP Model*

| Statistical parameters | GEP | |
|---|---|---|
| | Training set | Testing set |
| MSE | 679.2382 | 1108.2935 |
| RMSE | 26.0622 | 33.2910 |
| $R^2$ | 0.9624 | 0.9164 |

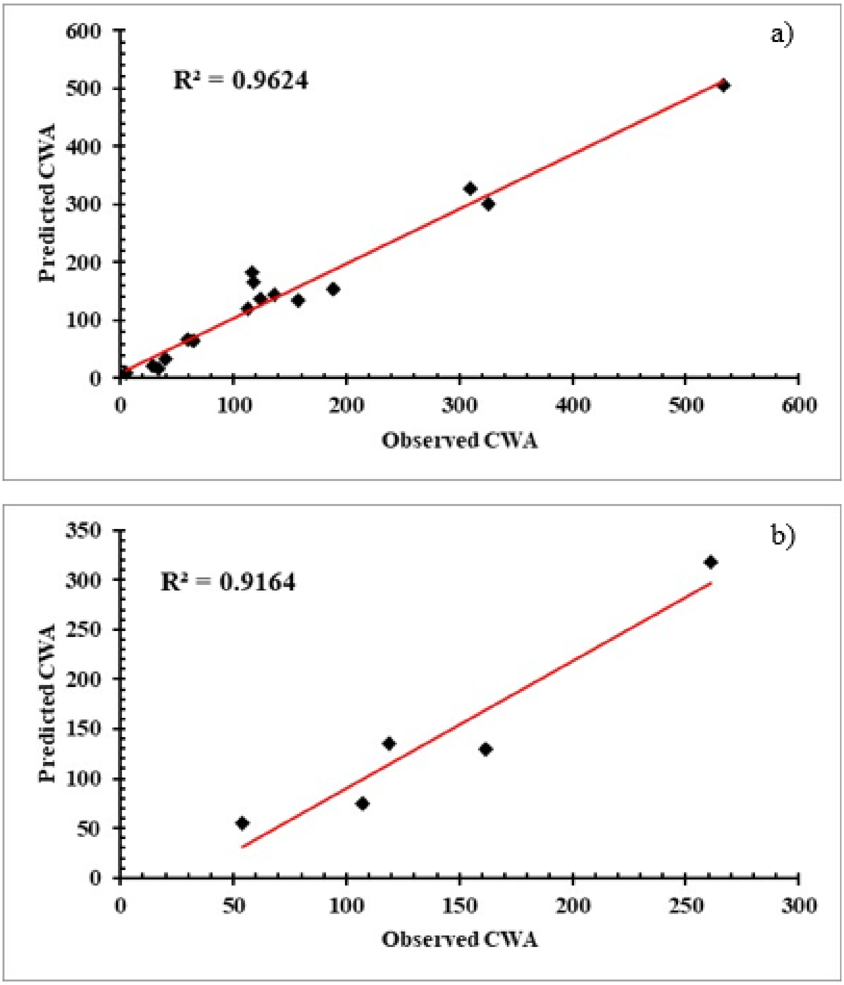


*Figure 2. Comparison of CWA Experimental Results with Results of GEP Model; a) Training, b) Testing*

## Conclusion

Pyroclastic rocks are components forming the cultural texture with common use as building materials for many years due to outcropping over large areas of the Earth, ease of processing and low density. The CWA values of these building stones, which vary over a large interval, cause different responses to deterioration processes. The importance of determining the CWA value, the most effective parameter in the deterioration process, has increased. This study developed a GEP model with the aim of predicting the CWA values for 21 different pyroclastic rocks using index features (Vp, $\rho_d$, and n).

- The GEP model developed for the assessed samples successfully predicted the CWA value. Statistical values like MSE, RMSE and $R^2$ proved this consistency.

- The $R^2$ values for the training and test sets for the developed GEP model were higher than 0.91.

- Due to the proposed GEP model, the CWA value, determined with difficult and time-consuming methods, can be predicted without any experiments.

With more detailed and comprehensive studies, the types of equations developed in this study for pyroclastic rocks collected from the Anatolian region will be evaluated by increasing the number and diversity of samples. It is recommended to evaluate the usability of similar index properties in determining CWA values of pyroclastic rocks from other parts of the world.

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