ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 6, December 2022, pp.57-66

Investigating the potential of liquefaction issue of some Turkish dams during earthquakes

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ABSTRACT

This research is carried out to investigate and assess the critical role of soil properties and their content in influencing the soil liquefaction phenomenon that takes place when an earthquake happens. A case study is considered in this work, representing the Karakaya Dam. Two research approaches were implemented to achieve the research goal, including extrapolation in Excel and numerical optimization using linear regression. The outputs revealed that the annual temperature in the future of zones around the Karakaya Dam, including Azami, Ortalama, and Asgari, would witness a moderate increase of about 3 to 6 degrees Celsius in the next decade. Moreover, the research confirmed that the Euphrates River discharge rate at the Karakaya Dam would witness a significant increase from (100-350 m^3) to (2,590-2,640 m^3) in 2029, explaining that temperature and discharge rate may influence the liquefaction. Meanwhile, the research outputs indicated that soil temperature under the Karakaya Dam and chemical elements would not vary significantly in the next decade. Notwithstanding, the pH number will change widely from 4.14 to 9.74 in 2029. Besides, the most significant chemical molecule concentration in the soil under the Karakaya Dam is the phosphite anion, corresponding to a minimum and maximum concentration of 1 and 2 $\mu g/m^2$, respectively.

Keywords: Karakaya Dam, Soil Liquefaction, Construction, Earthquake, Extrapolation, Soil Parameters, Optimization, Linear Regression

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1. Introduction

The construction sector has been significantly expanding due to remarkable urbanization development and the migration of citizens from rural to urban areas [1]. Massive facilities like bridges, tunnels, dams, and skyscrapers were built in these zones. However, the construction of these facilities should consider some building criteria and codes that enable their robustness and workability when subjected to difficult circumstances or natural accidents [2]. For example, Japan, which is considered a greatly seismically active country, utilizes some criteria and building approaches that can redistribute the forces in the building and alleviate the dangerous impacts of seismic events [3]. Figure 1 represents some examples of novel methods implemented to mitigate the earthquake influences and redistribute forces in the building to avoid an overall collapse. Furthermore, researchers reported the utilization of moment-resisting frames, diaphragms, cross braces, and shear walls to control the momentum and shear forces when seismic activities occur [4-6]. Moreover, scholars remarked on the significance of using a tuned mass (pendulum) damper in which a mass is suspended in the center of the building and controls the frequency of the building when earthquakes cause significant vibrations [7, 8]. The tuned mass damper tries to resist these vibrations by mitigating the motion and returning the building to its original state, thus, improving its stability. Through extensive research and development (R&D) work, scholars and engineers have designed and prepared state-of-the-art software tools that can estimate and assess the dangerous impacts of natural disasters, namely earthquakes, on several large urban facilities, such as bridges, tunnels, dams, and skyscrapers. One example of these software tools is the Plane Strain and Axial Symmetry (PLAXIS) software package [9]. This software can apply finite element analysis (FEA) to predict the failure characteristics, deformations, water flow, stability, and robustness of large structures when they are subjected to severe geological accidents, such as earthquakes [10].

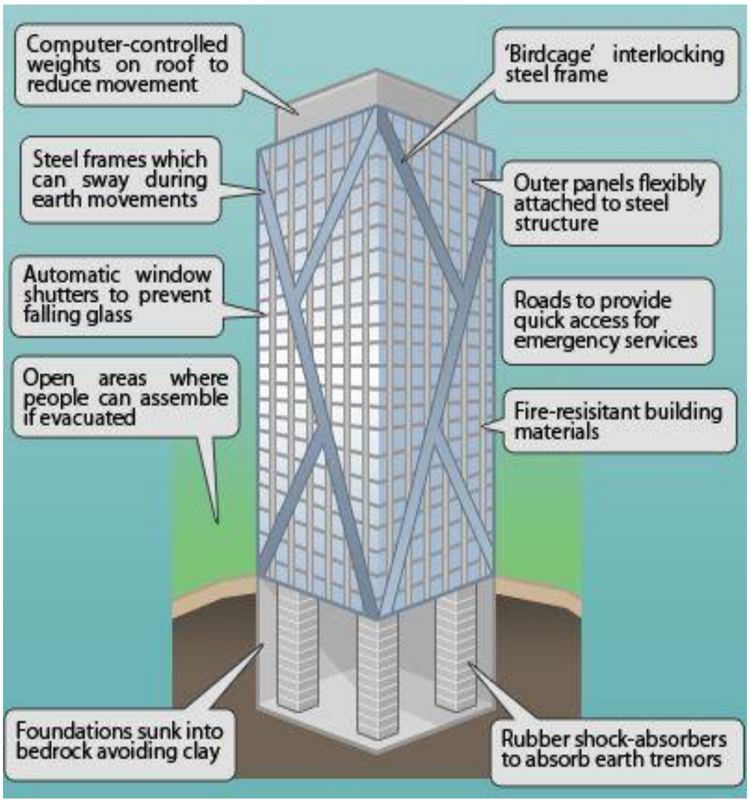

Figure 1. Several methods to mitigate the destructive seismic impacts of buildings [11].

Over the last decades, large-scale construction projects have been established to meet the elevated infrastructure requirements associated with the increase in the global population. One of the critical large-scale construction projects is the dams. Dams are concrete barriers built to save water and act as reservoirs. They raise the water level to be used later for electrical power generation via hydropower energy besides their essential role in providing water for regions around the and increasing countries' water security [12] . Nevertheless, dams may be subjected to dangerous natural disasters and accidents that affect their structural stability and performance [13]. One example of these nature accidents is earthquakes. In general, the time at which earthquakes take place cannot be predicted. They occur abruptly without giving a chance for responsible authorities and people to act or save themselves from severe impacts and damage. Therefore, large-scale facilities and structural objects should be strengthened and carefully built to enable significant effectiveness and protection against severe natural accidents. When earthquakes strike large-scale structures, they may cause significant damage and devastation to properties and buildings around them. If earthquakes hit dams, a large volume of water may spread in all directions and damage facilities around the dam. In this context, smart protection strategies and intelligent building techniques should be implemented. An example of negative earthquake impacts on dams is the soil liquefaction problem. This phenomenon occurs when an earthquake shakes the dam's foundation intensively, affecting its soil and sediment characteristics on the base and breaking their robust connection and bonds, converting these particles into liquid [14]. Therefore, the overall devastation of the dam structure can take place. In this work, numerical modeling, analysis, and simulations are executed on an Iraqi dam (case study) via the PLAXIS software package to identify and determine the critical contributions and significant benefits of intelligent techniques and smart approaches that can be adopted to boost the dam structure's effectiveness, performance, stability, and robustness when severe earthquakes occur [15-21]. Conducted an analysis exploring the soil liquefaction phenomenon and classifying critical characteristics and observations of this problem. They reported that soil liquefaction issues could contribute to significant damage to the infrastructure and several facilities due to the remarkable losses in the soil's stiffness, strength, and valid mechanical properties. This phenomenon could cause buildings to topple over abruptly, sink, and tilt. Furthermore, [22-26] guided research works to identify some intelligent strategies and practical approaches that can be adopted to mitigate the soil liquefaction problem in construction. They found that employing kaolinite-clay, stone columns, nanomaterials, recycled materials, colloidal silica, bentonite, laponite, and short synthetic fibers could be applied and implemented to improve the soil mechanical characteristics by enhancing its potential to resist the liquefaction problem when an earthquake occurs and making amendments in its structure.

2. Materials and methods

The research methodology implemented in this work includes the adoption of two study approaches followed to predict some parameters associated with the soil liquefaction phenomenon in the Karakaya dam, Turkey. The first technique comprises the employment of extrapolation principles using Excel software. The second method consists of using machine learning to predict the concentration of some elements in the soil under the Karakaya dam, which may influence the occurrence of soil liquefaction situation in the dam. The following paragraphs indicate an illustration of these two study methods.

2.1. Extrapolation

Extrapolation can be described as a statistical research procedure through which the trends of data in the future can be determined and forecasted according to some data existing currently. Excel software can be employed to draw a conclusion regarding the relationship between one variable with time and give a formula, which can be utilized to predict the future values of the same parameters next years. Extrapolation has significant advantages and benefits translated by its practicality for several broad engineering, medical, statistical, mathematical, and other applications. In addition, extrapolation can help scholars and engineers identify the behavior of some variables, whether they would increase, maintain constant, or decline in the next decades [27]. In this work, extrapolation is employed to predict two major dam variables that can affect the soil's mechanical characteristics in the future and influence the opportunity of soil liquefaction occurrence. These variables include (1) the ambient temperature around the soil and (2) the dam discharge rate. Figure 1 represents the datasets defined for the extrapolation process regarding the temperature amounts of the Azami region closer to the Karakaya dam.

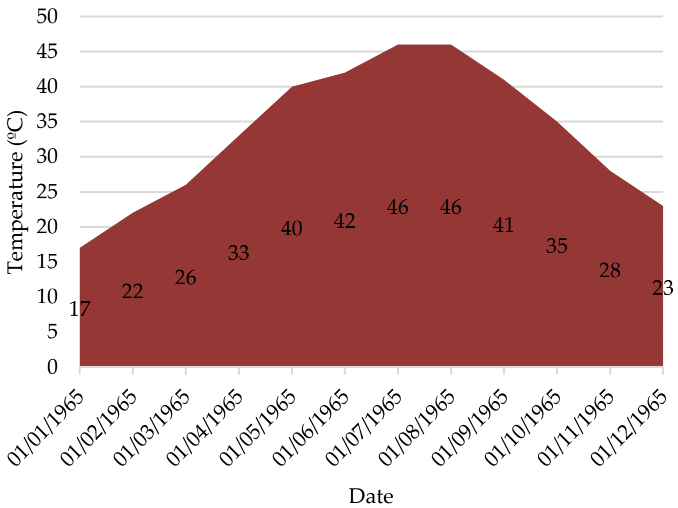

Figure 1. The temperature profile of the Azami area near the Karakaya dam in 1965 (datasets defined).

In addition, Figure 2 represents the temperature profile of another region located closer to the Karakaya dam, which is Ortalama.

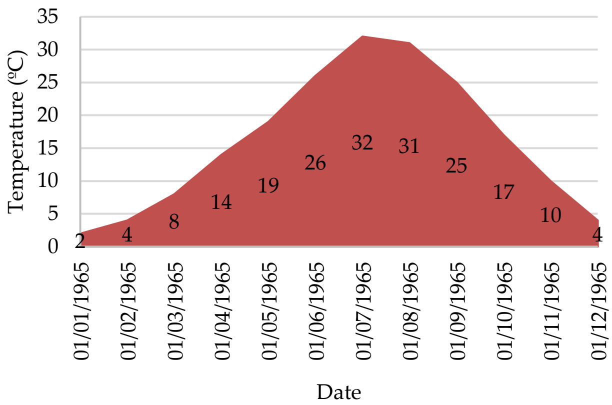

Figure 2. The temperature profile of the Ortalama area near the Karakaya dam in 1965 (datasets defined).

Further, a third zone is selected around the Karakaya dam to predict its temperature profile, representing the Asgari zone. Figure 3 illustrates the temperature profile of this region. All these data are obtained from the Turkish Ministry of Environment and Forestry.

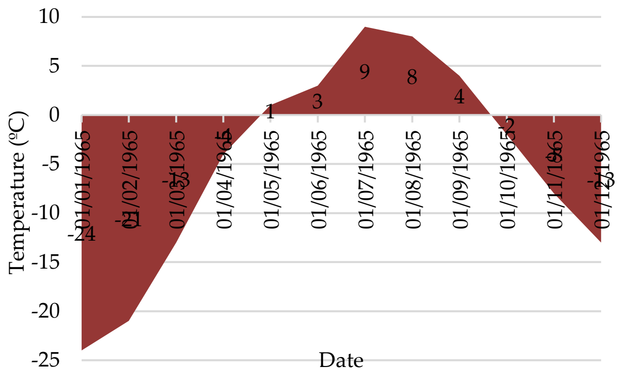

Figure 3. The temperature profile of the Asgari area near the Karakaya dam in 1965 (datasets defined).

It can be indicated from Figures 1, 2, and 3 that the Karakaya dam is located in variant temperature zones in which the temperature values in two of them are closer to the tropical regions. At the same time, one of them, which is Asgari includes very low-temperature values in January, February, March, April, October, November, and December. Also, data associated with the dam discharge rate were depicted from the Turkish Ministry of Environment and Forestry, as illustrated in Figure 4.

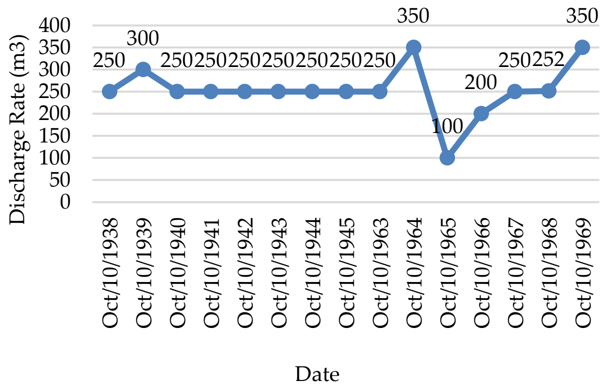

Figure 4. The Karakaya dam discharge rate between 1938 and 1969 (datasets defined).

2.2. Machine learning

Machine learning is used in this work to train Linear Regression Optimization Algorithm (LROA) to help forecast the concentrations of (a) NO_2, (b) PO_3, (c) pH and other elements in the soil under the Karakaya dam. Hence, the soil liquefaction occurrence opportunity can be determined by assessing the amounts of these variables. To achieve this research approach, datasets were defined in Python software using the database from the TensorFlow library. This process can help Python and Artificial Neural Networks (ANNs) make data visualization, analysis, and forecasting more reliable and flexible. Figure 5 represents some of the datasets defined in the Python software to predict the three parameters using the LROA.

	id	location	Date	Season	COD_mgl	pH	Temp_C	Conduc.	Cu	Cd	Pb	Mn	NO2-N
0	1	St-1	1.4.2001	Spring	13	6.12	20.2	391	0.010	0.002	Ur	Ur	0.003
1	2	St-1	1.9.2001	Summer	20	8.32	27.7	295	0.020	0.005	0.003	0	0.007
2	3	St-1	1.12.2001	Autumn	28	9.71	20.4	380	0.010	0.001	0.003	0.1	0.003
3	4	St-1	1.12.2001	Mean	20.3	8.05	22.8	355	0.013	0.0027	0.002	0.03	0.004
4	5	St-2	1.4.2001	Spring	5	8.43	21.3	411	0.060	0.002	Ur	0.05	0.019
5	6	St-2	1.9.2001	Summer	27	4.14	26.8	642	0.030	0.006	0.006	0.1	0.013
6	7	St-2	1.12.2001	Autumn	nd	8.32	20.4	418	0.080	0.002	0.004	0.1	0.016
7	8	St-2	1.12.2001	Mean	10.7	6.96	22.8	490	0.600	0.003	0.003	0.08	0.016
8	9	St-3	1.4.2001	Spring	11	6.38	21.3	401	0.010	0.002	Ur	0.05	0.008
9	10	St-3	1.9.2001	Summer	28	9.04	26.1	389	0.040	0.001	0.003	0.1	0.014
10	11	St-3	1.12.2001	Autumn	6	9.74	19.5	405	0.010	0	0.003	0.1	0.003
11	12	St-3	1.12.2001	Mean	15	8.39	22.3	398	0.020	0.001	0.002	0.08	0.008
12	13	St-4	1.4.2001	Spring	14	6.50	19.9	388	0.010	0.001	Ur	0.09	0.003
13	14	St-4	1.9.2001	Summer	27	8.71	26.7	490	0.010	0.001	0.005	0.1	0.010
14	15	St-4	1.12.2001	Autumn	18	9.21	20.3	518	0.030	ur	0.002	0	0.003
15	16	St-4	1.12.2001	Mean	19.7	8.14	22.3	465	0.020	0.0007	0.002	0.06	0.005

Figure 5. Some of the datasets defined in the Python software to predict the three parameters using the LROA.

3. Results

This section describes the research findings obtained from the two study methodologies implemented in this work, including the extrapolation and numerical forecasting using LROA.

3.1. Extrapolation results

Figure 6 represents the extrapolation results related to the temperature profile in 2025 obtained using excel software after using the data defined for the Azami region, which is close to the Karakaya dam.

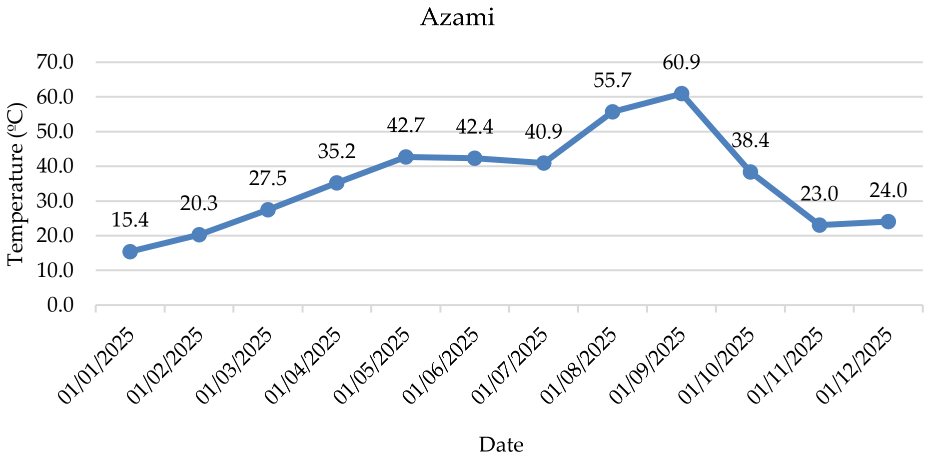

Figure 6. The research forecasting findings, according to the extrapolation method of Azami temperature.

It can be noted from Figure 6 that the temperature values in Azami for the months of 2025 are larger than the temperature values in 1965. These results can indicate that the soil properties under the Karakaya dam may be influenced due to the high-temperature values. Furthermore, the extrapolation results indicated the temperature profile linked to the Ortalama zone near the Karakaya dam in 2025, as shown in Figure 7.

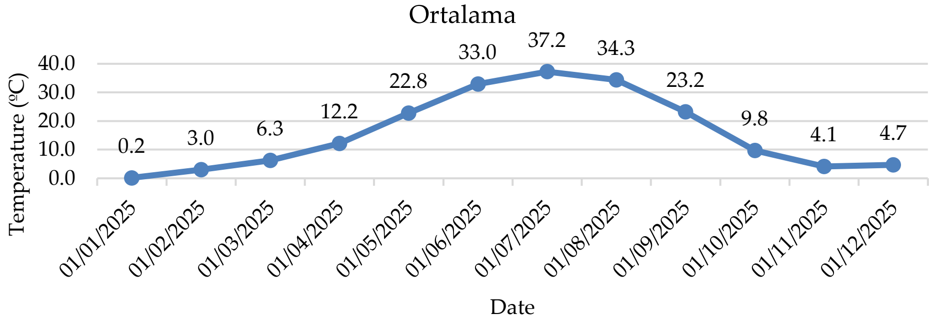

Figure 7. The research forecasting findings, according to the extrapolation method of Ortalama temperature.

It can be noted from Figure 7 that the temperature values in Ortalama for the months of 2025 are more significant compared with the temperature values in 1965. These results can indicate that the soil properties under the Karakaya dam may be affected because of the high-temperature values. Besides, the extrapolation procedures revealed the temperature profile associated with the Ortalama zone near the Karakaya dam in 2025, as shown in Figure 8.

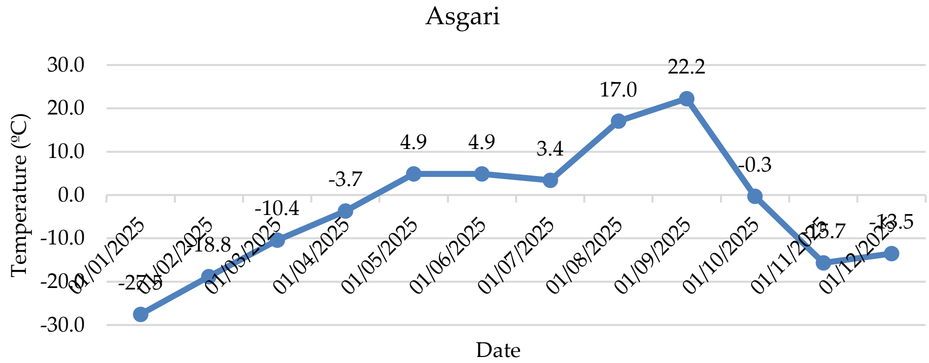

Figure 8. The research forecasting findings, according to the extrapolation method of Asgari temperature

Similar to the two previous regions, it can be noted from Figure 8 that the temperature values in Asagari for the months of 2025 are more significant compared with the temperature values in 1965. These results express that the soil characteristics under the Karakaya dam may be impacted because of the high-temperature weights. Besides, the extrapolation procedures revealed the forecasting results associated with the discharge rate of the Euphrates River closer to the Karakaya Dam for the year 2029. Figure 9 represents the prediction findings related to this parameter.

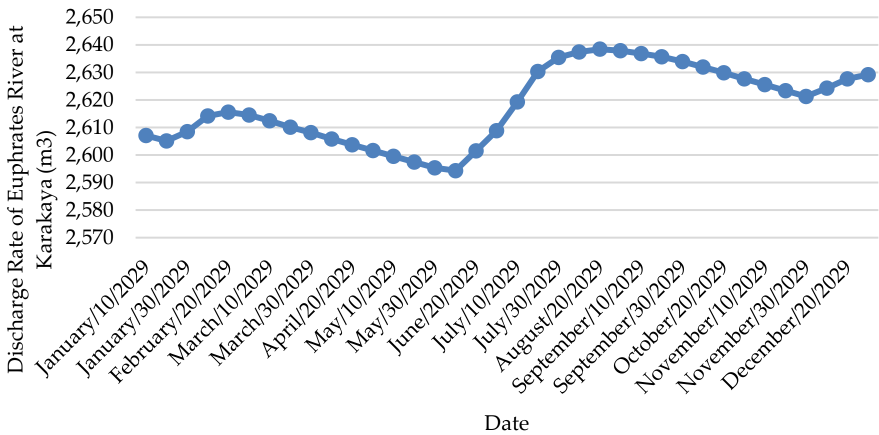

Figure 9. The research forecasting findings, according to the extrapolation method of Asgari temperature for 2029

It can be inferred from Figure 9 that the discharge rate of the Euphrates River amounts to approximately 2,605 m^3 at the beginning of January. Then, it starts to increase until it reaches around 2,615 m^3 on March 10. After that, the Euphrates River discharge rate witnesses a continuous decrease until it amounts to a minimum annual discharge value of about 2,595 m^3 on June 20, 2029. Then, it increases until it amounts to a maximum yearly value discharge of 2,645 m^3 on August 20, 2029. Then, it decreases slightly to reach around 2,620 m^3 at the end of November. Then, it increases again to attain a quantity of 2,630 m^3 at the end of December 2029.

3.2. Numerical LROA results

In addition to the preceded results, the concentrations of some elements in the soil were assessed to examine their impact on the soil liquefaction problem. Table 1 illustrates the forecasting results obtained from the optimization process using the ANN algorithm of linear regression for 2029. It can be inferred from Table 1 that the predicted soil pH number for 2029 will record a minimum value of 4.140 compared with a maximum amount of 9.740. Further, the soil temperature will record a minimum amount of 19.5 ºC compared with a maximum amount of 27.7 ºC. At the same time, copper concentration will reach a minimal quantity of 0.01 µg/m2 and a maximum quantity of 0.6 µg/m2 at some time during 2029. Similarly, the concentrations of other chemical elements in the soil under the Karakaya Dam will not significantly vary in 2029. These results can indicate that soil characteristics may not be remarkably affected or changed in the next years. Therefore, the opportunity of soil liquefaction phenomenon has a lower opportunity of occurring.

Table 1. The LROA numerical forecasting results of some soil parameters and elements for 2029

Category	Symbol	Unit	Minimum	Maximum	Standard Deviation
Potential Hydrogen Number	pH No.	---	4.140	9.740	1.499
Soil Temperature	T_{Soil}	ºC	19.500	27.70	2.756
Copper	Cu	µg/m^2	0.010	0.600	0.145
Nitrogen Dioxide	NO_2	µg/m^2	0.003	0.020	0.006
Phosphite Anion	PO_3	µg/m^2	0.990	2.030	0.343
Ammonium Ion	NH_4^+	µg/m^2	0.040	0.320	0.082
Ammonia	NH_3	µg/m^2	0.030	0.300	0.079

Figure 10 represents a graphical representation of the chemical elements' concentrations obtained from the LROA analysis (which are described in Table 1).

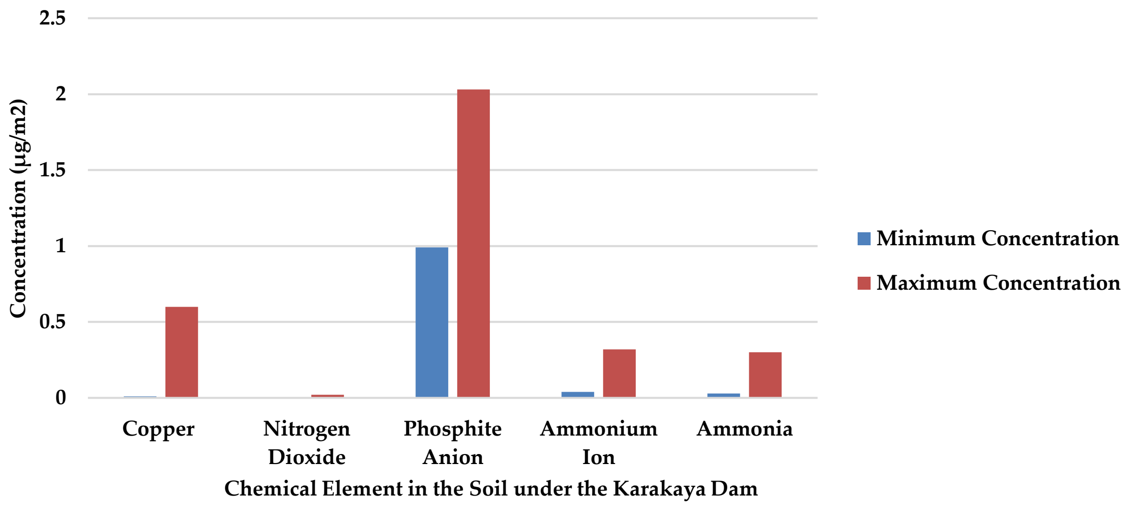

Figure 10. The chemical elements' concentrations in the soil under the Karakaya Dam.

It can be indicated from Figure 10 that the largest chemical molecule existing in the soil under the Karakaya Dam is the phosphite anion, corresponding to a minimum and maximum concentration of 1 and 2 µg/m^2, respectively, followed by copper, ammonia, and ammonium ion, with a concentration between 0 and 0.5 µg/m^2.

4. Discussion

The results of this work revealed that the annual temperature in the future of zones and regions around the Karakaya Dam, including Azami, Ortalama, and Asgari, would witness a moderate increase of about 3 to 6 degrees Celsius in the next decade. Moreover, the research forecasting analysis confirmed that the Euphrates River discharge rate at the Karakaya Dam would witness a significant increase from (100-350 m^3) to (2,590-2,640 m^3) in 2029, explaining that temperature and discharge rate may influence the occurrence of liquefaction problems due to the increase in the ambient temperature and water flow in the future. On the other hand, the research findings indicated that soil temperature under the Karakaya Dam and chemical elements would not vary significantly in the next decade. Nonetheless, the pH number will vary widely from 4.14 to 9.74 in 2029. Also, the numerical linear regression optimization affirmed that the most significant chemical molecule concentration in the soil under the Karakaya Dam is the phosphite anion, corresponding to a minimum and maximum concentration of 1 and 2 $\mu g/m^2$, respectively. Also, data analysis on earthquakes around the Karakaya Dam was not implemented as earthquake opportunities cannot be numerically predicted. These results are consistent with the results of [22]-[27], who conducted an analysis on the soil liquefaction problem that occurs in different infrastructure and significant construction projects, such as earth dams, and found that soil temperature, discharge, soil content, and soil properties play a critical role in affecting the behavior of soil liquefaction problem and this problem can be mitigated by enhancing, promoting, and modifying the soil features and increase its resistance to this severe phenomenon when earthquakes occur.

5. Conclusions

This research is carried out to investigate the critical role of soil properties and content in influencing the soil liquefaction phenomenon that occurs when an earthquake happens. A case study is taken into account in this work, representing the Karakaya Dam. Two research approaches were implemented to achieve the research goal, including extrapolation in Excel and numerical optimization using linear regression. Datasets were collected of the temperature in three regions (Azami, Ortalama, and Asgari), and the Euphrates River discharge rate database was collected from the Turkish Ministry of Environment and Forestry. The extrapolation and numerical optimization findings can be summarized in the following paragraphs:

- The annual temperature in the future of zones and regions around the Karakaya Dam, including Azami, Ortalama, and Asgari, would witness a moderate increase of about 3 to 6 degrees Celsius next decade.
- The Euphrates River discharge rate at the Karakaya Dam would witness a significant increase from (100-350 m^3) to (2,590-2,640 m^3) in 2029, explaining that temperature and discharge rate may influence the occurrence of liquefaction problems.
- Soil temperature under the Karakaya Dam and chemical elements would not variate significantly next decade.
- The pH number will variate widely from 4.14 to 9.74 in 2029.
- The most significant chemical molecule concentration in the soil under the Karakaya Dam is the phosphite anion, corresponding to a minimum and maximum concentration of 1 and 2 $\mu g/m^2$, respectively.
- Data analysis on earthquakes around the Karakaya Dam was not implemented as earthquake opportunities cannot be numerically predicted.

Acknowledgments

The author would like to acknowledge the Turkish Ministry of Environment and Forestry for their cooperation in providing the necessary database to analyze and investigate in this work.

Conflicts of Interest

The authors declare no conflict of interest.

Funding information

No funding was received from any financial organization to conduct this research.

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