Impact of Quarrying on Soil Degradation: Assessment and Modeling

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Abstract. The activities of aggregate quarries result in pollution of soil and the possible loss of soil fertility and destruction of ecosystems. This pollution is quantified in this study and the future evolution will be predicted using the ARIMA model. The results indicate the presence of severe alkalinization (pH 9.00), salinization (electrical conductivity of 7900 µS/cm), and precipitation of calcium carbonate (80%). Organic matter values drop to 0.05% which has grave implications for soil fertility. Predictions indicate a continuing deterioration, the limits of soil quality is surpassed in the future, in particular for the agricultural soils. While the impact diminishes with distance from the quarry there is uncertainty surrounding cation exchange capacity, and consequently the accompanying mechanisms are complex. The study emphasizes that management plans will have to implement sustainable practices in order to reverse the soil degeneration and protect ecosystems at the sites of quarrying.

Keywords: aggregate quarries, environmental assessment, modeling, soil

1 Introduction

Aggregates quarries are a vital input in the construction industry by providing the construction materials that are used to construct the major infrastructures such as roads, bridges, and buildings [1-2]. Though the sector is a key facilitator of modern societies' development, it generates environmental risks of which one of the most notable is soil erosion. The intensive extraction of aggregates impacts the physical and chemical properties of soils, which consequently has potential effects on soil water retention, structure, and biodiversity [3-5].

Its effect will lower the quality of soil in the area, particularly with regard to the alteration of their chemical and physical composition. Nevertheless, it is crucial to know the extent of such potential disturbances more and ascertain the risks of quarry exploitation [6-7]. Such degradation endangers soil fertility and hinders local ecosystems from regenerating, thereby compromising the ecological stability of the subject areas [8-10].

One of the major difficulties is dealing with the timeframes of these impacts. The degradation of the soil from quarrying, for example, does not occur overnight; it occurs over years and can even continue for many years after the closure of any extraction sites [11-12]. Knowing and predicting this relationship will require the application of predictive modeling tools. This is possible because we can predict future change in the quality of the soil, or a loss of fertility, chemical changes, or physical structure, using the properties of the soils we have in the dataset [13-15]. These tools can show evidence of trends of soil degradation due to exploitation, and therefore predict changes to the environment into the future, while giving necessary information to sustainably manage quarries and surrounding environments [16-18]. By these trend analyses, the study will not only help understand the long-term effects of aggregate exploitation but furthermore provide reliable information for implementing sustainable management measures [19-21].

In this regard, this study will help us to better determine the environmental risks associated with using these resources and provide a valuable platform for future studies aimed at decreasing these long-term impacts [22-23].

2 Materiels and methods

2.1 Study area description

Study Area. The study area is located in northern Morocco, in the Haouz chain of limestone. The region is predominantly rural with agricultural activities such as cereal cultivation, legume production, and the keeping of small animals (goats and sheep) [24]. Quarrying, or the mining of materials, is also a significant economic contributor to the area, providing employment opportunities and contributing to the supply of materials to the building sector as well as other industries [25]. Geologically, the area is dominated by Triassic and Jurassic limestone and dolomite facies common to karst terrains, so it is possible to extract quality construction materials [26]. The geologic setting imbues the area with some aspects, particularly geotechnical qualities and extractable mineral resources. The prevailing winds of the region are South-Southwest (SSW) and East-Southeast (ESE), and they have an impact on fine particle dispersion within the region [26].

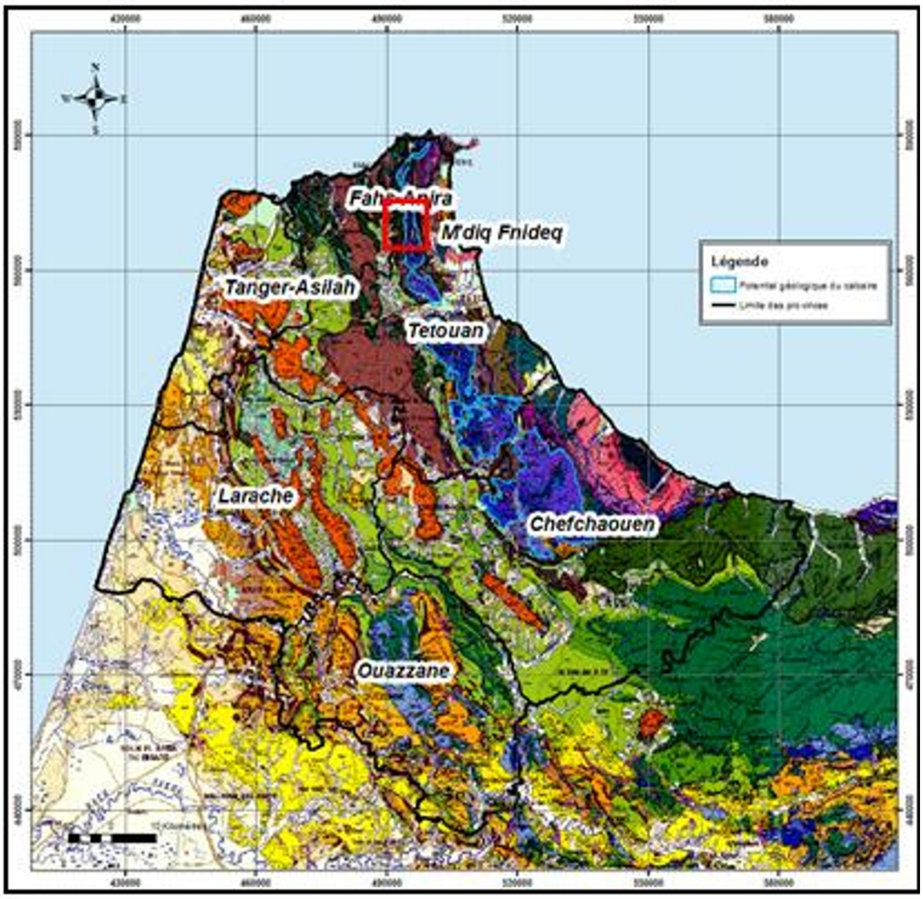


Fig 1. Location of the study area (Geological map of Morocco 1:1,000,000 scale)

Description of the Studied Site. The primary criterion for selecting the study site was the distance of the quarry from any major industrial activity. This was essential to ensure that the study focused solely on the environmental impacts related to mining operations, without interference from other sources of industrial pollution. The site under study is an open-pit quarry that has been in operation since 2005. The quarry has an annual output of around 1,200,000 m^3 of materials, mainly aggregates, crushed sand and general fill, for use in various construction and industrial operations. The extraction process of aggregates is done by realistically following a stepped method, using mechanical shovels and sometimes selected explosions to assist in extracting parts of geological layers. This quarry is prized for the material quality, predominantly limestone and dolomite, that is extracted and processed into aggregates and related features [27].

2.2 Sampling Technique

Sampling sites were established in every cardinal direction (north, south, east and west) surrounding the quarry at different distances from quarry activity in order to compare soil quality for closer and further distances to mining activities. Sampling occurred at different depths with augers in order to minimize the opportunity for cross-contamination. Samples were labeled with necessary information (location, depth, date) at the time of collection, then placed in sterile bags, stored in the best conditions as useful, before being brought to the lab [28].

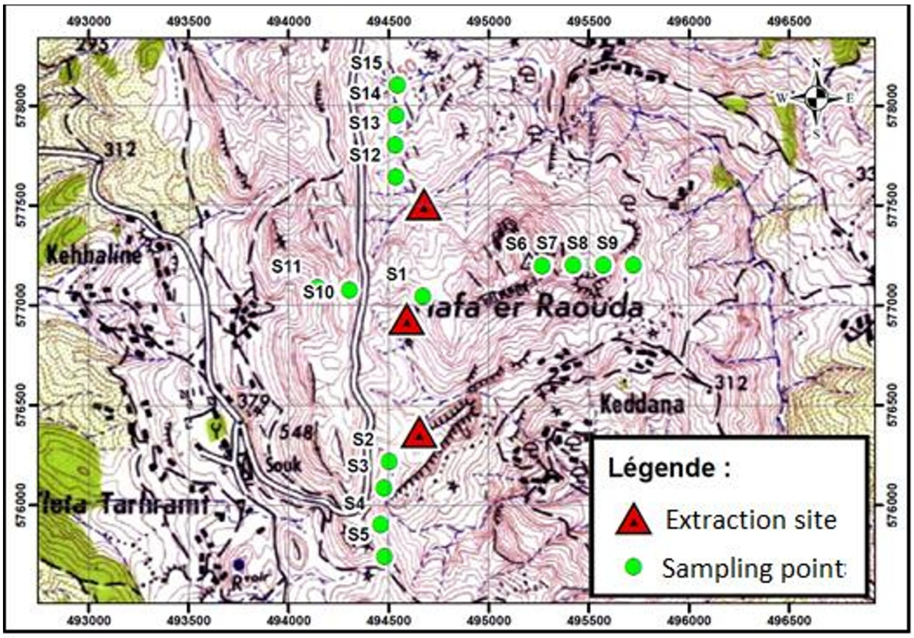


Fig 2. Location of soil sample collection points

2.3 Methods and Measurement Techniques

The soil samples' physio-chemical properties were identified. These included cation exchange capacity, heavy metals, calcium (CaCO3), electrical conductivity (EC), and pH. A pH meter was used to measure the pH, and a multimeter was used to measure electrical conductivity. Acid-base titration techniques were employed to measure calcium, atomic absorption spectrometres were used to test heavy metals, and cation solutions were utilized to saturate the soil samples in order to evaluate the cation exchange capacity [29].

2.4 Simulation and Modeling Method

The ARIMA (AutoRegressive Integrated Moving Average) tool, which is utilized in an integrated development environment with the R programming language, was used to model the quality of the soil. This model works well for assessing patterns in the gathered data and analyzing autoregressive time series [30–31].

When the value of a series (or process) at any given time t relies linearly on the values of the preceding n values, the series is said to be autoregressive of order n.

$$xt=c+\epsilon t+n\sum i=1pixt-I \quad (1)$$

- ϵ : represents white noise
- c : is a constant.

ARIMA is founded on the linear association between a time series and past values, and it defines three parameters:

- p: Autoregressive component
- d: Number of differencing needed to obtain stationarity
- q: Moving average component.

The analysis process involved historical data collection from nine sample sites made possible by [30], exploratory analysis to detect trends and seasonality [31], and differencing methods to achieve stationarity [32]. The model orders of AR (auto-regressive) and MA (moving average) were found from correlogram and partial autocorrelation function (PACF) studies [33].The model was trained to find trends and seasonality as data were divided into training and test subsets [34, 35]. To evaluate the model's performance, predictions were made for the next three years to assess the soil quality of the region, and the predictions were assessed against the real data using a measure defined: root mean square error (RMSE) (Gao et al., 2020).

3 Results and discussion

3.1 Soil characterization

The study of soil quality between 2018 and 2020 highlights a gradual evolution in the physico-chemical properties of the soil due to quarrying activities.

In 2018.

- At the center of the quarry (P1) The soil showed high alkalinity, with a pH reaching 8.7 in winter and 8.8 in summer, exceeding the acceptable range (6.0 to 7.5). The electrical conductivity (EC) was significantly high (7600-7650 µs/cm), and calcium carbonate ($CaCO_3$) levels were elevated (75-76.4%), indicating high concentrations of dissolved salts and limestone. Meanwhile, organic matter was extremely low (0.1% in winter and 0.085% in summer, compared to 4.1% in the reference soil), and cation exchange capacity (CEC) was reduced (3.2-3.4 meq/l).
- South (P2-P5) and West (P10-P11): A gradual improvement in soil quality was observed, with decreases in alkalinity, conductivity, and calcium carbonate levels.

- North (P12-P15): A similar trend was noted, with the soil characteristics progressively resembling those of the reference soil.
- East (P6-P9): Slight variations were recorded, likely due to wind-driven transport of fine particles from the quarry.
- Heavy metals: Concentrations remained similar to the reference soil and within acceptable limits.

In 2019. Similar trends to 2018 intensified. pH rose to 9 illustrating higher alkalinity; the EC seemed to rise (7650-7700 µs/cm), as did $CaCO_3$ (78-79.5%), while organic matter reduced again (0.07% winter; 0.06 % summer). CEC increased slightly (3.6-3.8 meq/l).

As was observed in 2018, soil quality got better further from P1, except in the east where few changes were observed. Relative to 2018, pH, EC, and $CaCO_3$ increased, and organic matter decreased slightly indicating that soil degradation may still be happening. Heavy metal levels were consistent.

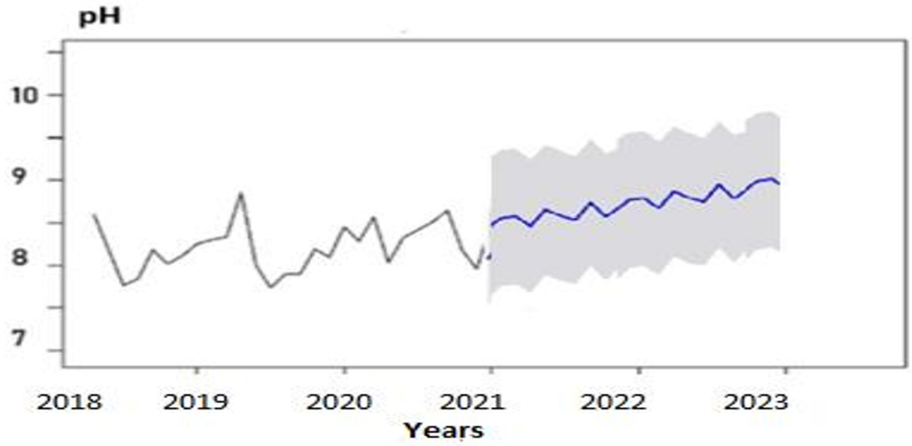
In 2020. The general trends continued in 2020. pH rose slightly again, EC stayed high, and $CaCO_3$ remained high indicating continuing salinity and alkalinity issues. Organic matter content dropped again slightly, and CEC continued an upward trend again.

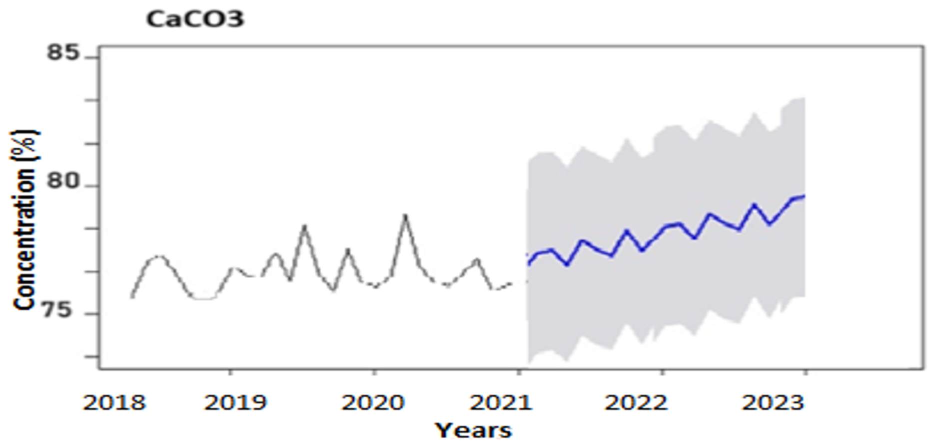
3.2 Modeling of soil quality parameters

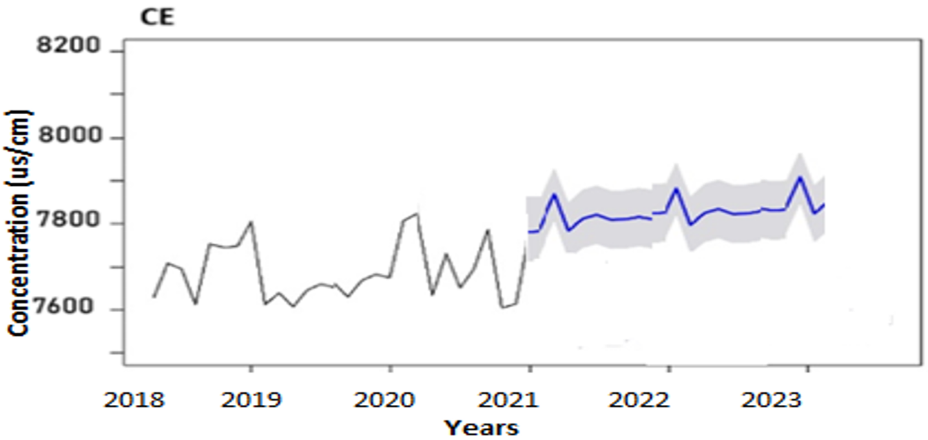
The ARIMA model trained on 36 months of soil quality data (2018-2020) produced fairly accurate forecasts (RMAE: 0.15 - 0.41) with certain variables varying over time (correlation: 0.4 - 0.74).

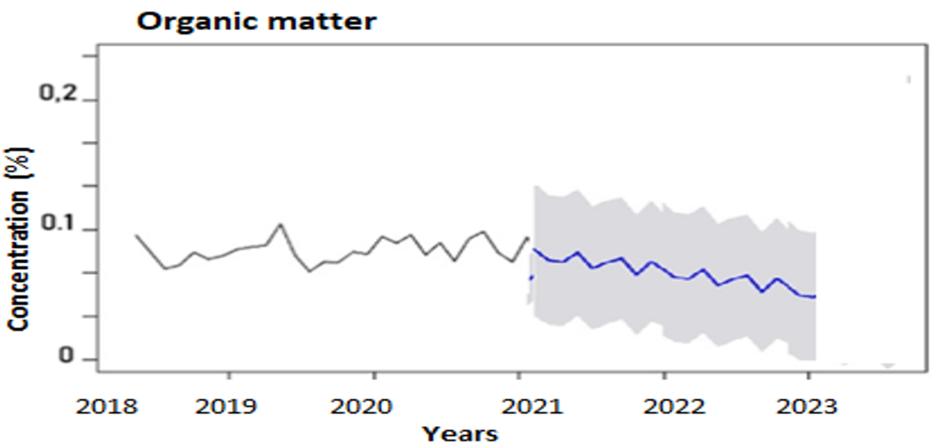
At the middle locality in the quarry site the forecasts suggest an increase in calcium carbonate (80%), electric conductivity (7900 µS/cm), and pH (9) based on possible limestone infiltration. Organic matter is recorded at 0.05%, indicating a decline in soil fertility. All these changes surpass soil quality thresholds indicating an ongoing decline in soil quality due to quarrying.

The model was unable to produce results for cation exchange capacity (CEC), indicating multivariate variation. These results demonstrate the environmental impact of quarrying in soil quality over time.




CaCO3
85
80
75
Concentration (%)
2018
2019
2020
2021
2022
2023
Years


CE
8200
8000
7800
7600
Concentration (us/cm)
2018
2019
2020
2021
2022
2023
Years


Organic matter
0,2
0.1
0
Concentration (%)
2018
2019
2020
2021
2022
2023
Years

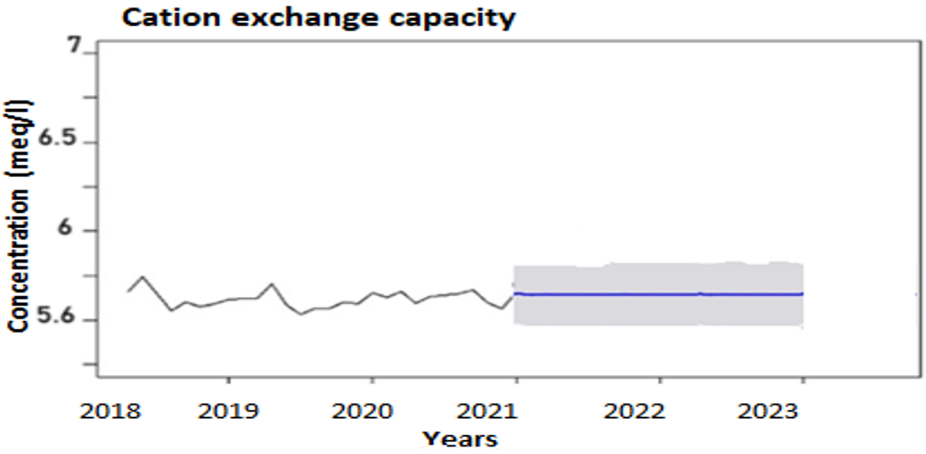
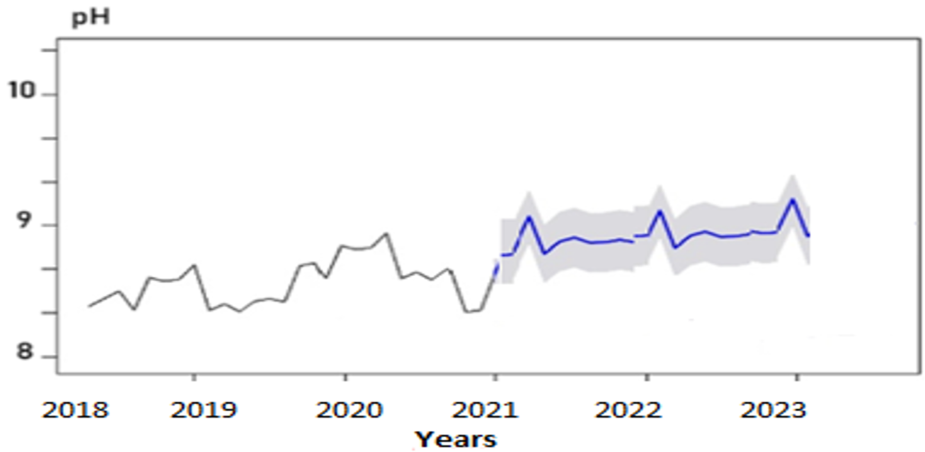
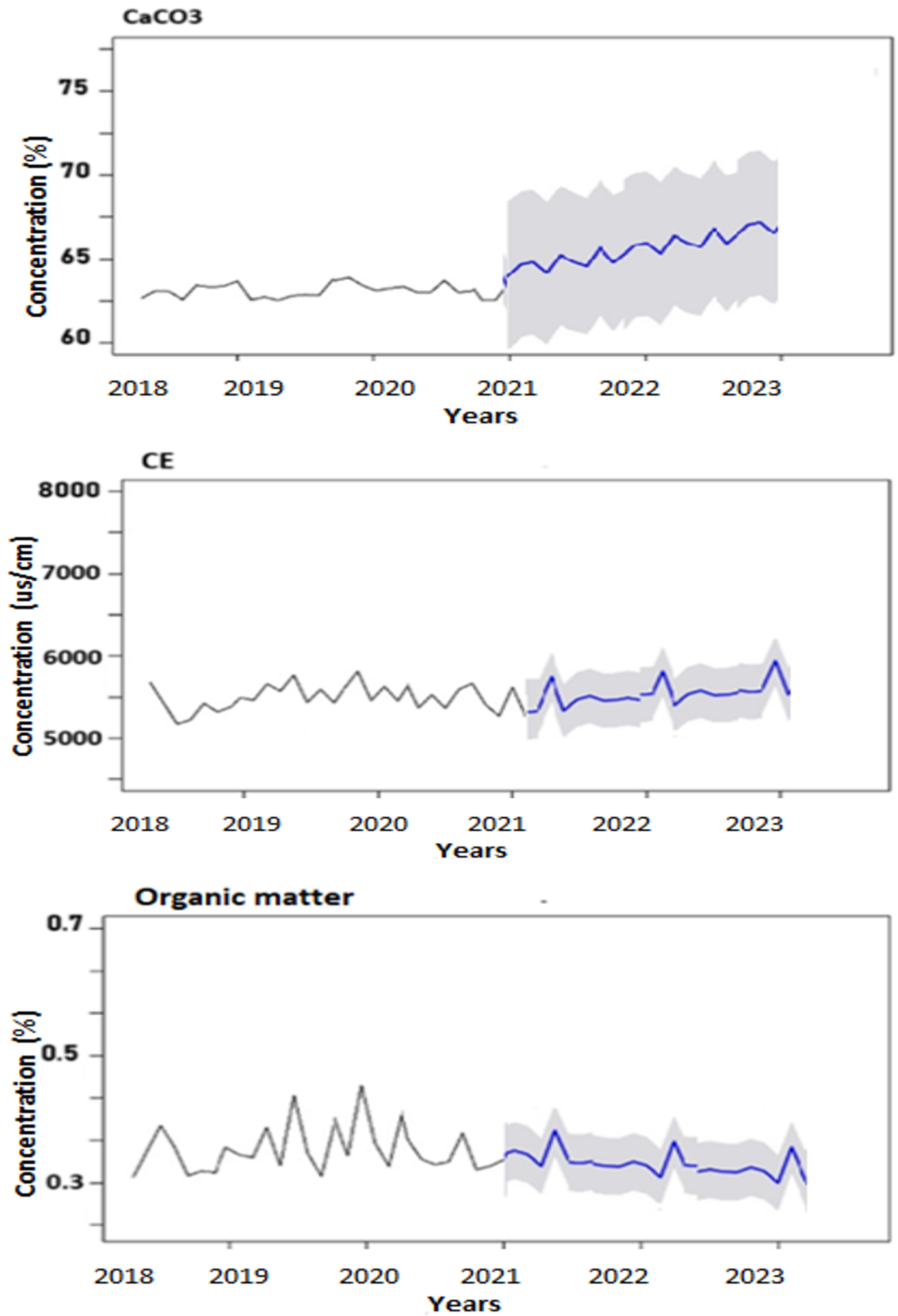


Fig 3. Annual trends in soil parameters for sampling point 1 (quarry center) from 2018 to 2020 and forecasts for 2021 to 2023.

According to the ARIMA model, soil quality changes south of the quarry are notable with considerable variations occurring over three years (2021 - 2023). Specifically, increases in calcium carbonate (68% P3; 65% P5), electrical conductivity (6000 µS/cm P3; 5800 µS/cm P5), and pH (9 P3; 8.25 P5) were noted. While the levels of organic matter declines (0.3% P3, 0.31% P5) from 2021 to 2023, indicating that soil fertility continues to decrease due to mining activity, these changes were all above soil quality thresholds for degradation noted in the soil quality literature describing the degradation and deterioration of soil quality.

The changes to the cation exchange capacity (CEC) did not yield results, likely due to the high variability in these data. Nonetheless, there appears to be gradual improvement to soil quality, the approximate distance from the quarry indicates that quarrying effects decrease with distance. The differences between P3 and P5 synthetic samples may be attributed to proximity influencing soil quality changes.




CaCO3
Concentration (%)
75
70
65
60
2018
2019
2020
2021
2022
2023
Years
CE
Concentration (us/cm)
8000
7000
6000
5000
2018
2019
2020
2021
2022
2023
Years
Organic matter
Concentration (%)
0.7
0.5
0.3
2018
2019
2020
2021
2022
2023
Years

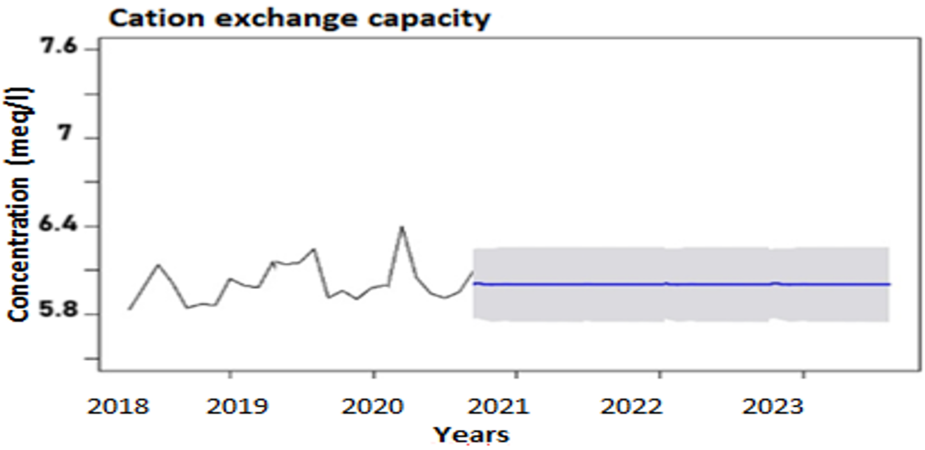
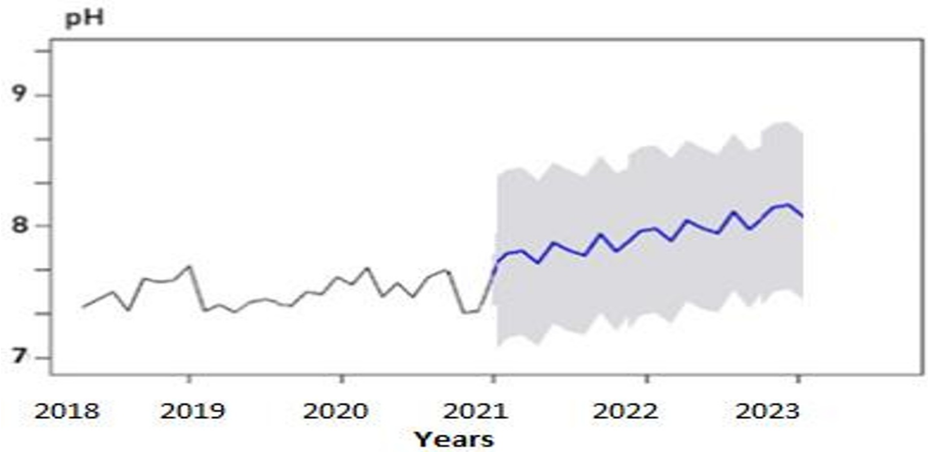
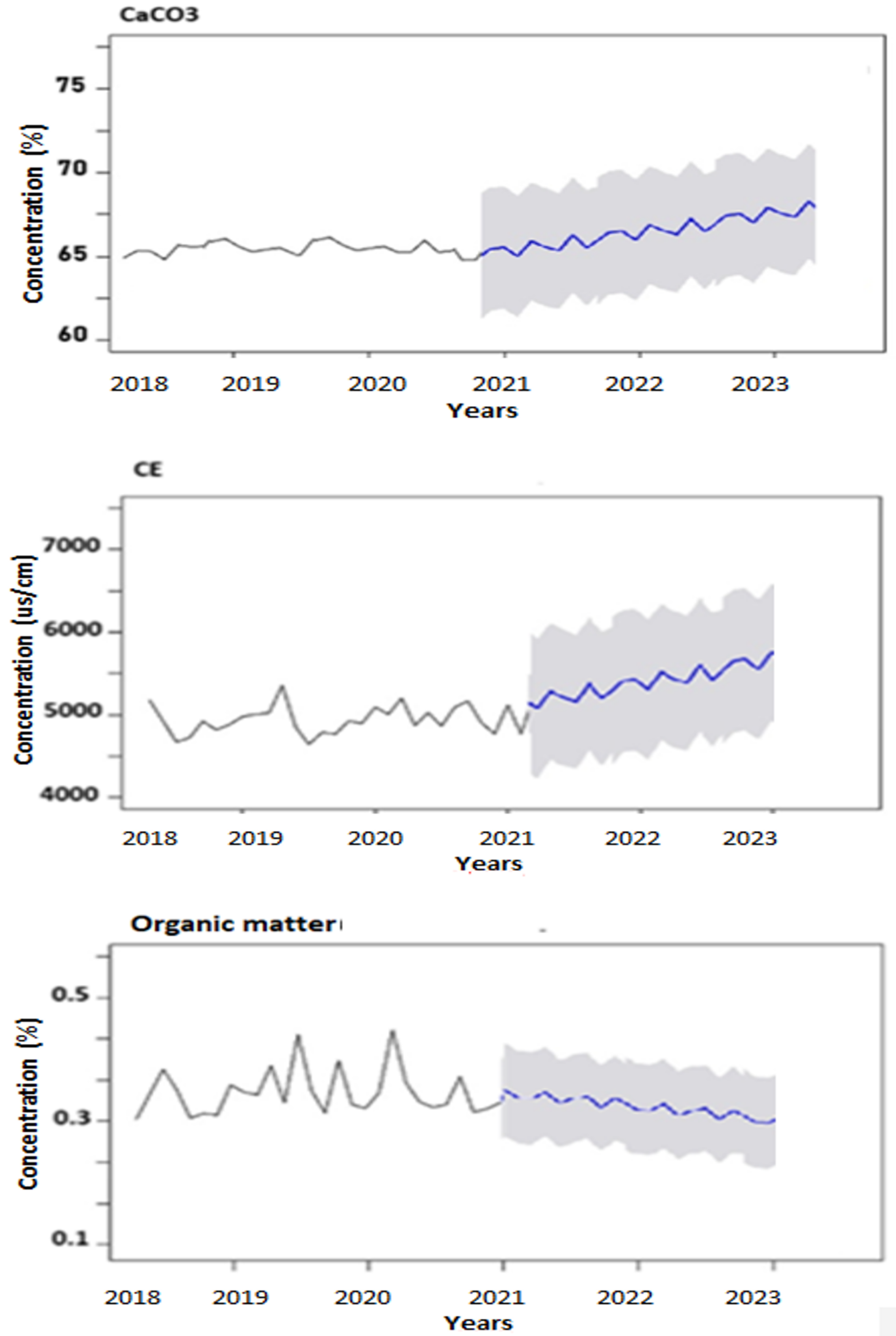


Fig 4. Annual trends in soil parameters for sampling point 3 (South of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023.




CaCO3
Concentration (%)
75
70
65
60
2018
2019
2020
2021
2022
2023
Years
CE
Concentration (us/cm)
7000
6000
5000
4000
2018
2019
2020
2021
2022
2023
Years
Organic matter
Concentration (%)
0.5
0.3
0.1
2018
2019
2020
2021
2022
2023
Years

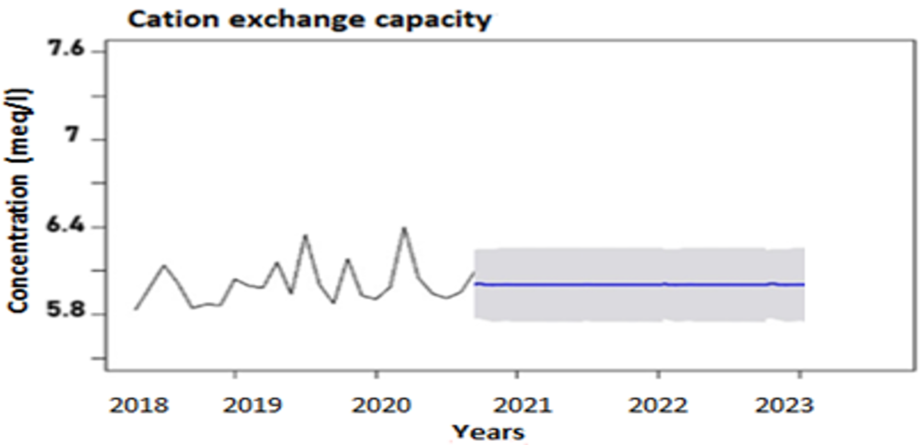
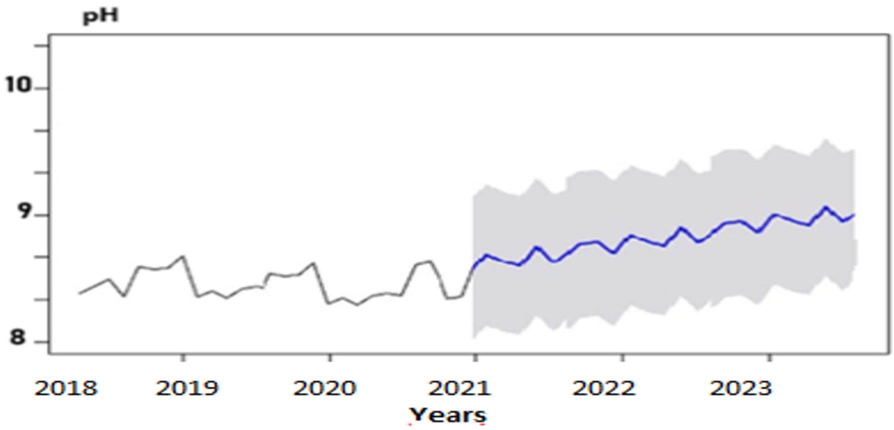


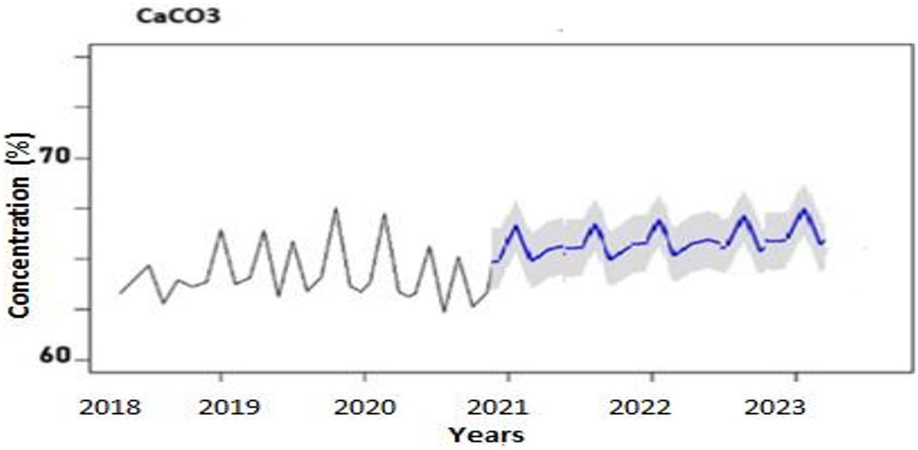
Fig 5. Annual trends in soil parameters for sampling point 5 (South of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023.

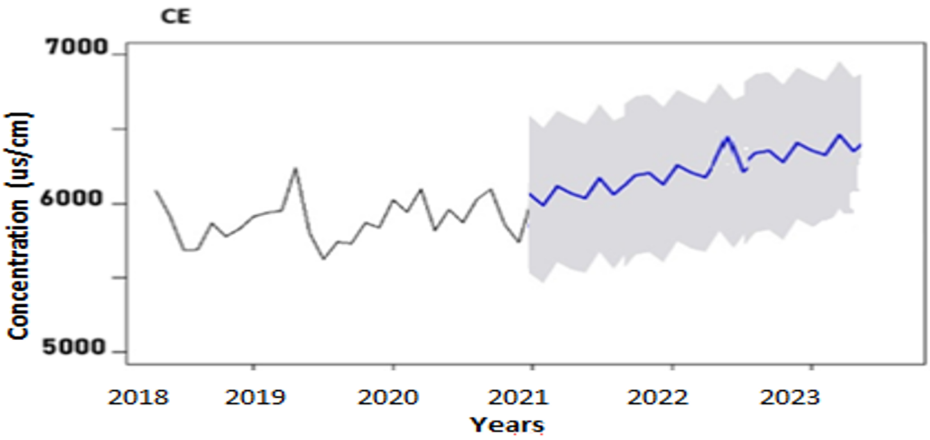
The ARIMA model predicts significant changes in soil quality east of the quarry over three years. Notable increases include calcium carbonate (67% at P7, 62% at P9), electrical conductivity (6500 µS/cm at P7, 6000 µS/cm at P9), and pH (9 at P7, 8.4 at P9).

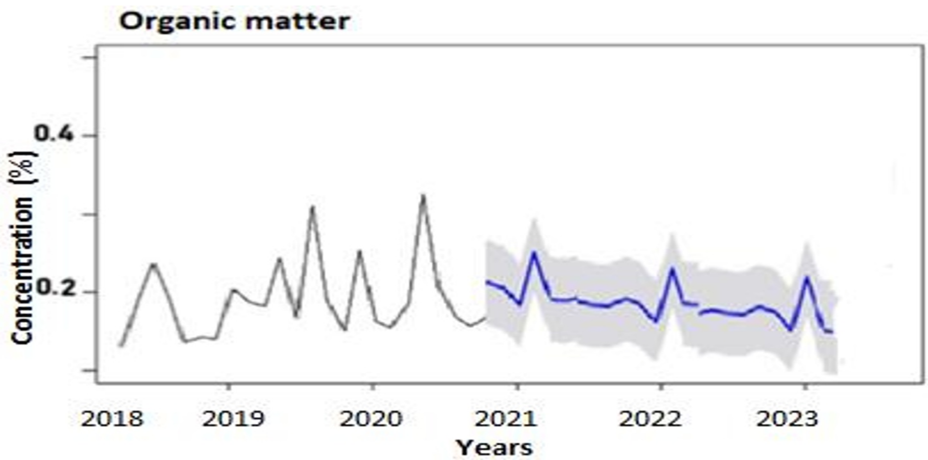
At the same time, organic matter declines to 0.22% (P7) and 0.28% (P9), indicating possible soil compaction and degradation due to mining activities. While most values remain within soil quality guidelines, conductivity and pH exceed acceptable limits.

The model failed to provide conclusive results for cation exchange capacity (CEC), suggesting high variability. However, as distance from the quarry increases, soil quality shows improvement, indicating a gradual reduction in mining impact over distance.




CaCO3
Concentration (%)
70
60
2018
2019
2020
2021
2022
2023
Years


CE
Concentration (us/cm)
7000
6000
5000
2018
2019
2020
2021
2022
2023
Years


Organic matter
Concentration (%)
0.4
0.2
2018
2019
2020
2021
2022
2023
Years

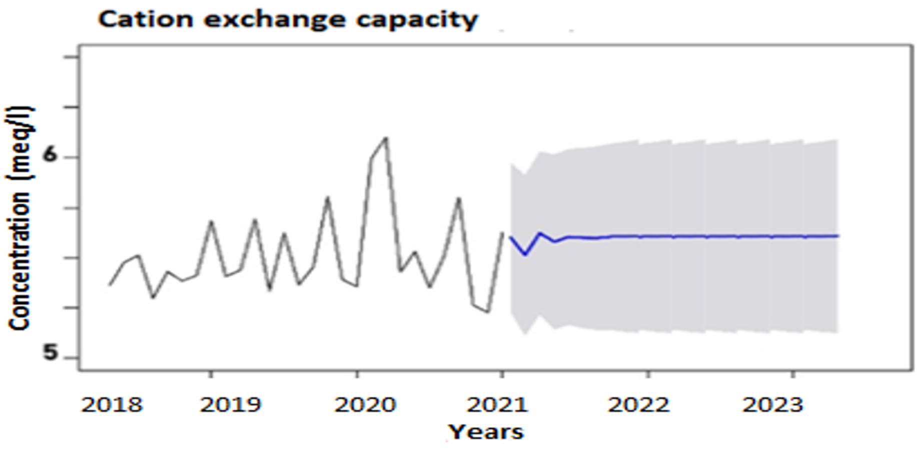
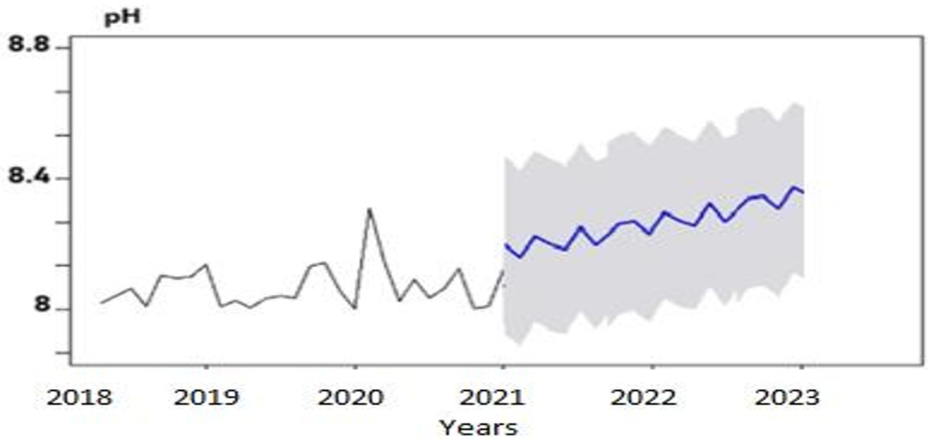
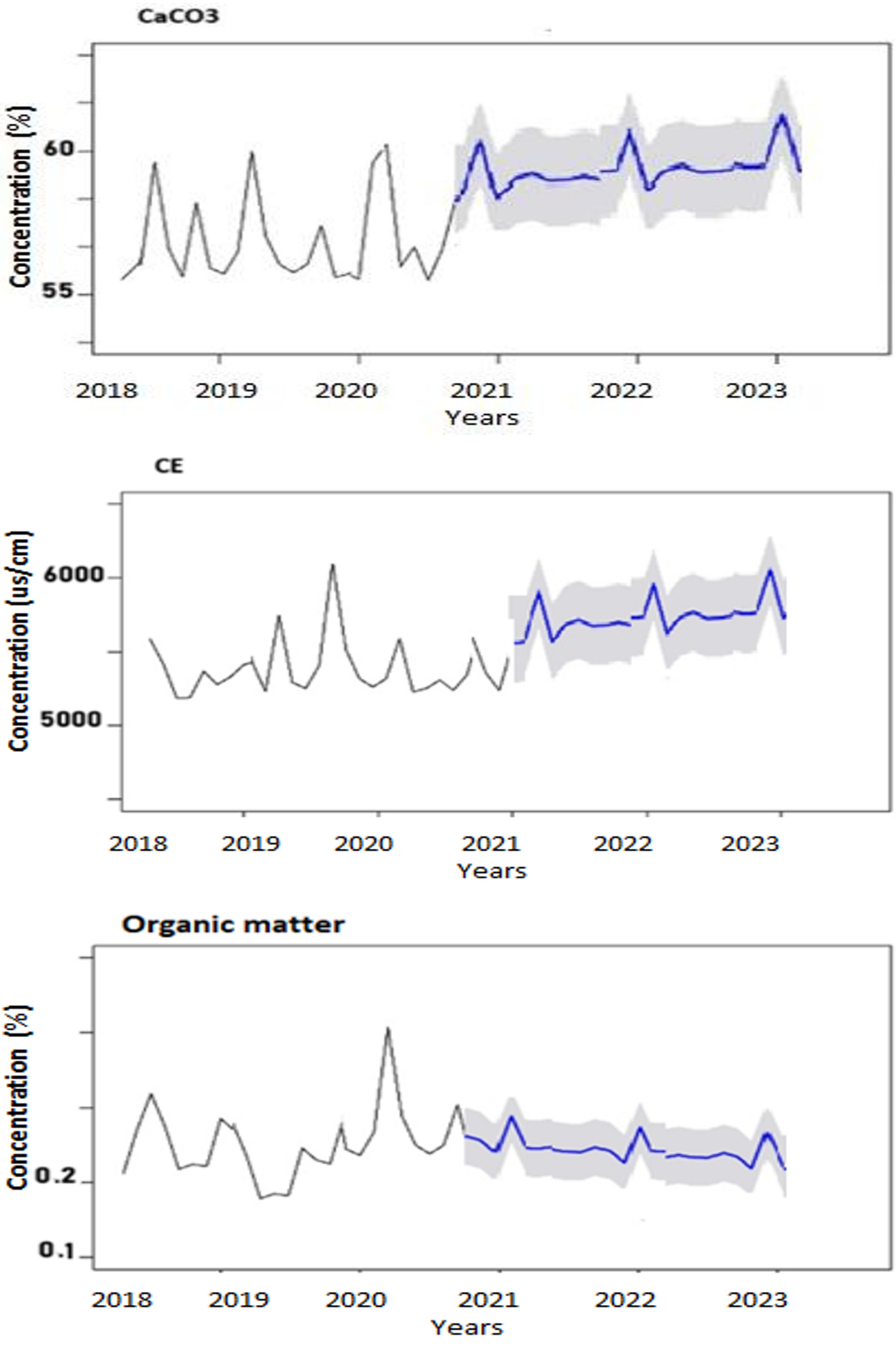


Fig 6. Annual trends in soil parameters for sampling point 7 (East of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023..

Fig. 1.




CaCO3
Concentration (%)
60
55
2018
2019
2020
2021
2022
2023
Years
CE
Concentration (us/cm)
6000
5000
2018
2019
2020
2021
2022
2023
Years
Organic matter
Concentration (%)
0.2
0.1
2018
2019
2020
2021
2022
2023
Years

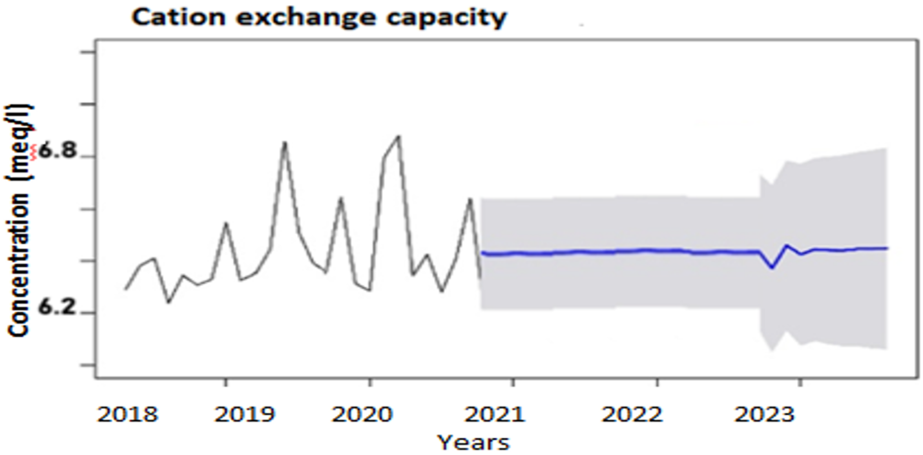
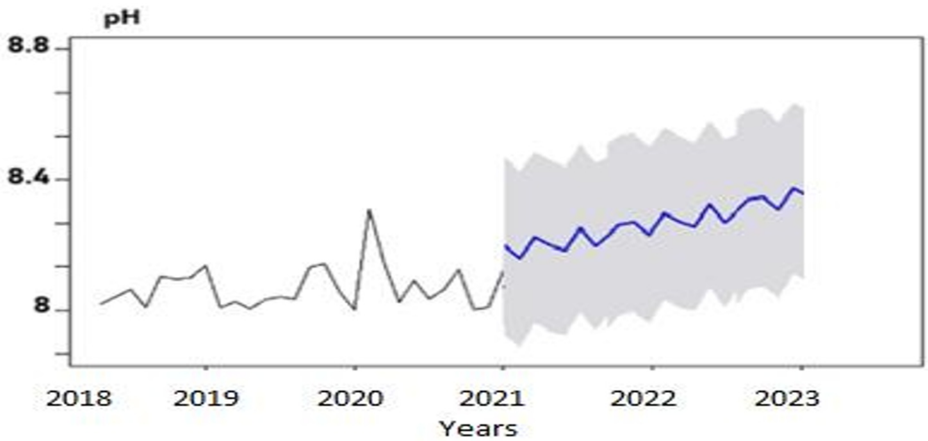


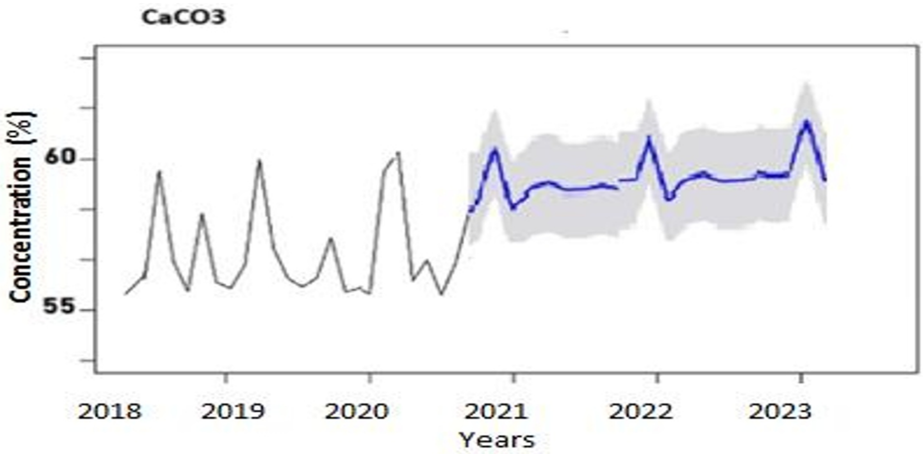
Fig 7. Annual trends in soil parameters for sampling point 9 (East of the quarry) from 2018 to 2020 and foreca sts for 2021 to 2023.

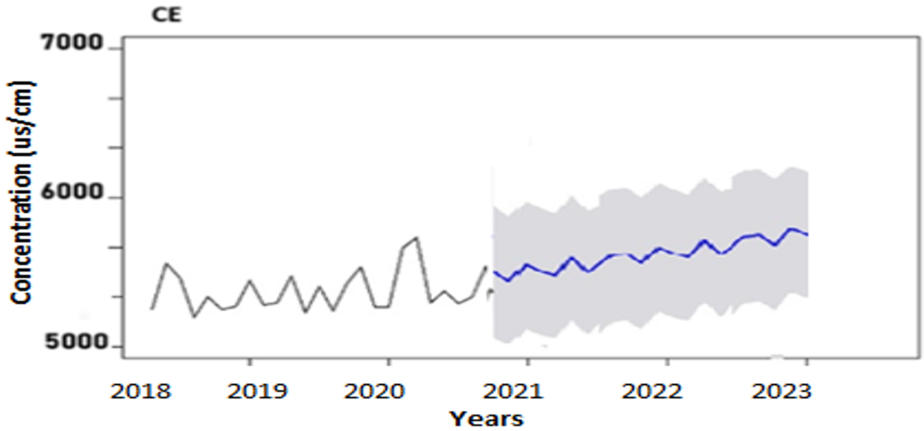
In west of the Quarry: The review of results determined from the ARIMA modelling applied to the western boundary of the quarry in prediction of changes in soil quality across the period 2021-2023, shows major changes and fluctuations in many of the significant parameters.

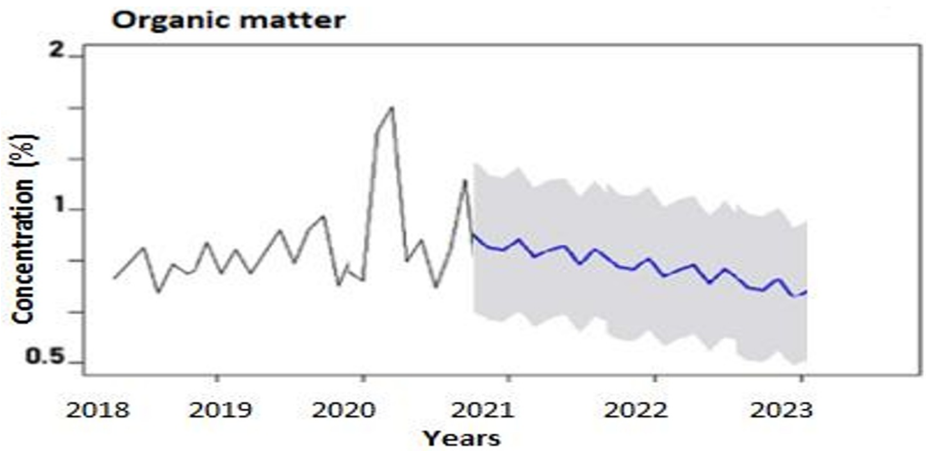
In this period there was a marked increase in CaCO3 content, electrical conductivity (EC), and pH; with corresponding increases of 59%, 5900 µS/cm, and 8.9, respectively. The modelling of these results indicated a significant alteration in the soil which may or may not include the effect of the mining activity.

It should be noted that only two sample points were achieved in this direction based on natural impediments. For consistency in model application, a sampling point was established in the model that represented a comparable distance to the location of the sampling points in other directions reported.




CaCO3
Concentration (%)
60
55
2018
2019
2020
2021
2022
2023
Years


CE
7000
6000
5000
Concentration (us/cm)
2018
2019
2020
2021
2022
2023
Years


Organic matter
2
1
0.5
Concentration (%)
2018
2019
2020
2021
2022
2023
Years

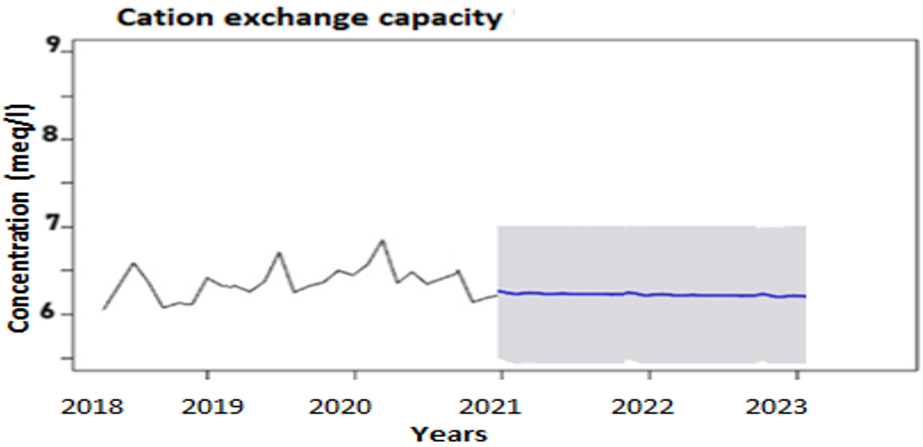


Fig 8. Annual trends in soil parameters for sampling point 11 (West of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023.

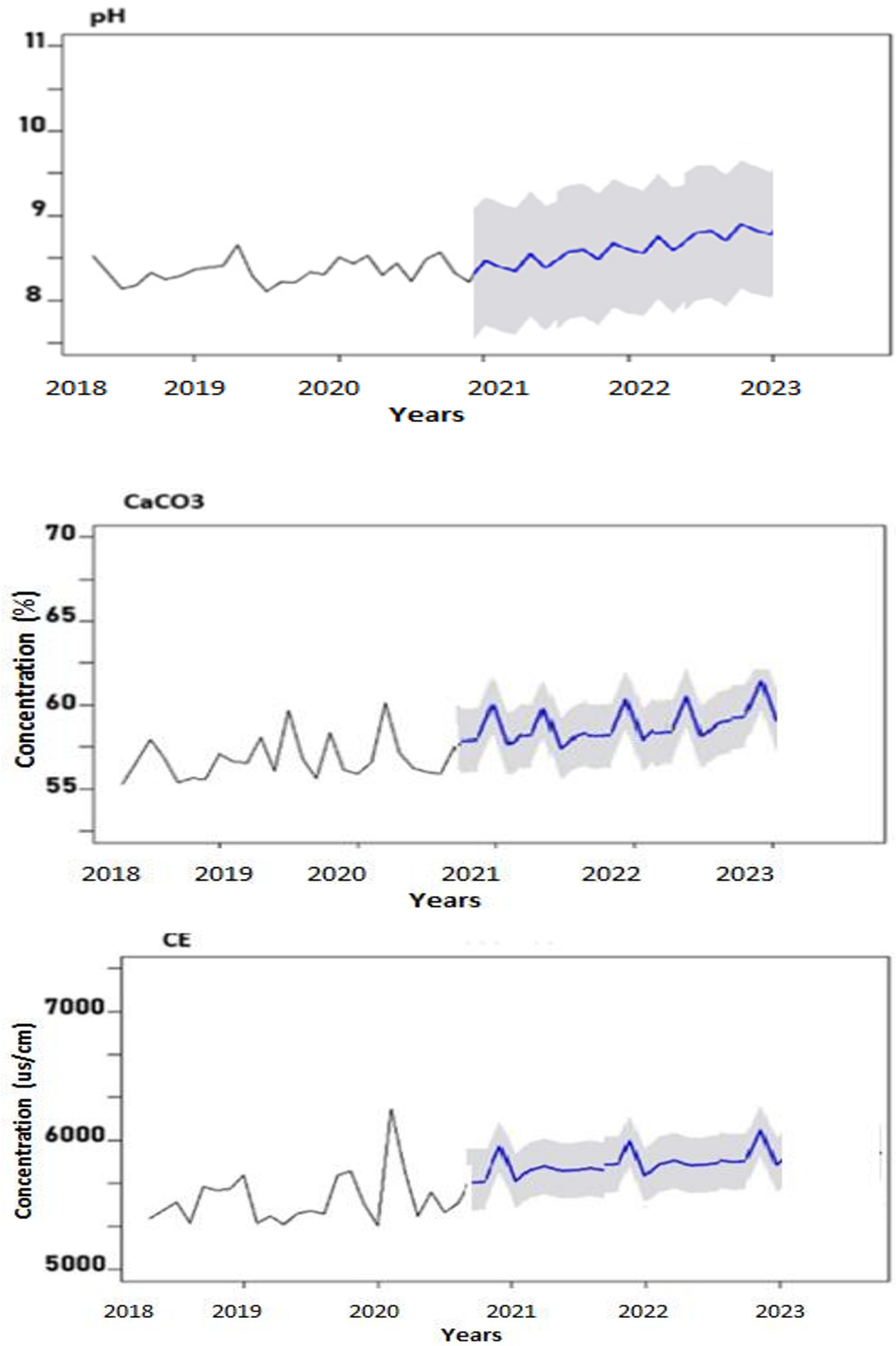
The results of the ARIMA modeling, performed to predict changes to soil quality in the northern part of the quarry from 2021 to 2023, reveal some clear patterns, and considerable differences in some of the parameters.

The CaCO3 content, EC, and soil pH, had considerable increases over this time. At sampling point 13: 62%, 6000 µS/cm, and 9; and sampling point 15: 62%, 6000 µS/cm, and 8.4 (note that the EC is the same for all points).

It is clear that there are changes to some of the soil properties and quality as a result of mining activity.

Also, the four sampling points in the north were continuously getting identical trends in soil quality evolution, though there could be some differences in parameter concentrations.

The evidence points to an apparent gradual improvement of soil quality the further away from the quarry we get, showing that the impact of mining seems to dissipate with distance from the centre of extraction.


pH
11
10
9
8
2018 2019 2020 2021 2022 2023
Years
CaCO3
Concentration (%)
70
65
60
55
2018 2019 2020 2021 2022 2023
Years
CE
Concentration (us/cm)
7000
6000
5000
2018 2019 2020 2021 2022 2023
Years

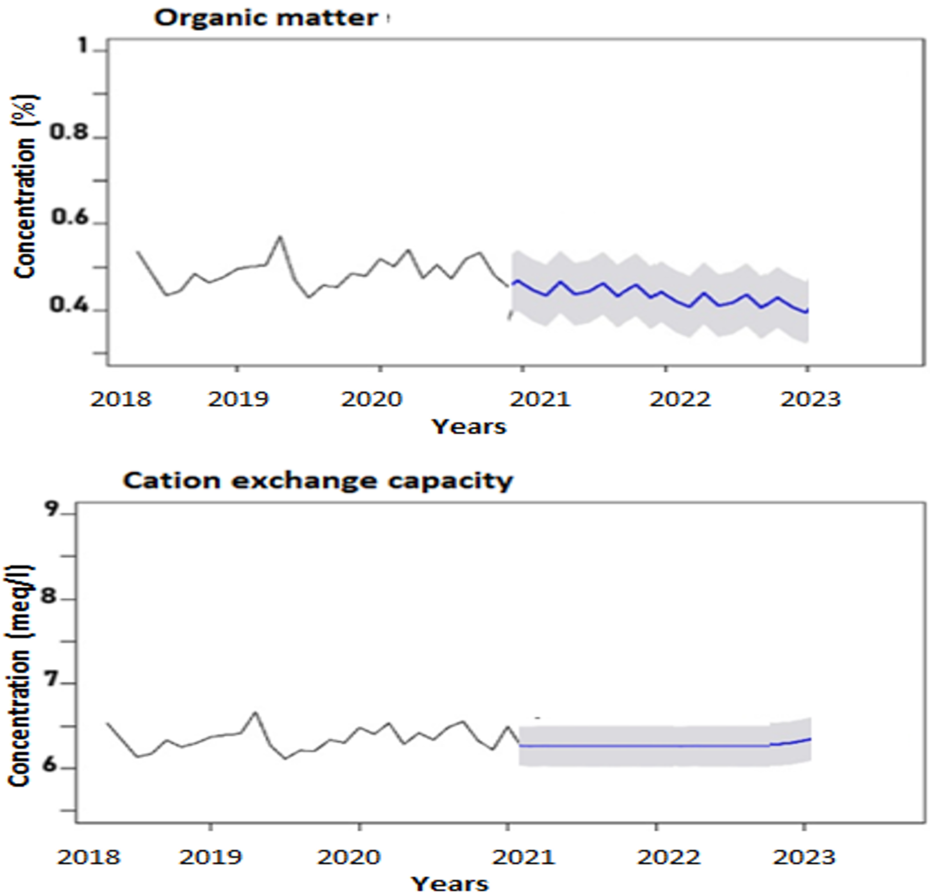
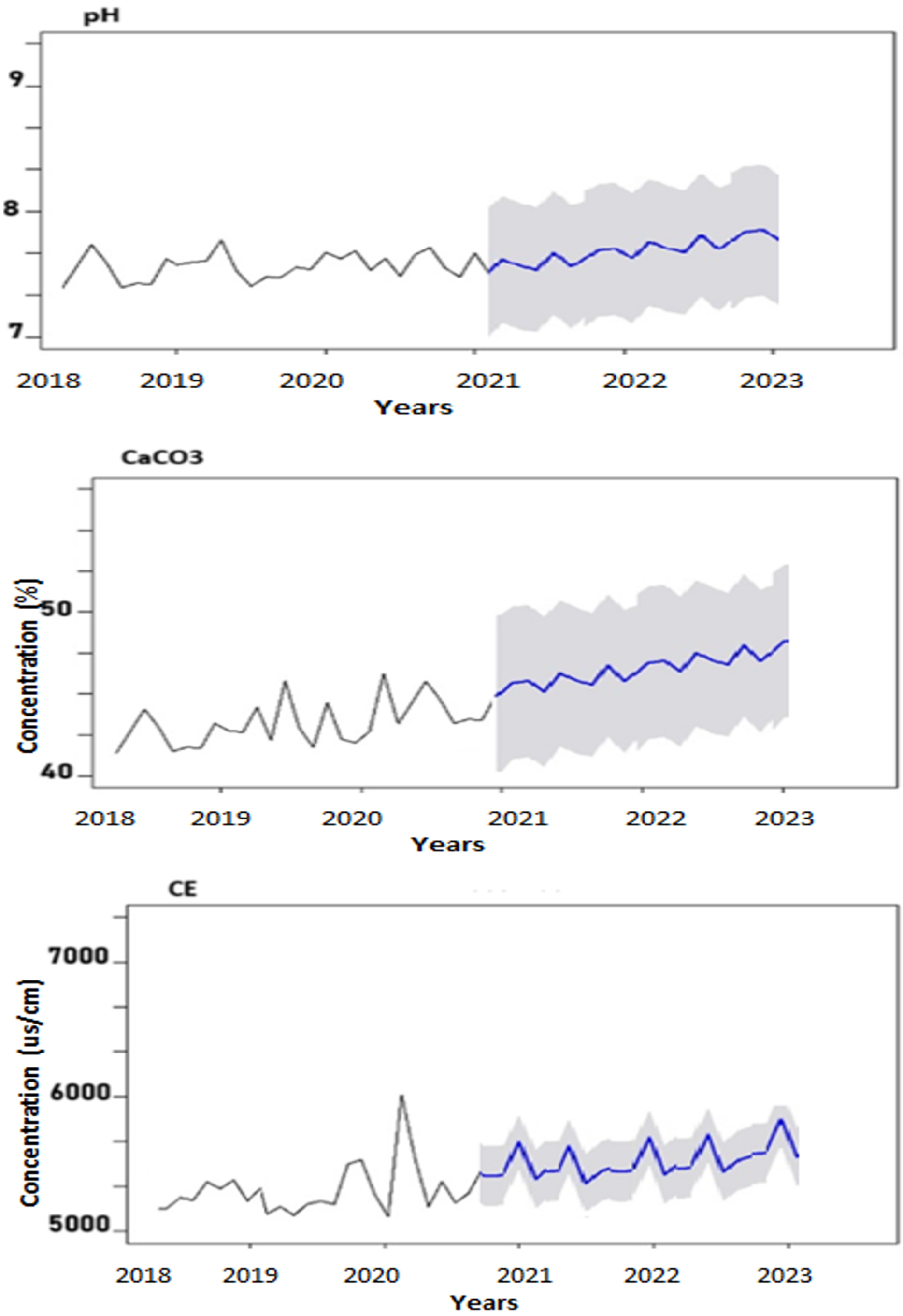


Fig 9. Annual trends in soil parameters for sampling point 13 (Northen of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023


pH
9
8
7
2018
2019
2020
2021
2022
2023
Years
CaCO3
Concentration (%)
50
40
2018
2019
2020
2021
2022
2023
Years
CE
Concentration (us/cm)
7000
6000
5000
2018
2019
2020
2021
2022
2023
Years

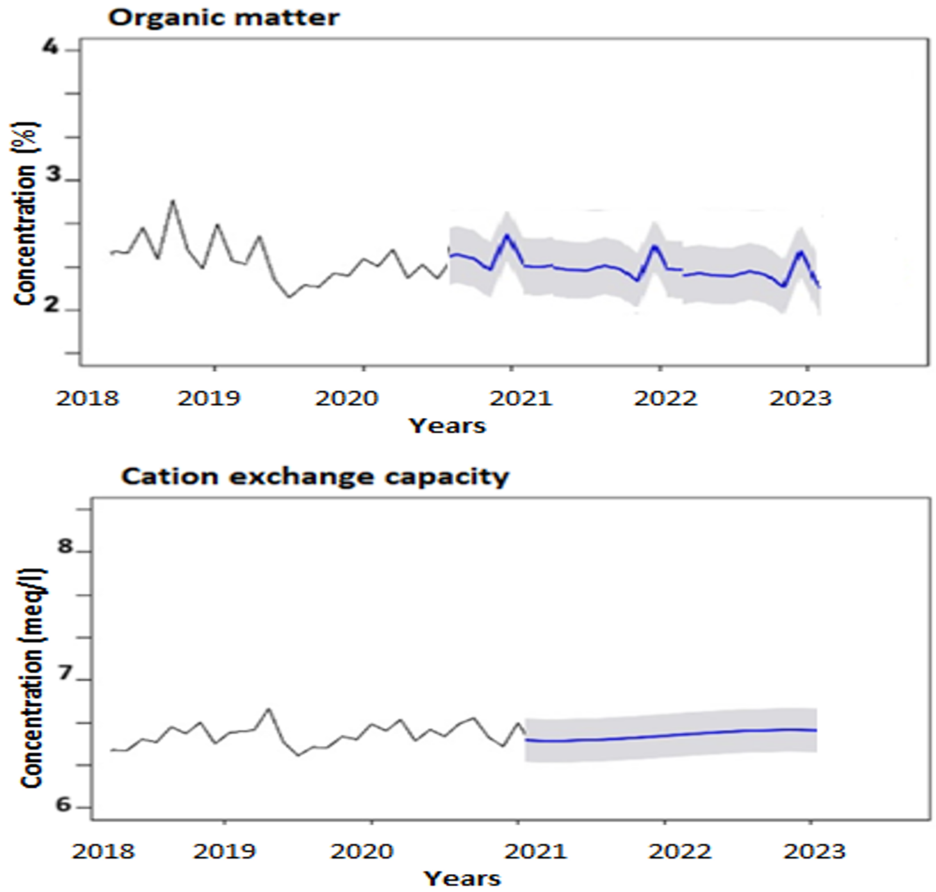


Fig 10. Annual trends in soil parameters for sampling point 15 (Northen of the quarry) from 2018 to 2020 and forecasts for 2021 to 2023

The operations of the quarry influence soil quality, particularly in the direction that the prevailing winds flow (East). Dust emissions from mining operations, carried by the wind, especially cause soil degradation by increasing calcium carbonate ($CaCO3$), electrical conductivity, and soil pH, which has directly impacted soil fertility and has continued to negatively affect agricultural yield around the quarry. Scientific predictions indicate that these circumstances will continue over time and, therefore, measures need to be established to mitigate the impact on the environment.

4 Conclusion

The operations of the quarry had an impact on soil quality, specifically the dust emissions from dropping the rocks into haul trucks. These dust emissions are carried by the predominant winds, influencing the chemical properties of the soil, in turn affecting fertility of the soil which means agricultural yields are altered. Increasing values in calcium carbonate (CaCO3), electrical conductivity and pH are indicators that soil quality is degraded. Continuing trends and forecasting suggest continued soil degradation, and possible eventual loss of agricultural land thing that has long-term implications for agriculture, and for local ecosystems.

In order to evaluate how various quarry operations affect soil, long-term monitoring studies of soil quality must continue. Monitoring study's will help evaluate changes in soils to anticipate the effects on downwind soils. We retain that there should be investigation of resource sustainability and engagement in research to help understand the additive impacts of mining on soil.

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References

1. Jensen, M., et al.: Environmental Impacts of Aggregate Extraction in Construction. Journal of Environmental Management 234(4), 234–245 (2020)
2. Kumar, R., et al.: Sustainability in the Quarrying Industry: A Review. Environmental Science and Technology 53(7), 5600–5610 (2019)
3. Zhang, W., et al.: Soil Properties and Biodiversity: A Review of Aggregate Extraction Impacts. Ecological Engineering 178, 106–117 (2021)
4. Gomez, P., et al.: Impact of Gravel and Sand Extraction on Soil Structure and Water Retention. Soil Science Journal 88(6), 845–854 (2018)
5. Kumar, P., et al.: Aggregate Mining and Soil Fertility: Long-term Effects and Management Strategies. Resources, Conservation and Recycling 166, 105–117 (2021)
6. Harrison, S., et al.: Impact of Aggregate Extraction on Soil Quality in Mining Areas. Geoscience and Environment Journal 18(2), 112–120 (2019)
7. Zhang, L., et al.: Soil Chemical Degradation from Quarrying and Mining. International Journal of Environmental Studies 76(2), 169–180 (2019)
8. Cabrera, M., et al.: Soil Fertility and Ecosystem Regeneration Post-Quarrying. Land Degradation & Development 31(1), 15–24 (2020)
9. Gani, S., et al.: Impact of Quarrying on Soil Fertility and Biodiversity. Sustainability in Natural Resources 23(4), 49–58 (2019)
10. Laing, A., et al.: Ecological Impacts of Aggregate Mining on Soil Quality. Environmental Management Review 42(1), 33–40 (2020)
11. Sharma, P., et al.: Temporal Evolution of Soil Degradation in Aggregate Mining Sites. Soil and Tillage Research 195, 26–34 (2020)
12. Martinez, J., et al.: Monitoring Long-Term Soil Impacts of Aggregate Quarries. Science of the Total Environment 738, 139802 (2021)
13. Lo, K., et al.: Predictive Modeling of Soil Fertility Changes Due to Mining Activities. Geospatial Data Science 5(3), 72–81 (2017)
14. Ji, Y., et al.: Soil Property Changes in Quarrying Areas: A Case Study. Environmental Earth Sciences 79(2), 110–119 (2020)

15. Wang, J., et al.: Modeling Soil Degradation Caused by Aggregate Quarrying. Environmental Modeling & Software 143, 104855 (2021)
16. Shrestha, S., et al.: Spatial and Temporal Trends of Soil Quality in Aggregate Extraction Areas. Environmental Pollution 236, 330–338 (2018)
17. Rathi, R., et al.: Integrated Strategies for Sustainable Quarrying and Soil Management. Environmental Monitoring and Assessment 192(4), 258–268 (2020)
18. Ahmed, S., et al.: Soil and Environmental Impacts of Aggregate Mining: A Review. Environmental Science and Policy 115, 86–96 (2020)
19. Ali, M., et al.: Effects of Mining on Soil Quality and Fertility: A Review. Environmental Monitoring and Assessment 191(6), 342–358 (2019)
20. Martins, L., et al.: Soil Contamination and Remediation in Mining Areas: A Global Overview. Science of the Total Environment 768, 144432 (2021)
21. Benomar, S., et al.: Soil Pollution from Mining Activities: A Critical Review. Environmental Pollution 236, 471–487 (2018)
22. Gonzalez, H., et al.: Assessing the Impact of Mining on Soil Chemical Properties in an Industrial Region. Journal of Soil Science and Plant Nutrition 19(3), 654–664 (2019)
23. Zhao, Q., et al.: Carbonate Content in Soils and Its Relation to Mining Activities. Journal of Environmental Management 280, 111595 (2021)
24. El Alami, A., et al.: Heavy Metal Contamination in Soils of Mining Areas: A Review of Impact and Remediation Techniques. Environmental Science and Pollution Research 25(22), 22071–22090 (2018)
25. Kumar, P., et al.: Impact of Mining on Soil Fertility and Environmental Health. Resources, Conservation and Recycling 166, 105–117 (2021)
26. Rahman, M., et al.: Analysis of Soil Quality in Mining-Affected Areas and Its Impact on Agriculture. Journal of Environmental Quality 49(5), 1210–1223 (2020)
27. Cheng, X., et al.: Soil Properties and Heavy Metal Contamination in Mining Areas. Environmental Geochemistry and Health 43(3), 765–776 (2021)
28. Khan, M., et al.: Assessing Soil Quality and Heavy Metal Concentration in Mining Regions. Environmental Toxicology and Chemistry 36(9), 2395–2403 (2017)
29. Xu, X., et al.: Modeling Soil Erosion and Contamination in Mining Areas Using ARIMA. Environmental Modelling & Software 136, 104921 (2021)
30. Liu, Y., et al.: Effect of Mining on Soil Degradation: A Case Study of Heavy Metal Contamination in Agricultural Lands. Soil & Tillage Research 192, 35–46 (2019)
31. Gao, X., et al.: Evaluation of Soil Quality in Mining-Affected Areas Using ARIMA Model. Environmental Science and Pollution Research 27(1), 150–159 (2020)
32. Fotsing, D., et al.: ARIMA Model for Environmental Data: An Application to Air Quality and Soil Contamination. Environmental Modelling & Software 24(7), 788–797 (2009)