Soil fertility analysis in and around magnesite mines, Salem, India

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**ABSTRACT**

The opencast mining operations have periodical effects in surrounding landscape and it is important to monitor the quality of the soil. The pre- and post-mining activities influence the soil quality due to removal of vegetation and topsoil cover. The low-grade magnesite ores and dumping of waste materials are the root causes of contamination of soil. The samples collected from the depth of 15 cm on the surface of soil with different physical (soil texture and soil moisture) and chemical (pH, organic carbon, and nitrogen) parameters are analyzed to study the effect of opencast mining on the surrounding soil. Nine soil samples collected from three magnesite mine sites include agriculture land in close proximity. The result of this analysis predicts the sample soils deficiency of nutrients contents like nitrogen, phosphorus, potassium, and calcium. The soil analysis comprises chemical parameters such as pH, lime status, texture, electrical conductivity, available macronutrients nitrogen (N), phosphorous (P), potassium (K), and micronutrients such as Fe, Mn, Zn, and Cu percentages which are used to determine the condition and quality of the soil. The STATISTICA software (ver.8) was used for analysis of Pearson’s correlation with linear relationship of soil samples and rows and columns of data matrix on cluster analysis.

**Introduction**

Soil defined as a thin layer of the Earth’s crust that serves as a natural medium for the growth of plants. It is an unconsolidated mineral matter influenced by the genetic and the environmental factors of the parent material, climate, organisms, and topography prevalent over a period of time (Masto et al., 2015; McKenzie, 2013). Soil provides a reservoir of nutrients required for the vegetation, but not necessarily at optimum levels of immediate availability to plants. Soil testing refers to the physicochemical analysis parameters and a scientific means for quick characterization of the fertility status and predicting the nutrient requirement for crop production. The purpose of soil analysis is to assess the adequacy, surplus, or deficiency of available nutrients for vegetation growth and to monitor the changes brought about by the mining practices. Mining activity distorts the natural environment, particularly the cultivatable land and the natural forest area (Debasis, 2014; Lad & Samant, 2015). This information is needed for optimum retention of natural vegetation to avoid transferring of undesirable levels of nutrients into the environment and further to ensure a suitable nutrient content in the soil. Regular soil analysis for every 3–5 years period is a vital part of good soil management practice (McKenzie, 2013). Recently, Savitha, Ramamoorthy, and Sudhakaran (2018) have found invasive plants with their unique species-specific trait and the changes invaded soil environment from surrounding native soil characters.

Topsoil management plays an important role in reclamation plan to prevent nutrient losses. Removal of soil and rock overburden in the magnesite-mining area causes loss of topsoil and exposes the parent material. Excavation results in the removal of fertile topsoil and thus generating a huge amount of spoil or overburden generally in the form of gravel, coarse sand, fragmented rock pieces, etc., which deteriorates the aesthetic beauty of the proximate landscape (Arvind Kumar Rai, Biswajit Paul, & Singh, 2011; Lad & Samant, 2013; Lamare & Singh, 2014).

Soil disturbance and associated compaction results in conditions conducive for erosion (Arvind Kumar Rai et al., 2011; Sheoran, Sheoran, & Poonia, 2010). Soil removal from the mining area alters many natural soil characteristics, reduces its biodiversity and the productivity of agriculture. The methods of mining process cause soil loss due to digging of strip mines and an open-pit mine requires removal of plants and soil from the surface of the ground. Mining industry affects the agricultural land area and induces human settlement pattern, thereby causing disruption of social relations (Debasis, 2014; Arvind Kumar Rai et al., 2011; McKenzie, 2013).

Mohapatra and Goswami (2012) and Arvind Kumar Rai et al. (2011) assessed the soil characteristics in opencast coal mining region under different monsoon conditions to find the soil texture, moisture, pH, organic carbon, nitrogen, phosphorous, and potassium. Ghose (2004) has studied the process of opencast mining...
activities and changes in physicochemical and the microbiological properties of soil in Eastern Coal Limited (ECL) coalfields.

Masto et al. (2015) have assessed the soil quality as one of the key parameters for the evaluation of environmental contamination in the coal mining area. High level of potential acidity (low pH) severely restricts the productivity of mine soils (Sang Yong, 2018). The reclamation is the process to restore the ecological integrity of disturbed mines land areas. It includes the management of physical, chemical, and biological disturbances of soil fertility, microbial community, and various soil nutrient cycles (Arvind Kumar Rai et al., 2011; Lad & Samant, 2013; Sheoran et al., 2010; SSM, 2009; Sudhakaran, Ramamoorthy, Savitha, & Balamurugan, 2018; Tola et al., 2017).

It is difficult to achieve successful soil analysis without proper site selection, sample collection, and preparation (SSM 2009; Zaware, 2014). The present study revealed that magnesite-mining activity is responsible for the alteration of physicochemical properties of soils in the mines area and the surrounding agricultural area soils, which implies an adverse effect on the quality of the soil. These opencast mining procedures result in the loss of major and minor nutrients. Soil quality status in and around the opencast mines is degraded day by day due to the removal of topsoil and it is vital to improve micro- and macronutrients to save soil quality (Ghose, 2004).

The anthropogenic activities influence physicochemical changes. Transport, waste disposal, industrialization, social, and agricultural activities have adverse effect on environmental pollution and the ecosystem (Oumenskou et al., 2018; Sudhakaran et al., 2018).

Further, the study strengthens with the statistical approach of Pearson’s correlation that provided the direction and the strength of linear relationship between the two variables with coefficient matrices. Two-way-joining cluster analysis is used for grouping objects of Q-mode and R-mode of the same data to reorganize the rows and columns of the data matrix. It’s built with the combination of cases (sample sites) and variables (chemical parameters) to make the discrete patterns of clusters (Andrew et al., 2018; Chung et al., 2016; Oumenskou et al., 2018; Tellen & Yerima, 2018; Venkatramanan, Chung, Ramkumar, Gnanachandrasamy, & Kim, 2015).

The aim of this paper is to study the impact of mining activity over the agriculture soil found in and around the mining site. Specifically, the results obtained from physiochemical parameters of the soil samples report that the soil fertility deteriorated in the mine’s waste dump found nearby agriculture land. Further, the statistical approach such as Pearson’s correlation method is applied to soil fertility indices to provide a scientific basis for monitoring the management of agriculture soil fertility. Therefore, the objective of this study is to analyze the soil quality of the samples collected from different locations and to correlate the physicochemical parameters of the soil samples to infer the macro- and micronutrient deficiency in the defined locations that caused by mining activity and tend to support vegetation in mining regions by improving the soil fertility.

**Material and methods**

**Location and geology of the study area**

The magnesite ore mineral deposit is predominant in Salem and spread over about 17-sq.km area and the total reserves estimated at 44 million tones of the ore deposits. Magnesite vein deposit occurs at 7 km north-west of Salem as white color ore, located in the part of southern part of peninsula (GSI, 2006). Geologically the region is bounded by ultramafic terrain of Archean period. The ultramafic intrusive of the chalk hills is invaded into preexisting country rocks that comprises foliated biotite gneisses, migmatite, magnetite quartzite, eclogite, hornblende gneisses, charnockite, and pegmatites. The ultramafic rocks include dunite, peridotite, and shonkinite and are important as they are the major contributors to the trace element budget of soil. These two ultramafic rocks occur as intrusive and gneissic rocks separate those formation(He et al., 2015). A number of shear zones are associated with the magnesite deposits. These shear zones confirm the several trends of the belt and seem to control the veins of the magnesite deposit. Shear zones vary in width and are traversing. The ultramafic rocks show general parallelism with the foliation of adjoining gneissic (GSI 2006; Satyanarayanan, Eswaramoorthi, Subramanian, & Periakali, 2016).

The climatic condition prevailing in and around magnesite-mining region is generally hot and dry. The climate in mining area is dry and moderate with temperature ranges from 23 to 38°C. The average annual rainfall varies from 800 to 1600 mm. The climate during January and February is generally pleasant; the dry summer begins in March, with the year’s highest temperatures reaching in May. The weather continues to be more temperate in June and July, and in August, it changes to cloudy. The northeast monsoon contributes rainfall during September–December. Most of the magnesite mines are surrounded by agricultural activities (Anbazhagan & Paramasivam, 2016). The regional scale includes trees such as acacia bushes, neem, pungun, ailanthus, nelli, bamboo, casuarina, and tamarind.

The major class of soil group “Vertisol soil” found in the study area is classified into five types as (a) red soil, (b) black soil, (c) brown soil, (d) alluvial soil, and (e) mixed soil. The basis of parent material, texture, permeability, and alkalinity soils is grouped as series under these categories. However, the mining region under investigation mostly contains red and brown soils (Figure 1) due to weathering of ultramafic and gneissic country rocks (Geological Survey of India (GSI), 2006).
Alfisols soils matured with an alluvial subsurface (argillic) horizon. The study area covers the underneath portion containing alfisols and occupies an area of 64.22 sq.km. Soil order entisol includes soils of slight and recent development of metagenetic process. Further, the study area includes NW portion and these soils occupy an area of 58.57 sq.km. Vertisol soils are typically dark colored and have high percentage of clay-dominated minerals (Murthy, 1988). Vertisol soil and their intergrades, with some inclusions of entisols, are found in the hills and pediments. The Vertisol soils are predominantly found to be in the NE portion of the study area and cover 36.47 sq.km. The part of mines and waste dump area covers 15.6 sq.km and categorized under miscellaneous group of soils.

**Soil sampling**

Totally, nine random soil samples were collected to represent the magnesite-mining area and nearby agricultural land. First, remove the surface litter at the sampling spot and tend to drive the shovel to a plough depth of 15 cm and draw the soil (McKenzie, 2013; Soil Survey Manual (SSM), 2009). These soil samples are collected in the month of May 2016 (Figure 2). The appropriate geographic locations of sample collection are measured through handheld GPS (Garmin Oregon 550) instrument. The soil sample used for laboratory analysis must be representative of the field from where it was taken and the soil substances were analyzed (Table 1). Soil maps follow the distribution of soil taxonomic units and provide descriptive summaries of the main properties of the soils (Dan Pennock et al, 2006).

The methodology adapted in the present study of soil quality assessment includes physicochemical parameters such as N, P, K, pH, and electrical conductivity (EC), Fe, Zn, Mn, and Cu using standard procedure (Figure 3). The statistical analysis brings out a clear correlation with the physicochemical parameters of the soil that aid in predicting the fertility of the sampling locations.

The requirement and procedure for obtaining soil samples vary according to the purpose of sampling. The random sampling method is adapted to collect the samples from the active mining area, adjacent agriculture land, and mine waste dump adjacent in mines (Figure 4).
The soil samples S1, S2, and S3 collected from agricultural land and S4 collected from the waste dump gully eroded point at SAIL (Keel board) mine. The open pit soil sample (S5) is collected from an existing pit on the road to Dalmia mines (MT block). The soil sample S6 is collected from waste dump leached zone soil at SAIL (Keel board) mine. The soil sample with traces of ore body is collected from the area adjacent to magnesite vein area at SAIL (Red Hills) mine. The topsoil samples S8 and S9 are collected from Dalmia and TANMAG mines.

Analysis of physicochemical properties of soil samples

The soil survey represents the association between soil classes and landscape units established in the field by judicious selection of sampling points (Dan Pennock & Braidek, 2006). The concept of the limit of quantification is that the measurements reported the level for high standard used for the quantification and not mere detection. Chemical analysis is conducted in a commercial laboratory to determine physicochemical parameters of soil samples collected in and around the magnesite-mining region. Soil differs from the parent material in the morphological, physical, chemical, and biological properties. In addition, soils differ among themselves depending on the different genetic identity factors (INM, 2011; APHA, 1999; Lad & Samant, 2015). The soil analysis results include the testing of chemical parameters such as pH, lime status, texture, EC, nitrogen, phosphorous, potassium, Fe, Mn, Zn, and Cu (Table 2).
Accuracy is a measure of how close an analytical result is to its true value. It has two components, bias and precision (Swyngedouw & Lessard, 2006). The physicochemical parameters analysis of pH, lime, texture, EC, macro- (N, P, and K), and micronutrients (Fe, Mn, Zn, and Cu) is followed by APHA and INM standard methods (Integrated Nutrient Management (INM), 2011; APHA, 1999).

pH: The pH of the soil suspension measured by a digital pH meter (Eutech-356C, India).

Lime status: The calcium hydroxide titration method to determine lime status.

Texture: In the soil-testing laboratory, soils divided into broad textural classes for which no specific equipment. Cast formed by squeezing moist soil in hand can be freely handled and grouping of categories textural classes. Sandy loam soils are compressed; they hold their shape but break apart easily.

EC: EC measured by a digital conductivity meter (ATC-975-C, India).

Nitrogen: Nitrogen content of soil estimated by the per sulfate oxidation method.

Phosphate: Available phosphorous of soil was determined by using ammonium molybdate solution and was measured in a spectrophotometer at 690 nm.

Potassium: Available potassium in soil extracted with neutral ammonium acetate of molarity value 1. This considered as plant available K in the soils and being estimated with the help of flame photometer.
All the values of macronutrients expressed as kg/acre soil.

Heavy metals: Heavy metals like Fe, Mn, Zn, and Cu were analyzed following the standard methods of atomic absorption spectrophotometer. The values are expressed as percentage in soil.

Results and discussion

Physicochemical analysis

The pH and EC conditions of soil samples S1–S9 represent the quality of the soil. While the micronutrients such as Fe, Mn, Zn, and Cu percentages of S1 soil sample range from low to sufficient level and the remaining shows a low index in percentage, the percentage of macronutrients present in the samples depicts a high difference in their results due to the selection of locations for acquiring soil samples. For example, in the soil samples S1 and S3, the value of N shows low, whereas the values of P and K show high per kg/acre. In the case of sample soils such as S2, S4, S5, S6, S7, S8, and S9, it reveals a low index value of macronutrients. Owing to mining activities, the topsoil is excavated, and as a result, the soil loses its property of vegetation growth (Arvind Kumar Rai et al., 2011).

The findings of pH, EC, lime status, texture, and available macro- and micronutrients are used to validate the fertility of the soil samples. The pH of soil samples varies for each location but it is neutral as shown in Figure 5. The soil sample collected in the surrounding of the mine also shows similarity in pH values. The presence of calcium carbonate in nine samples differs with each other and is categorized as absent, moderate, and high. It is absent in the mining area and its adjacent area (samples S1, S3, S4, S5, and S8), whereas the mining dump area and the mine vein area have moderate presence (samples S6 and S7) and agriculture land adjacent to mine sites has high content of lime (sample S2). The texture condition of all nine soil samples exhibits sandy loam, which is very essential for the plantation/revegetation on those soils. The EC for nine samples varies to each other, but all in limits of less than 1 concentration and so it is termed as good condition soil as shown in Figure 6. Based on these parameters, it is inferred that these soils afford plant growth (Arvind Kumar Rai et al., 2011).

Table 2. Physicochemical properties of soil samples.

| Parameters          | Soil samples | Limits* |
|---------------------|--------------|---------|
|                      | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  | S9  |
| pH                  | 7.1 | 8.3 | 7.8 | 8.2 | 7.7 | 8.1 | 8.1 | 7.8 | 8.2 |
| Lime status         | Absent | High | Absent | Absent | Absent | Moderate | Moderate | Absent | Moderate |
| Texture             | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam |
| EC                  | 0.6 | 0.2 | 0.1 | 0.1 | 0.4 | 0.1 | 0.08 | 0.1 | 0.3 |
| Nitrogen (kg/acre)  | 63  | 71  | 77  | 67  | 63  | 64  | 53  | 57  | 63  |
| Phosphorous (kg/acre)| 25  | 2.6 | 10.8 | 1.4 | 2.0 | 0.6 | 1.2 | 1.2 | 3.0 |
| Potassium (kg/acre) | 168 | 28  | 131 | 28  | 42  | 33  | 25  | 33  | 250 |
| Fe (%)              | 4.75 | 3.17 | 3.0 | 1.17 | 2.08 | 1.08 | 1.08 | 2.83 | 2.25 |
| Mn (%)              | 0.92 | 1.42 | 1.81 | 0.62 | 1.0 | 1.19 | 0.38 | 1.31 | 1.16 |
| Zn (%)              | 0.42 | 1.22 | 0.46 | 0.86 | 0.86 | 0.26 | 0.08 | 0.2  | 0.82 |
| Cu (%)              | 1.43 | 0.91 | 1.62 | 0.3  | 0.23 | 0.23 | 0.32 | 0.75 | 0.42 |
| *Source: Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India, 2011. |

Figure 5. Histogram distribution of pH conditions in different soil samples.
quantify the soils. It will be varying according to the terrain and the climatic condition. The presence of Fe percentage in sample S1 shows sufficient but all the remaining soil samples are low in percentage. The presence of Mn percentage varies with each soil sample but is limited to low percentage. The presence of Zn percentage also varies with each soil sample. Except for soil sample S2, which has sufficient percentage, remaining all samples show a low percentage. The presence of Cu percentage in soil samples S1 and S3 is sufficient, whereas the remaining samples show a low percentage as shown in Figure 8.

Hence, deficiencies of micronutrients in the soils are reported to affect the chances of vegetation growth (Arvind Kumar Rai et al., 2011). Thus, this shortfall of micronutrients is adjusted by adding the essential nutrients to the soil either naturally or by artificial fertilizers.

**Statistical analysis**

Statistical analysis of field-collected soil samples uses STATISTICA software (ver.8). Each soil property was assessed in terms of descriptive statistics like mean, median, mode, standard deviation, correlation matrix, and cluster analysis which strengthen the findings of geostatistical parameters analysis (Chung et al., 2016; Venkatramanan et al., 2015).

**Descriptive statistics for physicochemical parameters of soil**

The analysis of the field-collected soil samples is done through the study of physicochemical parameters (pH, EC, N, P, K, Fe, Mn, Cu, and Zn) using the conventional statistics as shown in Table 3. Standard
Correlation statistics for physicochemical parameters of soil.

| Parameters | Mean | Median | Minimum | Maximum | Std. dev. |
|------------|------|--------|---------|---------|-----------|
| pH         | 7.91111 | 8.10000 | 7.00000 | 8.30000 | 0.40139 |
| EC         | 0.22000 | 0.10000 | 0.08000 | 0.60000 | 0.18055 |
| N (kg/acre)| 64.22222 | 63.00000 | 53.00000 | 77.00000 | 7.06714 |
| P (kg/acre)| 5.31111 | 2.00000 | 0.60000 | 25.00000 | 8.00569 |
| K (kg/acre)| 80.66667 | 33.00000 | 16.00000 | 250.0000 | 82.86133 |
| Fe (%)     | 2.37889 | 2.25000 | 1.08000 | 4.75000 | 1.21341 |
| Zn (%)     | 0.57556 | 0.46000 | 0.08000 | 1.22000 | 0.38089 |
| Cu (%)     | 0.68000 | 0.42000 | 0.23000 | 1.62000 | 0.53891 |
| Mn (%)     | 1.12333 | 1.19000 | 0.34000 | 1.81000 | 0.44365 |

The presence or absence of a pathogen in relation to soil chemistry was determined through independent distribution (T-test), P > 0.05 as considered significant. The Pearson’s correlation coefficient matrices for the analyzed parameters are presented in Table 4. Correlation coefficients less than 0.5 are not considered as they are not at significant levels. The interrelationship of different parameters is useful in studying the association of soil parameters (Andrew et al., 2018; Tellen & Yerima, 2018; Chung et al., 2016).

The correlation matrix shows that there is a good relationship between the physicochemical constituents presence in the soil as shown for bold in Table 4. Though the parameter of pH is not in good correlation with the other parameters, it affects the availability of fertilizer nutrients. In addition, pH is not an indication of fertility, but still soil EC has good correlation with other soil parameters such as P, K, and Fe, which is the measure of the amount of salts in the soil.

The macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) play a key role in the healthy growth of the vegetation. The study area commonly has limited supply of these macronutrients. Further, the study of soil samples infers the following factors:

- Nitrogen has good correlation with micronutrients such as Zn, Cu, and Mn.
- Phosphorous has good correlation with EC, K, and Fe.
- Potassium has good correlation with EC, P, and Cu.
- Micronutrient Fe has good correlation with EC, P, and Cu. Similarly, the Cu has good correlation with P, K, Fe, and Mn. The Mn has good correlation with N and Cu.

Thus, the correlation study predicts about the soil deficits and fertility factors to support the improvisation process of soil quality.

Cluster analysis

The results of the cluster analysis are shown in a tree diagram with single linkage by a dendrogram (Figures 9 and 10), which lists all of the samples and indicates at what level of similarity any two clusters are joined. The x-axis is the measure of the similarity or distance at which clusters join and different programs use different measures on this axis (Venkatramanan et al., 2015).

In the dendrogram, it was shown that the macronutrients (N, P, and K), micronutrients (Fe, Mn, Zn, and Cu), and physical characters (EC and pH) were found in chain cluster measurements. In the soil samples, macronutrient cluster was in the distance of >200. In the small cluster, linkage with micronutrients was in the linkage distance of 15 (Figure 9 and Table 5).

In the dendrogram shown, the soil sampling stations (Figure 10) S1 and S3 are the most similar, joined to form the first cluster, and followed by the second cluster S9 associated with S1 and S3 in the linkage distance of 85. The S2 and S7 cluster has link with S3 and S9 cluster with the linkage distance of 90. A small cluster is formed of S2 and S7 with linkage clusters of S4, S8, S7, and S5.

Conclusions

The nine soil samples were collected from randomly chosen locations but limited to magnesite mines and
adjacent magnesite-mining area. The study of physicochemical parameters of soil samples reveals that the spread of mining region may cause hindrance in agricultural activity through mines waste dump. The interpretation of macronutrients such as N, P, and K reveals that the soil quality degrades due to the leaching of low-grade waste magnesite ore that is being dumped along the mine’s site. However, the heavy metals in micronutrients like Fe, Zn, Cu, and Mn are present in the sample soils which are found to be relatively insignificant due to the waste dump residue that are contaminated in those soil samples. The keen observation of the pH value exceeding index value 7 indicates alkalinity of the sample soils. The dumping of the mine waste is planned with accordance to the periodical physicochemical aspects of the mining region to ascertain the growth of plants. This will ensure an eco-friendly environment in the mining region and thus strengthening the adjacent agricultural fields. Perhaps, the soil profile shows that the surface and the subsurface characteristic and qualities,
namely, depth, texture, structure, conditions of soil moisture, and poor drainage relationship, will directly affect the growth of the plants.

The geostatistical analysis methods like correlation matrix show the magnitude of variability changes in the soil’s physicochemical parameters with maximum significance in soils. The correlation of EC with P, N with Cu, P with EC, K with Cu, Fe with P, Zn with N, Cu with Fe, and Mn with N, respectively, showed their associability characters of soil parameters. Effective treatment combined with monitoring is required to meet the portability of soils in and around magnesite-mining regions. These steps are contributed to find variation in the pattern of nutrient distribution in the soils of the study region.

The dendrogram of soils (R mode and Q mode) is drawn to compare the linear relationship among the soil samples collected from the agriculture land in and around the magnesite-mining area. Moreover, the similarity and variation of soil parameters decide the quality of the soil. The study of soil profile supplemented by physical, chemical, and biological properties of the soil will give a complete picture of soil fertility. The soil study exposed that the lack of vegetation in the mining region is due to nutrient deficiency and the removal of the topsoil is due to mining activity. Hence, the further study intended to include metal analysis and biological measurements determines soil quality. More efforts needed considering such facts in establishing reforestation to overcome issues on soil quality. In addition, the topsoil acquired as part of mining activity reused in reforestation process. The observations of the analysis shown as the dump materials are deficient in N, P, and K, which requires addition of extra fertilizer and manures to make the dump suitable for any purpose. The dump material is found to be unsuitable for plant growth due to deficit of sufficient micro- and macronutrients. The soil sample monitoring analysis in and around mines and surrounded agriculture is beneficial to know the concentrations of various parameters present in the soil samples. Although the remediation plan will support this study, the continuous monitoring and more detailed analysis are still required for the conservation of soil in and around the study region.

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No potential conflict of interest was reported by the authors.

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