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Distribution of Soil Chemical Properties of Smallholder Farms on Derelict Mined-Sites of Jos South LGA, Jos Plateau, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Tin mining environments have constituted a degrading challenge to smallholder farmers whose lands have been overtaken. Attempts by smallholder farmers to restore the lands to farming are faced with soil productivity constraints. Yet, these farmers struggle to cultivate farms in-between the mined lands to meet up with subsistence food requirements. To date, the farmers have identified areas with low and high potentials due to years of continuous cultivation. This study was conducted

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in an environment that had undergone mining on a larger scale and is now undergoing surface mining on a small scale. Thirty-one (31) soil samples were taken at a depth of 0-20cm to investigate the spread of soil chemical properties on smallholder farms. Coordinates of the samples were acquired using GPS to create georeferenced continuous surfaces. The results indicated that the majority of the soil's chemical properties varied moderately. Organic matter (0.89-1.74%) and nitrogen (0.045 - 0.096%) needed mostly by crops were very low due to uninformed distribution of soil chemical properties. Geostatistics was used to generate continuous surfaces through Kriging. The small nugget effect showed spatial continuity between the neighboring points. Strong spatial dependence occurred for all soil nutrients tested, due to intrinsic soil properties such as soil parent material, topography, texture, and mineralogy. Generally, the spread of soil nutrients on the smallholder farm coincides with the smallholder farmers' identified potential areas. The study suggests that for proper nutrient interventions on the farms, distribution of soil nutrients on the farms should be done to avoid excesses and shortages of inorganic and organic interventions.

Keywords: Smallholder; nutrients; distribution; mining; fertility.

1. INTRODUCTION

Continuous cultivation of farmlands with declining soil fertility by smallholder farmers has remained a persistent constraint to crop yield improvement in sub-Saharan Africa (SSA). This leads to low productivity as a result of low inherent soil fertility, soil nutrient depletion, and limited nutrient inputs [1, 2, 3]. The region has eventually sustained low crop yields, which is a major threat to food security and rural livelihoods [4, 5]. The declining soil fertility results from poor management of arable lands and the changes introduced on cultivated smallholder farms. This requires an enabling policy environment for the smallholder farming sector through inputs; restoring soil fertility; and making sustainable intensification with high-value products [6].

The pressure of nutrient deficiencies at the smallholder scale is intense in SSA because arable land is put to different uses that are mostly unsustainable, and is severely depleted of vital nutrients [7]. The major challenge in some agricultural lands is the conversion of such lands for other purposes, which worsens the degradation. Tin mining is one activity that has affected agricultural lands and lowered food production. Dumping and tailing areas have very low soil fertility because tailing areas have lost soil colloids during the spraying process; while reversal of soil layers due to the "cut and fill" processes have occurred in the dumping sites. Therefore, topsoil is mixed or overturned, leaving nutrient-deficient soil for crops to grow on [8]. This becomes more serious when there is poor management from smallholder farmers. No wonder, 80% of arable land in Africa has low soil fertility from physical soil degradation due to unsustainable soil management practices [9].

The consequential effects of changes on agricultural lands are the alteration of the soil's chemical, physical, and biological properties, especially where there is a sustained nutrient inputs intervention without knowledge of the distribution of soil properties. Unfortunately, the nutrients (N, P, K) that influence crops the most, are yet the most variably misunderstood. This similar view was reported by Tabi et al [10]. where they stated that any soil intervention through inputs without precise knowledge of both physical and chemical properties to recover fertility homogeneity could be an exercise in futility. Knowledge of soil properties before designing site-specific input applications is a necessity that leads to better management decisions toward productive sustainability of the soil [11, 12, 13, 14, 15].

Aligning with this is the submission that due to soil heterogeneity, soil properties variation has now become a prerequisite for optimal and sustainable agricultural production [16]. It is the failure to follow due precision for input intervention that results in shortages and excesses in different areas even on the same plot of land under smallholder cultivation [17]. Spatial knowledge of soil variation can help in managing the productivity of arable lands by tailoring agricultural inputs to fit the spatial requirements of soils and crops [18].

In the tin mining areas of Jos Plateau, much large-scale tin mining had occurred in the past, leaving behind unproductive lands for smallholder farmers to cope with. At present, the initially mined areas are undergoing mining again, and in most cases affect the cultivated lands through dumps and even water from the mining wells. Some of the farms in between the mined areas are identified by farmers as productive or non-productive areas even on the same cultivated plots of land. Familiarity with cultivated plots and years of input application has not amended smallholder farms. This area of Jos South local government area is extensively mined, and highly overburdened by infertile deposits [19, 20]. Therefore, agricultural land is becoming limited on the Jos Plateau due to mining activities, and these mined areas are poorer in agricultural value than areas where mining has not occurred.

Ishak et al [8]. made known that the soils of an abandoned tin-mining area in Bangka Belitung Islands were acidic, with low OC, N, P, K, Ca, Mg, and CEC levels. In a similar study, Shamshuddin, Mokhtar and Paramananthan [21] revealed that the bases, organic carbon, phosphorus, and nitrogen contents were very low, cation exchange capacity was low, but pH was very high in an ex-mining land in IPoh, Perak. Agus et al [22]. also researched on the role of soil amendment in tropical post-tin mining areas in Bangka Island Indonesia for a dignified and sustainable environment and life. They reported that post-tropical tin mining acid soil of (pH 4.97) was dominated by sand particles (88%) with very low cation exchange capacity, very low nutrient contents (N, P, K, Ca, Mg), and high toxicity of Zn, Cu, B, Cd, and Ti, but still have low toxicity of Al, Fe, Mn, Mo, Pb.

Arefieva et al [23]. published a significant negative correlation between pH and the content of metal compounds including chromium and copper at "Avangard" mine (r=-0.95); and between alkalinity and chromium content at the "Glubokaya" mine (r=-0.94). In a like manner, Rachman et al [24]. showed degraded lands, very low organic matter content; the lowest clay content; the highest soil bulk density and low soil porosity; and the highest sand content. Essandoh et al [25]. publicized that soils from mined sites with unfilled/partially filled pits had higher levels of K, Mg, and Na. As mined sites' fallow period increased, concentrations of OC and Cd increased, while Ca, Mg, pH, Cu, Pb, S, and EC decreased.

Ideriah and Abere [26] reported sandy clay loam; acidic and deficient in N, P, and exchangeable bases in non-vegetated tin mine spoilt soils on Jos Plateau. Concentrations of most parameters were higher in the cultivated spoilt soils than in the uncultivated spoilt soils. Organic wastes and town refuse ash were recommended for soils in the area. Irrigation with mining pond water should be done with caution as it could be toxic to some crops. Likewise, in the findings of [27], tin mining activities reduced farmland through soil erosion problems, the swampy nature of neglected mined excavation, mine dumps, and pits on the arable land in Jos South LGA of Plateau state.

From the early researches conducted on soil property variation on tin-mined cultivated soils, there is need for site specific (one site) and precise nutrient intervention in order to improve soil productivity through the requisite knowledge of the distribution of soil chemical properties on smallholder farms.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Jos South Local Government Area, located within latitudes 9˚ 45ˈ 22˝ N and 9˚ 45ˈ 24˝ N, and longitudes 8˚ 51ˈ 4˝ E and 8˚ 51ˈ 7˝ E (Fig.1).

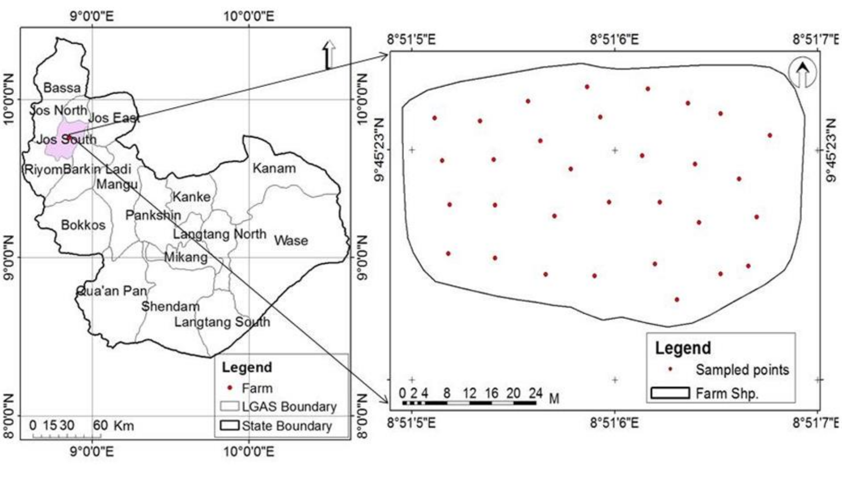

Fig. 1. Plateau state showing the study area

The study area has cool climatic conditions due to its altitude. The coldest period is between November and February with an average mean daily temperature of 18 °C, while it gets warm between March and April before the onset of rain. The rainy season, which is between April and October, has its peak in August. According to Gwom [28], the people were predominantly farmers and hunters, but the early occupation of the inhabitants has been overtaken by mining activities. Common food crops grown in the area include Irish potato, sweet potato, maize, millet, Hungary rice, tomato, and many other varieties of vegetables [27]. The area has a mean monthly temperature range of 20-24 ^{o}C and annual total rainfall of 1400 mm which falls primarily from April to October [29].

2.2 Sampling and Sample Preparation

Thirty-one (31) soil samples were taken at a depth of 0-20cm to investigate the spread of soil chemical properties on smallholder farms. Coordinates of the soil samples were acquired using GPS to create georeferenced continuous surfaces. Soil samples were taken from each smallholder location, then mixed and taken to the laboratory for analysis.

2.3 Soil Laboratory Analysis

The soil samples were analyzed for primary nutrients (N, P, and K), secondary nutrients (Mg and Ca), pH, and Organic Matter (OM). The pH was determined using a glass electrode pH meter [30]. Soil OM was determined using Walkley-Black wet oxidation method [31]. Nitrogen was determined using the micro-Kjeldahl digestion method [32]. Phosphorus, exchangeable cation (K,) was analyzed using Mehlich 3 extraction procedure [33] and reading with ICP-OEC. Ca and Mg were analyzed using the EDTA titration method [34]. Exchangeable acidity ($H^+ + Al^{3+}$) was determined by shaking soil with 1N KCl and titration with 0.5N NaOH [35].

2.4 Data Analysis

Statistical analysis was done on the primary data using Microsoft Excel and ArcGIS 10.3. Descriptive statistics like percentages, mean, minimum, maximum, standard deviation, and coefficient of variation were derived for variation of soil chemical property within the smallholder farm.

2.4.1 Coefficient of variation

The coefficient of variation was used to understand the classical variation of the soil properties on the farm**.** Based on the coefficient of variation (CV) values, variability was classified as low (0–15%), medium (15–75%), and high (>75%) [36].

2.4.2 Geostatistical analysis

The georeferenced point dataset for each soil variable was run on the different models, and the best-fitted models were used to generate the best-fit experimental semivariogram. The stable model was the most fitted for most of the soil properties. Nugget (Co), partial sill (C), range (A), and sill (C + C0), and nugget/sill ratio were also extracted from the suitable semivariograms of the fitted models. The spatial dependence of the soil properties as ordered by Cambardella et al. [37]; Ersahin [38]; and Robertson [39] where strong spatial dependence if the nugget/sill ratio is <25, moderate if the ratio is between 25 and 75%, and weak if the ratio is >75% were adopted. In the case of coefficient of variation (CV) values, the variability of soil properties was classified as low (0–15%), medium (15–75%), and high (>75%) [36, 40]. Best fit models were determined based on the RMSSE value close to 1, and ME close to zero [41].

3. RESULTS

3.1 Descriptive Nature of Soil Chemical Properties

The pH ranged from 5.63-6.5 and is due to attempts by smallholder farmers to improve soil fertility through the blanket applications of organic and inorganic fertilizers over a long time. The soils are slightly acidic and within the range for most crops [42] (Table 1). The OM ranged from 0.89-1.74% is very low according to Landon [43] (Table 1). This is due to continuous cultivation and extraction by crop, low manure application, and residue removal for cooking purposes. Nitrogen ranged from 0.045 - 0.096% which is very low [44]. The low nitrogen is due to uniform application, low amount of N-fertilizer applied, and continuous cultivation of the farm by the farmer. The implication is the successive low yields recorded by the farmer, and until precise nutrient intervention is made, the declining yield will continue. The smallholder plot undergoes both rainy and dry season cultivation.

Lower variability was observed for pH, Ca, and $H^+ + Al^{3+}$.The lowest coefficient of variation was observed in Ca with a value of 1.19%, which could be as a result of the uniform conditions in the area such as little changes in slope and its direction leading to a uniformity of soil in the area. All the other nutrients (OM, N, P, Mg, and K) had medium variability (Table 1). The implication of these on the farm is that unless the variation is spatially understood and minimized, instances of varied crop performances will continue at close ranges. That will negatively affect crop yield on the farm. The highest variability of soil nutrients was P with a value of 50.54%, meaning there is high dissimilarity in P distribution on the smallholder farm. It implies that where necessary interventions are not made; poor crop development especially at a later stage can affect seed formation and maturity which will eventually lead to poor yield.

3.2 Geostatistical Analysis of Soil Chemical Properties

Various models were used for semivariogram analysis to estimate the hypothetical semivariogram parameter in ArcGIS 10.3. The sill value is representing the upper limit of the fitted semivariogram model [45]. Results of the geostatistical analysis indicated that the Mean Error (ME) values close to 0 and Root Mean Square Standardized Error (RMSSE) values close to 1 pointed to unbiased prediction. The nugget value denotes the random variation usually derived from the accuracy of measurement or variations of the properties that cannot be detected in the sample range [46]. The small nugget effect showed spatial continuity between the neighboring points [47], corroborating the findings of Vieira and Gonzalez [48] and Jafarian and Kavian [49] which indicated nitrogen had a very small nugget effect. Soil chemical properties with a lower nugget effect were generally defined by the spherical semivariogram model (Table 2).

Strong spatial dependence occurred for the cations (Ca and Mg), OC, pH, and P, exchangeable base (K), OC, and N (Table 2). This strong spatial dependence is due to intrinsic soil properties such as soil parent material, topography, texture, and mineralogy on the farm [50]. It shows that anthropogenic or human interventions through fertilization were not sufficient in influencing soil chemical properties. This may also be caused by uniform fertilization without considering the spatial variation of soil chemical properties on the farm. This is as indicated in the results of the earlier descriptive or classical statistics in this study. The nugget-to-sill ratio implies the spatial dependence of soil chemical properties, which all had a strong dependency.

The range of the semivariogram denotes the average distance through which the variable semivariance reaches its highest value. A small effective range indicates a distribution pattern composed of small patches [51]. The small ranges of soil chemical properties on the plot are due to external factors [52], occasioned by the activities of the smallholder farmer. This is possible for the fact the smallholder farmer applied fertilization uniformly across the farm with observed poor crop performance in identified areas on the farm. The distribution of soil chemical properties varies within short ranges and this model can calculate the unsampled points within a neighboring distance of about 12.22 m for pH, OM, N, P, Ca, Mg, K, and 13.33 m for H^++Al^{3+} (Table 2). These short distances are realistic as the sampled points were acquired on the same smallholder farm with high precision for intervention through fertilization.

Table 1. Descriptive statistics of soil chemical properties

Nut/Unit	Min	Max	Mean	Median	CV (%)	CV Class	Std.
pH (value)	5.63	6.5	6.03	5.92	4.59	Low	0.277
OM (%)	0.89	1.74	1.40	1.41	19.57	Medium	0.274
N (%)	0.045	0.096	0.072	0.07	23.61	Medium	0.017
P (ppm)	1	10	5.58	5	50.54	Medium	2.80
Ca (ppm)	380	392	386	386	1.19	Low	4.62
Mg (ppm)	76	97	87.48	88	19.68	Medium	6.75
K (ppm)	2	8	4.90	5	37.35	Medium	1.83
($H^+ + Al^{3+)}$ cmol/kg	1.54	1.65	1.58	1.57	2.15	Low	0.034

CV=Coefficient of Variation, Std=Standard Deviation. OM=Organic Matter, N=Nitrogen, P=Phosphorus, Ca=Calcium, Mg=Magnesium, K=Potassium, $H^+ + Al^{3+}$=Exchangeable Acidity

Table 2. Geostatistics of soil chemical properties

Variable	Model	Nugget (Co)	Partial Sill(C)	Sill (Co+C)	Nugget/ Sill (%)	Spatial Class	Range (m)	RMSSE	ME
pH (value)	R.Quadratic	0.013	0.079	0.0928	0.14	Strong	12.22	0.9782	0.0029
OM (%)	Exponential	0	0.094	0.0941	0	Strong	12.22	0.9520	0.0035
N (%)	Stable	0	1.167	1.1677	0	Strong	12.22	0.9723	0
P (ppm)	Stable	0	0.581	0.5819	0	Strong	12.22	0.6482	0.3883
Ca (ppm)	Stable	0.0001	3.183	3.1839	0	Strong	12.22	0.9791	0.1898
Mg (ppm)	Exponential	0.0028	0.003	0.0057	0.97	Strong	12.22	0.978	0.0366
K (ppm)	Stable	0	4.004	4.0041	0	Strong	12.22	0.9673	0.0192
$H^+ + Al^{3+}$ (cmol/kg)	Stable	0	0.001	0.0010	0	Strong	13.33	1.0437	0.0008

RMSSE= Root Mean Square Standardized Error, ME=Mean Error, pH=Potential Hydrogen, OM=Organic Matter, N=Nitrogen, P=Phosphorus, Ca=Calcium, Mg=Magnesium, K=Potassium, H^++AL^{3+}=Exchangeable Acidity

3.3 Semivariograms of Mapped Soil Chemical Properties

The spread of soil chemical properties on the farm is indicated by continuous surfaces produced from geostatistics through their respective semivariograms relationship. They indicate the spread of variables considered on the smallholder plot (Fig. 2), the generated spatial parameters of geostatistics obtained directly from the semivariogram and the derived variables (Table 2). The nugget, partial sill, sill, and spatial dependencies are all products of the semivariogram. From Fig. 2, it is clear that the nugget for OM, N, P, K, and H+ + AL^{3+} as 0 indicates precision in measurement and soil homogeneity for the listed soil chemical properties.

3.4 Spatial Interpolation and Mapping of Soil Chemical Properties

The maps of soil chemical properties as presented in Figs. 3–10 indicates the spatial distribution of soil chemical properties created using the most suitable krigging models. The maps show soil chemical properties considered varied on the smallholder plot. The soil had a pH that is slightly acidic in the center of the farm and more acidic in the western and eastern parts of the farm (Fig. 3). Large areas were covered with 5.98-6.14 values of pH.

The spread of OM on the farm is higher in the central part of the farm with values ranging from 1.55-1.74%. It matched the farmer's identified poor areas in the eastern and western portions of the farm which was poor in organic matter, making crop yield to be poorer (Fig. 4). The western and eastern parts with low OM are coincidentally the dump sites of the tin mining deposits which are poor in vital nutrients needed for maize and Irish potato. The extensive part of the farm is covered by 1.40-1.54% of OM.

The distribution of N showed a similar pattern to that of the OM content due to the strong correlation between OM and N. The higher values of N (0.08-0.10) in the central patch in the southwestern part of the farm represent areas with identified high crop yields (Fig. 5). Vast areas were covered with 0.07-0.08% of N.

The spread of P on the farm matches that of OM and N where the concentrations are higher in the middle of the farm (8.27-10.00 ppm). However, for P, very high amounts (8.27-10.00) were also found in the southwestern part of the farm (Fig. 6). Likewise, the areas with low spread of P coincide with smallholder farmer's areas of low crop yield. This is because P deficiency reduces vegetative growth and grain yield.

The spread of Ca on the smallholder farm indicated a higher concentration at the center and edge of the farm towards the western part. Major Ca spread is within the 383.45-387.54 ppm range. The lowest values of Ca were noted in the eastern portion of the farm (Fig. 7). The most unproductive smallholder farmer's identified portion matches areas with the lowest Ca values.

The distribution of Mg on the smallholder farm indicates higher concentration in the middle of the farm with values ranging from 87.06-97.00 ppm. Lower values from 76.00-87.06 ppm occurred in the eastern and western portions of the farm. These lower values tallies with the smallholder farmer's identified low potential areas of the farm (Fig. 8), because when Mg is deficient, it leads to a shortage of chlorophyll and that leads to poor and stunted plant growth. Ultimately, the result is low yield as reported by the smallholder farmer.

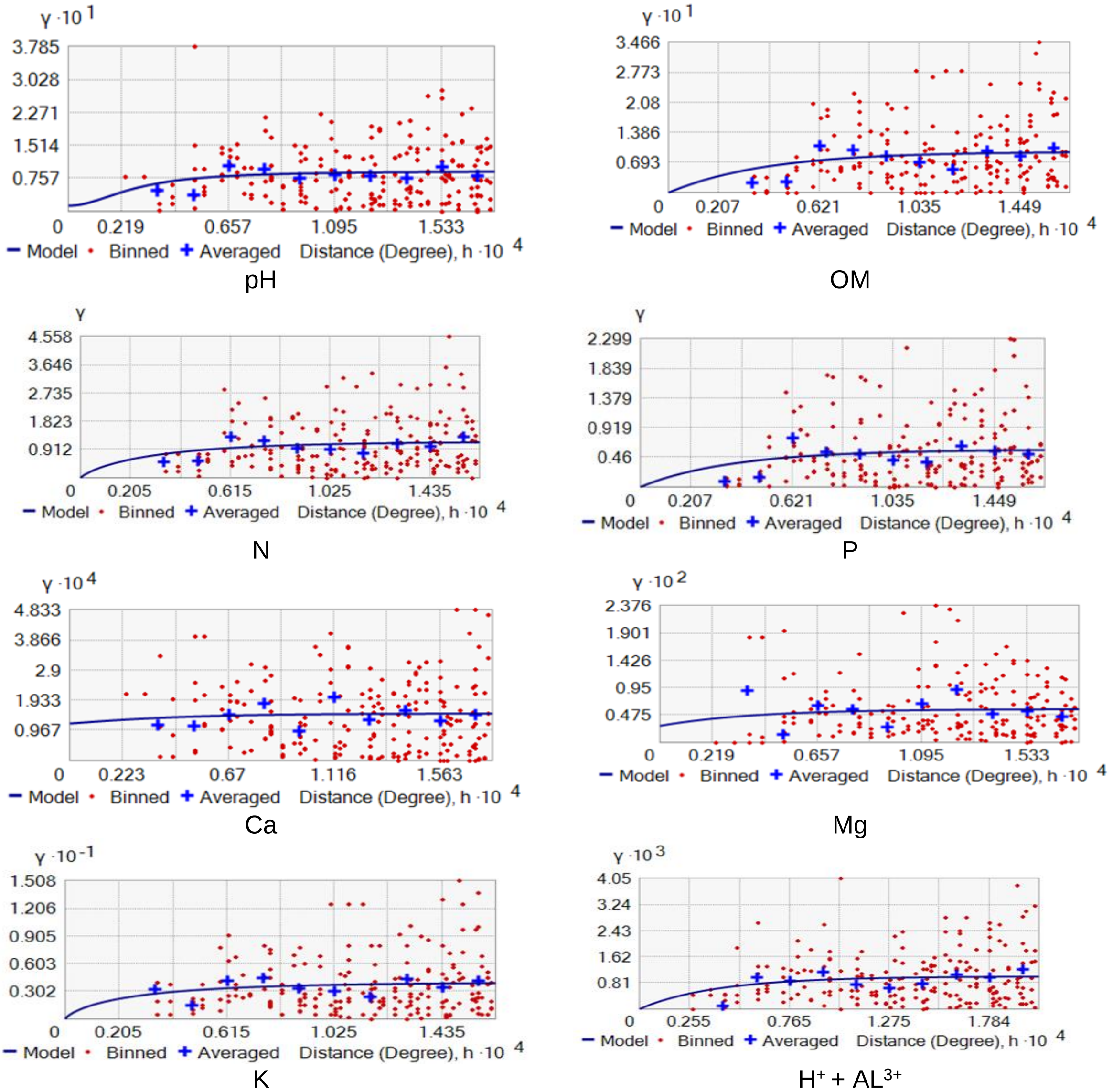

Fig. 2. Fitted Semivariograms Illustrating the Strength of Statistical Correlation between Major Soil Chemical Properties

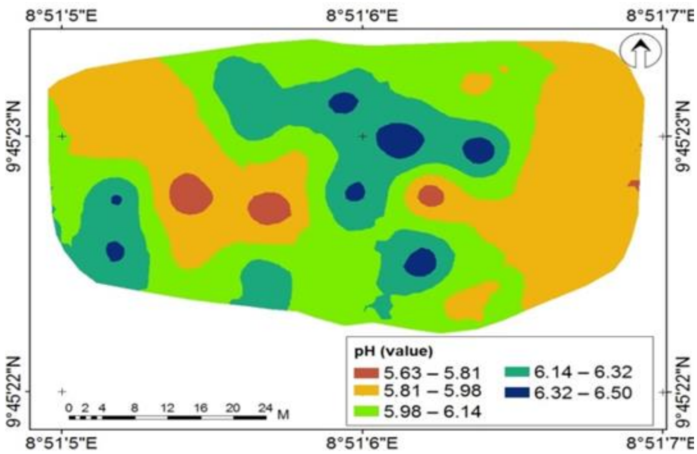

Fig. 3. Spatial distribution of soil pH in the study area

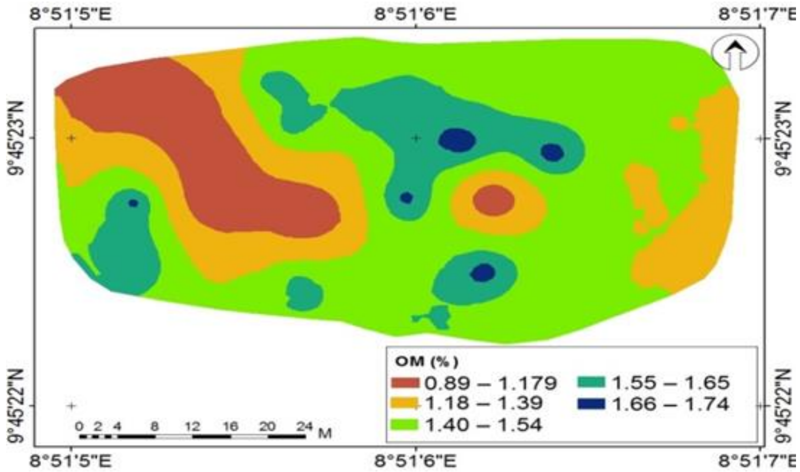

Fig. 4. Spatial distribution of OM content in the study area

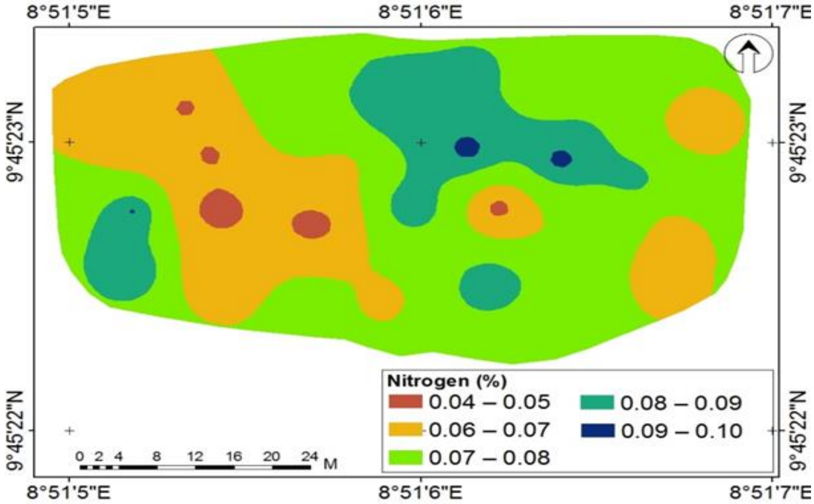

Fig. 5. Spatial distribution of N contents in the study area

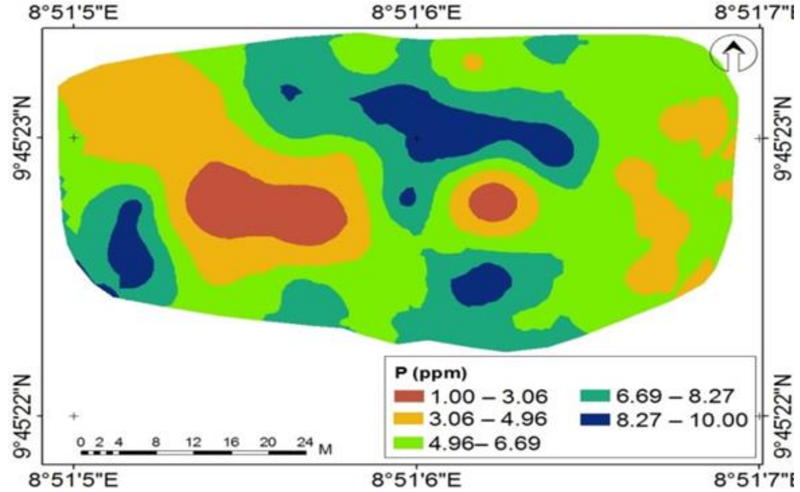

Fig. 6. Spatial distribution of P in the study area

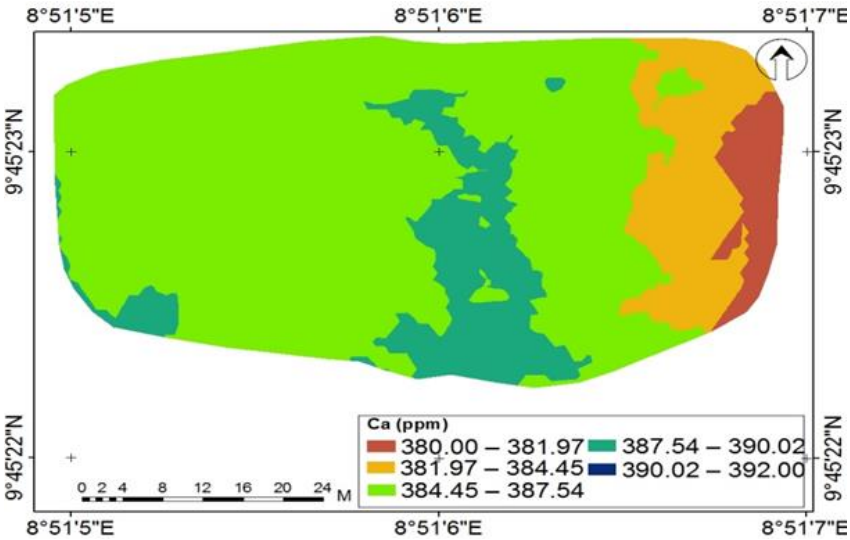

Fig. 7. Spatial distribution of Ca contents in the study area

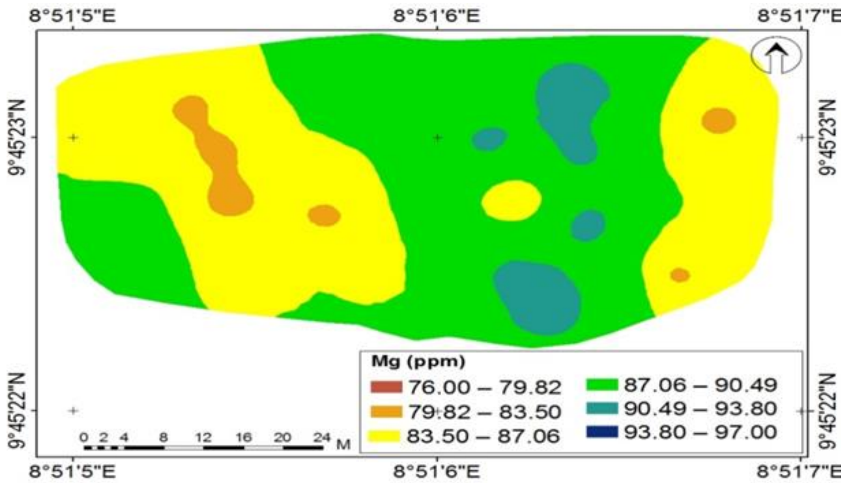

Fig. 8. Spatial distribution of Mg contents in the study area

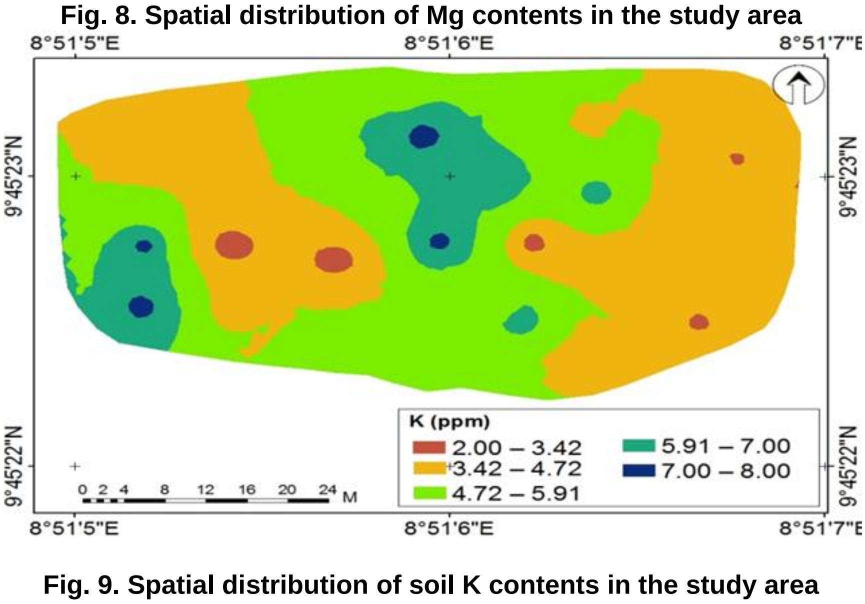

Fig. 9. Spatial distribution of soil K contents in the study area

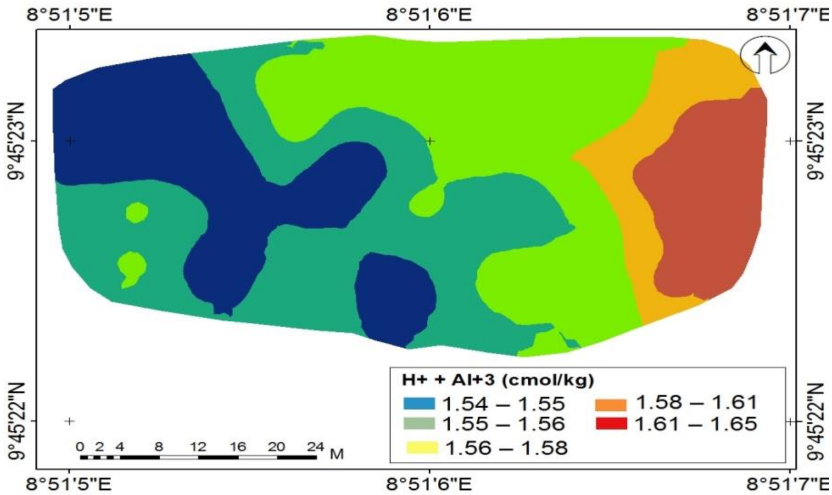

Fig. 10. Spatial distribution of exchangeable acidity in the study area

The spatial spread of K on the smallholder farm showed that high values of K ranging from 5.91-8.00 ppm were concentrated in the middle of the farm and the southwestern edge of the farm (Fig. 9). However, higher concentrations of high values in the range of 4.72-5.91 values dominated the whole farm. The lower values were majorly spread in the eastern part with 3.42-3.72 ppm values occupying the largest portion of the farm. The areas of low K are reported to have low yields. This is not unconnected to the fact that K deficiency causes stunted growth of plants and as well reduces crop yield.

The distribution of H^++AL^{3+} on the smallholder farm was highly concentrated (1.54-1.55 nmol/100g) in the western part of the farm. Very low concentrations (1.58-1.65 nmol/100g) were found in the eastern part of the farm. Contrary to the pattern of low spread of nutrients in the western part of the farm, very high values of H^++AL^{3+} were found in the eastern part of the farm (Fig. 10).

4. DISCUSSION

Descriptive results indicated that the medium variability of soil chemical properties in this study corroborates the medium variability by Dakagan [53] and Shehu et al [54]. The pH range of 5.63 to 6.5 falls within the slightly acidic range and is within the ideal range (5.5 – 7) acceptable by most cultivated crops [42, 55]. Soil pH is quite important in agriculture because it regulates nutrient availability to plants by controlling their chemical forms as well as influencing chemical reactions. The productivity of soil and crops are connected to pH value. So, while the optimal value is required for plants to do well, excessive pH levels inhibit plant root growth and development. In the long run, this poor growth and development limits crop yield [56]. It also concurs with the findings of Dakagan [53] where the same soil chemical properties mostly exhibited medium variability. However, this finding contradicts the very acidic report of Ishak et al. [8].

The exchangeable acidity on the farm modified soil pH by the addition of soluble or insoluble acid or base-inducing chemical elements and ions such as P, K, Ca, Lime, and OM which influenced soil productivity and plant growth [57]. The exchangeable acidity values on the farm are supposed to be inversely related to pH to increase crop productivity and yield. The remedy is to increase soil pH through carbonates of calcium and magnesium, liming via farm yard manure, and ash from different sources [58]. The high values of exchangeable acidity have impeded soil and crop productivity. Organic Matter of 0.89-1.74% on the smallholder farm is very low according to Landon [43], where OC >20% is very high; 10 – 20% is high; 4 - 10% is medium; 2 - 4% is low; and <2% is very low. Continuous cultivation and the effect of trailing and dumpsites are the reasons for poor OM.

The N of 0.045-0.096% is very low [44]. This is due to uniform fertilizer intervention without spatial understanding, low N fertilizer application, and continuous extraction of N fertilizer by cultivated crops. This agrees with the findings of Aliyu et al [59]. More than half the study region is covered by K of 2-5.91 ppm, though the maximum K value is 8 ppm, both fall under the critical limit for agricultural production [60]. Topography and intensive cropping systems with low application rates of K fertilizer are reasons for potassium depletion on the farm [61]. The P values on the farm ranging from 1-10 ppm contradict very high values of 173.11 to 204.23 ppm reported by Khan et al [62]. Fertilization with poor P nutrients and overturn of soil due to mining, erosion, and leaching are the cause of the very poor content of P on the farm.

The generally low nutrients on the farm concurs with the findings of Ishak et al [8]. where low OC, N, P, K, Ca, and Mg were reported. It also concurs with the findings of Shamshuddin et al. [21] where the bases, OM, P, and N contents were very low. The low nutrients in this mining area also concur with the findings of Agus et al. [22] where N, P, K, Ca, and Mg were very low. The low nutrient content in this study also agrees with the findings of Ideriah and Abere [26] where deficiencies were reported for N, P, and exchangeable bases. The low values of other soil chemical properties demand effective site-specific management by smallholder farmers in tin mining environments, for fruitful crop production.

The findings from the spatial variability where strong spatial dependence occurred for N, Ca, Mg, K, OC, pH, H^{+}+AL^{3+}, and P are due to intrinsic soil properties such as soil parent material, topography, texture, and mineralogy [50]. These findings agree with those of Aliyu et al [59]. and Dakagan [53] where the nutrients indicated similar strong spatial dependence. However, the strong spatial dependence of Ca contradicts their findings. The low range is due to external factors and interventions at short distances by the smallholder farmer [52].

For the distribution of nutrient content on digital maps, where the pH values of 5.81-6.14 covered much of the farm, contradicts that of Khan et al [62]. where the study area was widely covered by alkaline pH values of 7.35-7.82. This also contradicts lower pH values reported by Dakagan [63], necessitating the need for site specific analysis of the distribution or spread and nutrient intervention. The wide spatial spread of OM of 1.4-1.54% in this study contradicts that of Khan et al [62]. where the study area is highly covered with lower OM values of <0.26-0.79. The OM values here are lower than those obtained on greater portion of smallholder farm within 1.17%-3.00% by Dakagan [63], in similar environment. This again reveals micro variability and the need for precise nutrient management for optimal productivity. The result of N in this study where the study area is dominated by lower values of N (0.07-0.080%) contradicts the submission by Khan et al [62]. where their study area was covered by higher N values of 0.35-0.42%. Likewise, values of N in this study are lower compared to the 0.05-0.22% obtained by Dakagan [63] in an abandoned tin mining site. More contrasting is the spread of P in this study. While very high values of P (79.73-173), almost covered the whole studied area by Khan et al. [62], in this study, half of the study area is covered by very low values (4.06-6.69 ppm) of P. Another major contrasting finding is that of K distribution. While this study has K within the range of 3.42-5.91 ppm covering more than half of the study area, Khan et al [62]. mapped high values of 39.29-94.78 ppm covering over 80% of their study area.

It is therefore important for farmers in this area to incorporate integrated nutrient management (organic and inorganic fertilizers) for higher productivity where the soil fertility is depleted due to continuous cultivation and mining activities. This opinion is strongly supported as applied by Ranganadha et al [64]. It proved useful as higher amount of organic matter combined with NPK fertilizer were more effective in the yield realized.

5. CONCLUSION

In areas where management efforts have not yielded the required results on smallholder farms, understanding the distribution of nutrient contents of such areas becomes necessary for optimal crop production. Resources are erroneously wasted in tin mining environments in attempts to restore agricultural lands taken over by mining. There are resurgences of surface mining in mining environments that have added more pain to smallholder farmers who have already suffered the consequential effects of mechanized tin mining. With the understanding of soil spatial variability, areas of low potentials can be precisely managed through appropriate management strategies. Appropriate organic interventions like precise application of both NPK fertilizer and OM are highly recommended. The removal of crop residue as a sustained system by women for cooking in the area denies the farm OM from crop residue. The outcome of this study indicates the efficacy of GIS geostatistics in interpolating continuous surfaces of unsampled data. Conducting site specific distribution of soil chemical properties on smallholder farms in tin-mining environments will assist smallholder farmers precisely restore fertility on derelict mining sites of individual farms for optimal agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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