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Research Paper

Physicochemical properties and metal contents of soils of selected farmlands in Oromia Regional State, Ethiopia: implications to soil management

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Abstract

In this study, the physicochemical properties and the constituents of selected metallic substances from the farmland soils that were collected from four agricultural sites; namely, Boji, Gedo, Hirna and Kubsa Kidame of the Oromia Regional State of Ethiopia, have been investigated. The surface soil samples, collected from 0-20 cm depth and from identical slopes at each site, were pretreated following the standard methods to obtain composite samples. The selected physicochemical properties of the processed samples; specifically, moisture contents, pH, organic matter, electrical conductivity and soil texture, were also analyzed following the standard procedure. For determination of the metal contents, soil samples were digested and analyzed using Flame Atomic Absorption Spectrometry. The analyzed soil samples were found to contain organic matter of 3.24 to 3.96 (medium class); electrical conductivity in the range of 0.13 to 0.21 mScm^{-1}, indicating that the soil samples are not salt-affected; pH in the range of slightly acidic to neutral (5.75–6.94); and textural class dominated by clay, constituting 41.4–56.2%. Variations in the metal concentrations (mg kg^{-1}) were: Calcium (9330–18900), Cadmium (3.88–4.45), Chromium (30.7–99.5), Cupper (12.6–42.3), Iron (654–875), Manganese (133–255), Lead (14.9–30.2), and Zinc (217–289). Based on percent recovery, the accuracy of the results were within the acceptable range of 91.2–103 %. The experimental results fairly suggests that the farmland soils could safely be utilized for cultivating different agricultural products. There are possibilities of further extending the works at other farmlands.

1. Introduction

Ethiopia utilizes the oldest and most traditional farming practices in Sub-Saharan Africa with considerable agrarian potential (Temesgen, 2017). Agriculture is the backbone of the country's economy and a major source of income for most of its population; close to 85% (Gebissa, 2021). Furthermore, sustainable economic growth and poverty mitigation strategies in Ethiopia are principally focused on the improvement of the sector (Temesgen, 2017).

Moreover, Ethiopia is among the African countries where agriculture is the determining sector of the state economy, although agricultural production relies on the available natural resources (Aklilu et al., 2007). The recent increase in human population, on the other hand, seems to result in over use of natural resources and is gradually becoming a bottleneck to sustainable agriculture (Simachew, 2020). Depletion of soil resources due to both natural and anthropogenic

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processes like soil erosion, mining, improper land use, and insufficient supply of nutrients was also very common throughout the agricultural community (Ermias et al., 2022). Low soil fertility, as the cumulative effect of the stated practices, has also been realized as one of the serious threats to sustainable agricultural productivity. Therefore, integrated soil management could be a preferable option for the utilization of soil resources to develop environmentally friendly and economically feasible farming systems (Gan et al., 2018; Mensah-Bonsu et al., 2017).

For management of soil fertility to increase agricultural productivity through the effective use of the soils to secure food supply to the society and to preserve the resources for the coming generation, understanding the nature, physicochemical properties, and metal constituents of the soil resources is essential (Shimbahri et al., 2018). Based on the crucial scientific investigations forwarded by various workers regarding the soils nutrient status, authorities at various levels; namely, local, regional, national, and all others concerned should understand the relative responses of the soils to the types and amounts of fertilizer applied for the purpose of boosting the agricultural output. Site-specific investigation of the soil status, in a given agroecology, is therefore becoming inevitably essential for proper fertilizer applications and other soil protection practices (Nafiu et al., 2012).

In the sampling areas chosen for the current research work undertakings; namely, Boji, Gedo, Hirna, and Kubsa Kidame, it was noted that the farmers are engaged with the cultivation of agricultural products, as settled small-scale farmers. However, the physicochemical properties and elemental constituents (nutrient status) of the farmland soils have never been investigated and tested in any scientifically established and recommended procedures and as a result no published or systematically organized documents are available. In most modern agricultural practices, nowadays, sufficient knowledge of the above parameters is gaining due attention for effective management of the farmlands so as to understand the extents to which the soils have deteriorated and/or have been affected. As a response to these undertakings, the necessary subsequent measures could be considered for protecting and restoring the critical qualities before the soils lose their capacities needed for efficient productivity.

Availability of adequate information on the two crucial factors; that is, physicochemical properties and the metal contents, playing significant roles, during evaluation of the soil fertilities could also help the authorities during the development and revision of policies in the land uses for sustainable agriculture; locally, nationally and may be regionally. The current study has thus been designed with the major objectives of experimentally determining selected physicochemical properties and the metal constituents of soil samples collected from the selected farmlands of the Oromia Regional State, Ethiopia, and to investigate the comparative analysis of the parameters among the sampling areas. It is also believed that the verified quantitative data, obtained as outcome of the study, could be utilized by all inspired researchers.

2. Materials and Methods

2.1. Chemicals and reagents

Concentrated HCl, 36–38%, was purchased from Hopkin & Williams Ltd., (London, UK). Concentrated HNO_3, 69–72%, was obtained from Fine Chemical Industries, (Mumbai, India), and 30% H_2O_2 was purchased from Scharlaw Chemie S.A (Barcelona, Spain). Lanthanum nitrate hydrate (purity, 99.9 %) and potassium chloride (purity, 99%) were the products of Sigma Aldrich (St. Louis, USA). Atomic absorption spectroscopy (AAS) grade metal standard solutions (1000 mg L^{-1}), obtained from Buck Scientific Puro-Graphic[tm] (East Norwalk, USA), were used to prepare the working and serial standard solutions of each metal. Home-made distilled water was used throughout the experiment works.

2.2. Sample collection and preparation

The soil samples were taken from four sites located in various zones of the Oromia Regional State, Ethiopia. The sampling sites include Boji (E 37º52'12.51", N 8º52'28.33") and Gedo (E 37º26'59.99", N 9º01'00.01"), both located in West Shoa Administrative Zone; Hirna (E 41º02'48.58", N 9º10'16.16") which is located in West Hararghe Administrative Zone; while Kubsa Kidame (E 37º30'40.24", N 9º48'02.54") is situated in Horo Guduru Wallaga Administrative Zone. Soil samplings were performed from the month of March 2022 to May 2022, when intensive agricultural activities are carried out around all the sampling areas. The surface soil samples, 0–20 cm depth, were collected using stainless steel auger nearly from the identical slopes, for each site, to avoid effects of the land topography on the soil properties (Okalebo et al., 2002; Westbom et al., 2008). The collected soil samples were packed, labeled and transported to Haramaya University research laboratory. The samples were then air dried followed by oven drying (Genlab Limited, UK) to a constant weight, and then ground, and sieved through a 2 mm sieve. The processed samples were then sufficiently mixed and homogenized using mortar and pestle, and stored in a clean and dried container until further processing for analysis.

2.3. Analysis of physicochemical properties of the soil samples

The physicochemical properties of the processed soils were investigated for moisture by using the established procedures (Tellen and Yerima, 2018; Saidi, 2012). For pH determination, the soil to water was prepared at 1:2.5 ration and measurement was performed using a glass electrode; calibrated using buffer solution of pH 7. The electrical conductivity (EC) of the soil was conducted following the standard procedure used by other workers (Tellen & Yerima, 2018). Here a 1:5 soil-solution ratio was agitated for an hour before the final measurement, using conductivity meter (JENWAY 4510, UK), and organic matter was determined by Walkley-Black oxidation method (Ukalska-Jaruga et al., 2019). Soil texture was analyzed following the hydrometric method (Sedlackova and Sevelova, 2021) and textural classes of the soil samples were determined using the United States Department of Agriculture (USDA**)** triangular guideline for classifying soil textures. Soil samples were digested according to the EPA 3050B method using Kjeldahl block digester obtained from Gallenkamp (London, England) and analyzed for the metal contents using MODEL 210 VGB BUCK Scientific Flame Atomic Absorption Spectrometry (FAAS) (East Norwalk, USA) (Deribachew et al., 2015).

Calibration curves were plotted and used to quantify the metal concentrations in the sample solutions. The curves were plotted using six calibration points and a blank solution. The correlation coefficients of the calibration curves, for the whole analytes, were found to be greater than or equal to 0.995, which confirmed linearity of the instrument responses to each analyte. The FAAS instrument was operated based on the manufacturer's operation manual for better sensitivity. To control the interference effects during the analysis of calcium, a solution of lanthanum chloride was added followed by addition of potassium chloride solution, as suppressor, for determination of chromium (Meseret et al., 2013). For each soil sample, at least triplicate measurements were performed.

2.4. Recovery of the analytical method

Accurately weighed 1.0 g soil samples were spiked with known concentrations of each metal. Each spiked sample was digested, in triplicate, in the same way as the digestion technique utilized for the original samples, so that the same effect may be experienced as that of the analytes. Each digested spiked sample was finally analyzed for the respective metals. Percentage recovery (%R) was computed as a percentage ratio of the recovered quantity of the analyte to the amount initially spiked (equation 1):

$$\%R = \frac{C_f - C_i}{C_s} \times 100 \quad (1)$$

where C_f is the obtained concentration after spiking, C_i is the metal concentration before spiking, and C_i is the spiking concentration.

2.5. Limits of detection and quantification

For the analysis of metals, in the present study, six blank samples digestion was performed and analyzed, and the standard deviation of the six blank measurements was calculated. Limit of detection (LOD) is the lowest concentration of the analyte that a method can detect whereas, and limit of quantification (LOQ) is the level above which quantitative results may be obtained with a specified degree of confidence. The LOD and LOQ were determined using equation 2 and equation 3, respectively (Pourang and Noori, 2012).

$$LOD = 3 \times s \quad (2)$$

$$LOQ = 10 \times s \quad (3)$$

where s is the standard deviation of blank measurements (n = 6).

2.6. Statistical analysis

One-way ANOVA was used to investigate the significant differences between the means (Diribachew et al., 2015). In order to investigate the correlation between the soil properties (EC, pH, and % organic matter) and the selected metal concentrations, Pearson's correlation analysis was performed on the data sets (Minaleshewa et al., 2011). Microsoft Excel was used to perform the statistical analysis calculations.

3. Results and Discussion

3.1. Limits of detection and quantification

The LOD and LOQ values were calculated and the results are presented along with the instrument detection limit (IDL) (Table 1). The determined values, LOD (0.05–0.766) and LOQ (0.19–2.55 mg kg^{-1}) indicated good sensitivity of the method for quantitative analysis of the target metals in the soil samples considered.

3.2. Recovery of the analytical method

Percent recovery (%R) values were calculated and presented in Table 2, which were found to vary between 91.2–103%. This range is within the acceptable range (Meseret et al., 2013). Copper has exhibited the highest %R value of 103%, while zinc showed the least, 91.2%, among the investigated metals. It may not be easy to relate the probable causes of the variability of the results in %R for the studied metals, with certainty, though the loss in precision that arose from the atomization process could temporarily be taken as a probable reason (Daniel and Chandravanshi, 2010).

Table 1: Wavelength (λ), correlation coefficients (R^2) of the calibration curve, limit of detection (LOD), and quantitation (LOQ) for the soil samples and instrument detection limit (IDL)

Metal	λ (nm)	R^2	LOD (mg kg^{-1})	LOQ (mg kg^{-1})	IDL (mg kg^{-1})
Calcium (ca)	422.7	0.999	0.162	0.54	0.010
Cadmium (Cd)	228.9	0.996	0.196	0.65	0.005
Chromium (Cr)	357.9	0.997	0.297	0.99	0.050
Copper (Cu)	324.8	0.999	0.268	0.89	0.020
Iron (Fe)	248.3	0.995	0.766	2.55	0.030
Manganese (Mn)	279.5	0.996	0.058	0.19	0.001
Lead (Pb)	283.3	0.998	0.409	1.36	0.100
Zinc (Zn)	213.9	0.997	0.149	0.49	0.005

Table 2: Percentage recovery (%R) values of the soil samples

Metals	Soil			
	CIS (mg kg^{-1})	AA (mg kg^{-1})	AR (mg kg^{-1})	%R
Calcium (Ca)	15600.0	400	391.00±1.40	97.8
Cadmium (Cd)	3.9	1	0.93±0.06	93.0
Chromium (Cr)	43.0	10	9.49±0.35	94.9
Copper (Cu)	12.6	10	10.30±0.58	103.0
Iron (Fe)	654.0	200	183.00±1.50	91.5
Manganese (Mn)	255.0	50	46.30±1.90	92.6
Lead (Pb)	30.2	5	5.09±0.43	102.0
Zinc (Zn)	252.0	50	45.60±0.64	91.2

CIS: Concentration in soil sample; AA: Amount added; AR: Amount recovered; %R: Percent recovery

3.3. Physicochemical parameters of the soils

Physicochemical parameters of the farmland soils collected from the four identified sampling sites in this study are presented in Table 3.

3.3.1 Moisture contents and pH of the soil samples

As indicated in Table 3, the highest percentage of moisture was found in the soil samples from Boji and the least for the soil sampled from Hirna. High moisture content indicates that the soil holds water to a large extent than the others and the soil is also clayey (O'Geen, 2013). The moisture content of the soil samples is greatly influenced by the soil texture. Sandy soil can quickly be recharged with the soil moisture but is unable to hold as much water as the soil with heavier textures which is in good agreement with the findings of the current study. As texture becomes heavier, on the other hand, the wilting point increases because soils with small pore size have high water holding capacity than soils with more wide pore size.

The pH range determined for the target soil samples in this study was between 5.75 and 6.94 (Table 3), indicating that the soil samples can be classified as slightly acidic to nearly neutral (Taye and Yifru, 2010) and it is in the range for normal agricultural soils (Wongkiew et al., 2022). Based on the measured pH values, it could be reasonable to conclude that the soils of the study areas are appropriate for crop production and safe from the factor that may arise due to the extreme pH. It is a common practice, nowadays, for the farmers to use fertilizers to enhance the agricultural productivities, and frequent use of nitrogen fertilizers application normally escalate soil acidity (Sanjay-Swami & Singh, 2020). Therefore, extensive use of nitrogen, phosphorus, and potassium (NPK) fertilizers might be one of the possible reasons for the slight acidity of the investigated soils. It is also worth describing that soil pH is among the parameters which significantly determine bioavailability of metals in soil system. Low soil pH favors the metals solubility and bioavailability, and the approximate pH range of normal agricultural soils is 5.0–7.0 (Kicinska et al., 2022). Therefore, pH of the soils considered in this study can be described as convenient for agriculture.

3.3.2 Soil organic matter (OM) and textural class

The %OM values determined for the soil from the study areas (Table 3) may enable one to classify the analyzed soil samples in a medium range (2–4), and similar results were reported for soil samples of some other areas in Ethiopia (Taye and Yifru, 2010). The textural classes of the top soil samples of the four farmlands were found to be clay. However, higher and comparable clay content were also recorded in the soil samples of Boji, Gedo and Kubsa Kidame sites while least clay contents were noted compared to the Hirna site. The difference might be due to the geological and geographical locations, and anthropogenic hindrances on the study areas. In general, the textural classes noted in this study was found to be similar to the findings reported for some agricultural soils from Ethiopia and some other countries (Ashenafi et al., 2010; Attah, 2010; Taye and Yifru, 2010; Achalu et al., 2012; Mintesinot et al., 2018).

3.3.3 Electrical conductivity (EC)

EC measures the ion contents and salinity of the soil solutions that it gives a clear idea for the presence of soluble salts in the solution of soil samples. EC of the composite soil samples were found to be 0.21, 0.14, 0.18 and 0.13 ($mScm^{-1}$) for Boji, Gedo, Hirna and Kubsa Kidame, respectively (Table 3). Accordingly, the soil samples can be classified as soils with very low EC and not salt affected (Abegunrin et al., 2013).

Table 3: Physicochemical properties (mean ± SD, n=3) and textural class of the soil samples

Site	Moisture content	Organic matter (%)	pH	EC ($mS\ cm^{-1}$)	Sand (%)	Clay (%)	Silt (%)	Textural class
Boji	16.4±0.2	3.24±0.2	5.75±0.7	0.21±0.02	25.6±1.2	55.3±4.1	19.1±5.0	Clay
Gedo	13.7±0.5	3.39±0.4	6.59±0.4	0.14±0.06	21.7±3.1	55.9±2.5	22.4±2.0	Clay
Hirna	12.7±1.0	3.96±0.2	6.94±0.1	0.18±0.05	38.6±1.5	41.4±0.7	20.0±2.2	Clay
Kubsa Kidame	16.0±0.7	3.69±0.3	5.81±0.3	0.13±0.02	20.9±2.9	56.2±2.4	22.6±1.8	Clay

3.4. Concentration of the metals in the soil samples

Based on the metal contents of the soil samples (Table 4), Ca (9330–18900 mg kg^{-1}) was found to be predominant followed by Fe (654–875 mg kg^{-1}) in the four soil samples. Pb, Cu and Cd were of least concentrations among the investigated metals for all the soil samples. The metal concentrations in the four soil samples followed a decreasing trend of Ca > Fe > Mn > Zn > Cr > Pb > Cu > Cd for the Boji; Ca > Fe > Zn > Mn > Cr > Cu > Pb > Cd for the Gedo and Kubsa Kidame; and Ca > Fe > Zn > Mn > Cu > Cr > Pb > Cd for the Hirna site. Similar trends of metal ions concentration variations were also reported for the soil samples originated from different countries and the samples from similar locations collected during different seasons and meant for different purposes (Meseret et al., 2013; Kanakaraju et al., 2007; Rahman et al., 2018).

The concentrations of Cu, Pb and Zn were below the limit for all the soil samples of the present study relative to the FAO/WHO, Australia, Canada, China, Germany, Tanzania, and USA standards (Table 5). The contents of Cr, were also found to be below the WHO/FAO, Canada, China, Germany, and Tanzania standards and above Australia's (50 mg kg^{-1}) (for some sites) and the USA (11 mg kg^{-1}) standards. Fe and Mn concentration ranges are within the acceptable range for all the soil samples according to the FAO/WHO standards. The range obtained for Cd is below the standard limit for all soils as per the Germany standard (5 mg kg^{-1}) and all the soil samples of the farmlands had above the limits according to the FAO/WHO, Austaralia, Canada, China, Tanzania, UK, and USA standards (Table 5). Cd is a non-essential metal for human health with a high biological toxicity. It is mainly accumulated in the surface soils and consequently enters the body through the food web. Hence, this could possibly attract the attention of the local environmental protection authorities, whose mandate is to take measures to control pollutions caused by the metals and organic substances. On the other side, the concentration range of Ca determined in this work, is substantially contributing towards effective growth of the plants since tolerable Ca level is obtained in all soil samples.

Table 4: Concentrations of the investigated metals (mg kg^{-1}) in the soil samples (mean±SD, n=3)

Metals	Sampling sites			
	Boji	Gedo	Hirna	Kubsa Kidame
Calcium (Ca)	15920 ± 220	18680 ± 290	17800 ± 250	9330 ± 190
Cadmium (Cd)	3.88 ± 0.05	4.12 ± 0.07	4.45 ± 0.04	4.16 ± 0.08
Chromium (Cr)	43.0 ± 2.2	46.9 ± 1.8	30.7 ± 0.9	99.5 ± 2.7
Copper (Cu)	12.6 ± 1.1	33.5 ± 3.0	42.3 ± 2.9	32.6 ± 1.6
Iron (Fe)	654 ± 6.6	875 ± 9.4	831 ± 5.0	765 ± 5.1
Manganese (Mn)	255 ± 6.1	146 ± 3.1	133 ± 4.0	145 ± 7.2
Lead (Pb)	30.2 ± 1.6	28.6 ± 1.2	14.9 ± 0.9	23.9 ± 1.7
Zinc (Zn)	252 ± 7.2	217 ± 8.7	235 ± 4.5	289 ± 6.4

Table 5: Regulatory standards of selected heavy metals in agricultural soils
(Source: Chiroma et al. (2014) for FAO/WHO standard and He et al. (2015) for the others)

Organization/ Country	Metals and their regulatory standards (mg kg^{-1})						
	Cd	Cr	Cu	Fe	Mn	Pb	Zn
FAO/WHO	3	100	100	50000	2000	100	300
Australia	3	50	100	-	-	300	200
Canada	3	250	150	-	-	200	500
China	0.3–0.6	150–300	50–200	-	-	80	200–300
Germany	5	500	200	-	-	1000	600
Tanzania	1	100	200	-	-	200	150
UK	1.8	-	-	-	-	-	-
USA	0.48	11	270	-	-	200	1100

3.5. Correlation among the soil parameters

For the soils of the four farmlands, pairwise comparison was made to statistically analyze the effect of change in sample origin on the studied parameters. The Pearson correlation analysis results of soil samples of the four farmlands is shown in Table 6. Based on the output of single factor ANOVA**,** significant difference (p=0.05) was observed in %OM with Cu, Pb and Fe. Similarly, the differences were significant in EC with Cd and Mn (except for the soils from Gedo/Kubsa Kidame sites), pH (except for the soil samples of Boji/Kubsa Kidame), Zn (except for the soil samples of Boji/Hirna), and Cr (except for the soil samples of Boji/Gedo). However, insignificant difference (p=0.05) was noted with Ca when a pairwise comparison was made (except for the soil samples of Boji/Gedo, Boji/Hirna and Boji/Kubsa Kidame). These significant and insignificant variations might be due to the geological and geographical locations, and anthropogenic influences among the sampling areas.

The association among physicochemical and metal concentrations for the assayed soils indicate that Cu-(Cd, Fe, and pH), Cd-(Fe and pH), Pb-Mn, Zn-(Cr, %OM, and pH), Mn-EC and Cr-(%OM and pH) had moderate to strong and positive correlation (r > 0.5), indicating that the availability of one metal depends on the availability and quantity of the other. But, moderate to strong but negative association (between -0.5 and -1.0) was observed for: Cu-(Pb, Mn, and EC), Cd-(Pb and Mn), Pb-pH, Ca-(Zn, Cr, %OM, and pH), Zn-Fe, Mn-(Fe and pH), Fe-(%OM and EC) and Cr-EC, indicating that the availability of one hinders the solubility of the other. Other parameters had weak negative or positive associations.

4. Conclusions

In the presented study, physicochemical properties and metal ion contents of the farmland soils collected from four different farmlands; namely, Boji, Gedo, Hirna and Kubsa Kidame areas of the Oromia Regional State, Ethiopia, have been investigated. The major purpose was to obtain preliminary information and thus to evaluate the suitability of the agricultural soils of the areas for crop production, as the outcomes of the current study supplement quantitative information to those reported in scientific literatures. Based on the findings of the work, the soil samples were observed to be dominated by clay, and thus the clayey textural class was assigned to the soil samples. The results obtained for the percent organic matter signifies their classification in medium range. All the soil samples were not salt affected as the ranges of their electrical conductivity were considerable low. The pH determined also revealed that the soils were slightly acidic to neutral.

Table 6: Pearson correlation matrix for the physicochemical properties and metallic elements in this study

	Cu	Cd	Pb	Ca	Zn	Mn	Fe	Cr	%MC	% OM	pH	EC
Cu	1											
Cd	0.944	1										
Pb	-0.790	-0.943	1									
Ca	0.201	0.271	-0.180	1								
Zn	-0.206	-0.175	-0.003	-0.953	1							
Mn	-0.969	-0.840	0.642	-0.043	0.115	1						
Fe	0.857	0.685	-0.404	0.411	-0.541	-0.881	1					
Cr	-0.002	-0.158	0.1663	-0.953	0.834	-0.194	-0.132	1				
%MC	0.453	0.581	-0.739	-0.514	0.676	-0.409	-0.054	0.448	1			
%OM	0.765	0.812	-0.845	-0.333	0.429	-0.738	0.349	0.386	0.917	1		
pH	0.778	0.795	-0.644	0.771	-0.736	-0.652	0.808	-0.618	-0.018	0.294	1	
EC	-0.558	-0.280	0.040	0.414	-0.192	0.746	-0.635	-0.669	-0.176	-0.434	-0.081	1

Furthermore, the soil samples were found to contain the analyzed metals in a rather good level needed for crop production, which is fairly in agreement with the standard limits set by various international authorities. However, the observed level of Cd is slightly above the maximum limits set for farmland soils and hence it requires due attentions of the concerned authorities, as this may possibly cause biological toxicities, when entered the body through food web. On the other hand, the presence of relatively high concentration of calcium could be considered useful since its high concentrations in the agricultural soils is tolerable besides its contribution towards the effective growth of the plants.

One of the major challenges encountered during the soil sampling was the limited accessibility to travel far away from the targeted sites, which was principally caused by the temporary unrest conditions. In the future, soil sampling covering wider areas, where agricultural activities are intensively underway, will be included in the plan so as to come up with more detailed results that can also be assisted by the possible variation related to seasonal meteorological changes. In addition, the occurrences of metallic and nonmetallic substances could also be considered to give the necessary and sufficient information to all concerned professional agents and the researchers.

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