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Physicochemical characterization and agricultural soil amendment potential of sewage sludge from Debre Markos University wastewater treatment plant

Mastewal Tilaye Ayalew¹, Esubalew Meku Godie^{2*}

¹Injibara University, Medicine and Health Science College, Department of Environmental Health

²Bahir Dar University, College of Science, Department of Industrial Chemistry

*Corresponding Author Email address: esubalewmeku@gmail.com

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Abstract

Managing sewage sludge is an important environmental challenge for rapidly expanding urban and institutional centers in Ethiopia. This study aimed to characterize the physicochemical properties as well as toxic metal concentrations in the sewage sludge generated from Debre Markos University wastewater treatment plant and to evaluate its suitability for agricultural soil amendment. The sludge samples were collected using composite sampling techniques and their pH, electrical conductivity (EC), and nutrient content were analyzed. The Kjeldahl method was employed to determine total nitrogen (TN) while UV-Vis spectrophotometry and Walkley-Black wet oxidation method were used to measure the available phosphorus and organic carbon, respectively. The concentrations of trace and heavy metals (Na, K, Ca, Mg, Cu, Zn, Pb, and Cd) were measured using Flame Atomic Absorption Spectrophotometry (FAAS) following wet acid digestion. The sludge exhibited a near-neutral pH (6.91) and a slightly saline EC (2.52 mS/cm). The levels of organic matter (63.09%) and total nitrogen (3.38%) were significantly exceeding several international benchmarks for organic fertilizers. Available phosphorus was found to be 1.614%, while the macro-elemental profile was dominated by magnesium (228.57 ± 1.64 mg/kg) and calcium (175.49 ± 1.69 mg/kg). Crucially, the concentrations of toxic heavy metals, specifically lead (6.67 mg/kg) and cadmium (3.70 mg/kg), remained well below the maximum permissible limits set by the USA, EPA and South African regulatory standards. The findings indicate that the DMU sewage sludge is a nutrient-rich organic material with low heavy metal toxicity. Its high organic carbon and nitrogen content suggest that it is an excellent candidate for enhancing soil fertility in the East Gojjam region. However, due to its slight salinity, monitored application recommended for salt-sensitive crops. This study supports the circular economy approach of converting institutional wastewater into valuable agricultural inputs.

1. Introduction

Sludge is a semi-solid residue produced during wastewater treatment processes, and usually known as sewage sludge, whereas sewage itself implies a suspension of water and solid wastes. Sewage sludge contains substantial amounts of essential plant nutrients including nitrogen and phosphorus, along with organic matter and trace elements [1]. Owing to this composition, sewage sludge can enhance the physical, chemical, and biological properties of soil and has increasingly been used as either supplement or alternative organic fertilizer for soil amendment [2]. Excessive and continuous application of agrochemicals in agriculture can adversely affect soil flora, fauna, and enzymatic activities that are crucial for maintaining soil fertility and ecosystem balance. To mitigate these negative impacts and enhance soil quality, the incorporation of carbon-based amendments has been widely recommended due to their multiple agronomic and environmental benefits [3, 4]. Globally, sewage sludge production has risen significantly due to the expansion of organized institutions such as universities, hospitals, hotels, and industries. This growing volume of sludge necessitates safe and sustainable management strategies, particularly when considering its reuse for amendment of soil. Evaluating the physical and chemical properties of sewage sludge is

therefore crucial to guarantee the safety of the environment and to promote the “wealth from waste” concept [5]. The composition and quality of sewage sludge are highly variable and depend on the nature of the waste effluent as well as the treatment technologies employed at the wastewater treatment plant [6].

Debre Markos University generates wastewater from dormitories, offices, cafeterias, and laboratories, which is treated in a centralized treatment plant to reduce environmental and public health risks [7, 8]. Established in 2018, the plant uses an Imhoff tank for sedimentation and anaerobic digestion, an aeration tank for biological treatment, and a Dortmund tank for sludge separation. In many developed countries, treated sewage sludge is reused in agriculture because of established technologies and regulations. However, its use remains limited in developing countries, including Ethiopia, due to inadequate characterization and weak regulatory control [2, 9]. Previous studies have shown that sewage sludge can provide valuable nutrients and organic matter for agricultural soils [6, 10, 11]. Currently, sludge from the university treatment plant is mainly disposed of in nearby sandy areas and occasionally applied to pine trees within the facility. However, poorly treated sludge may contain pathogens, heavy metals, unpleasant odors, and other harmful contaminants. Despite

growing interest in its agricultural reuse, no detailed study has reported on the physicochemical properties and the content of heavy metals in the sludge produced at the university. This lack of information limits its safe and sustainable utilization. Therefore, this study aims to evaluate the physicochemical characteristics of the sludge and assess its appropriateness for agricultural soil amendment.

2. Material and methods

2.1. Study site description

The research was carried out at Debre Markos University (DMU), a second-generation public university in Ethiopia, situated about 300 km northwest of Addis Ababa. The university lies at approximately $10^{\circ}20'N$ latitude and $37^{\circ}43'E$ longitude and has an average elevation of 2,446 m above sea level. The wastewater treatment plant investigated in this study is located within the university premises, to the south of the main entrance gate, as shown in Figures 1, 2, and 3.



Figure 1: Debre Markos University waste treatment plant



Figure 2: The Sewage sludge



Figure 3: The drying beds of the sludge

2.2. Apparatus and chemicals

The physicochemical characteristics and elemental constituents of the sludge were analysed using standard analytical instruments. Concentrations of macro- and trace elements (Na, K, Ca, Mg, Cu, Zn, Pb, and Cd) were determined using Flame Atomic Absorption Spectrophotometer (Buck Scientific VGP 210). The electrical conductivity of the sample was measured by conductivity meter (SX723) and the pH of the sample was determined using pH meter (HANNA HI2223). Available phosphorus was analysed using a Jenway 6305 UV–Vis spectrophotometer while total nitrogen was estimated using the Kjeldahl method in 500 mL Schott Duran digestion and distillation flasks. Analytical-grade chemicals and reagents were used throughout the experiment. Sludge digestion was carried out using HNO_3 (65%), HCl (37%), H_2SO_4 (98%), and H_2O_2 (30%), while $\text{K}_2\text{Cr}_2\text{O}_7$ was used for chromate preparation. Calibration curves for FAAS analysis were prepared from 1000 mg/L stock standard solutions of the respective metals. All solutions and dilutions were prepared using standard volumetric flasks to ensure analytical accuracy.

2.3. Sample collection and preparation

The sewage sludge was collected from Debre Markos University wastewater treatment plant using plastic bag and dried in air at ambient temperature. The dried sample was pulverized with a mortar and pestle followed by screening through a 2 mm sieve to remove roots, stones, plastic fragments, grass, and other contaminants from the sample. After drying, sieving and homogenization, the sludge sample was stored in polyethylene bag for further use and analysis of PH EC, %TOM, major nutrients and toxic metals. A minimum of three replicate measurements was performed for each physicochemical parameter.

2.4. Analysis of sludge sample

2.4.1. Determination of pH and EC

The pH of the sludge was determined using a properly calibrated pH meter at a temperature of 20 °C by HANNA pH instrument (HI 2223 calibration, Germany). Briefly, a 10 g of air-dried ground sludge sample (< 2 mm) was mixed with 50 ml of distilled water in a 1:2.5 w/v and stirred mechanically for 30 minutes. One buffer tablet was dissolved in 100 mL of distilled water to prepare standard buffer solutions at pH 4, 7, and 9. The same solution preparation procedure was followed to measure electrical conductivity by a calibrated Conductometer (SX723)[12].

2.4.2. Determination of total nitrogen (%TN)

The content of total nitrogen in the sludge was determined by the Kjeldahl method following Werako and Tadele [13], which measures ammonium and organic nitrogen. Briefly, a 0.5 g portion of the sample was digested in concentrated H_2SO_4 and mixed catalysts at 350°C for 3 h until the solution turned light green. After cooling and dilution with distilled water, the digest was distilled using NaOH (40%), and the ammonia released was absorbed in 2% boric acid with methyl red – bromocresol green indicator mixture. Then, a 0.1 N H_2SO_4 was used to titrate the distillate to the endpoint indicated by a color change from green to pink. A blank determination was conducted simultaneously, and the formula below was used to calculate TN:

$$\% \text{TN} = \frac{(S - L) \times N \times 14 \times 100}{E \times 1000} \quad (1)$$

Where, S is the volume of 0.1N of H_2SO_4 for sample titration, L is the volume of 0.1N of H_2SO_4 for blank titration, N is normality of the acid, E is mass of sample and $\% N$ is total nitrogen and 1000 is constant that used to change mass of nitrogen in to gram milliequivalent per mass .

2.4.3. Determination of Available phosphorous

Available phosphorus in the sample was measured using the sodium bicarbonate

extraction technique followed by UV–Vis spectrophotometry. Specifically, the powdered sludge sample (5 g) was extracted using 100 mL 0.5 M NaHCO_3 by shaking for 30 min, followed by filtration through Whatman No. 42 filter paper. Phosphorus standards were prepared from a 100 ppm KH_2PO_4 stock solution, and a mixed reagent containing H_2SO_4 , ammonium molybdate, ascorbic acid, and potassium antimony tartrate was used for color development. The filtered extract was diluted, and 3 mL of the diluted sludge or standard was mixed in 3 mL of the reagent and allowed to stand for 1 h. Then, UV–Vis spectrophotometer was used to measure the absorbance at 882 nm followed by calculating the available phosphorus using the following formula [14]:

$$P \text{ (ppm)} = \frac{c \times v \times D \times V_2 \times 2.29}{wt \times V_1} \quad (2)$$

Where, C is concentration (mg/L) of P in the sample, V , total volume of the sludge extract (90 ml), V_1 , volume of sludge extract used for measurement (10 ml), V_2 , Volume of flask used for measurement (100ml) and wt , is sample weight in gram, 2.29 is constant to express P as P_2O_5 .

2.4.4. Elemental and heavy metal analysis
Macro- and trace-element concentrations (Na, K, Ca, Mg, Cu, Zn, Pb, and Cd) were determined using Flame Atomic Absorption Spectrophotometer (Buck Scientific VGP 210).

Prior to analysis, dried sludge samples were subjected to wet acid digestion with a mixture of HNO₃ (65%), HCl (37%), H₂SO₄ (98%), and H₂O₂ (30%) to ensure complete matrix decomposition. Operation of the FAAS involved the use of hollow cathode lamps tailored to each element and an air–acetylene flame system. Calibration was carried out using working standards prepared from 1000 mg/L stock solutions, with potassium dichromate (K₂Cr₂O₇) used for relevant chromate preparations. All analyses were conducted in triplicate to ensure precision and reliability [11, 12, 15]. Then, the metal concentrations were calculated using the following formula:

$$\text{Metal Conc. } \left(\frac{\text{mg}}{\text{kg}}\right) = \frac{C_o \times V \times D}{W \times 10} \quad (3)$$

Where C_o is the concentration of metal from the calibration curve, V is the prepared total volume of sample, W is the sample weight in gram, 10 constant used to change mg to g and D is dilution factor.

2.4.5. Total organic carbon (TOC) and organic matter (OM) analysis

The assessment of sludge organic content was carried out through analysis of TOC and OM. TOC measurement was carried out via the Walkley–Black method, involving oxidation of organic carbon in dried sludge with potassium dichromate (1 N) and concentrated sulfuric acid.

The remaining dichromate was determined by back titration with 0.5 N ferrous ammonium sulfate, employing the indicator diphenylamine. The content of organic matter was then calculated by multiplying the percentage of TOC by the Van Bemmelen factor (1.724), assuming that organic matter contains approximately 58% carbon [13, 16, 17].

2.5. Statistical data analysis

Quantitative data from the physicochemical and elemental analyses were processed using SPSS (Version 16.0) and Microsoft Excel 2016. Mean values and standard deviations (SD) were calculated from triplicate measurements to ensure data reliability and reproducibility. One-way Analysis of Variance (ANOVA) was employed at 95% confidence level ($p < 0.05$) to evaluate significant variances in nutrient and heavy metal concentrations among sampling points or sludge types.

2.6. Data quality management and assurance

Strict quality control (QC) procedures were implemented to confirm the accuracy and reliability of the analytical data. Precision of the FAAS and UV–Vis measurements was verified using reagent blanks, duplicate samples, and spiked recovery tests, with recovery rates maintained within the acceptable range of 80–120%. Calibration curves with correlation

coefficients (R^2) of at least 0.995 were established for all analytes. Raw data, including instrument records and titration results, were documented in digital spreadsheets with backup copies to prevent data loss. The results were evaluated against Ethiopian Environmental Protection Authority (EPA) standards and USA guidelines to evaluate the appropriateness of the sludge for soil amendment.

3. Results and discussion

3.1. The Physical characteristics of the sewage sludge: pH and EC

Electrical conductivity (EC) and pH are critical parameters for determining the suitability of organic materials for use as fertilizers [18]. As shown in Table 1 and Figure 4, the sludge exhibited a pH of 6.91, indicating a moderately acidic to near-neutral character. This value falls within the optimal range of 6.0–8.5 typically recommended for soil amendments in various studies [19, 20, 21]. Furthermore, the recorded pH complies with Environmental Quality Authority (EQA) standards. Compared to previous literature, the studied sludge was less acidic than those reported by Tanor et al [6] and Meghari and Omar [11], who found pH values of 6.05 and 6.55, respectively. From an agricultural perspective, this pH level is considered high-

quality as it promotes nutrient availability and microbial activity.

The electrical conductivity of the sludge was measured as 2.52 mS/cm, characterizing the material as slightly saline. This value is lower than the 3–4 mS/cm threshold recommended by Alayu and Leta suggesting a significant accumulation of soluble salts [22]. The salinity likely originates from the intensive use of detergents and food wastes in the university's student cafeteria. Although the EC in this study is comparable to the 2.49 mS/cm reported by El-Nahhal et al.[12] and notably lower than the 5.48 mS/cm found by Praveen and Baby[23], it still poses limitations. Specifically, the salt content implies that the sludge may not be suitable for all agricultural crops, particularly salt-sensitive varieties, necessitating cautious in application for soil management.

3.2. The chemical characteristics of the sewage sludge: TOC, OM, TN and AP

As presented in Table 1 and figure 4, the TOC and OM of the sewage sludge were 36.60% and 63.09%, respectively. These values demonstrate a nutrient-rich profile as organic matter is vital for soil structure stability and fertility enhancement. The OM content of this research work is notably large compared to other published reports such as sludge in Lesotho (35–

55.4%) [6], Benghazi (16.46–56.36%) [24], and industrial parks in Isfahan (58.85%) [25]. Furthermore, the OM concentration exceeded the >40% threshold recommended by EQA guidelines for agricultural applications [11]. This high organic load suggests that the sludge from Debre Markos University (DMU) has significant potential to improve soil structure and microbial activity.

The TN content of the sludge was obtained as 3.38%, which falls within the ideal range of 2–4% for plant availability [26]. This elevated nitrogen level is likely attributed to the high concentration of urine and protein-rich food waste generated by the DMU community. As a

fundamental component of chlorophyll and a driver of photosynthesis, nitrogen is essential for plant growth [27]. The TN value in this research work is considerably larger than previously reported results for Gaza sewage sludge (0.544%) [11] but slightly lower than the 3.98% observed by Pöykiö et al. [28]. Similarly, available phosphorus (P) was recorded at 1.614%, meeting the EQA recommended range of 1.5–2% [29]. This P concentration is considerably higher than results from Gaza (0.0213%) [11] and aligns with the ranges reported for the North Gaza Emergency Sewage Treatment Plant (0.5–2.5%) [30].

Table 1: The physicochemical properties of the sewage sludge sample

properties	Mean $\pm$ standard deviation
PH	6.91 $\pm$ 0.21
EC (mS cm ⁻¹)	2.52 $\pm$ 0.12
% TOC	36.60 $\pm$ 1.34
% TOM	63.09 $\pm$ 2.31
% TKN	3.38 $\pm$ 0.25
% P ₂ O ₅	1.614 $\pm$ 1.16

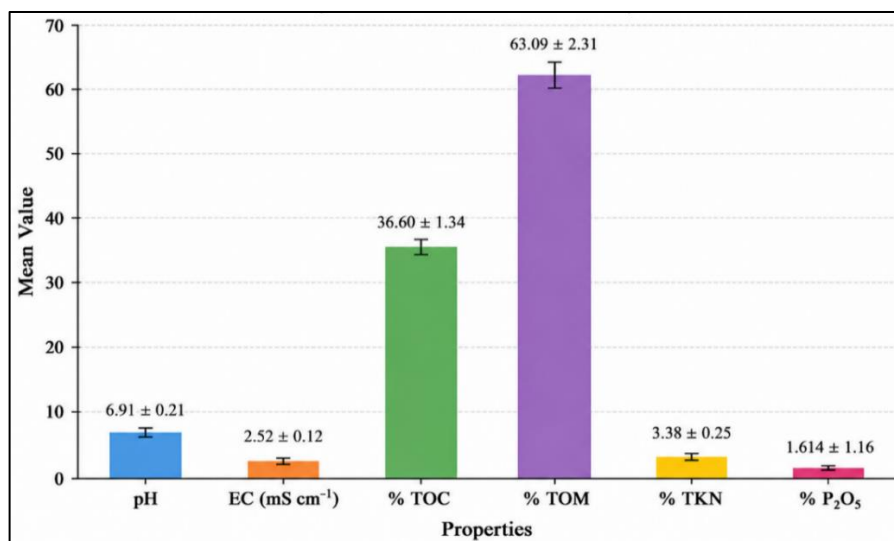


Figure 4: Physicochemical properties of the sewage sludge sample

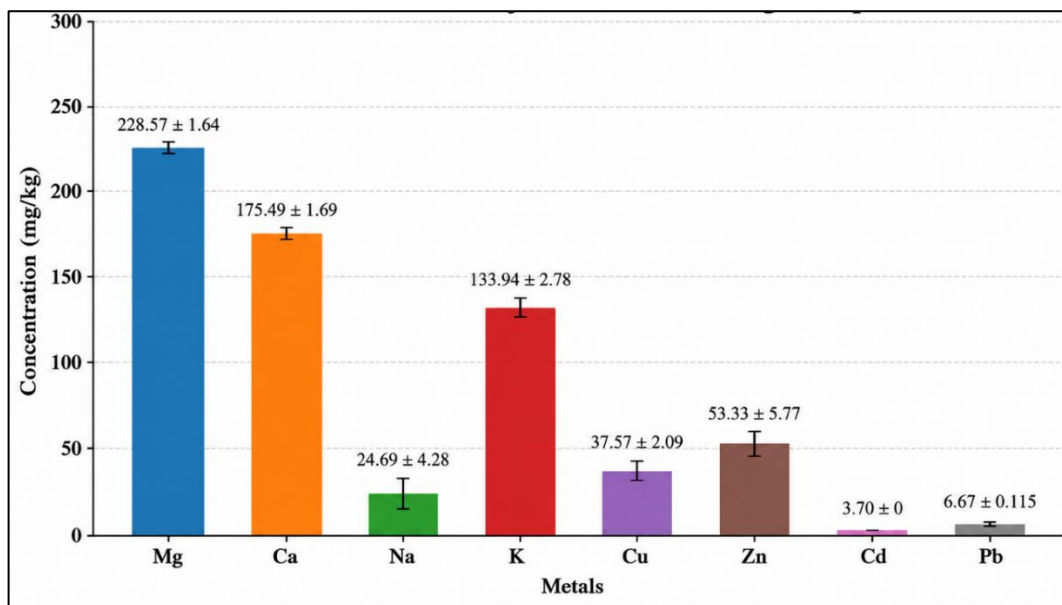
3.3. The elemental composition and heavy metal concentration

As shown in Table 2 as well as Figure 5, the sewage sludge generated from DMU treatment plant exhibited a primary macronutrient profile dominated by magnesium (228.57 ± 1.64 mg/kg), followed by calcium (175.49 ± 1.69 mg/kg) and potassium (133.94 ± 2.78 mg/kg). While the Mg content is significantly higher than that found in brewery sludge (1.19 mg/kg) [22], it remains lower than levels reported in Gaza (1623 mg/kg) [11] and Poland (5000 mg/kg) [31]. Similarly, Ca and K levels were notably lower than those reported in literature where Ca concentrations have reached up to 74,400 mg/kg [32]. The relatively lower K concentration compared to Mg and Ca may be attributed to the specific degradation pathways of cosmetics and

detergents during sludge formation. Nevertheless, K levels remain within the beneficial range for agricultural utilization as recommended levels of these essential macronutrients that support plant physiological processes [22]. The sodium (Na) concentration in the sludge was recorded at 24.69 ± 4.28 mg/kg (Table 2 and figure 5). This value is substantially lower than those reported for sludge from Gaza (1000 mg/kg) [11] and RWWTP (3200 mg/kg) [6]. The presence of Na is likely derived from kitchen salts, soaps, and laboratory reagents present in the DMU sewage system. Although sodium is not classified as an essential plant nutrient, its soluble compounds can enhance the growth of specific crops by partially substituting for potassium in various osmotic and metabolic functions [33].

Table 2: The concentrations of major elements (mean $\pm$ SD, $n=3$) in the sludge sample

Metals	Concentration		Equation for calibration curves and correlation coefficient	
	Mean $\pm$ SD (mg/kg)	%RSD	Equation for calibration curves	Correlation coefficient (R^2)
Mg	228.57 $\pm$ 1.64	0.721	$y = 0.007x + 0.458$	1
Ca	175.49 $\pm$ 1.69	0.9676	$y = 0.068x + 0.307$	0.998
Na	24.69 $\pm$ 4.28	9.676	$y = 0.027x + 0.377$	0.997
K	133.94 $\pm$ 2.78	0.0017	$y = 0.011x + 0.084$	0.999
Cu	37.57 $\pm$ 2.09	0.0002	$y = 0.011x + 1.972$	0.998
Zn	53.33 $\pm$ 5.77	10.825	$y = 0.004x + 0.023$	0.995
Cd	3.70 $\pm$ 0	0	$y = 0.005x$	0.998
Pb	6.67 $\pm$ 0.115	1.732	$y = 0.0027x$	0.997

**Figure 5:** Concentrations of Major elements in the sludge sample

Heavy metals such as cadmium (Cd) and lead (Pb) are harmful to people as well as livestock, and their accumulation can adversely affect soil microbial populations and biological properties. In this study, the concentrations of Cd (3.70 $\pm$ 0.00 mg/kg) and Pb (6.67 $\pm$ 0.115 mg/kg) were notably low (Table 3 and Figure 6). The values

observed for both Cd and Pb are below the stringent regulatory thresholds defined by South African Standards (40–85 mg/kg for Cd; 300–840 mg/kg for Pb), USA and EPA regulations (39 mg/kg for Cd; 300 mg/kg for Pb) [1]. Additionally, Copper (Cu) and Zinc (Zn) were recorded at 37.57 $\pm$ 2.09 mg/kg and 53.33 $\pm$

5.77mg/kg, respectively. While the Cu content exceeded the levels found in Swaziland sludge (32 mg/kg) [2], the Zn concentration remained well within the safe ceiling limits for agricultural use (2800–7500 mg/kg). The observed results collectively demonstrate that the sludge generated from DMU poses a low risk regarding heavy metal toxicity and is safe for soil amendment.

To mitigate potential risks to soil health, plant development, and the food chain, the management of sewage sludge is strictly regulated internationally. In 1986, the European Union established the European Council

Directive 86/278/EEC, which set rigorous thresholds on the permissible concentrations of toxic metals such as copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) in sludge destined for agricultural use [34]. These restrictions are designed to prevent the long-standing accumulation of toxic metals in the environment and protect animal and human health. Currently, a dedicated national framework does not govern the reuse of sewage sludge in Ethiopia. Consequently, the assessment of sludge quality in this study relies on international standards and guidelines from other jurisdictions to ensure environmental safety and agricultural efficacy.

Table 3: Concentration of toxic metals and their recommended limits in the sewage sludge proposed for agricultural use [1]

Heavy Metals	Value of metals in sewage sludge of this study (mg / kg)	Limit value according to different countries regulation (mg / kg)	
		USA Regulation	South A. Guideline
Cd	3.70	39	40 -85
Cu	37.57	1500	1500 – 4300
Pb	6.67	300	300 – 840
Zn	53.33	2800	2800 – 7500

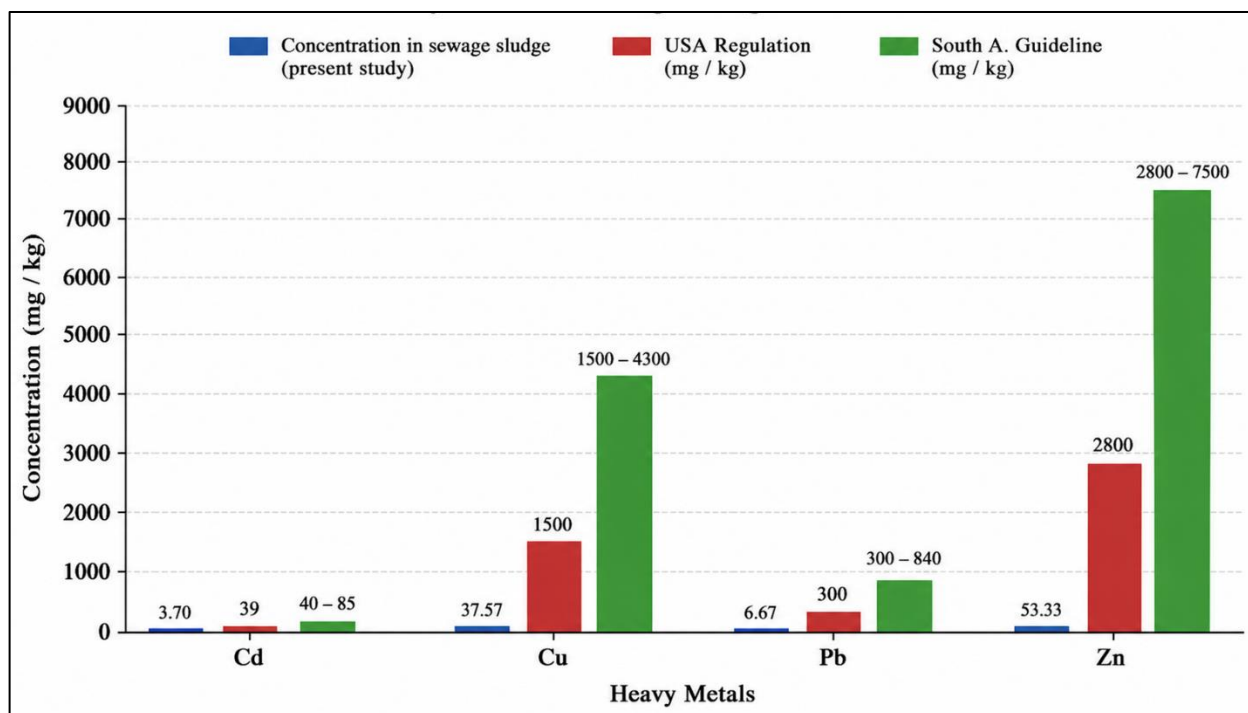


Figure 6: Concentration of toxic metals in DMU sewage sludge and their recommended limits

3.4. Evaluation of results using statistical methods

The data obtained from the physicochemical and elemental analyses were subjected to rigorous statistical evaluation to ensure the reliability of the findings. Descriptive statistics, presented as Mean $\pm$ Standard Deviation (SD) for triplicate measurements indicate high analytical precision across all parameters. The One-way Analysis of Variance (ANOVA) demonstrated substantial differences ($p < 0.05$) in the distribution of macronutrients compared to trace heavy metals, confirming that the sludge is predominantly organic and nutrient-based rather than mineral-heavy. All statistical operations were executed

using SPSS version 16.0, and the high R^2 values (> 0.995) obtained from the FAAS calibration curves further validate the accuracy of the reported elemental concentrations.

The analytical precision was evaluated using the Relative Standard Deviation (RSD%). The results demonstrated high reproducibility with RSD values for most macro and trace elements (Mg, Ca, K, and Pb) falling below 3%. (Table 4) The slightly higher RSD for Sodium (17.33%) and Zinc (10.82%) reflects the inherent heterogeneity of the sludge matrix though all values remained within acceptable analytical limits.

Table 4: Precision analysis (RSD%) of the elements analyzed

Metal	Mean (mg/kg)	SD	RSD (%)	Precision Interpretation
Mg	228.57	1.64	0.72	Excellent
Ca	175.49	1.69	0.96	Excellent
Na	24.69	4.28	17.33	Moderate
K	133.94	2.78	2.08	Excellent
Cu	37.57	2.09	5.56	Good
Zn	53.33	5.77	10.82	Acceptable
Cd	3.70	0.00	0.00	Perfect Consistency
Pb	6.67	0.12	1.72	Excellent

3.5. Method Validation

In the present study, known concentrations of each metal from standard solutions were added to the digested solution of a 0.5 g sample to evaluate the validity of the digestion procedure and the precision and accuracy of FAAS. The spiked and unspiked sludge samples were subjected to the same digestion method used for the first sample and analyzed under similar conditions. For the recovery analysis, equal amount of the standard and sample solutions (2 ml each) were mixed for each metal such as Na, K, Ca, Mg, Cu, Zn, Cd and Pb. The recovery test for each metal was then performed in triplicate. Standard metal solutions were used to fortify the sample to the specified metal given in the solution. The percentage recoveries and percentage of relative standard

deviations were calculated to evaluate the accuracy and precision of the analytical method as presented in Table 5 below.

The values of mean % Recovery of the metals analyzed in the sludge samples were ranged between 83 - 123%, which lies in the acceptable range for accurate and precise results (80-120%) confirming that the performance of the experimental method used for each metal was under control. The recovery of Na was 123% (Table 5), indicating a slight positive bias in the analytical determination. Although the value exceeds the commonly accepted range of 80–120%, it remains close to the upper limit and may be attributed to matrix-induced enhancement or minor analytical interferences.

$$\text{Recovery}(\%) = \frac{\text{Conc. in spiked sample} - \text{Conc. in unspiked sample}}{\text{Added conc}} \times 100 \quad (4)$$

Table 5: Results of the recovery analysis for the sludge sample

Elements	Concentration before spiking (mg /kg)	Concentration after spiking (mg/kg)	Amount added (mg/kg)	% Recovery
Mg	228.49± 1.64	232.109± 1.65	4	90.475
Ca	175.49± 1.69	179.33 ± 0.169	4	96
Na	24.69± 4.28	29.63±0.427	4	123.46
K	133.94± 2.78	138.18 ± 0.104	4	106.060
Cu	37.575± 2.09	41.21 ± 0.419	4	90.909
Zn	53.333± 5.77	56.667 ± 0.577	4	83.333
Cd	3.70 ± 0	8 ± 4.61	4	107.407
Pb	6.666± 0.115	10.666 ± 1.154	4	100

3.6. Method Detection Limit and Method Quantification Limit

The minimum detectable concentration of an analyte is the level that can be identified with 99% confidence above zero, whereas the limit of quantification refers to the lowest concentration that can be reliably measured with acceptable precision and accuracy. Each blank was analyzed

for each metal in the sample (Na, Ca, Mg, k, Cd, Zn, Pb, and Cu) by FAAS in three replicates. Method detection limits (MDLs) were calculated using three times the standard deviation of blank reagent replicates, while method quantification limits (MQLs) were determined using a factor of ten for each element according to the following formula:

$$\text{MDL} = \frac{3 \times \text{standard deviation}}{\text{Slope}} \times 100 \quad (5)$$

$$\text{MQL} = \frac{10 \times \text{standard deviation}}{\text{Slope}} \times 100 \quad (6)$$

Table 6: Instrument detection, method detection and method quantification limits

Elements	IDL in mg / kg	MDL of sludge sample (mg/kg)	MQL of sludge sample (mg/kg)
Mg	0.005	1.07823	3.5941
Ca	0.01	0.20811	0.6937
Na	0.005	0.1112	0.3705
K	0.01	0.15186	0.5062
Cu	0.005	0.27285	0.9095
Zn	0.005	0.01731	0.0577
Cd	0.01	0.34641	1.1547
Pb	0.04	0.01731	0.0577

4. Conclusion

The physicochemical properties of the sewage sludge generated from the wastewater treatment plant in DMU confirms its high potential for agricultural recovery. The sludge is characterized by a near-neutral pH (6.91) and moderate electrical conductivity (2.52 mS/cm), making it suitable for soil application without immediate risks of acidification or extreme salinity. Most notably, the high Total Organic Matter (63.09%) and Total Nitrogen (3.38%) concentrations exceed several international benchmarks, indicating that the sludge can significantly improve soil aggregate stability and nutrient availability. While phosphorus levels (1.614%) and essential macro-elements (Mg, Ca, and K) are lower than those found in some municipal systems, they remain within beneficial ranges for crop growth. Crucially, the concentrations of heavy metals (Cd, Pb, Cu, and Zn) were obtained

below the stringent safety limits set by the USA, EPA and South African guidelines, classifying the sludge as a low-risk, nutrient-dense organic soil amendment.

According to the results obtained from this research work, the following actions are recommended to optimize the use of DMU sewage sludge:

- **Agricultural Integration:** The sludge should be promoted as a cost-effective organic fertilizer for local farming communities in East Gojjam, particularly for nitrogen-demanding crops.
- **Application Rates:** Although heavy metal levels are low, application rates should be calculated based on the phosphorus and nitrogen requirements of specific crops to prevent nutrient leaching into local water bodies.

- **Salinity Monitoring:** Due to the slightly saline nature of the sludge (likely from detergents), its use should be monitored when applied to salt-sensitive crops or in poorly drained soils.
- **Pre-treatment Standards:** To further enhance safety, the university should implement a stabilized composting period before distribution to ensure the complete elimination of any potential pathogens not covered in this chemical analysis.
- **Long-term Research:** Future studies should focus on field trials to evaluate the actual uptake of these nutrients by Ethiopian staple crops (such as Teff or Maize) and the long-term impact on soil microbial health.

5. Acknowledgments

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6. References

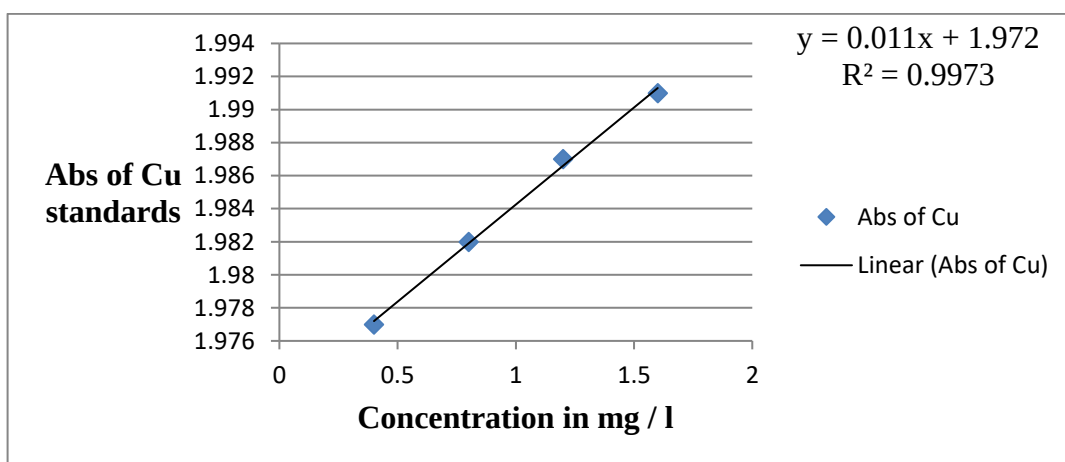
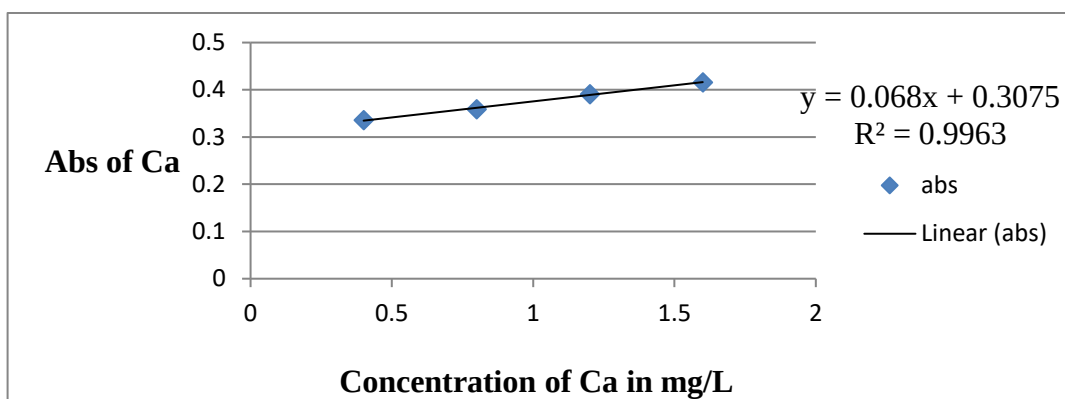
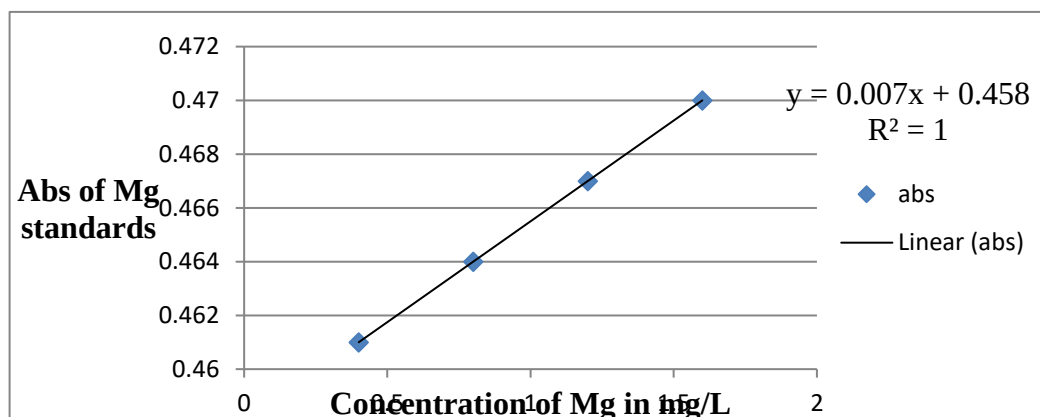
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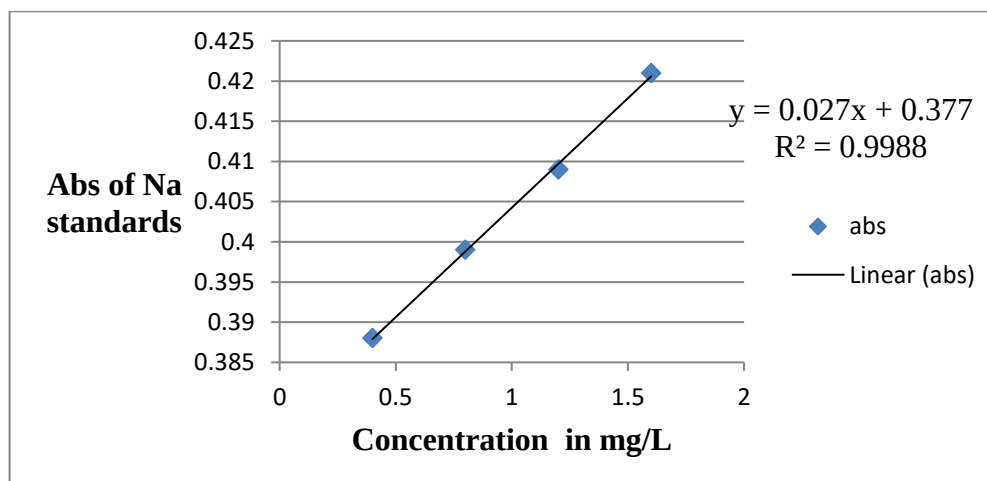
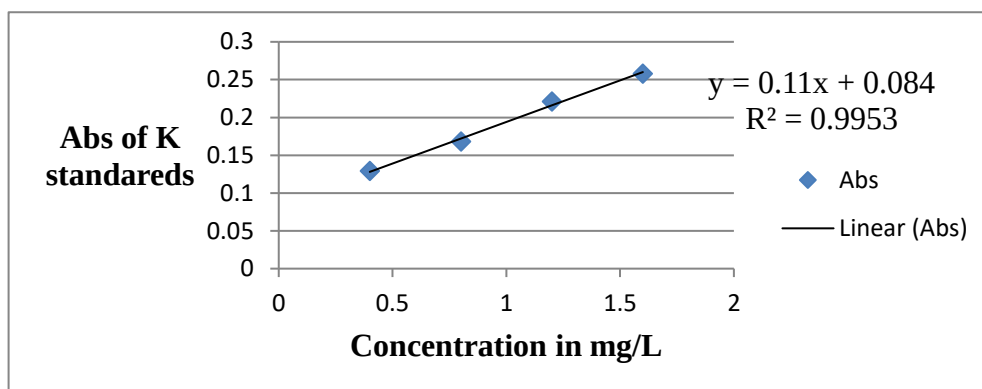
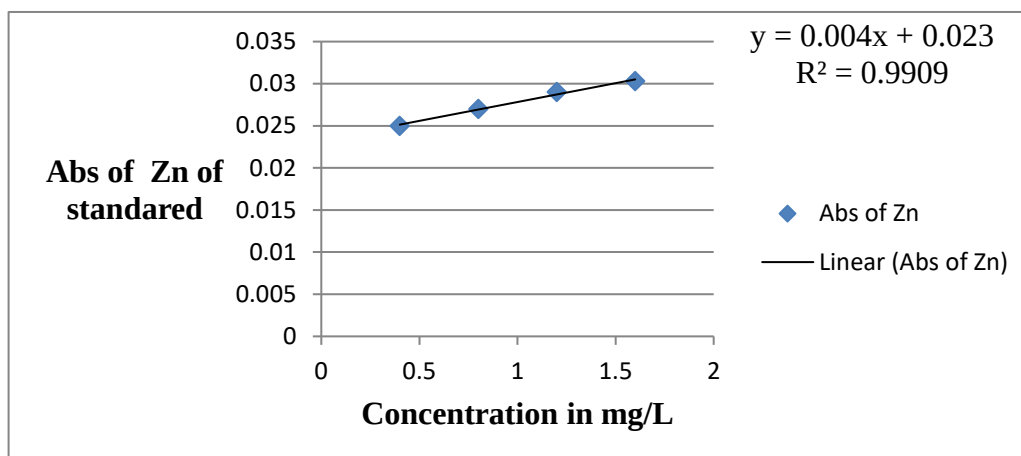
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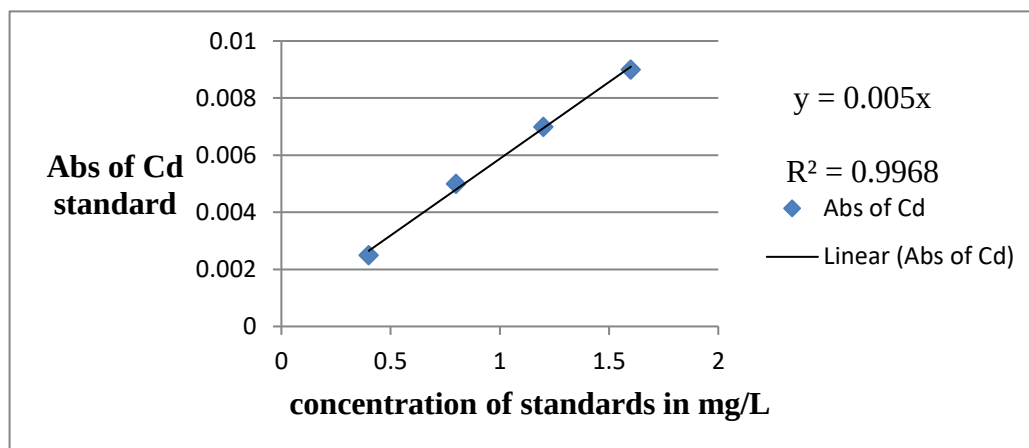
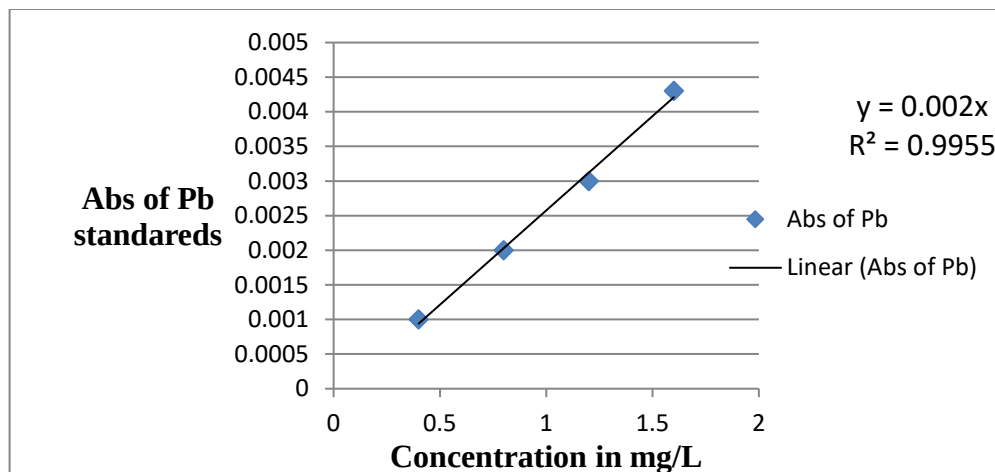
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Appendix

The standard calibration curve for metals in sludge sample







Calibration curve for phosphorus analysis from sludge

