Original Research Article||

Physico-chemical Characterization of Domestic Sludge of Hawassa Industry Park and Evaluation of its Potential Use as Fertilizer

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Abstract

Using domestic sewage sludge on cultivated soils may increase agricultural yield in developing countries; nevertheless, the environmental damages must be properly examined and addressed before application. This research was undertaken to determine the physical and chemical characteristics of domestic sludge from Hawassa Industrial Park in Ethiopia and assess its potential applicability as organic fertilizer for crop production and hence to reduce environmental problems related to their disposal. For this purpose, five domestic sewage sludge samples were collected over five consecutive days in a week and the samples were then analyzed at the College of Agriculture soil laboratory of Hawassa University for physical and chemical properties. Descriptive statistics were conducted to describe the physico-chemical properties of the domestic sewage sludge. The results revealed that organic carbon, total nitrogen, and available phosphorus contents were higher in all domestic sludge samples than conventional organic fertilizers. The bulk density of the sludge samples was low and the water holding capacities were high. These results indicated that the domestic sludge could improve the soil's physical and chemical properties. The analyses also revealed that the sludge is slightly alkaline (pH>7.4) and with low electrical conductivity (EC, 2.06 mS/cm). The analyses of concentrations of heavy metals (Zn, Cu, Cd, Pb, Ni, and Cr) showed that concentrations in the domestic sewage sludge are below the Ethiopian standard and FAO limits. In general, the majority of the physical and chemical properties revealed that the sewage sludge is potentially suitable for use as a fertilizer. However, further research should be conducted on the effect of the sewage sludge on crop growth. Also, the biological characteristics of sludge and the content of polychlorinated byphenyls (PCB) should be studied for a solid recommendation.

Key words: brewery dried grain, egg mass, egg production, egg quality, egg weight, feed conversion ratio

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INTRODUCTION

Domestic sludge, commonly referred to as sewage sludge, is a processed organic residue produced by residential wastewater treatment facilities. The byproduct produced after sewage treatment is denoted as bio-solid or sewage sludge (Jatav et al., 2021). Currently, industrial waste materials are rising in volume and might potentially be a source of organic materials for soils (Moreno-Barriga et al., 2017). Sewage sludge has been used in developed nations for horticulture and agriculture to increase soil fertility since it contains different quantities of plant nutrients and organic matter (Jamil et al., 2006; Rodríguez-morgado et al., 2015).

Domestic sludge could be potentially used as fertilizer to enrich agricultural soils and might replace/supplement synthetic fertilizers since it could contain high levels of nitrogen and phosphorus (Iticescu et al., 2018; Suanon et al., 2016) and trace elements that are beneficial for plant growth (Aggelides and Londra, 2000; Mtshali et al., 2014). For example, 200 kg of organic matter, 6 kg of nitrogen, 8 kg of phosphorus, and 10 kg of various soluble salts are typically found in one ton of dry sludge (Iticescu et al., 2018). Adding sewage sludge to the soil can improve its physical, chemical, and biological qualities, fostering a more sustainable soil ecosystem and promoting plant growth (Jatav et al., 2018).

Currently, some of the industrial parks, in Ethiopia particularly the Zero Liquid Discharge (ZLD) Hawassa Industry Park (HIP) have deployed innovative wastewater treatment technologies consisting of screening, equalization, and an up-low anaerobic sludge blanket process to minimize negative effects on the environment. The domestic sludge, which comes from the disposal of the pit latrine of the HIP is passed through the sewage treatment plant (STP), and its accumulation has created environmental concern. Ethiopia is a low-income country that invests a huge amount of foreign currency in the purchase of synthetic fertilizer every year. Organic fertilization options should be explored as a replacement or supplement to mineral fertilizer use.

The use of sewage sludge as fertilizer reduces the cost of commercial fertilizers and could be a viable option (Pengcheng et al., 2008; Roca-Pérez et al., 2009). At present, the global production of sewage sludge is estimated at 45 Mg of dry matter per year (Zhang et al., 2017), and this figure is expected to double in the coming years (Wang et al., 2017), which calls for immediate interventions since the growing sludge production could lead to environmental problems. Sewage sludge often has high organic carbon, nitrogen, phosphorus, porosity, and water holding capacity, implying its potential for use as fertilizer (Delibacak et al., 2009; Poykio et al., 2019; Suanon et al., 2016).

Sludge properties could modify the soil's physical chemical, and biological properties, which could enhance its capacity to support plant growth. As a result, changes in soil quality induced by sewage sludge usage could have a positive impact on agricultural productivity (Baloch et al., 2023).

When compared to soil supplemented with inorganic fertilizers, the amount of organic carbon in sludge-amended soil can rise by as much as three times (Nyamangara and Mzezewa, 2001). In situations where sewage sludge does not contain the optimum nutrient ratio for plant growth, it can be applied combined with mineral fertilizers (Mtshali et al., 2014).

The majority of research findings indicated that using sludge from agro-industrial wastewater treatment plants for agricultural applications as a soil conditioner is the best possible disposal mechanism without affecting the ecosystem (Babel et al., 2009; Latare et al., 2014; López-Mosquera et al., 2000; Poykio et al., 2019; Suanon et al., 2016). Due to its high organic carbon content, sewage sludge has the potential to enhance soil's physical properties (Khaleel et al., 1981). This could include reducing bulk density, improving aggregate stability, and soils' ability to retain water, and encourages greater water infiltration (Kladivko and Nelson, 1979). Due to the potential for recycling, domestic sludge's features make it an interesting material for agricultural reuse, particularly in farmland and wooded regions, instead of direct disposal (Erdem and Sözüdoğru, 2002; Garg and Kumar, 2015; Mondal et al., 2015).

Sludge management has grown in importance as a result of the possible environmental risk and higher disposal costs (Suanon et al., 2016). Sewage sludge's potential use as a fertilizer offers a practical and affordable disposal option. However, the knowledge of heavy metal and other contaminants concentration in the sludge is needed to ensure that national limit values are not exceeded if the sludge is to be used for agriculture (Poykio et al., 2019). Moreover, there are insufficient scientific pieces of evidence in Ethiopia on the potential of application of domestic sludge as fertilizer on soils. Therefore, managing a considerable and steadily rising amount of sewage sludge is the top priority for both developed and emerging countries (Ghorbani et al., 2022). For the safe use of sewage sludge, it must be characterized in terms of its composition, as this residue may contain toxic compounds, causing environmental pollution. Several scholars have attempted to describe the brewery sludges that may be utilized in Ethiopia to produce crops among other agricultural uses (Alayu et al., 2018; Merga et al. 2021), Nevertheless, little attempt was made to conduct additional research for the characterization of effluents from the emerging Ethiopia's industrial parks.

The purpose of this study was, therefore, to evaluate the physico-chemical properties of sewage sludge produced from zero liquid discharge (ZLD) at HIP in Ethiopia, to look into its nutrient contents and potential use as fertilizer and to determine whether it can be recommended for soil amendment.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out at Ethiopia's Sidama National Regional State's Hawassa Industrial Park (HIP), in the city of Hawassa. HIP, which started operation in July 2016 and has been referred to as the "flagship" industrial park of the Ethiopian government (Figure 1). It is situated in Hawassa City, which is roughly 275 kilometers from Ethiopia's capital Addis Abeba. The park has a total area of 1.3 million m2, of which a manufacturing shed build-up constitutes an area of 300,000 m2. Currently, the park is home to 22 top worldwide garment and textile enterprises from the USA, China, India, and Sri Lanka, as well as many local manufacturers (Xiaodi et al., 2018). Currently, HIP has a total of 13,700 workers across 52 shades and around 80% of the employees are female.

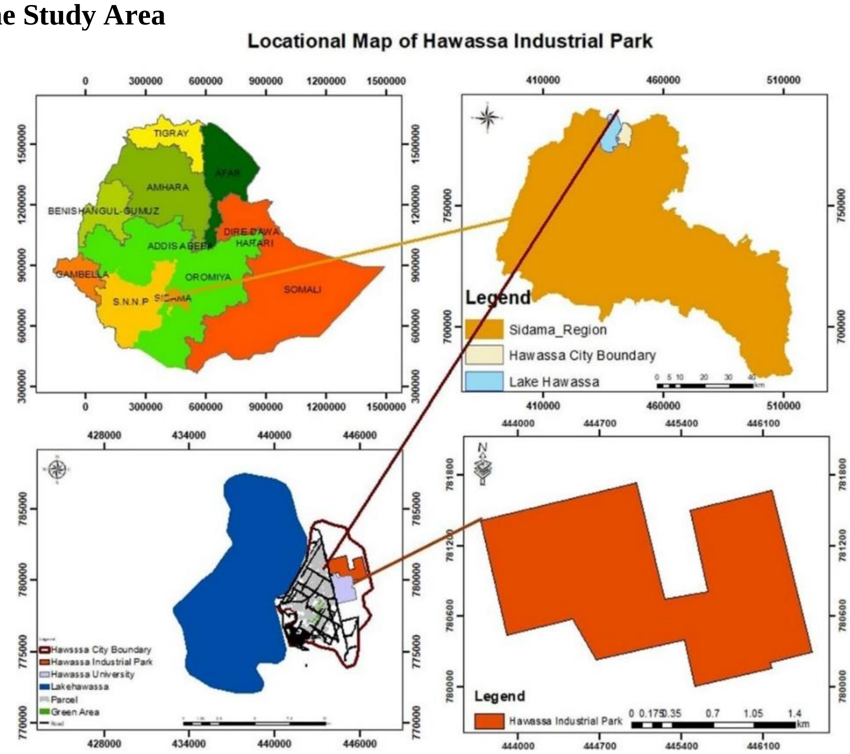

Figure 1. Hawassa Industrial Park location map

The park has a zero-liquid discharge (ZLD) plant that treats and recycles wastewater to reduce environmental impact. This is supposed to help businesses to satisfy the environmental requirements needed by global markets, allowing them to concentrate on exports.

Domestic Sludge Sampling and Preparation for Analysis

The source of the domestic sludge for this study is the ZLD wastewater treatment plant at Hawassa Industry Park. The HIP has sewage treatment plant (STP) which treats three million litres per day. This domestic wastewater is discharged from toilets of the different sheds. The sludge samples were collected from semisolid obtained from STP based on the environmental standards of the Environmental Protection Agency (EPA) (EPA, 1983). Five domestic sludge samples were collected from the sedimentation tank daily for consecutive five days. The domestic sludge was collected, carefully mixed, dried and then passed through a 2 mm sieve and stored in a plastic bag for further analysis in the laboratory. The prepared samples were then analyzed for different physical and chemical properties including content of heavy metals in the soil laboratory of the college of agriculture, Hawassa University.

The bulk density (BD) of the domestic sludge was ascertained by using the core sampler technique as described in Blake (1965). Using the pressure plate apparatus technique, the water retention at field capacity (FC) and permanent wilting point (PWP) were determined at water potentials of -1/3 bar and -15 bar, respectively (Richards, 1965). The available water content (AWC) of the domestic sludge (mm/m) was calculated using Equation 1 described below:

$$AWC=10\times[FC-PWP]\times BD \qquad (1)$$

Where AWC= available water content, FC = moisture content at field capacity, and PWP= moisture content at the permanent wilting point
The pH of the sludge was measured in 1:2.5 sludge and water suspension, electrochemically using a pH meter (Jackson, 1958). The amount of organic carbon (OC) in the domestic sludge was determined with the aid of a rapid titration approach (Walkley and Black, 1934) whereas in a sludge water extract (1:2.5), the electrical conductivity (EC) was measured using a conductivity meter (Okalebo et al., 2002). Kjeldahl method was employed to estimate the amount of total nitrogen (TN) in the sludge as described by Jackson (1958). The available phosphorus content was determined using the Olsen extraction process as described by Olsen et al. (1954). The ammonium acetate method was used to determine the exchangeable bases and cation exchange capacity (Van Reeuwijk, 2002). Atomic absorption spectrophotometer was used to measure Ca^{2+} and Mg^{2+}, whereas flame photometer was employed to measure Na^{+} and K^{+}.

Analyses of Sludge Samples for Heavy Metals

The heavy metal test was carried out at Horticoop Ethiopia (Horticulture) PLC, soil, water and plant analysis laboratory which is found at Debreziet city. Cu, Zn, Mn, Cr, Mo, Co, Pb, Se, and Cd, were extracted using the DTPA extraction technique (Lindsay and Norvell, 1978), and their concentrations were all determined using inductively coupled plasma-optical emission spectrophotometer (ICP-OES). The apparatus was set up properly to analyze the sample, including the wavelength selector, plasma, auxiliary, nebulizer, and gas settings (Dilebo et al., 2023).

Data Analysis

The domestic sludge samples' physical and chemical characteristics and heavy metal concentration were determined and the data were analyzed with the help of Microsoft Excel for descriptive statistics.

RESULTS AND DISCUSSION

Physico-Chemical Properties of Domestic Sludge (DS)

Physical Characteristics of the Domestic Sludge at HIP

The data of the physical properties of the domestic sludge samples are presented in Table 1.

Table 1. Physical properties of domestic sludge (n=5).

Physical properties	Unit	Mean±SD	Minimum	Maximum	CV
BD	g cm^{-3}	0.85±0.02	0.82	0.87	1.91
FC	%	92.06±5.88	86.00	99.30	6.39
PWP	%	47.40±11.55	35.00	65.00	24.36
AWC	%	44.66±8.93	30.00	52.00	19.99

BD= bulk density; FC=field capacity; PWP=permanent wilting point; AWC= available water content; SD=standard deviation; CV=coefficient of variation

The results in Table 1 clearly show that the domestic sludge has favorable physical characteristics that may be useful to enhance its potential use as a soil amendment. The mean bulk density value is 0.85 g/cm^3, and ranges from 0.82 to 0.87 g cm^{-3}. Higher values of BD (1.19 g cm^{-3}) were reported by Jatav et al. (2021), 1.18 gm cm^{-3} by EI-Nahhal et al. (2014), and 1.05 gm cm^{-3} by Hu et al. (2012) which is essential to improve soil BD. The domestic sludge also has a good water holding capacity of 44.6%, which is an excellent signal as it can be useful in enhancing the soil's water holding capacity, and this finding is similar to the finding by Jatav et al. (2021) who found higher moisture content in Bhagwanpur STP, India in sludge amended soils. Similarly, Alayu et al. (2018) found a mean water holding capacity (WHC) of 54% for bio-solid from the Kombolcha Brewery sewage treatment facility of Amhara regional state. The greater water holding capacity of the sewage might be due to the elevated organic matter content. El-Nahhal et al. (2014) showed that the moisture retention capacity of sludge can be 2 times higher than that of a sandy soil, and they explained that the lesser permeability and higher porosity in the sludge could be responsible for the higher water holding capacity.

The analyses of the physical properties of the domestic sludge (DS) at HIP indicated that it could be a great supplement to enhance the bulk density of soils as suggested by various authors (Jatav et al., 2018; Latare et al., 2014). Similarly, various studies revealed that DS has advantageous physical characteristics that can enhance soils' physical attributes (Jatav et al., 2021). Application of waste sludge results in an increase in porosity, moisture content at field capacity, and permanent wilting point (Delibacak et al., 2009). Sludge would also help to activate the various microbes in the soil (Jatav et al., 2021).

Chemical Properties of the Domestic Sludge at HIP

The domestic sludge samples were also analyzed for their chemical properties and the results are presented in Table 2. The pH of the domestic sludge at HIP was found to be slightly alkaline and had values ranging from 7.48 to 7.98 (Table 2). The chemical, and biological features of the soil are significantly influenced by the sewage sludge's alkalinity and acidity, which also impacts the likelihood of nutrients being available for plant growth (Alayu et al., 2018; Obasi et al., 2012). The reported sludge pH values are optimum for the majority of crops (Mcconnell et al., 1993). Comparable results were reported by Alayu et al. (2018) in Kombolcha Brewery Factory with a mean pH value of 7.85. For soils that had been sewage sludge treated, it is advised keep the soil pH above 6.5 (Henning et al., 2001).

Table 2. Chemical properties of domestic sludge (n=5).

Chemical properties	Unit	Mean±SD	minimum	maximum	CV
pH (H_2O)		7.74±0.21	7.48	7.98	2.70
EC	$mScm^{-1}$	2.06±0.37	1.74	2.65	17.80
P	mg/kg	911.80±225.52	739.20	1300.20	0.25
Ca^{2+}	meq. $100g^{-1}$ soil	33.23±11.87	16.79	43.91	35.73
K^{+}	meq. $100g^{-1}$ soil	6.02±1.56	4.78	8.38	25.98
Mg^{2+}	meq. $100g^{-1}$ soil	18.68±1.34	16.89	20.35	7.15
Na^{+}	meq. $100g^{-1}$ soil	14.32±1.64	11.88	16.10	11.46
S	meq. $100g^{-1}$ soil	1.31±0.60	0.51	1.85	45.75
CEC	meq. $100g^{-1}$ soil	36.57±2.33	33.46	38.81	6.37
OC	%	14.35±2.92	10.33	17.80	20.37
TN	%	2.95±0.71	2.34	3.99	24.16
C/N	-	5.25±2.54	2.59	7.51	38.83

EC= electrical conductivity; P=phosphorus; S=Sulphur; CEC=cation exchange capacity; OC=organic carbon; TN=total nitrogen; C/N= carbon to nitrogen ratio; SD= standard deviation; CV=coefficient variation

The mean value of electrical conductivity (EC) of the domestic sludge was 2.06 mS/cm. This EC result is consistent with the waste sludges' reported EC values, which ranged from 1.38 to 2.12 $mScm^{-1}$ (Obasi et al., 2012). According to Soumaré et al. (2003), the EC value in this study is within the range required to be utilized as a good fertilizer, which is 3 mS/cm, and this range is suitable for plant growth in Ethiopian conditions.

As shown in Table 2, the domestic sludge had an average organic carbon (OC) content of 14.35%, with a range of 10.33 to 17.80%. Sharma et al. (2022) disclosed that the amount of organic matter in dewatered sludge can be as high as 50 to 70%. Other researchers also found a high amount of organic matter, 70.5% (Wang et al., 2022) and 51.5% (Hurley et al., 2018). Domestic sludge's high OC content makes it a potential soil fertilizer that could significantly increase the amount of essential nutrients required by crops, improve the physical characteristics of the soil, and contribute more to an increase in crop production if used as soil amendment (Alayu et al., 2018).

The total nitrogen (TN) content in the domestic sludge was found to be 2.95% with a range from 2.34 to 3.99 % (Table 2). The amount of total nitrogen found in this domestic sludge indicates that it can potentially be a good source of nitrogen if applied to soils (Alayu et al., 2018, Mtshali et al., 2014).). Another study conducted by Singh et al. (2022) showed that dry sludge may contain 2.35–4.2% nitrogen, 2.46–3.2% phosphorus, and 0.83–1.24% potassium making it an excellent organic fertilizer for growing crops.

The mean value of C/N of the sewage sludge in this study is 5.25. This value is lower than reported C/N ratio of brewery sludge, malting sludge, compost, and brewery spent grain, were 12.78, 7.47, 11.2, and 7.1, respectively, (Alayu et al., 2018; Mtshali et al., 2014; Sampson, 2016). The result is in line with the allowable range of C/N for organic fertilizers for agricultural use of <35:1 (Meghari and Omar, 2017).

The available phosphorus (911.80 $mgkg^{-1}$) satisfies the Ethiopian standard established (ESA, 2021), and the value is higher than that obtained by the Environmental Qualifications Authority for the country of Israel for the fertilizer value of sludge for agricultural application (Meghari and Omar, 2017). Therefore, the amount of available phosphorus found in the DS samples is optimum for its potential use as fertilizer. In general, the high OM and nutrient (nitrogen and phosphorus) contents found in this domestic sludge potentially makes it a valuable organic fertilizer.

The Calcium content of the domestic sludge was found to be 33.23 meq. $100g^{-1}$ soil. This value is higher than values obtained by Alayu et al. (2018) and Dolgen et al. (2004) with Ca values in brewery sludge of 3.19 and 28.81 meq. $100g^{-1}$ soil, respectively. The mean concentration of Magnesium was found to be 18.68meq/100g soil. This result is higher than brewery sludge contents reported for other sludge materials (Alayu et al., 2018; Campaña et al., 2014). The mean value of potassium in domestic sludge was found to be 6.02 meq. $100g^{-1}$ soil, whereas other studies reported a value of 5 meq. 100 g^{-1} soil (Alayu et al., 2018). This domestic sewage sludge contains potassium, which suggests that it may be available for plants. The measured value of sodium (14.32 meq.$100g^{-1}$ soil in the domestic sludge was lower than the one in the study by Campana et al. (2014) for a brewery sludge of 21.30 meq. $100g^{-1}$, it offers the benefit of avoiding issues with salt buildup in soil and plant roots. In general, the HIP domestic sewage sludge was found to be suitable in terms of secondary plant nutrients such as sulfur calcium, and magnesium so that if this DS is applied to soils, these nutrients will be available for crop growth.

The mean value of CEC of domestic sludge is 36.57 meq. 100 g^{-1} which is high. Domestic sludge application could modestly improve the cation exchange capacity (CEC) of soils. This is most likely because of the high organic matter content in the sludge (Erdem and Sözüdoğru, 2002).

Heavy Metal Concentration in the Domestic Sludge at HIP

The analysis results of heavy metals in the domestic sludge (Table 3) indicated that the sludge could potentially be used as fertilizer since the values fall below the Ethiopian standard and FAO limits (ESA, 2021; Council of the European Communities, 1986).

Table 3. Heavy metals contents of domestic sludge in the HIP and recommended standards (n=5)

Chemical properties	Unit	Mean±standard deviation	minimum	maximum	Permissible limits	Source
Manganese	mg kg^{-1}	255.11±34.86	215.56	292.49	2000	(Council of the European Communities, 1986)
Zinc	mg kg^{-1}	399.79±37.37	357.26	451.63	2500	(ESA, 2021)
Boron	mg kg^{-1}	34.77±3.82	29.48	39.42		
Copper	mg kg^{-1}	71.61±5.28	64.24	78.93	800	(ESA, 2021)
Arsenic	mg kg^{-1}	12.10±0.32	11.64	12.42	40	ESA, 2021
Lead	mg kg^{-1}	41.57±2.21	38.66	44.55	900	(ESA, 2021)
Chromium	mg kg^{-1}	24.97±3.54	20.38	29.77	900	(ESA, 2021)
Cadmium	mg kg^{-1}	3.71±0.34	3.31	4.11	10	(ESA, 2021)
Cobalt	mg kg^{-1}	17.88±2.44	14.67	20.46	100	(Water Research Commission, 1997)
Nickel	mg kg^{-1}	16.83±0.73	15.78	17.52	200	(ESA, 2021)
Mercury	mg kg^{-1}	3.54+0.14	3.39	3.74	8	(ESA, 2021)
Selenium	mg kg^{-1}	19.40±0.72	18.18	20.06	15	(Water Research Commission, 1997)

The allowable limits for possible toxicity levels of Zn, Cu, Cd, Pb, Ni, and Cr in sewage that can be applied in agricultural soils are 2500, 800, 10, 900, 200, and 900 mg/kg, respectively, as presented in Table 3 (ESA, 2021). However, the mean concentration of lead, zinc, and copper in the sludge were found to be 41.57, 399.79, and 71.61 mg/kg, respectively. Similarly, the levels of cadmium, chromium, cobalt, manganese, and nickel were also below the thresholds recommended for sludge used in agriculture (Alayu et al., 2018; Khanal et al., 2014; ESA, 2021). In addition, the concentration of Manganese ranged from 215.56 to 292.49 mg/kg, which was lower than the FAO/WHO (2001) recommendation (a maximum of 2000 mg/kg). The mean concentration of Nickel was 16.83 mg/kg, which was lower than the values reported for sludges in China and the UK, which were 214.29 mg/kg and 58.5 mg/kg, respectively (Hua et al., 2008; Milik et al., 2017). The level of Nickel was also found to be lower than the limit of FAO recommendations.

The mean value of arsenic was 12.10 m/kg and this is lower than the standard set, which is 40 mg/kg (ESA, 2021). Heavy metals are needed in suitable concentrations for the structural and catalytic components of proteins and enzymes as co-factors and essential for optimal plant development (Mahdi et al., 2007). Moreover, the mean value of Cobalt was 17.88 mg/kg, which was much less than the threshold set by scholars from South Africa and Ethiopia which were 100 mg/kg (DWAF, 1997; ESA, 2021).

Generally, the heavy metal concentrations were found to be much lower than the Ethiopian standard for sludge management for the majority of the heavy metals (ESA, 2021). On the contrary, the content of selenium in the sludge was found to be 19.40 mg/kg which was a bit higher than the recommended limit of 15 mg/kg (Taylor et al., 2021). On the other hand, Alemu et al. (2017) found a lower selenium content in sludge (12.56 mg/kg) in Harari Regional State, eastern Ethiopia.

CONCLUSIONS

Characterization of sewage sludge is important before application of sewage sludge to soil as fertilizer. Such characterization helps to determine the potential of sewage sludge for nutrient supplementation and for increasing crop yields. The high water-holding capacity of domestic sludge has the potential to enhance the water retention capacity soils if used as fertilizer.

The domestic sludge in the study area showed high contents of organic matter, nitrogen, and phosphorus. The concentrations of heavy metals (Zn, Cu, Cd, Pb, Ni, and Cr) in the domestic sludge are below the Ethiopian standard and FAO limits.

Analysis of domestic sludge also revealed that it contains significant amounts of secondary nutrients like sulfur, calcium, magnesium, as well as macro nutrients like nitrogen and phosphorus. The majority of physical and chemical properties revealed that it is potentially suitable for agricultural purposes. It is advisable to conduct soil testing when sludge is applied for proper risk management, especially for sensitive crops at the field level.

The use of sewage sludge for agricultural land could lead to lower production costs as reduced amounts of inorganic fertilizers will be used and also reduce the risk of problems created by the accumulation of increasing amounts of domestic sludge in the environment. Further research on analysis of the content of polychlorinated byphenyls (PCB) before the domestic sludge can be used for agricultural purposes is recommended.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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