

## Characterization of the Physicochemical and Biological Properties of Kombolcha Brewery Wastewater Treatment Plant Bio-solid in Relative to Agricultural Uses

Ermias Alayu\*, Seyoum Leta and Temesgen Aragaw

Centre for Environmental Science, College of Natural Science, Addis Ababa University, Ethiopia

\*Corresponding author: Alayu E, Centre for Environmental Science, College of Natural Science, Addis Ababa University, Ethiopia, Tel: +251920257482; E-mail: ermias.alayu@gmail.com

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### Abstract

Agro-industrial sectors in Ethiopia are highly expanding and offering environmental problems. Some brewery factories in Ethiopia had installed advanced wastewater treatment technologies. Sludge generated from waste treatment plants are recognized as good alternative options for agricultural reuse. However, the difference in sludge properties due to the wastewater action process variation and the inconstant nature of contaminant inputs to the original wastewater, the fertilizer prospective and contaminant risks should be evaluated. Hence, the goal of this study was to illustrate the physical, chemical and biological properties of Kombolcha brewery wastewater treatment plant bio-solid in relative to agricultural reuse. The physicochemical and biological characteristics of the brewery sludge were 7.85, 2.35 mS $\text{cm}^{-1}$ , 54%, 92.9%, 49.1%, 84.6%, 3.84%, 5.92%, 12.78:1, 5.46 CFU/ml and 3.06 CFU/ml for pH, EC, WHC, TS, OC, OM, TKN, P<sub>2</sub>O<sub>5</sub>, C/N ratio and TFC (as fresh and dry weight) respectively. The secondary and other plant nutrient contents of the BS were 0.24%, 1.61 mg/Kg for K<sub>2</sub>O and K, 4.74%, 3.19 mg/Kg for CaO and Ca, 0.76%, 1.19 mg/Kg for MgO and Mg, 0.86%, 0.37 mg/Kg for Na<sub>2</sub>O and Na, 2.94% for Al<sub>2</sub>O<sub>3</sub>, 27.98% for SiO<sub>2</sub> and 0.18% for TiO<sub>2</sub> with the detected heavy metals concentration of 0.07, 0.05, 10211.5 and 0.77 mg/Kg for Zn, Pb, Fe and Cu respectively. Overall, the result revealed that the sludge has high OM and P<sub>2</sub>O<sub>5</sub> content that fulfills the suggested standards for the fertilizer value of sludge, optimum pH and EC values, substantial qualities of nitrogen and high WHC and deficient secondary plant nutrients (calcium, magnesium, potassium and sodium), all able to contribute beneficial improvement of soil properties. In line with this, the very lower heavy metals concentration, existed below both the EPA and Canadian class A limits and ideal C/N ratio, meets the fertilizer value of sludge and make it to serve as a valuable organic fertilizer. However, the higher pathogen contents are stabilized to the required standard (<10<sup>-3</sup>) for unrestricted reuse of the sludge for agricultural application.

**Keywords:** Advanced wastewater treatment; Brewery sludge fertilizer potential; Plant nutrients; Waste management

### Introduction

Agro-industrial sectors in Ethiopia are highly expanding sector along with increasing in their production capacity to hold a planned economic position, but they offer substantial challenges to the environment [1,2]. Among these, beverage industry discharges large amount of wastes that contains high strength organic pollutants which are hazardous to the environment [3]. Currently in Ethiopia, some brewery industries adopted advanced wastewater treatment technologies composed of screening, equalization, up-flow anaerobic sludge blanket (UASB) process extended with aeration followed by final polishing unit (FPU) to manage their liquid waste in an environmentally sustainable way. The sludge generated from the aerobic unit undergoes dewatered using belt pressing process, collected in sedimentation tank and transported to land disposal. Disposal of sludge has been very costly, often requiring over 50% of the operators budget for wastewater treatment plant [4], besides causing environmental problems. Among the different sludge disposal methods, landfilling is the common one. Whereas, land application is an alternative option to avoid the high landfill cost, available land space limitation as well as hygienic problems [5].

Therefore, disposal of sludge in a sustainable approach has got a global attention [6], and has a great significance to local communities, authorities and the industry. Brewery industry discharging large volumes of organic materials (spent grain, yeast, kieselguhr and sludge) with each brewing. Such disposal of brewery sludge gets consideration to look available options to manage it in an eco-friendly manner either alone or combined with others for agricultural practices to increase crop yields from a limited area by reducing more chemical fertilizers and pesticides [7-9]. Most research investigation results showed that land application of agro-industrial wastewater treatment plant sludges for agricultural purposes is an ultimate disposal alternative option without any hazardous effect for soil conditioner [10-12]. However, sludges intended for agricultural use may contain toxic metals, persistent organic pollutants and pathogens that cause harmful effects to humans through transmission into the food chain [13].

Generally, the increases in the amount of sludge generation from waste treatment plants bring significant pressure on its disposal method. Therefore, use of these waste materials for land application is increasingly being identified as an important issue to address the problem [14]. The characteristics of brewery sludge make it one of the most interesting material for agricultural reuse particularly to cropland and forested lands instead of straight disposals, due to the possibility of recycling its appreciated plant nutrients (nitrogen and phosphorus) to plant growth [15,16]. Kombolcha brewery wastewater treatment plant

generates 25 m<sup>3</sup> of sludge per day and mostly dumped into the open land. This present disposal practice couldn't be feasible option when land disposal space is scarce and may cause environmental problems in future. Therefore, it is important to characterize the quality of the brewery sludge in order to develop feasible and sustainable treatment technique for better management and provide baseline data on the physicochemical, biological and heavy metal contents in the sludge to the industry, decision makers and local farmers who wants to start the practices of the sludge application for farming. Accordingly, the objective of this study was to characterize the physical, chemical and biological properties of brewery bio-solid/sludge (BS) generated from Kombolcha brewery wastewater treatment plant in relative to agricultural uses at least to substitute the 25,000 farmers urban horticultural (vegetables and fruits) activities including cereals in the town.

## Materials and Methods

### Sludge sample sampling and preparation

The source of sludge sample was Kombolcha brewery wastewater treatment plant, located in the Amhara regional state, northern part of Ethiopia. Sludge sampling was performed based on the EPA procedure [17]. The sludge was collected from the sedimentation tank daily for a period of three weeks. The collected sludge samples were mixed well and processed to obtain appropriate quality through air drying. The mixed sample was divided and conned to 1 Kg to obtain a representative sludge sample for evaluating its physicochemical and biological characteristics including heavy metals in the laboratory. A 1 Kg dried sludge sample was ground with mortar and pestle and sieved by passing through <2 mm stainless steel sieve and stored in the plastic bag for further laboratory analysis.

### Determination of sludge physicochemical and biological characteristics

Three replicates of the sludge sample was taken for evaluation of the selected physicochemical and biological characteristics of the BS sample and each properties were determined as follows: the pH of the sludge/distilled water mixture (1:5) was determined using pH meter [18]; the electrical conductivity (EC) was measured from the sludge/distilled water extract saturated paste [19]; the water holding capacity (WHC) was measured by Skene et al. [20]. Total solid (TS) and total fecal coliforms (TFC) were determined following standard procedure [21]; Total Kjeldhal Nitrogen (TKN) was determined using Kjeldhal method [22]; Organic carbon (OC) content was measured by loss of ignition (LOI) method [23]; organic matter (OM) content was estimated by multiplying total organic carbon content by the Van Bemmelen factor (1.724); major and minor mineral oxides of secondary plant nutrients and other nutrients of K<sub>2</sub>O, Na<sub>2</sub>O, CaO, MgO, Fe<sub>2</sub>O<sub>3</sub>, MnO, Al<sub>2</sub>O<sub>3</sub>, P<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub> were measured through LiBO<sub>2</sub> using AAS (Varian Spectr AA.20 Plus) at detection limit of <0.01% and Colometric method and SiO<sub>2</sub> was analyzed using HF attack and AAS (Varian Spectr AA.20 Plus) following [24-26] procedures.

### Heavy metals analysis in the brewery sludge

The ground sludge sample (1 g) was placed in 25 ml beakers and next, 10 ml 69-70% HNO<sub>3</sub> and 10 ml 35.4% HCl (obtained from research lab-Fine Chem. Industries, Mumbai, India) were added along

with 30% H<sub>2</sub>O<sub>2</sub> (Scharlau, European Union) following Method 3050 [27]. Selected soluble salts were used to prepare standard solutions for each element and a calibration curve was drawn from them in the instrument before unknown samples were used. Then, the total metal concentrations were determined using flame atomic absorption spectrophotometer (Shimadzu AA-7000, Japan) equipped with a deuterium background corrector and hollow cathode lamps with an air acetylene flame at wavelength (nm) and detection limits (DL) of 228.8 and 0.02 for Cd; 324.8 and 0.035 for Cu; 279.8 and 0.03 for Mn; 240.7 and 0.075 for Co; 283 and 0.01 for Pb; 357.9 and 0.01 for Cr; 213.9 and 0.012 for Zn; 232 and 0.07 for Ni; 248 and 0.08 for Fe; 239 and 0.0035 for Ca; 285.2 and 0.035 for Mg; 766.5 and 0.02 for K and 589 and 0.007 for Na respectively.

### Descriptive statistical data analysis

The sludge sample physicochemical, biological and heavy metal means, standard deviations and coefficient variation values were analyzed using R-software, version 3.2.2.

## Results and Discussion

### Physicochemical and biological properties of BS

The physicochemical and biological characterization of the BS was first investigated to evaluate its potential use for agricultural purpose. The main physical, chemical and biological properties of the sludge sample were present in Table 1. The determination of the pH of brewery sludge was found slightly alkaline and it was found in the reported brewery sludge pH values ranging from 6.5 to 11.5 [28]. This slightly alkaline property of BS may be arising from certain pH adjustment measures taken to regulate fluctuations in the biological processes carried out in wastewater treatment plant. Sludge alkalinity or acidity is a key factor that affects the soil physical, chemical and biological characteristics and determines the availability of many nutrients for plant growth and maintenance [29,30]. The electrical conductivity (EC) of the sludge was 2.353 mS/cm. This EC value lies in the reported EC of the refuse, waste soils values ranged from 1.38-3.12 mS/cm [30]. The EC value meets the salinity limit value of 3 mS/cm to be used as a good fertilizer [31]. Beside this, it is almost equal to the standard, i.e., EC <2 mS/cm in soil, sludge and irrigation water which is generally a safe level for plants. However, most of the plants can tolerate EC values ranges from 3-4 mS/cm [32]. The EC of sludge is associated with salinity and it is used to indicate the soluble salt concentrations which exert severe stress on non-salt tolerant plants and inhibit the plant growth in the soil [33]. The EC value obtained in this study may be attributed due to the presence of soluble salts like sodium (0.37 mg/Kg as Na and 0.86% as Na<sub>2</sub>O) and chloride content of the sludge, which comes from the use of sodium hydroxide (NaOH) and ferric chloride (FeCl<sub>3</sub>) in the wastewater treatment processes. The TS value was 92.93%, which is quite high and implies that the sludge content can be used for different purposes like landfilling or land reclamation. The mean water holding capacity of the BS was 54%. The higher WHC of this sludge may be due to the presence of the high OM content. According to Aboukila et al. investigation, soil amended with brewery spent grain showed significantly increased WHC as compared to other treatments [33]. Similarly, other research report also indicates that the addition of compost fertilizer and cow manure increased the water holding capacity of the soil [34], all these may be due to the positive correlations between OM content and available WHC of soil

[35]. The high WHC of Kombolcha brewery sludge implicates that it can have the capability to enhance the WHC of soil.

The total mean percentage of organic carbon and organic matter contents of brewery sludge were 49.1% and 84.6% respectively. The result of OM content found in this study was achieved Taiwan recommended regulations for specification of organic matter content (dry weight) >50% for utilizing sludge as a material resource sustainable [36]. The OC content of BS obtained in this study was quite high and greater than the OC content of compost (consisted of animal waste and plant residues); i.e., 23.5%, brewery sludge OC values of 43.3% [37] and 42.5% [38]. Generally, the high OC content found in the brewery sludge can make it a potential soil fertilizer, which can significantly increase the supplement of essential nutrients to crops, enriching the soil physical properties and boosting the organic matter content in the soil and overall contributing an increment in crop production. In literatures, an increased addition of OM increases the WHC, exchangeable ions, porosity, nutrient storage and turnover, decrease soil erosion, reduce soil acidity, and improve the microbial activity in the soil through utilizing OM as a source of food and in general, enhance full health and the optimum growth rate of plants [32,37-39].

C/N ratio is one of the most important chemical characteristics of sludge for microorganisms; carbon is the building block of life and source of energy; while, nitrogen is necessary as proteins, genetic material and cell structure. The C/N result obtained in this study was 12.78. This result is higher than the reported C/N ratio of malting sludge (i.e., 7.47) [40], compost (i.e., 11.2) and brewery spent grain (i.e., 7.1) [33]. The result is also found in line with the allowable range of C/N of the fertilizer value of sludge for agricultural use set by the environmental qualification authority <35:1 [41,42]. The carbon to nitrogen ratio ranged from 11.0 to 20.45 implicates that the soil would support plant species diversity and growth. Therefore, we can conclude that the C/N ratio of brewery sludge obtained in this study can support the plant species diversity and growth.

The total Kjeldhal nitrogen (TKN) and phosphorus (as  $P_2O_5$ ) contents in the sludge were 3.84% and 5.92% respectively. The TKN result obtained in this brewery sludge normally existed in the range of nitrogen concentration used by most plants, averages from 2-4%. The obtained TKN result is higher than sewage sludge (1.97%) [43], compost (consisted of animal waste and plant residues) (2.1%) [33], and brewery sludge (1.33%) [2], implies that it is quite sufficient enough for agricultural application. Nitrogen is a main macro-nutrient element and presence of it in high amounts, stimulates shoot growth and root growth. Because, nitrogen is needed to make chlorophyll besides the genetic proteins and cell walls needed by all cells [41]. Similarly, phosphorus is another essential element for plants which is absorbed by plant roots in the orthophosphate form and can boost plant growth [44]. The determined available phosphorus (5.92%) is beyond the guideline values assigned by the environmental qualifications authority for the fertilizer value of sludge for agricultural use, 1.5-2% [42]. This  $P_2O_5$  value is higher than the phosphorus content of the dairy plant sludge ( $2.4 \text{ Kg m}^{-3}$ ) [12], and compost (consisted of animal waste and plant residues) (1.03%) [34]. Therefore, the amount of available phosphorus found in this study is enough for plant uptake and sufficient for crop requirement. In general, the high OM and nutrient (nitrogen and phosphorus) contents found in this brewery sludge can serve as a valuable organic fertilizer.

The secondary macronutrients in terms of free and oxide forms in the sludge sample were also indicated in Table 1 along with their

equations for calibration curves and correlation coefficients. The calcium content of the brewery sludge was 4.74% as CaO and 3.19 mg/Kg as Ca. This value is lower when compared with Dolgen et al. [11] investigated the value of Ca in brewery sludge which is 5762 mg/Kg. But it contains significant quantities of Ca as compared to dairy plant sludge CaO content ( $2.0 \text{ Kg m}^{-3}$ ) [12], and pulp and paper mill sludge which value ranged from 0.36-1.28% [32]. The concentration of magnesium was found 1.19 mg/Kg as Mg and 0.76% as MgO in the sludge. The achieved Mg content of the brewery sludge is observed lower in value than the brewery sludge Mg content of 5 g/Kg reported by Couce et al. respectively [45]. Measured potassium and sodium contents in the sludge were (1.61 mg/Kg, 0.24%) and (0.37 mg/Kg, 0.86%) respectively in their free and oxide forms. In literature, the potassium content as  $K_2O$  was varied between 0.1-1.95 g/Kg [4]. The K content of this sludge sample is higher than 0.08 mg/Kg reported by Vriens et al. [46]. However, some reported research outputs proved that the potassium level in the sludge is usually low and can range from 0.02-2.64%, but this is adequate enough for plant uptake and still sufficient for crop requirement Sommers [47]. The potassium content existed in this brewery sludge implies that it can be adequate enough for plant uptake. Similarly, the determined Na concentration was lower than the research report of Couce et al. [45] in the brewery sludge (i.e., 4.9 g/Kg), which has an advantages to avoid problems of salt accumulation in the plant root and saline nature of the soil. In general, Kombolcha brewery sludge was deficient in terms of secondary plant nutrients such as potassium, sodium, calcium and manganese. These deficient in values of secondary plant nutrients may be due to the quality of the bore and municipal water used in the malting process and probably no use of chemical additives for the production process or cleaning aids.

In brewery sludge, other varying amounts of essential micro elements were also found; the concentration of Al as  $Al_2O_3$  and Fe as  $Fe_2O_3$  and Fe was 2.94%, 5.84% and 10211.5 mg/Kg respectively. The level of Al content in the brewery sludge was within the range indicated by the United State Environmental Protection Agency, USEPA, 1983 [17]. The content of Fe in this study is lower than the iron content (11,525 mg/Kg) in residual sludge of malting barley Couce et al. [45]. The source of iron in this brewery sludge was due to the use of ferric chloride in the wastewater treatment processes for phosphorous removal through coagulation and precipitation. But, this iron is insufficient for agricultural uses. Because, measured iron content of the brewery sludge was 10211.5 mg/Kg while it should be 13000 mg/Kg in the literature [38]. The silicate ( $SiO_2$ ) content in brewery sludge was 27.98%, which is higher than the silicate content of dried sewage sludge ash (9.57%) [48]. The source of this silica may be associated with the keiselguhr, is a diatomaceous earth that is rich in silicates from fossils of prehistoric algae (diatomite) [49]. The titanium content of BS was 0.18%, which is lower than the titanium content (0.949%) of dried sewage sludge ash reported by Tempest and Pando [50]. The source of titanium may be associated with paint pigment used to coat the sludge tank. Conversely, the MnO was below the detection limit of the instrument. In this experiment, the concentrations of total fecal coliforms (TFC) as fresh and dry weight in the brewery sludge sample were determined. The densities of the TFC in the dewatered fresh and dry weight were 5.46 CFU/mL and 3.06 CFU/mL respectively (Table 1). The fresh weight TFC density of this sludge sample was higher than the *E.coli* content (5 CFU/g) of the brewery sludge reported by Ediget [51]. However, the air-dried sludge sample TFC content was lower than the reported value, indicates that air drying process reduces the TFC concentrations. In this regard, the

air-dried sludge sample TFC content found in this study was not meet the EPA standards of sludge (i.e., <10-3) and therefore, it should be stabilized for sustainable agricultural land reuse.

Sludge properties	Values			Equation for calibration curves and Correlation coefficient (r)
	Mean	Mean ± SD	CV	
pH	7.85	7.85 ± 0.005	0.00066	-
EC (mS/cm)	2.35	2.35 ± 2.52	0.00107	-
WHC (%)	54.0	54.0 ± 1.00	0.01852	-
TS (%)	92.93	92.93 ± 0.30	0.00329	-
OC (%)	49.10	49.1 ± 0.10	0.00204	-
OM (%)	84.60	84.60 ± 0.17	0.00204	-
TKN (%)	3.84	3.84 ± 0.038	0.00985	-
P <sub>2</sub> O <sub>5</sub> (%)	5.92	5.92 ± 0.01	0.00258	y=3.641x+0.0.0356, r=0.9993
K <sub>2</sub> O (%)	0.24	0.24 ± 0.01	0.04167	y=0.0115x-0.0125, r=0.9995
K (mg/Kg)	1.61	1.61 ± 0.38	0.23785	y=0.3648x+3E-05, r=1.0000
Na <sub>2</sub> O (%)	0.86	0.86 ± 0.01	0.01163	y=0.0146x+0.0059, r=0.9990
Na (mg/Kg)	0.37	0.37 ± 0.02	0.06667	y=0.0681x+3E-05, r=1.0000
CaO (%)	4.74	4.74 ± 0.23	0.04852	y=0.0118x-0.0025, r=0.9997
Ca (mg/Kg)	3.19	3.19 ± 0.34	0.10598	y=0.697x+0.115, r=0.9970
MgO (%)	0.76	0.76 ± 0.01	0.09210	y=0.0236x+0.0162, r=0.9998
Mg (mg/Kg)	1.19	1.19 ± 0.26	0.21625	y=0.1883x+2E-16, r=0.998
Fe <sub>2</sub> O <sub>3</sub> (%)	5.84	5.84 ± 0.01	0.04794	y=0.0208x+0.0594, r=0.9856
MnO (%)	<0.01	ND	-	y=0.076x+0.0015, r=0.9991
Al <sub>2</sub> O <sub>3</sub> (%)	2.94	2.94 ± 0.07	0.02381	y=0.001x+0.0003, r=0.9991
SiO <sub>2</sub> (%)	27.98	27.98 ± 1.09	0.03896	y=0.016x-0.0106, r=0.9999
TiO <sub>2</sub> (%)	0.18	0.18 ± 0.01	0.055556	y=0.1107x+0.0755, r=0.8952
C/N ratio	12.78	12.78 ± 0.11	0.00837	-
FC (CFU/ml) as FW	5.46	5.46 ± 0.02	0.81649	-
FC (CFU/ml) as DW	3.06	3.06 ± 0.01	0.81649	-

ND=Not detected, CV=Coefficient of Variation between measurement trials.

**Table 1:** Physicochemical and biological properties of brewery sludge.

### Heavy metals concentration of BS

The heavy metals concentration of the brewery sludge is presented in Table 2 together with the equation for calibration curves, correlation coefficients (r) and the recommended EPA limits for sludge and Canadian allowable Limits for compost in agricultural use. The mean concentration of lead (Pb), zinc (Zn), and copper (Cu) were 0.05, 0.07 and 0.77 mg/Kg respectively. On the contrary, the concentrations of cadmium (Cd), chromium (Cr), cobalt (Co), manganese (Mn), and nickel (Ni) were below the detection limits of the instrument. The

previously reported research result of the Pb content in the same factory liquid waste was 214 µg/L [51]. In the same regard, 0.05 mg/Kg lead was also found in the sludge sample of this factory. The Pb content found in this study is very low when compared to the Pb contents of 33.88 µg/g in the brewery sludge [52], and the maximum allowable limit of Pb content recommended for agriculture by EPA [53] and Canadian class A limits (Table 2). The probable source of Pb in the sludge may be due to emission from the exhaust pipe of the generating plant used to power the machines during production. The copper

content of the sludge was 0.77 mg/Kg which is below the EPA [53,54] standard limits of 4300 mg/Kg and Canadian class A limit of 400 mg/Kg. Cu content is appeared low compared to other published values for the brewing effluent sludge (i.e., 110 mg/Kg) [46], and sewage sludge ranges from 85-2900 mg/Kg [17]. The possible way of contamination of the BS with Cu may be due to the chemical additives in the brewery making process and presence of cyan ink. The Zn content of the sludge is again below EPA [53] class limit of 7500 mg/Kg and Canadian allowable class A limit of 700 mg/Kg. The Zn content found in this result is also lower than the previous reported Zn content in the brewery and sewage sludges by Alemu et al. [2] and Ize-Imayu et al. [55] which are 28.5 mg/Kg and 3.20 mg/L respectively. Similar to others, the probable source of Zn contamination in the BS may be attributed from water pipes, wastewater planting works and storage tanks.

In general, the content of Cu, Zn and Pb found in this brewery sludge sample were much lower than tannery sludge heavy metals

content of Cu (80 mg/Kg), Zn (200 mg/Kg), and Pb (10 mg/Kg) [55]. Heavy metals like Fe, Zn and Cu are required at appropriate concentrations for structural and catalytic components of proteins and enzymes as cofactor and essential for normal growth of plants [56]. However, beyond the optimal concentrations, these micronutrients and other heavy metals in plants operate a stress factor [57,58]. Therefore, the heavy metals concentration in the industrial sludge is one of the major issues as it needs to be verified that either they are above the critical limits or not. Generally, the heavy metals concentration found in this brewery sludge are much lower than the recommended concentrations of EPA [53] standards for all sludge and Canadian class A limit for compost. This positive outcome of the research result can be a good source of information to the local community who wants to start this sludge for agricultural application in environmentally friendly approach with no risk of heavy metal toxicity.

Heavy Metals	Concentration of metals (mg/Kg)			Equation for calibration curves and Correlation coefficient (r)	Standards	
	Mean	Mean ± SD	CV		1	2
Zn	0.07	0.07 ± 0.02	0.23766	y=0.39x-0.0102, r=0.989	700	7,500
Pb	0.05	0.05 ± 0.01	0.32695	y=0.058x-0.0021, r=0.991	150	840
Cu	0.77	0.77 ± 0.05	0.06330	y=0.819x-0.0234, r=0.991	400	4,300
Fe	10211.5	10211.5 ± 10	0.00015	y=0.062x+0.0024, r=0.998	-	-
Cd	ND	ND	-	y=0.0426x+0.0008, r=0.992	-	-
Cr	ND	ND	-	y=0.5197x-0.0144, r=0.990	-	-
Co	ND	ND	-	y=0.066x-0.0022, r=0.988	-	-
Ni	ND	ND	-	y= 1.0102x-0.0362, r = 0.989	-	-
Mn	ND	ND	-	y=0.0581x-0.0008, r=0.992	-	-

<sup>1</sup>Canadian class A composts limit (mg/Kg), which have no restrictions in use; <sup>2</sup>EPA, ceiling concentration limits (mg/Kg) for all sludge applied to land EPA [53].

**Table 2:** Concentrations of heavy metals in brewery sludge and recommended standards.

## Conclusion

Characterization of the BS revealed that the presence of important primary nutrients like nitrogen, phosphorus and secondary nutrients such as potassium, calcium, magnesium, sodium and others like iron, copper and aluminum with high organic matter content, high water holding capacity in combination with very low concentration of heavy metals that meets the allowed EPA ceiling standards for recycling bio-solids for agricultural purposes can be a potential source of cheap fertilizer without risk of heavy metal toxicity. However, the pathogen content was high which needs further treatment to achieve the limit before introduced into agricultural application. Therefore, a cost effective, user friendly technique should develop to convert brewery sludge into a bio-fertilizer that can substitute the need of inorganic fertilizers at least for the 25,000 farmers urban horticultural (vegetables and fruits) activities including cereals in the study area.

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