Characterization of the Drinking Water Sludge for Agricultural Usage

A.B.M. Jesfar[1], M.G. Mohamed Thariq[2], and M.I.M. Mowjood[3]

[1]*Department of Agriculture, Sri Lanka Institute of Advanced Technological Education, Sri Lanka.*
[2]*Department of Biosystems Technology, Faculty of Technology, South Eastern University of Sri Lanka.*
[3]*Faculty of Agriculture, University of Peradeniya, Sri Lanka.*

[1]jesfarabm@sliate.ac.lk, [2]mgmthariq@seu.ac.lk, [3]mowjood2010@gmail.com

Abstract

Water treatment plants generate large quantities of sludge resulting from treatment processes. "Konduwatuwan" water treatment plant located in Ampara in Sri Lanka, generates a huge amount of sludge annually and is disposed directly to the adjacent environment. Concerns have been raised by various authorities regarding the potential risk of the sludge on human and environmental health. This study was conducted to characterize the sludge and to evaluate the potentials to utilize it for soil application in agriculture. Physical and chemical parameters were analyzed using sludge samples in the laboratory. The result showed that the average moisture, total solid, ash and organic matter contents present in the sludge were 79.44%, 20.55%, 60.73% and 39.27% respectively and the monthly mean values of ash and organic matter contents did not significantly vary with time during the study period. The pH, electrical Conductivity, levels of cadmium, chromium, iron, lead and nitrogen were promising in the sludge when compare with aluminium based water sludges used for comparison in this study. Further, the levels of pH, electrical conductivity, nitrogen and phosphorous present in the sludge were within the suitable range for land application and the concentrations of cadmium, chromium and lead were far below the threshold values for composting according to Sri Lankan standards. Thus, the sludge can be utilized for the cultivation of non-food crops. However, further studies are recommended to investigate the effects of sludge on long-term application over the metal loading on cropping lands.

Keywords: sludge characters, metals, analysis, composting

I. INTRODUCTION

Treatment of water for drinking is one of the essential services worldwide. A large quantity of drinking water sludge (DWS) is generated during the water treatment processes. Konduwatuwan water treatment plant (WTP) is one of the large-scale plants operated by the National Water Supply and Drainage Board in Sri Lanka. According to our preliminary assessment, it was estimated that during the treatment about 25-30 m^3 of sludge is generated and disposed of daily which fluctuates depending on the climate. The Gal-Oya river, which is feeding the Konduwatuwan tank, passes through many agricultural areas on its way crossing from Badulla district to Ampara district carrying a huge load of potential agrochemical residues causing an increased algal population in its water. The sludge is rich in clay particles and residual chemicals (Uwimana *et al.*, 2010). Our estimate suggests that about 5% (W/W) of Poly Aluminium Chloride, 0.3 % (W/W) of powder activated carbon and 0.04% (W/W) of Polyacrylamide are used in the water treatment process as a coagulant, for the removal of taste, odor & toxic chemicals and to treat the sludge respectively. Disposal of drinking water sludge has become a serious problem not only in Ampara but also in many other districts where such treatment plants operate.

Figure 01: Sludge dumping site of the Water treatment plant in Ampara

II. LITERATURE REVIEW

Direct discharge of DWS into rivers and water bodies might cause metal pollution, such as contamination with aluminum (Barakwan et al., 2019). Al movement into surface water has

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potential plant Al toxicities and damage to the aquatic environment (Ippolito, Barbarick and Elliott, 2011). Further, the heavy metal residues may be toxic to humans, resulting in central nervous system failure, dementia, memory loss, lethargy, and severe trembling (Ahmad, Ahmad and Alam, 2016). The simple method of discharging sludge directly into nearby water bodies or dumping in the landfill sites is not a sustainable solution, therefore, suitable sludge management strategies need to be formulated for sustainable development (Ahmad, Ahmad and Alam, 2016). As a way for the disposal of DWS, research studies in other countries suggested that DWS can be utilized as building and construction material (Odimegwu *et al.*, 2018), to produce brick (Hegazy, Fouad and Hassanain, 2012. Further, sludge can be used as a good candidate material for P adsorption (Hou *et al.*, 2018), as a cement material (Pan, Huang and Lin, 2004), to remove heavy metal pollutants such as Hg, Se, and As (Ippolito, Barbarick and Elliott, 2011). DWS also utilized to adsorb pollutants in wastewaters (Feria-Díaz, Polo-Corrales and Hernández-Ramos, 2016); Yang et al., 2006), and for wastewater treatment in constructed wetland systems (Zhao *et al.*, 2011) and as a coagulant to remove the turbidity, Chemical oxygen demand (COD) and anionic surfactants (Jangkorn *et al.*, 2011).

Appropriate application of this sludge will not pose any negative effect on the soil properties or plant when they are used as soil fertilizer with appropriate sludge content (Odimegwu et al., 2018; Caniani et al., 2013) and it can be considered suitable for agricultural use (Caniani *et al.*, 2013). Therefore, the reuse of the DWS as fertilizer is considered a sustainable form of disposal method (Odimegwu *et al.*, 2018).
Investigations on sludge toxicity did not find acute toxicity effects in a variety of situations, the heavy metal concentrations were less than regulatory levels and pose few environmental risks (Maiden *et al.*, 2015). Water treatment sludge can be used as an organic matter stabilizing agent with active adsorption surfaces (Haynes and Zhou, 2015). Water treatment sludge is made up of inorganic and organic compounds varies in physical and chemical characteristics depending on the chemicals used in the treatment process and the water source (Odimegwu *et al.*, 2018). The characterization of sludge samples showed that their organic matter content would open up the possibilities for application in soil improvement (Hidalgo *et al.*, 2017). Therefore, land application of sludge generated from water treatment plant is possible with non-food crops, mine reclamation areas, and in forestlands (USEPA, 2011).

III. PROBLEM STATEMENT

Drinking water sludge disposal has become a serious problem in Ampara because a large quantity of sludge is disposed directly in to the nearby environment daily as no alternative solutions are put forwarded to utilize it in a safe manner (Figure 01). Public, health and environmental authorities are concerned regarding the potential risk of the sludge on human and environmental health. Even though a number of investigations on potential industrial reuse and recycling of DWS are available, studies on its agricultural utilization are limited (Dassanayake *et al.*, 2015). Scientific characterization of DWS is necessary for safe agricultural uses locally owing to its source of generation. However, literature on the characteristics of the sludge for agricultural uses, which influence the growth and development of agricultural crops, are limited. As such the present research work was carried out to characterize the DWS based on the physical and chemical properties with the purpose of utilizing the sludge as an ingredient in plant growth media which in turn is expected to be a green solution for its disposal.

IV. METHODOLOGY

Sludge samples were collected in plastic containers from the centrifugal dewatering outlet of the Konduwatuwan water treatment plant during 10.00 am to 11.00 am in the morning at weekly intervals. A total number of 12 samples collected during March to May were used for the analysis of moisture content, total solid content, organic matter content and ash content (Ramirez and Possan, 2018), Whereas a total number of 16 samples collected weekly during March to June were used for analysis of pH, electrical conductivity, total nitrogen, phosphorous, potassium and metals concentration levels. Immediately after collection, the samples were dried at 105 °C for 24 hours until constant weight was reached. The dried sludge samples were ground and sieved using a 75 μm (200 mesh) metal sieve and stored at 4 °C for further analysis of physical and chemical characters (Zhang, Qin and Yi, 2020).

The moisture content (MC) was determined by the weight loss after the sample dried at 105 °C for 24 hours in an electric oven, total solid content (TS) was calculated from the residuals. The oven dried sample was subjected for combustion at 550 °C for 5 hours in the furnace to determine the organic matter content (OM) by weight loss (Bożym and Siemiątkowski, 2018). Ash content (AC) was calculated by the final weight after ignition (Ahmad, Ahmad and Alam, 2016). Analysis of inorganic parameters was performed according to the Standard methods for examination of waste and wastewater (Brandi and Wilson-Wilde, 2013). The pH and the electrical conductivity (EC) were determined by using a professional pH meter (model-BP300) and a conductivity meter (model-ST300C-B) respectively in 1:5 (W/V) sludge: distilled water ratio. Total nitrogen was determined by Kjeldahl digestion method whereas total phosphorous & potassium were determined using dry ash method (Brandi and Wilson-Wilde, 2013). Concentrations of aluminum, iron, lead, arsenic, cadmium and chromium were determined using Thermo Scientific iCAP 7000 plus series ICP-OES. Sample analyses were carried out in the laboratory of the department of biosystems technology of the Faculty of Technology, South Eastern University and in the Central soil testing laboratory of the Horticultural crop research & development institute in Sri Lanka. The data analysis was carried out using MINITAB statistical software version 18. Analysis of variance (ANOVA) was performed to find out whether the mean values of studied parameters are significantly different within the studied months.

V. RESULTS AND DISCUSSION

A. The mean values of the moisture content, total solid content, organic matter content and ash content for the sludge samples collected from March to May in 2021.

Table 3: ANOVA for monthly mean values of moisture content, total solid content, organic matter content and ash content.

Sampling Month	**Moisture content (%)**	**Total solid content (%)**	**Ash content (%)**	**Organic matter content (%)**
March	78.7 (77.2, 80.2)	21.2 (19.7, 22.9)	60.9 (59.1, 62.2)	39.3 (37.8, 40.9)
April	81.1 (79.5, 82.6)	18.9 (17.4, 20.5)	60.7 (59.4, 62.5)	39.0 (37.4, 40.6)
May	78.5 (76.9, 80.0)	21.5 (19.9, 23.0)	60.5 (58.9, 62.1)	39.5 (37.9, 41.0)
P- value	0.04*	0.04*	0.92	0.92

Note: 1. All data represent the mean values and 95% CI values (n = 4).
2. *Monthly mean values are significantly different at p<0.05.

B. The mean pH value, electrical conductivity, total nitrogen, total phosphorous, total potassium, level of aluminum, iron, lead, arsenic, cadmium and chromium for the samples collected from March to June in 2021.

Table 4: ANOVA for monthly mean values of pH, electrical conductivity, total nitrogen, total phosphorous and total potassium.

Month	**pH**	**EC (dS/m)**	**N (ppm)**	**P (ppm)**	**K (ppm)**
March	6.6 (6.5, 6.8)	0.72 (0.66, 0.78)	14800 (14304, 15296)	1465 (1358.1, 1571.9)	275 (216.2, 333.8)
April	6.5 (6.4, 6.6)	0.62 (0.56, 0.68)	16500 (16004, 16996)	1337.5 (1230.6, 1444.3)	250 (191.2, 308.8)
May	6.5 (6.3, 6.6)	0.65 (0.59, 0.70)	17375 (16879, 17871)	1572.5 (1465.6, 1679.4)	275 (216.2, 333.8)
June	6.5 (6.4, 6.6)	0.68 (0.61, 0.73)	14700 (14204, 15196)	1307.5 (1200.6, 1414.4)	250 (191.2, 308.8)
P-value	0.377	0.093	0.001*	0.009*	0.0835

Note: 1. All data represent the mean values and 95% CI values (n = 4).
2. *Monthly mean values are significantly different at p<0.05.

Table 5: Comparison of the mean values of chemical parameters with nutrient requirements for compost.

Parameters	Mean values for the entire study period	Nutrient requirements for compost according to Sri Lankan standard specification (SLS 1246: 2003)
pH	6.5	6.5-8.5
EC dS/m	0.67	0.5-3.0
N (ppm)	15798	>10000
P (ppm)	1414	>500
K (ppm)	257.7	>10000

Table 6: ANOVA for monthly mean values of aluminum, iron, lead, arsenic, cadmium and chromium.

Month	Aluminum (000, ppm)	Iron (000, ppm)	Arsenic (ppm)	Cadmium (ppm)	Chromium (ppm)	Lead (ppm)
March	120.7 (120.1, 121.3)	103.2 (101.9, 104.5)	1.162 (1.142, 1.182)	0.029 (0.027, 0.030)	5.875 (5.298, 6.451)	ND
April	120.7 (120.1, 121.3)	102.2 (100.9, 103.5)	1.13 (1.110, 1.149)	0.040 (0.038, 0.041)	5.950 (5.374, 6.526)	ND
May	120.2 (119.6, 120.8)	985.1 (972.1, 998.1)	1.13 (1.110, 1.149)	0.032 (0.030, 0.033)	7.100 (6.524, 7.676)	ND
June	121.2 (120.6, 121.8)	101.3 (100.0, 102.6)	1.14 (1.122, 1.162)	0.033 (0.032, 0.035)	7.500 (6.924, 8.076)	ND
P-value	0.163	0.001*	0.081	0.001*	0.002*	-

Note: 1. All data represent the mean values and 95% CI values (n = 4).
2. ND-Not detected.
3.*Monthly mean values are Significantly different at $p<0.05$.

Table 7: Comparison of the Mean values of metal with threshold values for compost.

Parameters studied	Mean values for the entire study period	Limit for heavy metals threshold values according to Sri Lankan standard specification for compost (SLS 1246: 2003).
Cadmium (ppm)	0.0335	< 10
Chromium (ppm)	6.55	< 1000
Lead (ppm)	ND	< 250
Aluminium (ppm)	120745	NA
Iron (ppm)	10134	NA
Arsenic (ppm)	1.141	NA

Note: 1. NA-Not available.
2. ND- Not detected

Table 6: Comparison of physicochemical characteristics of DWS from Konduwatuwan WTP with previous studies.

Parameter	Mean values of present study	Average values of Aluminium based water treatment sludge as calculated by Ippolito et al. (2011)	Values from ASCE et al. (1996) based on 12 WTR (U.S. EPA, ASCE and AWWA., 1996)
pH	6.5	6.5 ± 0.3	7.0
EC dS/m	0.67	1.6	0.6 ± 0.5
Total N (ppm)	15798	4,065 ± 7404.06	4950 ± 2560
Total P (ppm)	1414	2,157 ± 361	2,260 ± 2,480
Total K (ppm)	257.7	3,547 ± 582	2,250 ± 3,170
Cadmium(ppm)	0.0335	0.12 ± 0.02	5.15 ± 11.7
Chromium(ppm)	6.55	20 ± 7	50 ± 56
Lead (ppm)	ND	22 ± 12	80 ± 100
Aluminium(ppm)	120745	118700± 24260	60,100± 52,100
Iron(ppm)	10134	37,000±19,740	52,75± 63,64
Arsenic (ppm)	1.141	NA	NA

Note: 1. NA-Not available.
2. ND- Not detected

Analysis of variance (ANOVA) showed that, the ash content and organic matter content during the studied months were not significantly different($p<0.05$) whereas monthly mean values of moisture content and total solid content are significantly different($p<0.05$), which may be due to the difference in the dewatering operation in the plant (Table 1). The average moisture content and the total solid content of sludge samples were 79.44% and 20.55 % respectively which are almost similar to the values reported by Ramirez and Possan (2018) where the average moisture content and total solid content were recorded as 76.36% and 23.63% respectively for DWS. The reason for obtaining similar moisture and solid contents in the present study compared to previous studies may be due to plant operation as predetermined by the dewatering plant operator and also due to the similar dewatering procedures adopted by different dewatering units in different treatment plants.

The average ash content was 60.73 % during the sampling period, this is almost similar to the value reported by Awab, Paramalinggam and Mohd Yusoff (2012) where, the ash content was 66.67%. The ash content in the present study indicated that the WTP sludge presented similar characteristics throughout the study period as reported by Ramirez and Possan (2018) may be due to minimum climatic variation prevailed during the study period. The average organic matter content of the sludge sample over the study period was 39.27 % which highly deviated from the previous studies. Gmurkowska (2019) reported in a study, that the organic matter content is 69% in sludge samples collected at the ZUW Raba water treatment in Poland. Further stated that this may be due to the accumulation of organic compounds in summer (Gmurkowska, 2019). According to Odimegwu *et al*. (2018) the organic matter content of alum sludge differs from treatment plant to plant based on the origin of water source. The organic matter present in the water sludge will help to improve the physical and chemical characteristics as well as the nutrient availability of the agriculture soil. (Jamil Khan, Qasim and Umar, 2006 ; Bozkurt, Yarılgaç and Yazıcı, 2010).

The analysis of variance (ANOVA) showed that the monthly mean values of pH, electrical conductivity and the level of potassium were not significantly different ($P<0.05$) throughout the study period but significant differences were found in levels of nitrogen and phosphorous (Table 2). The mean pH value obtained as 6.5 in the present study is similar to the value found in a study conducted by Ahmad, Ahmad and Alam in 2016. The mean values of total nitrogen (15 843ppm) and total potassium (262.5 ppm) identified in the present study were higher than the values obtained by Feria-Díaz, Polo-Corrales and Hernández-Ramos,in 2016 which are 4000-4800 ppm and 148ppm respectively. However, the level of total phosphorous (1420.6 ppm) is lower than the value (3001-3500 ppm) obtained in the said study (Feria-Díaz, Polo-Corrales and Hernández-Ramos, 2016). The chemical characteristics of DWS are influenced by water source used for it and the cultivation practices in the surroundings. Further the catchment areas and climatic factors influence the characteristics of water source. Therefore, the variations of pH, electrical conductivity, N, P and K in DWS from different treatment plants fed by different water sources are anticipated.

The mean values of pH, EC, total nitrogen and total phosphorous present in the sludge are within the suitable range of nutrient requirements for compost as determined by Sri Lankan standards for nutrient requirements for compost (Table 3) indicating the suitability of DWS for agricultural usage.

According to Table 4, the analysis of variance (ANOVA) of metals showed that the monthly mean values of aluminum and arsenic were not significantly different($P<0.05$), whereas iron, cadmium and chromium concentrations showed significant difference($p<0.05$) between months in the sludge. The heavy metals content in the DWS may vary with time due to variations in leaching of the heavy metals into the reservoir and agricultural runoffs (Dahhou *et al.*, 2017). According to a study conducted by Yiew *et al.* (2018) in Malaysia the concentration aluminum and iron were recorded as 170 000 ppm and 49 900 ppm respectively and these values are much higher than the values obtained in the present study (Table 4). A study conducted by Uwimana *et al.* (2010) in Rwanda on characterization of the sludge generated at Kadahokwa WTP found that the concentrations of cadmium, chromium and iron were 1.1 ppm, 29.9 ppm and 45, 007 ppm respectively and these values are comparatively higher than the concentrations of the said elements found in the present study (Table 4).

According to Table 5, the concentrations of cadmium and chromium were found as 0.0335ppm and 6.55pm respectively in the sludge. Further, these values are far below than the toxicity threshold level for land application set according to SLS standards (SLS 1246: 2003) hence it is found to be safe for land application as well as for making compost (Central Environmental Authority Sri Lanka, 2003). However, the limit for threshold values of aluminum, iron and arsenic are not available in Sri Lankan standards for comparisons. The concentration of lead was not found up to detectable level. According to Uwimana *et al.* (2010) WTP sludge possess no serious detrimental properties and in particular no soluble aluminum. Further, according to Caniani *et al.* (2013) the chemical composition of the drinking water sludge does not show substances that could be dangerous for the environment, as it is found with a low risk of contamination for human beings and low concentrations of transfer of pollutants to soil and groundwater. On the other hand, a number of beneficial properties were found in DWS such as low bulk density, high infiltration rate, available nitrogen and a neutral to alkaline pH which are favorable for plant growth. Further Ippolito, Barbarick and Redente (1996) observed a linear relationship between increasing WTP sludge application rate and crop yield. Hence, the beneficial physical and chemical properties of the WTP sludge make it a good plant growth medium. However, loading effects of heavy metals as a result of continuous application on cultivation field should be considered and investigated.

When compare the physicochemical characteristics of sludge from Konduwatuwan WTP with the average values of aluminium based water treatment sludge as calculated by Ippolito, Barbarick and Elliott (2011) the pH and the Level of aluminium are comparable whereas the level of cadmium, chromium, lead and iron are lower while the total nitrogen level is higher in the studied sludge (Table 6).

A comparison between the present sludge with the values found by the American Society of Civil Engineers (ASCE) *et al.* (1996) based on 12 water treatment residuals reveals that the electrical conductivity and the pH values are comparable while the level of iron, cadmium, chromium and lead are comparatively lower in concentration (Table 6) in the present study with higher level of total nitrogen and aluminium.

VI. CONCLUSION

Based on the evaluation of the physical and chemical characteristics of the Konduwatuwan sludge, it is concluded that the sludge contains a higher percentage of organic matter content up to 39% throughout the period studied without significant fluctuation. The levels of pH, EC, total nitrogen and total phosphorous present in the sludge is within the suitable range for land application as it complies with the nutrient requirement for composting as per Sri Lankan standards. Further the concentrations of cadmium, chromium and lead are found far below than the threshold values for heavy metals for composting. Further, the pH, EC, levels of cadmium, chromium, iron, lead and nitrogen were promising in the sludge when compare with the characteristics of aluminium based water sludges used for a comparative analysis in this study. Though, the level of aluminum is higher in the DWS, the sludge can be recommended for land application and as an ingredient in making compost for non-food crops. However, further studies are necessary to evaluate the effects of aluminium and iron on crop growth and development on long term basis.

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