Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

ASSESSMENT OF THE APPLICABILITY OF TANNERY SLUDGE COMPOSTING IN BANGLADESH

Md. Zubayer Hossain[1], Aysha Khanam[2] , Md. Ariful Islam Juel*[3] and Al-Mizan[4]

[1]*Department of Leather Engineering, Khulna University of Engineering &Technology, Khulna, Bangladesh, e-mail: zubayerakunji@gmail.com*

[2]*Department of Leather Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: ayshameherunemm@gmail.com*

[3]*Department of Leather Engineering, Khulna University of Engineering &Technology,Khulna, Bangladesh, e-mail: juelbclt@gmail.com**

[4]*Department of Leather Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: almizan@le.kuet.ac.bd*

***Corresponding Author**

ABSTRACT

Chromium rich tannery sludge can be utilized through composting though heavy metals can be leached to the surrounding environment which isn't determined yet in Bangladesh. This research is carried out to find out the suitability of prepared tannery sludge (TS) compost in terms of pH, moisture content, organic matter, NPKS (Nitrogen, Phosphorous, Potassium and Sulphur), water solubility and the extent of bioavailability of heavy metals. Tannery sludge were mixed with cattle manure and domestic waste at different ratio for composting through preparing trapezoidal shaped piles. The composting process was evaluated during 80 days with monitoring the parameters at 20 days interval. Results indicate that the organic content was reduced from 46 to 39% for the suggested pile, pH value and NPKS content was in satisfactory level for composting. In addition, the water solubility of heavy metals increased with the increasing period of composting. In this study, concentration of Zn, Ni, Cd, Cu, and Pb were far below the standard value for composting whereas the very high Cr concentration (26,558-51,182 mg/kg) during 80 days composting was found to be exceeded the standard limit. Therefore, the presence of Cr in huge amount in compost discouraged the usability of tannery sludge compost in farming in Bangladesh.

Keywords: *Chromium, bioavailability, NPKS, heavy metals, compost.*

1. INTRODUCTION

Tannery sludge is seemed to be muddy, soft and thick in nature and produced mainly from the tannery effluent treatment process. Processing of leather through tanning process evolve a large amount of waste water that carries a massive amount of suspended solids, resulting in huge amount of tannery sludge. In Bangladesh, per year 85,000 tons of wet salted raw hides and skins are utilized for tanning (Paul et al. 2013). If all tanneries ETP (effluent treatment plant) become operational, then the amount of the partly dried sludge will be nearly about 19,000 tons (Juel et al. 2017). It contains eminent concentrations of heavy metals such as Cr, As, Pb, Ni, Cu, Cd, and Zn for using different syntans, basic chromium salt, dyes, tanning agents, retanning agents, pigments etc. in the leather processing (Juel et al. 2017; Mizan et al. 2016; Alam et al. 2019). It has the capability to contaminate soil, groundwater, surface water and conferments leading to a significant threat to the natural resources and environment if it is not managed suitably (Thomson et al. 1999). These detrimental heavy metals in sludge having non-biodegradability nature, lingering biological half-lives, potentiality to accumulate in biological systems which may cause complications to human health (Juel et al. 2017; Wilson and Pyatt. 2007; Singh et al. 2004).

Due to the nature of tannery sludge there is no certain universal utilization process for sludge management in the world. A number of solution have been proposed, tested, practiced and applied for semi-pilot, pilot and industrial scale. Several studies have shown that tannery sludge can be stabilized effectively in construction materials like bricks concrete, tiles, ceramic and some other engineering materials (Montañés et al. 2014; Basegio et al. 2002; Juel et al. 2017; Giugliano and Paggi, 1985) but no one process mentioned previously have been suited and developed at certain level that can meet the industrial need. Furthermore, treatment processes of this hazardous tannery sludge is still need more attention (Alibardi and Cossu, 2016).

Proper management of solid waste ia a big challenge througout the world. In Bangladesh, generation of solid waste (Sewage sludge, domestic waste, wood-chips etc) other than tannery sludge is near about 8000 tons per day, which is enhancing with the increase of urban population. However, managing these huge amount of waste in Bangladesh is hardly observed in a organized and scientific way. Although some steps have been taken to mitigate the issue which includes the practice of waste gathering, recycling, extrusion, land filling and incineration. Among them the most common practice is to dump the tannery sludge in a land known as landfills which is not a good practice in Bangladesh due to its limited space. Further, this huge amount of sludge when dumped in land makes the soil sterile and the crops can not grow properly (Juel et al. 2017). By incineration of tannery sludge harmful gasses like greenhouse gas, carbonaceous gas etc. are produced continuously which is a threat to environment, human being and animals. Despite the gas emmision, large quantity of energy is needed for incineration which is quite impossible to support for our country in terms of cost effectiveness. In addition, it is a matter of big concern that around 50 percent of waste remains uncollected and untreated that may contaminate water, air and is also liable for greenhouse gas emission and diseases. (Anwarul et al. 2015).

On the other hand, as a low cost method and efficient solid waste management system composting is recognized worldwide. In this system, labile organic matter is degraded by biological aerobic decomposition to water vapor, carbon dioxide (CO_2), ammonia (NH_3), inorganic nutrients and stable organic substance containing humic like materials that helps to process organic matters of different sources, such as sewage sludge, animal manure, agro-industrial wastes (Dinel et al. 2004). It allows waste firstly to the reduction of mass and volume then to be disposed off providing an environment that contains nutrient rich growth medium for plants as manure. Ahmed et al. (2007) had worked on chemical and physicochemical characterization of tannery sludge compost. Their analysis shows that all necessary parameters attain comparatively stable levels providing the maturity and stability of the decisive compost, and elicited that microorganism can be spontaneously soaked by the biodegradation of components. Akinci et al. (2013) outlined about the beneficial use of tannery wastewater treatment sludge compost where the tannery sludge was composted by mixing with other wastes of tannery.

In Bangladesh, there are very rare works done on tannery sludge composting. The aim of this study is to know the applicability and suitability of composting the mixture of tannery sludge, cattle manure and domestic waste for cultivation purposes which will be evaluated by measuring NPKS concentration, organic substance degradation and total heavy metal content.

2. MATERIALS AND METHODOLOGY

2.1 Materials

2.1.1 Collection of tannery sludge, domestic waste and cattle manure

Tannery Sludge (TS) samples was collected from Superex Leather Ltd, Uttar dihi, Phultola, Khulna, Bangladesh. The collected TS was damp in condition and muddy in color. The sample was collected in clean plastic sacks. Domestic wastes (DW) were collected from Rokeya Hall, KUET that includes rotten tomato, cauliflower, ladies' finger, papaya, string bean, red amaranth, eggplant etc. Clean polyethylene bag was used for the collection of DW. Another component of the mixture, cattle manure (CM) was collected from the house of a local habitat of Teligati, fulbarigate, Khulna. Plastic sack was also used to collect the cattle manure.

2.1.2 Chemicals

For the extraction process and other tests carried out in this study, a set of analytical grade chemicals were used that includes 70% Nitric acid (HNO_3), 30% Hydrogen peroxide (H_2O_2), Concentrated sulfuric acid (H_2SO_4), Sodium hydroxide (NaOH), Boric Acid (HBO_3), Acetic acid (CH_3COOH), Barium chloride ($BaCl_2$) etc.

2.2 Methodology

2.2.1 Composting

The collected tannery sludge was crushed to make small in particle size and domestic waste were cut into small pieces to make suitable for composting. TS, DW and CM were mixed thoroughly at a distinct ratio for different piles. Ratios of mixture of tannery sludge: cattle manure: domestic waste were 4.5: 4.0: 1.5 (Pile 1); 6.0: 3.0: 1.0 (Pile 2); 10.0: 0: 0 (Pile 3). All the piles were maintained for a fixed measurement, environment and formed a trapezoidal shape with 70cm long, base width 25cm, and top (height) width 30cm. Pile 3 have been considered as the control pile for composting. The total period of composting was decided for 80 days. Every pile was agitated and turned manually after every 10 days from the beginning and agitated piles contained approximately 50 kg of different waste combinations. The similar method for composting was followed by some authors (Singh et al. 2013; Das and Kalamdhad, 2011; Dhal et al. 2012). The samples for chemical test and analysis were collected after every 20 days.

2.2.2 Sample analysis

2.2.2.1 pH, EC and TDS, moisture content, organic content determination

Collection of compost sample for test was done by taking sample from five different positions of the prepared pile with the help of a sampler. After sampling, all five samples were mixed thoroughly for its homogenization and baked at 105°C for 24 hours. This dried sample was used for the determination of moisture content and organic content. 10g of dried sample was taken and diluted to 100ml by distilled water in a conical flask which was covered and kept in a shaker for 2 hours at 120 rpm for determining pH, EC and TDS. Another10gm of sample was taken in the crucible and kept in the oven at 105°C for 24 hours. The sample was cooled, stored in a desiccator for 15 minutes and finally weighted for moisture content determination. Then another dried sample was kept in a furnace at 550°C for 2 hours. The sample was cooled and stored in a desiccator and finally weighted for organic content determination.

2.2.2.2 Water Solubility Determination

Ground and powdered 2.5gm of sample was weighted and diluted with 50ml of distilled water for maintaining sample and solution ratio at 1:20. Then the container was kept in a shaker at 100rpm for 2hours to determine the solubility of compost in the water (Singh et al. 2013).

2.2.2.3 Heavy metal Determination

In a beaker, 1g dried compost sample was taken. 10 mL of HNO_3 was mixed in the sample and covered with watch glass. Then heat was applied in the sample at 95 ± 5°C and refluxed for 15 minutes except boiling. Then 5 mL of conc. Nitric acid was added and again refluxed for 30 mins. The addition of 5 mL HNO_3 was continued until no brown fumes were evolved from the sample. Brown fumes indicate incompletion of digestion procedure with HNO_3. Again, by covering the sample with watch glass, it was heated at 95°C ± 5°C for two hours to reduce the volume of the solution to approximately 5 ml. Sample was cooled to add 2 mL water and 3 mL 30% H_2O_2 and warmed for initiating peroxide reaction. Successive addition of H_2O_2 (not more than 10mL of H_2O_2) was continued with warming until the effervescence was minimal or the sample appearance was unchanged. When the peroxide reaction seemed to be completed, final sample volume was reduced to 5 mL by applying heat. Then the sample was allowed to cool, diluted with water and filtered through a 0.45 µm filter paper (Juel et al. 2017). Cr, Zn, Cu, Ni, Cd and Pb concentration were determined by Atomic Absorption Spectrophotometer (AAS) (Shimadzu AA 7000).

2.2.2.4 NPKS Determination

Dried and ground 30g of sample was taken for NPKS determination by following Kjeldahl method (Nitrogen analysis), Flame Photometer or by an Atomic Absorption Spectrophotometer method (Potassium analysis), Ascorbic acid method (Phosphorous analysis) and Turbidity metric method (Sulphur analysis).

3. RESULTS AND DISCUSSIONS

3.1 Physico-chemical characteristics of the compost

Figure 1 depicts the pH variation of the different piles of compost which ranges from 6.7 to 8. The optimum pH for the development of bacteria and mold are 6.0–7.5 and 5.5-8.0 respectively (Amir et al. 2005). Initially (1-20 days) the pH was slightly higher for all piles, exceptiionally high pH was observed for pile 1 upto 20 days in this study. This increase of pH might occur due to the release of NH_3 during composting from the degradation of protein because this pile contained the highest percentage of proteinous organic matter which is in the agreement with other research (Singh et al. 2013). This increasing trends ceased at 40 days and followed a constant pH around 7.4 for all of the piles. Whereas, for pile 3, sudden pH fall (6.7) was observed at 40 days which might be the result of formation of CO_2 and organic acids evolved from the microbial metabolism, although this pH is not harmful for composting (Haimi and Hutha, 1986). In addition, adequate aeration was supplied in all piles through turning the piles by maintaining 10 days interval as such level of CO_2 decreased which forced to increase pH in the compost and made an obligation to proceed anaerobic conditions (Haug et al. 1993).

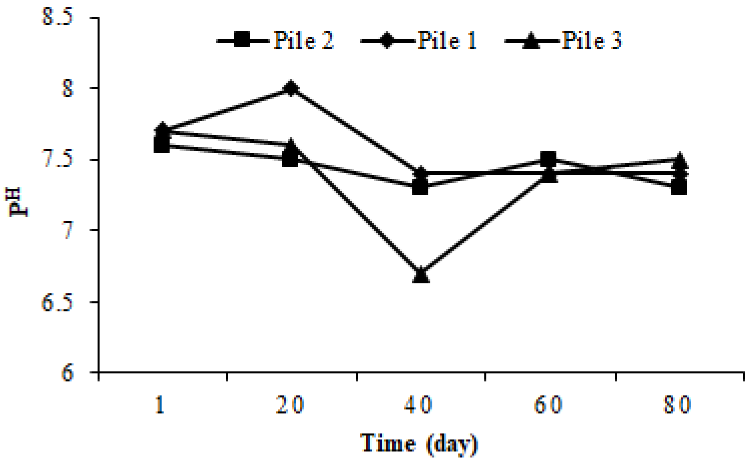

Figure 1: Variation of pH during composting process

Moisture content variation is shown in figure 2. Initial moisture content of TS, CM and DW were 59%, 74% and 91% successively (table 1). In pile 1, 2 and 3, MC were 71.30%, 67.30%, and 61% which reduced to 55%, 48%, and 48.57% after the whole period of composting (80days) respectively. The trend of moisture content loss is almost same for all of the piles and order of MC for the three piles in this study is following: pile 1>pile 2> Pile 3. That implies that high proportion of CM and DW led to increase the moisture content of compost. However, optimum MC for composting was observed for all piles. In this research, moisture content of pile 1, 2, and 3 was in a decreasing order which is in congruence with the other study (Amir et al. 2005).

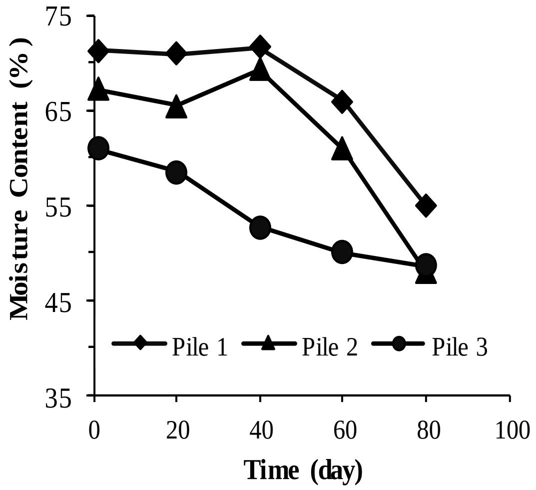

Figure 2: Variation of moisture content with period of composting for different piles.

Organic matter which is the most significant part of a compost due to its nutrient value were in the range 32-48% (Figure 3). From the figure 3, the organic content decreases with the increase of days of composting. The loss of organic content took place for the decomposition and transformation of organic matter. During composting, organic matter is also converted into stable humic compounds (Amir et al. 2005) which is considered as a potential source of nutrients and poses the pH buffering capacity and also capable to interact with inorganic metal ions (Singh et al. 2009). In this research, the lowest organic content was found for pile 3 (32%). A significant organic matter loss was noticed for all the piles (Figure 3). However, the organic content was in suitable conditions for all the piles in this work. Similar result was found by other research of composting (Singh et al. 2013).

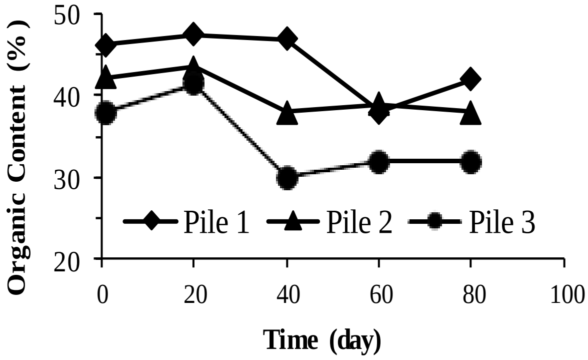

Figure 3: Variation of organic content with period of composting for different piles.

Nitrogen, phosphorous, potassium and sulphur are the vital element of plants and vegetables. Nitrogen helps in making structure of protein inside plants and assist the photosynthesis process, when phosphorous acts as the key structure compounds and catalysts for inner biochemical reaction in plants, phosphorous and sulphur are responsible for plants growth (Othman et al. 2012). Figure 4 represents the NPKS concentration of 80 days compost. In this study, 0.64 - 0.94 mg/kg N, 5.6 – 13 mg/kg P, 18 – 27 mg/kg K, and 13 – 22 mg/kg of S were noticed in the prepared compost which is suitable for the plant's nutrition. The amount of NPKS in pile 1 were 0.90, 6.20, 27, and 22 mg/kg respectively, which is higher than pile 2 and 3 because of the high amount of organic matter in pile 1 with respect to pile 2 and 3 except for the nutrient P in pile 3. The high amount of P in pile 3 might be happened for the high content of P in tannery sludge. The probable source of P may be the use of salt during leather processing.

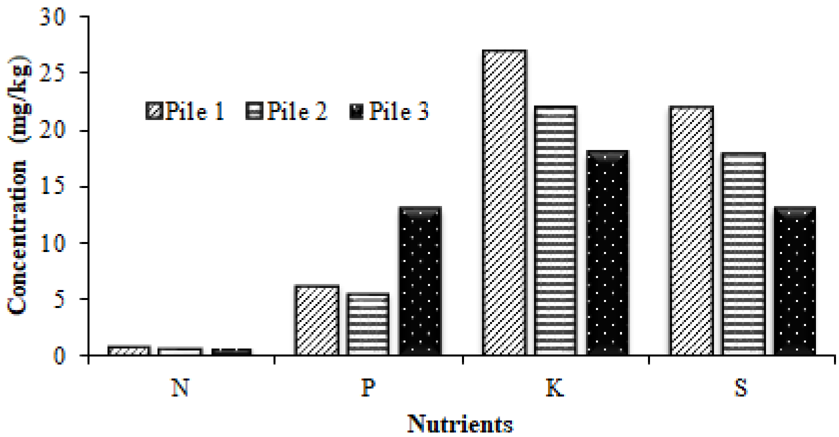

Figure 4: Concentration of NPKS after 80 days.

Table 1: Characterization of tannery sludge, cattle manure and domestic waste.

Ingredients	Moisture content (%)	pH	Organic content (%)	Electrical conductivity (µS)	Total Dissolve Solid (mg/L)
TS	59	5.8	36	1167	535
CM	74	6.2	45	1357	624
DW	91	6.7	85	678	540

Table 2 illustrates electrical conductivity of the compost with respect to time. It has been revealed that a decreasing order of EC in pile 1 is observed up to 60 days but increased during 80 days composting. After 60 days, the organic content loss was noticed more than 80 days composting (Figure 3) which signifies that the organic matter converted into humic substances and interacted with the metal ion to form compound that led to lowering the EC. On the other hand, during 80 days for pile 1 and 2, the organic matter increases somehow that prompted to increase in EC. Further, an increasing trend of EC was found for pile 3 as this pile consists of TS which contain a huge amount of inorganic substances.

Table 2: Variation of EC (µS) during composting process.

Pile	No of days				
	01	20	40	60	80
Pile 1	1199	934	862	727	828
Pile 2	996	822	876	892	1134
Pile 3	850	973	1555	1383	1042

The TDS of tannery sludge, cattle manure and domestic waste were 535, 624, 540 mg/L (table 1). During composting, TDS followed a lowering trend upto 60 days for pile 1 and 2 (Table 3) while TDS value maintained the increasing order for pile 3 ranging 455 to 668 mg/kg during 60 days. Interestingly, during 80 days TDS value for pile 1 and 2 increases, whereas for pile 3 the value decreases from 668 to 555 mg/kg (Table 3).

Table 3: Variation of TDS during the composting process (all values are in mg/kg).

Pile	01	20	40	60	80
Pile 1	535	443	413	396	563
Pile 2	453	398	424	403	506
Pile 3	455	463	744	668	555

Concentration of heavy metal during 80 days composting is focussed in table 4. It is revealed that Cr concentration in pile 1, 2, and 3 was found to be 26,558 to 51,182 mg/kg, which exceeded the standard limit 900 mg/kg set by DoE, Bangladesh of 2nd grade compost for sludge. Ni, Pb, Zn, and Cu concentration were within standard limit. The heavy metal Cd is also above the set standard limit showing risk for compost utilization. The availability of this high amount of Cr is for the use of basic chromium salt in leather tanning which make a huge Cr containing effluent that is being discharged in the effluent treatment plant. Thus the main challenge for the composting by tannery sludge is the enormous concentration of Cr in compost.

Table 4: Concentration of heavy metals (mg/kg) after 80 days

Pile	Cr	Pb	Zn	Cd	Cu	Ni
Pile 1	26558	28	1031	12	23	4
Pile 2	44320	57	1424	32	35	6
Pile 3	51182	77	1750	51	42	9
Standard[a]	900	900	2500	10	800	200

[a]DoE, Bangladesh, 2015

Table 5 elucidate about the water-soluble metal concentration during 80 days composting. From the table 5, only the metal Cr for pile 1 and 2 possessed the higher solubility in water. Solubility in water increases the probability of heavy metal contamination in surface water, food chain and leaching to the ground water which may lead bioaccumulation further (Liu et al. 2008). The solubility of metal Zn, Cd, and Ni were in negligible amount after the composting period in this research. Pb and Cu were not found to be soluble with water in any piles of compost during 80 days. This result is in the agreement with other study (Singh et al. 2012).

Table 5: Concentration of water-soluble metals (mg/kg) during 80 days

Pile	Cr	Pb	Zn	Cd	Cu	Ni
Pile 1	5.88	ND	0.12	0.56	ND	0.28
Pile 2	29.64	ND	0.56	ND	ND	ND
Pile 3	1.56	ND	0.06	0.46	ND	0.06

ND = Not Detectable; detection limit = >0.001mg/L

4. CONCLUSIONS

The tannery sludge that is housed with extra chromium has the probability to cause severe environmental burden by polluting surface water, groundwater, soil etc. This study was an approach to prepare compost by which tannery sludge can be utilized to a large extent in Bangladesh. Considerably higher levels of major nutrients NPKS were found in compost compared to chemical fertilizer and compost prepared by respective organic wastes for plant growth. The observed pH, moisture content was in a well manner for composting. Organic content which plays a vital role in the composting and plant growth mechanism also was in line. But the heavy metal concentration of prepared compost after 80 days especially Cr was manifold (30) greater than the standard permissible limit set by DoE, Bangladesh. Furthermore, the high concentration and water solubility of Cr discouraged the use of tannery sludge compost in farming and plantation. The reason for higher concentration of heavy metal Cr may be due to the initial higher concentration of Cr present in tannery sludge. However, if the initial concentration of heavy metal in tannery sludge can be reduced by means of onsite Cr removal or any other process then composting by this process may bring attention to apply in agricultural purpose.

ACKNOWLEDGEMENTS

Authors wish to thanks Department of Leather Engineering, Khulna University of Engineering and Technology for providing the test facilities. The authors also want to thank “Asia Arsenic Network”, Jashore, Bangladesh for carrying out necessary test.

REFERENCES

Ahmed, M., Idris, A. and Omar, S.R.S. (2007). Physicochemical characterization of compost of the industrial tannery sludge. *J. Eng. Sci. Technol*., **2**, (1) 81-94.

Akinci, G., Dikmelik, Y., Kaman, Y.N. (2013). Composting and Beneficial Use of Tanner Wastewater Treatment Sludges DOI: 10.1016/j.compag.2013.07.006.

Alam, M.S., Han, B., Al-Mizan. and Pichtel. J. (2019). Assessment of soil and groundwater contamination at a former Tannery district in Dhaka, Bangladesh. Environ. Geochem. Health. https://doi.org/10.1007/s10653-019-00457-6.

Alibardi, L. and Cossu, R.. (2016). Pre-treatment of tannery sludge for sustainable landfilling. Waste Manage. 52, 202–211. http://dx.doi.org/10.1016/j.

Amir, S., Hafidi, M., Merlina, G. and Revel, J.C. (2005). Sequential extraction of heavy metals during composting of sewage sludge. *Chemosphere*, **59**, 801–810. DOI: 10.1016/j.chemosphere.2004.11.016.

Basegio, T., Berutti, F., Bernardes, A., Bergmann, C.P. (2002). Environmental and technical aspects of the utilisation of tannery sludge as a raw material for clay products. J. Eur. Ceram. Soc. 22, 2251–2259. http://dx.doi.org/10.1016/S0955-2219(02)00024-9.

Das, A. and Kalamdhad, A.S. (2011). Evaluation of water hyacinth compost stability using respirometric techniques. *Int. J. Res. Chem. Environ.*, **1** (1), 109-113. DOI: 10.4491/eer.2012.17.2.069

Dhal, G.C., Singh, W.R., Khwairakpam, M. and Kalamdhad, A.S. (2012). Composting of water hyacinth using saw dust/rice straw as a bulking agent. *Int. J. Environ. Sci.*, **2** (3), 1223-1238. doi:10.6088/ijes.00202030009

Dinel, H., Marche, T., Schnitzer, M., Pare, T. and Champagne, P. (2004). Co–composting of paper mill sludge and hardwood sawdust under two types of in–vessel processes, Journal of Environmental Science and Health, Part b: Pesticides, Food Contaminants and Agricultural Wastes, Vol. 39 (1), 2004, 139–151. DOI:10.1081/pfc-120027445.

DoE, Bangladesh, (2015). Bangladesh Standards and Guidelines for Sludge Management.Liu, S., Wang, X., Lu, L., Diao, S. and Zhang, J. (2008) Competitive complexation of copper and zinc by sequentially extracted humic substances from manure compost. Agr. Sci. China, 7 (10), 1253-1259.

Giugliano, M., Paggi, A. (1985). Use of tannery sludge in brick production. Waste Manage. Res. 3, 361–368. http://dx.doi.org/10.1016/0734-242X(85)90129-6.

Haimi, J. and Hutha, V. (1986). Capacity of various organic residuesto support adequate earthworm biomass in vermicomposting.*Biol. Fertil. Soils,* **2,** 23–27.

Haug, R.T. (1993). The practical handbook of composting engineering. Lewis Publishers, Boca Raton. DOI: https://doi.org/10.1201/9780203736234

Juel MAI, Mizan A. and Ahmed T. (2017). Environmental and technical aspects of recycling of tannery sludge in brick production, 5th International Conference on Solid Waste Management in South Asian Countries.

Juel MAI, Mizan A. and Ahmed T. (2017). Sustainable use of tannery sludge in brick manufacturing in Bangladesh, 60, 259-269. DOI: 10.1016/j.wasman.2016.12.041

Kalamdhad, A.S., Singh, Y.K., Ali, M., Khwairakpam and Kazmi, A.A. (2009). Rotary drum composting of vegetable waste and tree leaves. *Bioresour. Technol*., **100,** 6442–6450. DOI: 10.1016/j.biortech.2009.07.030

Mizan, A., Zohra, F.T., Ahmed, S., Nurnabi, M. and Alam, M.Z. (2016). Low cost adsorbent for mitigation of water pollution caused by tannery effluents at Hazaribagh. *Bangladesh J. Sci. Ind. Res.* 51(3): 215-220.

Montañés, M.T., Sánchez-Tovar, R. and Roux, M.S. (2014). The effectiveness of the stabilization/solidification process on the leachability and toxicity of the tannery sludge chromium. J. Environ. Manage. 143, 71–79. DOI: 10.1016/j.jenvman.2014.04.026

Othman, N., J.M. Irwa, N. and Roslan, M.A. (2012). Composting of food waste, International Journal of Integrated Engineering, Vol. 4 (2), 2012, 39–48.

Paul, H.L., Antunes, A.P.M., Covington, A.D., Evans, P. and Phillips, P.S. (2013). Bangladeshi leather industry: an overview of recent sustainable developments. SLTC J. 97, 25–32.

Singh, CR ., He, H.,Yamamoto, Y. and Asano, K. (2004). Efficient incorporation of eukaryotic initiation factor 1 into the multifactor complex is critical for formation of functional ribosomal preinitiation complexes in vivo. *J Biol Chem* 279(30):31910-20

Singh, J. and Kalamdhad, A.S. (2013). Bioavailability and leachability of heavy metals during water hyacinth composting, Chemical Speciation & Bioavailability, 25:1, 1-14.DOI: 10.3184/095422913X13584520294651.

Singh, S.; Kushwaha, B. P. ; Nag, S. K. ; Mishra, A. K. ; Singh, A. ; Anele, U. Y. (2012). *In vitro* ruminal fermentation, protein and carbohydrate fractionation, methane production and prediction of twelve commonly used Indian green forages. Anim. Feed Sci. Technol.,178 (1/2): 2-11

Singh, Y.K., Kalamdhad, A.S., Ali, M. and Kazmi, A.A. (2009). Maturation of primary stabilised compost from rotary drum composter. *Resour. Conserv. Recycl.,* **53,** 386–392. DOI:10.1016/j.resconrec.2009.02.004

Thomson, J.C., Azariah, J., Viji, A.G.R. (1999). Impact of textile industries on river Noyyal and riverine groundwater quality in Tirupur, India. Environ. Monit. Assess. 18, 359–368.

Wilson, B., Pyatt, F.B. (2007). Heavy metal dispersion, persistence, and bioaccumulation around an ancient copper mine situated in Anglesey, UK. Ecotoxicol. Environ. Saf. 66, 224–231. DOI: 10.1016/j.ecoenv.2006.02.015.