Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH – Promotion of Social and Environmental Standards in the Industry (PSES)

Technical Report on

Textile Sludge Management in Bangladesh

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Abbreviation

AOX	Adsorbable organic Halogen
BAT	Best Available Techniques
BIS	Bureau of Indian Standards
CPCB	Central Pollution Control Board, India
CETP	Common/Central Effluent Treatment Plant
DoE	Department of Environment
ETP	Effluent Treatment Plant
GIZ	Gesellschaft für Internationale Zusammenarbeit (German International Co-operation)
GoB	Government of Bangladesh
HDPE	High Density Polyethylene
I-TEQ	International-Toxicity Equivalent
LDPE	Low Density Polyethylene
MEP	Ministry of Environmental Protection, China
MOEF	Ministry of Environment & Forests
PCDD	Polychlorinated dibenzodioxins
PCDF	Polychlorinated dibenzofurans
PSES	Promotion of Social and Environmental Standards, GIZ
SOP	Standard Operating Procedure
TOC	Total Organic Carbon
USEPA	United States Environmental Protection Agency
WDF	Washing/Dyeing/Finishing

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1 Introduction

Sludge is the residual, semi-solid material left from industrial and municipal wastewater treatment processes. Industries with wastewater treatment facilities continuously produce large amount of sludge that needs proper attention in terms of handling and disposal. Sludge handling and processing is becoming a big issue to the companies which are running their effluent treatment plant (ETP) continuously or intending to run it continuously. It is important to evaluate the sludge to determine if a specific sludge is suitable for certain disposal options. It is also required to characterize the sludge in terms of their chemical, physical, and biological characteristics to determine the most cost-effective sludge-management options. A proper sludge management method is crucial to ensure that human health and the environment are strictly protected from any negative impacts of sludge management.

The principles behind sludge management are coherent with the concept of reducing, reusing and recycling (National 3R strategy) followed by disposal. Efficient sludge management includes a systematic plan, proper sampling procedure at appropriate location, analysis and disposal. Different types of ETP treat wastewater to extract the pollutant out and reduce the volume of pollutant. However, all these can go in vain if the extracted sludge containing all pollutants are not processed before releasing to the atmosphere. This calls for a proper sludge management approach ensuring no further dissemination of the pollutant into the atmosphere.

2 Classification of Sludge

According to the Bangladesh Environment Conservation Act, 1995 (Amendment 2010) proper management of sludge is mandatory. In order to further detail the requirements to this regard, the Department of Environment (DoE), Ministry of Environment and Forests, with the technical support from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH prepared and published 'Bangladesh Standards and Guidelines for Sludge Management' in 2015. These sludge guideline outlines, (i) General requirements for classification and management, (ii) Classification of sludge, and (iii) Sludge management options.

Sludge can be classified based on their origin and compositions. According to the Standards & Guidelines for Sludge Management approved by the Ministry of Environment & Forests, Government of Bangladesh sludge can be classified as

***Category A*:** Municipal sludge including comparable sludge.

If the sludge is produced in a sewage treatment plant treating only domestic or urban wastewaters it may be counted as municipal sludge and classified as *Category A.*

If the sludge is produced in a sewage treatment plant treating wastewater comparable to domestic or urban wastewaters such as food processing industries, it may be counted as municipal or comparable sludge and classified as *Category A.*

***Category B*:** Sludge from industry including sludge from the Central Effluent Treatment Plant (CETP).

If the sludge cannot be categorized either as *Category A* or as *Category C*, it will be considered as sludge of *Category B*.

Category C: Sludge from industry including sludge from CETP belonging to the category of hazardous waste.

If the sludge or the wastewater are from hazardous labelled industry or contain any chemical recognized as hazardous it must be counted as hazardous waste and classified as *Category C*. These wastes exhibit one or more hazardous characteristics such as high flammability, explosive property, oxidizing property, poisonous, infectious etc.

Sludge under *Category A* is generally considered safer compared to *Category B*, and the sludge under *Category C* is considered to be the most hazardous. In case of a sludge mixture containing more than one category of sludge, the combined sludge category is generally considered to be the next level of hazardous category (*e.g.* for a mixture of *Categories A* and *B*, the combined sludge is considered to be of *Category B*).

3 Literature review: Sludge from Textile Industry

The textile wet processing industry uses a wide variety of chemical products. The pre-treatment processes (desizing, scouring, bleaching etc.) of fabrics and yarns uses detergent and other surface active agents such as antifoaming, demineralizing agents as well as halogenated solvents (usually tetrachloroethylene). Including acid and alkali (for pH adjustment) and other finishing chemicals to impart water repellency, fire retardancy, durable press or insect repellency may leave residues which will eventually end up in the waste stream.

Annex 2B in Bangladesh Standards and Guidelines for sludge management shows list of waste process as far as the sludge production is concerned. In that list, textile sludge comes under section 4. Table 1 (from Annex 2B) for textile industry allows to determine whether the sludge is hazardous or not according by looking at the waste generating process.

Table 1 Different wastes from textile industries according to European waste category

04 02	wastes from the textile industry	Hazardous
04 02 09	wastes from composite materials (impregnated textile, elastomer, plastomer)	
04 02 10	organic matter from natural products (for example grease, wax)	
04 02 14*	wastes from finishing containing organic solvents	x
04 02 15	wastes from finishing other than those mentioned in 04 02 14	
04 02 16*	dyestuffs and pigments containing dangerous substances	x
04 02 17	dyestuffs and pigments other than those mentioned in 04 02 16	
04 02 19*	sludges from on-site effluent treatment containing dangerous substances	x
04 02 20	sludges from on-site effluent treatment other than those mentioned in 04 02 19	
04 02 21	wastes from unprocessed textile fibres	
04 02 22	wastes from processed textile fibres	
04 02 99	wastes not otherwise specified	

In the list 04 02 14, 04 02 16 and 04 02 19 are marked as hazardous. However, if these wastes do not also include organic solvents they should be classified as non-hazardous under 04 02 15. Solvent containing wastes should be considered under H3B; H4 to H7 (carcinogenic at $\geq$ 1%) and H10, and additionally under H8 and H11 if acid, alkali or heavy metal contamination is present. Dyestuffs and pigments, and sludges from effluent treatment, can contain a range of organic and inorganic substances, including heavy metals. These wastes should be considered under H3B; H4 to H8 and H10 to H12 [1]. The code of hazardous characteristics is given in Table 2.

Table 2 Hazardous code and associated characteristics

Code	List of Hazardous Characteristics
H1	Explosive
H3	Flammable liquids
H4	Flammable Solids
H5	Oxidising/Organic peroxide
H6	Poisonous (acute)/Infectious substances
H7	Carcinogenic
H8	Corrosive
H10	Liberation of toxic gases in contact with air and water
H11	Toxic (delayed or chronic)
H12	Ecotoxic

The wastewater generated from these textile processes is treated in effluent treatment plants (ETP) utilizing different chemicals such as Alum, Ferric chloride, Lime and Polyelectrolyte etc. During the treatment process, sludge gets accumulated in different stages, which is not only troublesome to that industry but also adversely affects the environment. The sludge generated from ETP needs to be further treated and disposed of safely. Production of sludge indirectly indicates the performance of the ETP, and whether the ETP is running continuously or not. Both physicochemical and biological stages of ETP generate sludge, however, the sludge characteristics might vary. Despite the differences in the nature of the sludge from each process stage, all the sludge is usually combined and handled together.

3.1 Textile Sludge in Bangladesh

The current practice of sludge disposal in Bangladesh is not very organized and environmentally safe. Department of Environment (DoE), Bangladesh instructed the industries to store the sludge for 6 months and after that there is no indication on what to do with these sludge. After these period, industries dump their sludge into the adjacent low lands. These piles of dumped sludge come in contact with flood, rain and the surrounding land and water get contaminated. Therefore, there is a growing need to look for various disposal options of textile sludge which will be safe to human health and environment.

3.1.1 Types and quantities of sludge generated in an ETP

In a study by GIZ it was found that 60% of the ETPs are of physico-chemical nature in Bangladesh. The capacity of the ETPs varies from 5 - 350 m^3/hr and with an average capacity is almost 50 m^3/hr [2]. It was estimated that in 2007, the total amount of sludge from textile sector generated was 113,720 tons/year which was projected to rise to 2.81 million tons/year in 2012[1]. It was estimated that 1 m^3 effluent approximately generated 1.14 Kg dry sludge in 2007.

It was found in a survey carried out by GIZ PSES in 2011 that 20 factories generated approximately 60 tons of dry sludge per day with the spread given in Table 3. However, this value gives us an indication of the sludge produced rather than the actual generation of sludge since very few factories actually treat all their wastewater through ETP to the standard required and at the same time few measures daily generation of sludge.

Table 3 - Sludge generated from different types of ETPs

Type of ETPs	No. of ETP surveyed	Dry sludge (tons)
Physico-Chemical	4	1.3
Biological	4	0.7
Combined chemical and biological	12	58

Because of the nature of the chemicals used in the textile industries, sludge are most like to fall in *Category B* and *C*. Considering the potential health and environmental impact hazardous sludge is not recommended to use in agricultural purpose unless proven that there is no hazardous substances in it. Some industries might have flow segregation and less polluted streams may produce safer sludge. Therefore, textile industries must test their sludge before making any disposal plan.

[1] DoE, Waste Concern and ADB 2008

Depending on the category of sludge, disposal option could be incineration, mixing with raw materials of different industries, controlled landfilling are few other alternatives that can be considered. Recycling and use of wastes are the preferred options for sustainable development, rather than incineration or landfilling, but sometimes it is not environmentally sound as for example contaminants like heavy metals etc. have to be phased out of the recycling circle.

3.2 Sludge Disposal Situation in India

In India, nearly 290 million tonnes of industrial wastes are generated annually of which around 7.2 million tonnes are hazardous and require careful disposal [3,4]. Landfilling and agricultural applications are the most common practices in India along with rising trend of incineration [5]. However, applications as fuel (biogas) and utilization in building and construction materials production are moderately practiced in India as well [5,6].

3.2.1 Landfilling

One of the reasons for landfilling being the most common practice in India is the classification of CETP sludge as hazardous under the Hazardous Waste Management Act 1986 and amendments [7]. Central Pollution Control Board (CPCB), India has suggested criteria for direct disposal of hazardous waste into secured landfill [8].

3.2.2 Building and Construction Materials

Several research work have been performed in India to assess the suitability of the sludge application in different fields. One of the ideas is to find an environmental friendly material as well as alternative low cost material for building purposes [9,10]. Recycling of waste generated from industrial or agricultural activities as building materials appear to be a solution for economic design of the building as well as in environment pollution problem.

The inorganic materials from sludge can be used as building and construction materials. Unless the chloride concentration is high, chemical sludge can be utilized in preparing clinker in cement kilns. Dry solid sludge with low moisture and VOC can be supplemented with cement, fly ash and lime and used as ingredient in preparing building/road construction materials e.g. tiles and pavement blocks.

For the applications in the field of construction, the solidification and stabilization technology has been used to treat industrial solid waste containing toxic constituents to make them biologically inert and to prevent their release into the environment [11]. On the other hand, incinerated sludge produces energy and ashes which partly contain heavy metals and phosphorus. Processed sludge can also be used as supplementary fuel. The recovered energy may be used as heat or electricity. Ash can be used as building and construction material like brick making, cement manufacturing and use in pavement. In case of incineration, emission limits are very important. Apart from furans, dioxins and a number of other flue gases, about 5 to 10 % of the total chromium is converted from chromium (Cr^{+3}) to the carcinogenic chromium (Cr^{+6}). Therefore, hazardous waste incinerators are required to comply with the gaseous emission standards applicable in the country following best available techniques (BAT). In India, emission results need to comply with norms notified under the Environment (Protection) Fifth Amendment Rules, 2008 [8], and similarly in Bangladesh it should comply with Air Quality Standards (Bangladesh Govt. Gazette S.R.O. No: 220-Law/2005 of 16 July 2005). CPCB has already performed trial run for co-processing of few categories of wastes and granted regular permission to industries. As of 2010, total 22 cement manufacturing units in various states already started co-processing of these few categories of wastes with the approval of CPCB [12].

3.2.2.1 In Brick Industry

Sludge from textile mills has a high potential to be used in brick industries. One of the studies in India has reported that bricks can be made with different sludge and clay mixing ratio (5% to 35%) and also different firing duration as well [13]. Based on the results, textile sludge could be added up to 15% as it provided compressive strength above 3.5MPa and the water absorption ratio was also less than 20%. Sludge has been utilized as raw material in brick industries and the properties of these bricks were reported to meet the Bureau of Indian Standards (BIS) [14,15,16]. The utilization of the sludge in clay bricks usually has positive effects on the properties such as lightweight bricks with improved shrinkage, porosity, thermal properties, and strength resulting in reduced transportation and manufacturing cost [17,18].

In a separate study in Brazil, it was suggested that sludge can be incorporated up to 20% in terms of the mechanical properties resulting in 4.62 MPa compressive strength compared to 3.73 MPa of the control brick [19]. Water absorption result was reported to be 15.73% and 10.10% for control and sludge brick, respectively. In addition, the brick was tested safe in terms of leaching behaviour. However, in contrast to these findings, one of the studies in India has reported the optimum sludge mixing ratio only up to 9% in order to fulfil the brick standards of the Bureau of Indian Standard (BIS) [6]. This idea of sludge being used as brick making raw material has been verified in several other countries such as China [20], Taiwan [21], Egypt [22] and Spain [23].

3.2.2.2 In Cement industry

As mentioned before, another interesting application of sludge is the partial replacement of cement as the construction raw material. Several researchers investigated this possibility by making and then evaluating concrete blocks using cement and sludge mixture [4,24,25]. It has been suggested that concrete with a partial replacement of cement with ETP sludge might be suitable as building material. However, the compressive strength of concrete decreased as the sludge content increased. Concrete with Sludge content of 10% or more cannot be used as this will reduce the setting and the mechanical properties of concrete will be significantly affected [26]. In addition, long-term analysis of the sludge-mixed concrete has shown its durability to be comparable to regular concrete [27]. Similar studies have been performed to prepare ceramic, however, only up to 5% sludge content displayed good mechanical properties in term of water absorption, compressive strength and water suction [28]. These studies indicate that the potential use of sludge in construction industry is an alternative to the treatment and disposal of sludge considering the huge cost and complexity involved in the treatment. In addition, researches have been going on to search for other potential applications of the sludge as well [29].

3.3 Sludge Disposal Situation in China

According to the report of Ministry of Environmental Protection (MEP) of China, there were 1692 ETPs with design capacity of 907.9 billion m^3/day. In 2008 these ETPs treated annually $237.3*10^8$ m^3 industrial wastewater and $202.9*10^8$ m^3 domestic wastewater. However, the estimated wastewater which needs to be treated by 2020 is $536*10^8$ m^3 in a year [30].

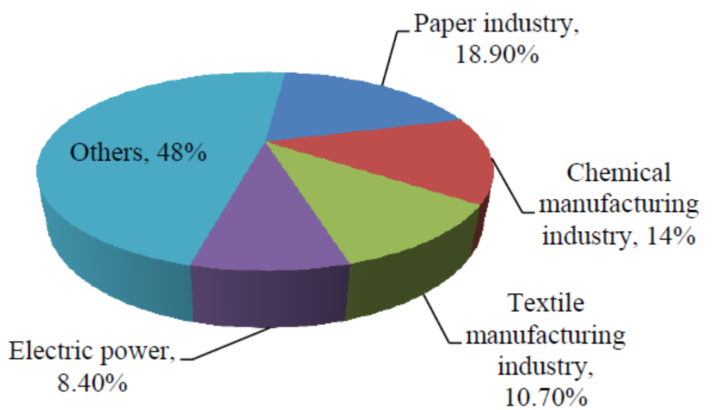
Although not declassified but in 2011 3.25 billion tons industrial solid waste (Hazardous and medical waste) was generated of which almost 2 billion tonnes industrial wastes were comprehensively utilized, a utilization rate of 60.5%. By the year end of 2011, 36 hazardous waste disposal projects were in operation and 1,500 hazardous waste business licenses had been issued by MEP [31].

Similarly in a recent survey by the Ministry of Environmental Protection and the Ministry of Land and Resources, it was reported that 16.1% of China's surveyed land is polluted by heavy metals such as cadmium, lead, mercury and Arsenic [32]. In addition, 19.4% of the surveyed arable lands i.e. 3.3 million hectors of land are not suitable for agricultural use due to higher level of pollution than the national standard. The most contaminated area due to heavy metals in is the central and southwestern areas and the severity of situation led to tainted crops, health hazard (e.g. loose teeth by children, adults and goats) and other environmental concerns. In Baiyin city in Northwest China's Gansu Province, the silt from 38-kilometer-long Dongdagou River contained levels of cadmium 2,200 times the national standard, while mercury was 2,000 times higher. In 2010, a national level restoration project in Huanjiang province led to planting heavy metal accumulating plants such as Pteris Vittala, Sedum Alfredii and mulberry, which helped improve soil quality [32].

3.3.1 Sludge generation in China by industry

Among the 39 categories of industries in China, the paper industry produces the highest percentage of wastewater discharge rates. After this, the chemical manufacturing industries, the textile manufacturing industries and the electricity production industries follow. These, combined with the paper industry, make up 52.0% of the wastewater discharge rate (Figure 1).

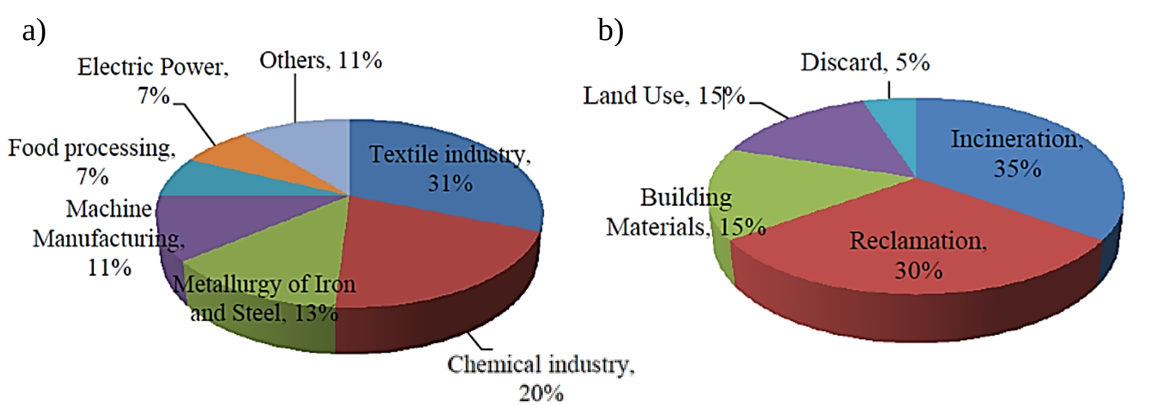
Figure 1 Wastewater discharge rate (MEP 2008)



3.3.2 Sludge disposal options in Shanghai

The most important 70 industrial enterprises in Shanghai, which are sources of wastewater, are mainly from 6 sectors (Figure 2a).The major disposal modes of sludge are given in Figure 2b).

Figure 2 a) Sectors Distribution of Industrial Enterprises b) disposal mode of industrial sludge in Shanghai



Although very few data is available, however, average contents of heavy metals in Sludge of Shanghai wastewater treatment plants are given in Table 4. The heavy dosage of Manganese (Mn) is coming from iron, steel and chemical industry of which Shanghai is known for. Mn is used as deoxidizer and in desulphurization in these industries.

Table 4 Average heavy metal contents on sludge of Shanghai ETP

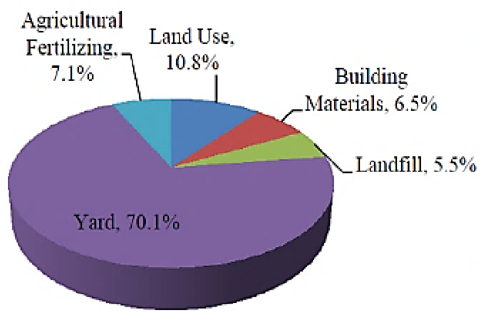
Parameters	Zn	Cu	Cr	Ni	Mn	Pb
mg/kg	2841.2	1926.7	1130.5	1100.6	6170.2	55.4

The conventional methods for disposal of sludge in China is safe landfill deposition, reclamation and sludge incineration [33].

3.3.3 Sludge disposal options in Beijing

The wastewater generated in Beijing in 2009 was approximately $13.4*10^9$ m^3/year, of which 78% of wastewater can be treated. These ETPs generated approximately 2,700 tonnes of sludge per day of which moisture content was around 80%. It is estimated that until 2015, the amount of generated sludge was 3,956 tonnes/day. The disposal of mode of sludge in 2008 is roughly given in Figure 3 [34].

Figure 3 Disposal mode of sludge in Beijing



Although Beijing was known to be an industrial city but due to environmental issues most of the industries were moved to Northern part of China. However, the concentration of heavy metals in sludge from six representative ETP operators: They are Gaobeidian (GBD), Beixiaohe (BXH), Fangzhuang (FZH), Jiuxianqiao (JXQ), Qinghe (QH) and Wujiacun (WJC) Plants, were still high in 2006, Table 5.

Table 5 Concentration of heavy metals in sludge from six different ETPs in Beijing in 2006 [35]

Heavy Metals	GBD(mg/kg)	BXH(mg/kg)	FZH(mg/kg)	JXQ(mg/kg)	QH(mg/kg)	WJC(mg/kg)
Cd	7.0±1.2	7.3±3.4	5.9±1.4	13.0±4.4	12.7±1.8	9.3±1.3
As	16.7±4.0	23.7±6.5	23.5±5.4	21.2±1.5	25.2±4.8	26.0±7.7
Cr	57.8±22.3	45.8±19.6	45.8±7.5	59.2±12.4	78.4±19.1	54.8±11.1
Hg	21.8±2.9	19.3±2.7	23.4±3.4	18.8 ± 2.2	17.0±2.4	24.0±6.0
Ni	49.9±12.8	49.3±17.1	51.8±21.2	95.5±10.1	56.8±10.2	60.0±15.1
Pb	57.5±10.4	57.5±18.3	70.4±21.6	109.3±33.5	81.3±7.4	95±22.6
Cu	229.0±70.4	218.0±97.5	131.2±27.8	272.2±66.7	253.6±84.2	394.5±204.9
Zn	1431.4±395.1	1088.2±259.6	783.4±118.1	1182.8±172.2	1376.8±267.9	3096.3±1303.5

3.3.4 Sludge disposal options in Chongqing

Chongqing is one of the oldest heavy industrial area in China and located at upper headwaters of Yangtze River. The city is mainly known for biggest cars, Chinese patent medicine, and apparatus and fine chemistry industrial base in China. The wastewater generated in 2006 was approximately

989 thousand m^3/year and the amount of sludge generated was 871.53 tonnes/day. The heavy metals found in five separate ETPs, which treats the wastewater from industrial bases are given in Table 5.

Table 6 Heavy Metal Content of the Sludge in Wastewater Treatment Plants in Chongqing in 2009 [36]

Wastewater Treatment Plants	Sludge Treatment Methods	Cu(mg/kg)	Zn(mg/kg)	Pb(mg/kg)	Cd(mg/kg)	Cr(mg/kg)	Ni(mg/kg)	As(mg/kg)	Hg(mg/kg)
Tangjiaqiao	Digestion	94.46	16.76	36.06	1.38	62.96	29.87	-	0.26
Chengnan	Drying	69.8	430	90.2	2.72	48.5	56	-	-
Changshou	Digestion	80.2	397	52.6	1.87	95	176	7.98	2.01
Fengdou	Digestion	170	502	50.1	2.78	47.4	46.7	13.5	3.04
Fuling	Digestion	135	444	68.8	2.94	70.8	40.6	17	2.61

Chongqing does not have naturally dry climate, which prohibits use in composting. The main disposals of sludge are building materials, landscaping, land use, reclamation and landfill, Table 6.

Table 7 Disposal Modes of Sludge in Chongqing [36]

Disposal ways		Disposal Amount(*10^4t/year)	Disposal Amount(*t/day)
Building Materials	Cement	108.84	2982
	Brick Making	23	630
landscaping	Fertilizer	0.02	0.61
	Soil Medium	100.23	2747.6
	Potting Soil	0.03	8.22
Land Use	Agriculture	159.51	4370
	Woodland	1153.4	31600
Reclamation		593.67	16265
Landfill		67.45	1848
Total		2206.42	60451.43

3.3.5 Estimated cost of Sludge treatment

Wang [30] investigated sludge disposal cost in three different cities of China in 2011 based on the volume of sludge, transportation distance, electricity, labour and particular disposal cost as appropriate. The estimated cost is given in Table 7. It is seen that composting (includes land use, landscaping and fertilizing) cost is the cheapest option compared to other alternatives but may be not the safe option due to presence of heavy metals in the sludge.

Table 8 Estimated cost of sludge disposal in three Chinese city [30]

City	Transportation Distance, km	Cost of Disposal, RMB/tonnes		
		Reclamation	Incineration	Compost
Shanghai	20- 60	1,066 - 2,314	2,243 - 2,926	294 - 328
Beijing	50	539 - 975	2,656 - 3,325	294 - 328
Chongqing	10- 60	774 -794	3,109 - 3,148	294 - 328

4 Standard operating procedure (SOP) for sludge collection and testing

4.1 Sludge pre-treatment

Sludge pre-treatment is part of the waste management plant to make the sludge easier to handle and utilize. Pre-treatment mainly includes sludge thickening, conditioning and dewatering. There are multiple options for each of the stages and a selection of these processes depends on the cost and suitability of the initial sludge. As the first step of sludge handling, sludge thickeners are considered to reduce the volume of sludge. Sludge conditioning is sometimes performed either chemically or physically with the same objective. Finally, dewatering can be done in a drying bed or by mechanical means such as vacuum filters or filter press.

4.2 Physical properties of sludge generated from ETP

Sludge can be physically different in different ETPs because of the pre-treatment and the overall ETP scheme. It can be like thick slurry or solid cake. Figure 4 shows sludge produced from ETPs of different textile industries.

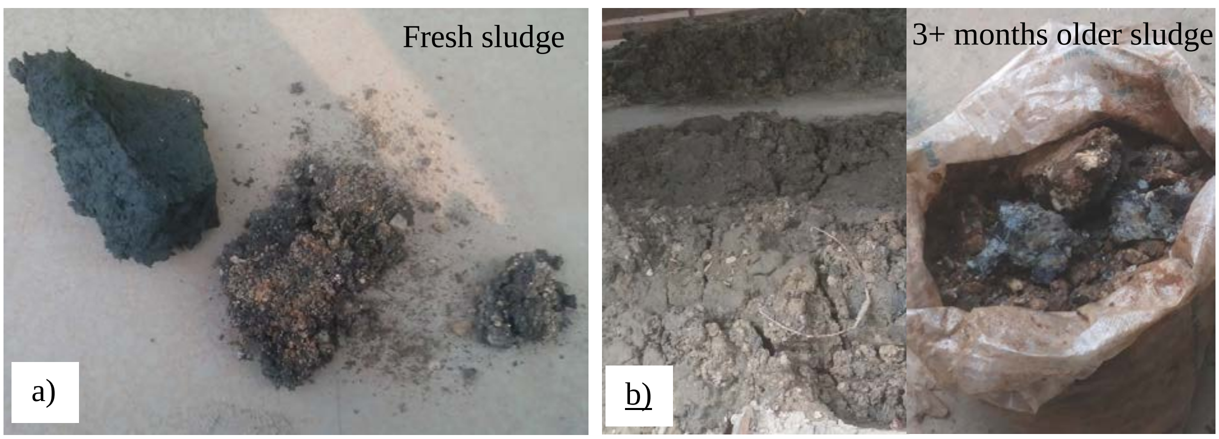
Figure 4 Semi-dry sludge from different ETPs of textile industries.

Sludge produced from the ETP normally contains high amount of moisture and is very difficult to handle and transport. Sludge generally loses moisture with time and becomes drier while being kept under shade. Industries are required to keep the sludge for sufficiently long time before it can be sent for landfilling. Figure 5 shows the differences between fresh and older sludge (kept for ~ 3 months or longer).

Recommendations for storage of the sludge

- *Storage Duration from 3 to 6 months*
- *Sealed and labelled basin/container/pit under shade*
- *No contact to water/rain/flooding/agricultural land*
- *Provision for safety for designated staff*
- *No un-authorised access to people and animal*
- *in areas with good access for workers to safely store the sludge without being harmed by already stored sludge*
- *labelling of storage container*

Figure 5 Sludge storage a) fresh or recent sludge b) at least 3 month older.



It is therefore recommended to store the sludge under a shade for sufficient time before disposal. The present stipulation is to keep it for a minimum period of six months to ensure maximum drying and stabilisation before disposal. Sludge does not dry at the same rate during the different seasons in Bangladesh, so it is difficult to predict an optimum storage time suitable for all seasons. Also, it is better to limit the storage for some disposal/reuse options. Accordingly, it is recommended to keep the sludge in accordance with the disposal option chosen and permission may be sought from DoE accordingly. This storage period may generally be in between 3 to 6 months, except in case of production of biogas where fresh sludge is needed.

It is highly recommended to arrange a defined storage area where contact to water or agricultural land is prevented and isolated from rain and flooding in the rainy season. Common practice is a masonry construction with HDPE/LDPE lining at the bottom to prevent any leachate joining the ground water. In addition, access should be restricted for un-authorised people and animals. The storage area should be selected such that it has good access for workers to safely store the sludge without being harmed by the already stored sludge.

4.3 Selection of sampling points

It is very important to identify specifically and accurately all sample collection points. The selected sampling points should be chosen to produce a representative sample of the sludge source. In addition, when the sampling locations are chosen, several factors should be considered such as type of process (batch or continuous), accessibility and safety. There are few points to be remembered:

- If it is possible to collect sludge from several stages before and after pre-treatment, it is recommended to choose the location that produces a representative sample, meaning that the chosen location meets the stated goals of the sampling plan. For example, if the sludge is to be used for agricultural purpose, it is better to sample from the pre-treated sludge that is ready for land application. If there is any disposal plan for raw, wet sludge, sampling should be done from the raw, wet sludge before any pre-treatment.
- If the objective is to observe changes in sludge quality or track the fate of a specific pollutant during sludge processing, then samples before sludge pre-treatment and completely processed sludge should be collected.
- Standard sampling generally requires that the sludge be collected at the end of the sludge treatment process in the form in which it will be recycled or disposed.
- Sampling sludge from batch process (e.g. lagoon, tank, plate and frame filter) requires collecting a number of grab samples from different areas throughout the sludge volume. Later, a composite sample should be generated from predetermined number of grab samples at random points throughout the batch.

Select Sample collection points based on the intended recycling/disposal options

- For continuous processes, multiple grab samples are collected from a single location within the process over time. For example, to sample from a belt filter press, a predetermined number of grab samples are typically collected from the first accessible or the most convenient location after the sludge has passed completely through the press.
- Lot of the times, the best sampling point may not be accessible, therefore, that sampling will need to be performed at the next best point of accessibility.
- If there is a risk of injury inherent to a particular sampling location, then a safer alternative should be considered. Once a sampling location is selected, the potential risks associated with that location needs to be identified. Appropriate safety precautions and protective equipment are to be considered as well.

4.4 Sampling procedure by ETP operator

Proper sampling is an integral part of monitoring the quality of sludge being removed for use or disposal. The key elements of a sampling plan can be divided into four groups focusing on consistency, communication, documentation and data handling.

- **Consistency** involves the assurance that all the samples are taken in the same way from the same location for every sampling event.
- **Communication** involves making sure that the laboratory understands the proper methods to run, types of the sample and key details regarding the facility.
- Proper sampling activity **documentation** includes proper sample labelling, sampling method and deviation from protocol, if any and a log book of sampling activities.
- **Data handling** involves proper reviewing of the collected information before the data gets submitted.

Sampling is the first, and perhaps the most critical area of the entire process of obtaining sludge quality information. A sample that is representative of the sludge being removed must be acquired in a manner that will not compromise its subsequent analysis. It is also desirable that the sampling procedures can be conducted at reasonable cost. To ensure the reproducibility, it is required that all sampling procedures are documented in a sampling plan. Some elements that should be documented in a sampling plan include: the sampling points, volumes to be drawn, days and times of collection, required equipment, instructions for labelling samples and ensuring chain of custody, and a list of contact persons and telephone numbers in case unexpected difficulties arised during sampling.

As mentioned earlier, it is equally important to identify the sludge sampling points at locations that assure homogeneity hence best represent the physical and chemical quality of all sludge of the plant. In case of heterogeneity, multiple grabs should be taken for each sampling step for better representation of the actual condition.

Sampling equipment to be utilized shall be identified and constructed of materials which will not contaminate or react with the sludge (for example, galvanized or zinc coated items may not be used).

- *Make sure Sludge sample is representative of the bulk*
- *Create a sampling plan with proper documentation*
- *Follow the same sampling procedure to ensure reproducibility*

BASIC STEPS TO BE FOLLOWED DURING SAMPLING ARE

1. Several days prior to the proposed sampling, it is important to ensure that sludge in the appropriate form (dewatered) would be available for sampling at the proposed date, time, and sampling point.
2. At the same time, it needs to be checked that the laboratory performing the analyses would be prepared to accept samples on the proposed sampling date.
3. At least one day before collecting samples, the sampling equipment should be assembled and ensured that those are clean and in good working order.
4. On the day of sampling, sufficient ice needs to be arranged for use in sample coolers to facilitate sample transportation in cold condition.
5. Operational procedure for sludge handling need to be reviewed before conducting sampling. Any observable deviations from normal operation should be noted prior to sample collection.
6. Nitrile gloves and any other required/desired personal safety equipment should be used.
7. At least 8 grab samples, all approximately equal in volume (~ 250 mL) need to be collected sequentially using a 500 mL glass beaker and a stainless steel trowel. If required, field duplicates or blanks should be collected.
8. *In case of sludge dispenser:* after the first grab sample, another grab sample should be collected in every 30 minutes and placed in the stainless steel bucket until all 8 grab samples have been collected. The grab samples should be of approximately equal size (weight or volume). During the time between samples, the stainless steel bucket should be covered and placed on ice or refrigerated. (This is necessary whenever the interval between grab samples is longer than five minutes.) The time of collection of the last grab sample should be recorded.
9. *In case of sludge storage:* after the first grab sample, 7 other grab samples should be collected from random locations of the sludge storage and placed in the stainless steel bucket.
10. Upon collection of the last grab sample, all material accumulated in the stainless steel bucket should be mixed thoroughly with a stainless steel trowel. The goal of the mixing process is to produce a homogeneous sample.
11. After mixing, all sample containers should be labelled with relevant information not limited to a) Sample identification number (ID), b) Date and time of collection, c) Sample location, d) Person collecting sample, e) Preservative, f) Required test(s)
12. Each sample container should be filled with portions of the homogenized material in the stainless steel bucket.
13. After each sample container is filled, it should be sealed with a signed custody seal and placed on ice in a cooler for transportation to the laboratory.
14. Prior to delivering the samples to the lab, a chain-of-custody sheet needs to be completed to document proper sample handling.
15. Finally, all equipment must be cleaned according to established procedures and stored in a clean, dry area.

4.5 Consistency of the sampling

There are several factors responsible for consistent sampling. One of the most important idea is to identify appropriate sampling points. In addition, sample collection procedure needs to be followed properly for consistent sampling. Critical points that must be addressed in a sampling procedure include sample type, sample size, and sampling equipment and containers. Samples can be grab or composite type depending on the source as discussed before. It is advisable to have adequate sample sizes to ensure analytical accuracy and precision. The amount of samples collected should exceed the amount needed for analysis, however, the sample size must be manageable for the analyst. Another important factor is the compatibility of the sampling equipment. Sampling equipment must be constructed of materials which will not contaminate or react with the sludge. Containers must not distort, rupture, or leak as a result of chemical reactions with constituents of waste samples. Therefore, it is highly important to have an idea of the properties and composition of the sludge. Finally, the cleaning procedure can severely affect the sampling consistency. Before using sampling equipment for the first time and after every use,must be thoroughly cleaned. In addition to these, sample handling procedure can have a big impact on the consistency of the sampling. Improper handling can change the sample property that could have been collected when following proper procedure. Samples must be stored and preserved to maintain the chemical and physical properties that it possessed at the time of collection. Although cooling is not a requirement of the analytical methods for most metals, it greatly reduces the microbial activity.

Be consistent with Sample collection procedure
Sampling equipment and containers are suitable and adequate
Proper handling is maintained during collection, transport, testing and analysing

4.6 Sample handling and preservation

When analysis is to be performed away from the sampling site, samples must be packaged, transported and preserved properly. Sample containers must be packaged in order to protect them and to reduce the risk of leakage. Preservation refers to sample handling processes aimed at preventing or minimizing chemical or biological activity within the sample after it has been collected. It is important as several phenomena can occur during storage such as development of odours due to anaerobic conditions, mineralization of organic matter with loss of ammonia, change of biological properties, as a consequence of pathogens reduction. Sludge samples are generally preserved by cooling and maintaining samples at 4°C, if possible. However, the samples should not be preserved for too long before analysis. The Table 9 shows the recommended maximum storage time for specific analysis at 4°C.

Table 9 Maximum allowable sample preservation time before testing [37]

Parameters to be tested	Maximum storage time before analysis
Most metals And Heavy metals: Al, As, Cd, Cr, Cu, Pb, Ni, Zn	6 Months
Hg, Nitrogen compounds, Phosphorus, Chloride, Sulfur compound, Organic Carbon	28 Days
Volatile organic compounds	14 Days
Total solid and volatile solids	7 Days
Biological parameters such as *Salmonella* and *Helminth Ova*, coliform, pathogen	24 Hours

4.7 Transportation procedure for lab test and disposal facilities

Proper sampling and preservation can provide a correct analysis if the transportation is performed carefully following proper protocol. Exposure to extreme temperatures may compromise collected samples, and testing results may not accurately reflect the true field conditions. High temperatures and freezing are not recommended as they can encourage growth of bacteria followed by degradation of the organic components in a sample, and therefore may cause sample containers to break. In addition, sample containers must be packaged properly in order to protect them and to reduce the risk of leakage.

Samples are generally hand delivered once the proper sampling and documentations are done. It can also be sent through postal service or courier if the container is properly sealed and packaged, provided that the parameters to be measured are not very time sensitive. However, sample transportation can be an issue in case of higher volume of sample. Transport by truck is the most convenient method for larger samples. This method requires relatively low investment costs and offers a high degree of flexibility. It is also easier to arrange rerouting and alteration of collection points. However, transportation by truck might cause a leakage and emission problem. Samples can be packaged following the method mentioned below.

- Put two large plastic trash bags into a cooler or large insulated container to create a double liner. Immediately before packing the cooler, put two plastic bags filled with ice. These bags should be inside another bag to prevent leakage.
- Each individual sample container needs to be packed into a plastic bag and sealed properly before putting into the cooler.
- The cooler lid should be properly closed and the horizontal joints needs to be sealed with duct or packing tape before transportation.

- Label the container properly with the sufficient details of sampling procedure, name of the relevant personnel etc.

4.8 Parameters that to be tested and available testing facilities

Sludges exhibit wide variations in their properties depending on origin and previous treatment, which needs to be characterized before planning their disposal method and potential applications. Many parameters have therefore been introduced and tests have been developed to measure specific properties of sludge. Conventional characterization parameters can be grouped in physical, chemical and biological parameters. Physical parameters give general information on sludge in terms of ease of processing and handling. Chemical parameters are relevant to the presence of nutrients and toxic/dangerous compounds, so they become necessary in the case of utilization in agriculture and other applications. Biological parameters give information on microbial activity and organic matter/pathogens presence, thus allowing the safety of use to be evaluated. However, estimation of all these parameters are expensive and time consuming. Therefore, it is necessary to focus on few important parameters which must be selected for a quick and convenient determination of sludge properties.

There are several parameters that should be tested before deciding on the further applications of the sludge from textile or other wastewater treatment plants. There are few parameters which are extremely important irrespective of the potential application. These parameters must be evaluated for sludge before any application, Table 10. It is not always feasible for developing countries to evaluate all the properties of the sludge. Therefore, parameters such as TOC, heavy metals, Chloride and Sulfur must be evaluated to assess the eligibility of the sludge for further application. Secondary parameters should also be tested in the later phase, once the recognized testing facilities are available. Some additional parameters should also be tested based on the specific disposal route. For example, *Salmonella*, *Helminth ova*, Phosphorous and Nitrogen are important for agricultural application, whereas Chloride is important for high temperature applications. Table 11 shows some additional parameters recommended to be tested relevant to specific application.

Table 10 Parameters needs to be measured before any application

Priority	Parameters
Primary Parameters	Total Organic Carbon (TOC) Moisture Content Calorific Value Heavy metals: Cr, Cd, As, Pb, Cu, Ni, Hg, Zn Sulfur Content
Secondary Parameters	Organohalogen Polychlorinated biphenyl (PCB) Polychlorinated dibenzodioxin (PCDD) Polychlorinated dibenzofuran (PCDF)

Table 11 Additional parameters relevant to specific application

Applications	Parameters
Agriculture	Salmonella, Helminth ova, Nitrogen and Phosphorus
Construction material/Brick	Benzene, Halogen,
Biogas	-
Incineration	Halogen, Benzene
Landfill	Benzol, Toluol, Ethylbenzol and ortho-xylol, Petroleum-derived hydrocarbon, Polychlorinated biphenyl, Polycyclic aromatic hydrocarbons, Chloride

5 Suitable systems (preferably locally available) to test and monitor the flue gas composition at the outlet

The flue gas composition must be evaluated during any trial application involving incineration of the sludge. Some basic air quality parameters such as particulate matters, Carbon monoxide, Oxides of Sulfur, Oxides of Nitrogen and heavy metal in the dust particle (if concentration is high in the sludge) should be analyzed. DoE has an allowable limit for ambient air quality parameters that should be followed before any incineration/combustion application is undertaken. Table 11 shows the DoE limits for ambient air quality parameters. Ambient air quality measurement and stack gas analysis facilities are available in Bangladesh through the Chemical Engineering Department of Bangladesh University of Engineering and Technology. Some of the parameters require to be measured at isokinetic condition, and this facility is well-equipped to address this.

Privately Qtex Solutions Limited (http://qtexsolutionsbd.com/) and SGS Dhaka can test regularly required parameters such as CO, NOx, O_2, excess air, flue temperature etc.

Table 11 Ambient Air Quality Standards for industrial areas in Bangladesh [Draft ECR, 2016]

Air Pollutant	Standard	Average Time
Carbon monoxide (CO)	10 mg/m^3	8-hour
	40 mg/m^3	1-hour
Lead (Pb)	0.15 µg/m^3	Annual
Mercury (Hg)	0.03 µg/m^3	Annual
Oxides of Nitrogen (NO_x)	120 µg/m^3	Annual
Suspended Particulate Matter (SPM)	250 µg/m^3	8-hour
PM_{10}	50 µg/m^3	Annual
	150 µg/m^3	24-hour
$PM_{2.5}$	30 µg/m^3	Annual
	50 µg/m^3	24-hour
Ozone (O_3)	200 µg/m^3	1-hour
	125 µg/m^3	8-hour
Sulfur dioxide (SO_2)	60 µg/m^3	Annual
	150 µg/m^3	24-hour

6 Textile Sludge disposal options

From the laboratory assessment of textile ETP sludge, it is evident that textile sludge contains different inorganic compounds and heavy metals. Therefore, this sludge fails to comply with the criteria of *Category A* sludge. So direct land disposal of this kind of sludge is not possible. Apart from direct disposal, there are several options to utilize the sludge, however, because of the nature of the sludge, all types of sludge are not suitable for same reuse option. Potential applications of sludge commonly observed in different countries are summarized in Table 12 and briefly discussed below.

Table 12 Generalized guide for selecting suitable sludge disposal option

Disposal Options	Waste class			Bangladesh Scenario
	A	*B*	*C*	
Anaerobic digestion (co-fermentation)	X*	X*	X¥	Pilot Trial
Aerobic digestion (composting)	X*			Need to be tested before application
Agricultural use	X			Need to be tested before application
Controlled landfill$^{\Psi}$	X	X	X	Not yet started but easily implementable
Thermal incineration	X*	X*	X*	Pilot Trial
Land application	X	X#	X¥	Commonly practiced
Recycling in brick, cement or asphalt making	X	X§	X¥	Formal and informal brick trial, pilot trial to make Compressed Stabilized Earth Blocks (CSEB).

* Residues will remain that have to be disposed of, fulfilling the requirements applicable to the category, on an alternative route e.g. by landfill.

Inert material (low organic matter required)

§ Availability and capacity limited by local conditions. Accepted sludge volume limited due to a loss of compressibility of the product

$^{\Psi}$ Requirements for the landfill class vary depending on category of the sludge.

¥ The producer may provide evidence that sludge categorised as category C sludge according to Annex 1a or 1b of Standards and Guidelines for Sludge management [38] does not possess any hazardous characteristics; in this case it may be categorised as category B sludge and the management options anaerobic digestion (co-fermentation), land application (filling material e.g. for flood prevention), recycling in brick, cement or asphalt making are permissible.

Transportation of sludge from the producer to the designated facility can be accomplished by several means of transportation: by highway, water, rail, or air. The most convenient method for transportation of sludge for disposal is by covered van or truck. This is commercially very available, low cost and offers a high degree of flexibility. It is also easier to arrange rerouting and alteration of collection points. However, it is necessary that transporter have a separate licensing system from both DoE and transporter authority and could have unique identification number to recordkeeping and traceability. The EPA standards applicable to transporters of hazardous waste can be found in http://www.ecfr.gov/cgi-bin/text-idx?SID=f8dbf7319774464838cb34cd865f2508&mc=true&node=pt40.26.263&rgn=div5. A similar guidelines for transportation of hazardous wastes by Maharashtra state government, India can be found in http://mpcb.gov.in/images/hwtransguide.pdf.

6.1 Agricultural use

The main purpose of using sludge in agriculture is partly to utilize nutrients such as phosphorus and nitrogen and partly to utilize organic substances for soil improvement. However, the sludge must meet the criteria to be suitable for this application. As mentioned in Table 1, heavy metals and few other parameters of the sludge and the soil must fulfill the criteria suggested by Department of Environment (DoE), Bangladesh. There is also a limit of the total amount of sludge that can be applied on specific land area. Currently, DoE guideline (adopted from German Sewage Sludge Ordinance) suggests less than 3 ton sewage sludge (similar to Category A) or less than 10 ton compost per hector land area in 3 years [38].

To address these issues, different processing and applications of the sludge have been under consideration around the world. As sludge generation is directly related to industrial growth, India, China and similar industrial countries are dealing with this in various ways. Because of the nature of the sludge, all types of sludge are not suitable for the same reuse/recycling option. Textile sludge might contain heavy metals and other hazardous chemicals. According to German sewage sludge ordinance [39], there are limits of the certain heavy metals in the sludge that are acceptable for agricultural use. This is also adopted and suggested by DoE. In addition, it must comply with the required soil properties where the sludge to be applied. Table 13 shows the maximum allowable limits for agricultural application.

Table 13 Parameter limits of sludge for use as compost/fertilizer [38]

Parameters	In sludge mg/kg dry sludge	In soil (before application) mg/kg dry sludge
Pb (Lead)	900	100
Cd (Cadmium)	5*/10	1*/1.5
Cr (Chromium)	900	100
Cu (Copper)	800	60
Ni (Nickel)	200	50
Hg (Mercury)	8	1
Zn (Zinc)	2000*/2500	150*/200

*These limit values only apply for the application of sludge on agricultural land with a clay content below 5% or pH values above 5 and below 6.

6.2 Composting/fertiliser

Composting and use as fertiliser are another option that aims at biologically stabilizing sludges while controlling pollution risks and exploiting the nutrient or organic value of sludges. Textile sludge contains valuable nutrient such as phosphorus and organic matters which can reduce the need for fertilizers and maintain soil fertility. The average nitrogen:phosphorus:potassium (NPK) value of textile sludge is in the range of 1:1:0; lower compared to commercial fertilisers but similar to organic manure. However, accumulation of metals in the soil and leaching to surface or ground water will be critical [40].

If the chemical and biological characteristics are within the acceptable range, composting is a common practice in many European countries such as Italy, France and Netherlands [41]. Composting involves aerobic degradation of organic matter, as well as a potential decrease of the sludge water content, and a balance of the nitrogen and carbon content. The latter one is necessary for the proper growth of micro-organisms. The optimum carbon to nitrogen ratio (C/N) of the mixture is between 25 and 30. Since the materials are composted at a temperature level sufficient to kill pathogens, the risk of pathogenic problems is minimized, however, the heavy metal content of the final compost product is critical.

Waste Concern group (http://www.wasteconcern.org/), a Social Business Enterprise (SBE), is actively working on waste management and recycling in Bangladesh through composting of domestic waste. Depending on the capacity of treatment of waste there are three different model is available: small (< 3 tons/day), medium (3 to 10 tons/day) and large (over 11 tons/day).

6.3 Land application

Land application refers to a wide variety of uses such as filling material for flood prevention, material/ substrate for re-cultivation of mining sites or covering landfill sites. Land application does not include agricultural use.

It can be assumed that sludge suitable for agricultural use or composting is also suitable for land application, but when using large amounts of sludge, nutrient contents must be taken into consideration to minimize leaching. For any specific land application of sludge, prior permission has be obtained from the Soil Resource Development Institute (SRDI) and the Department of Environment (DOE).

6.4 Production of Biogas

Biogas typically refers to a gas produced during anaerobic digestion of waste making the harmful components less hazardous. Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. So, for biogas production besides moisture content, the organic matter content is also an important factor. In an earlier study in Bangladesh, it was found that the average carbon content of textile sludge was 24%. Physico-chemical effluent treatment plant contained less organic carbon (6-12%), whereas biological effluent treatment plant contained 25-48% organic carbon [42]. One of the benefits of this application is that the industries can utilized high moisture containing sludge and therefore do not need to keep the sludge accumulated in their premises for several month as recommended by DoE. However, Biogas production will be efficient if the TOC is sufficiently high and the proper condition is maintained.

6.5 Utilization in Brick manufacturing

Application of waste sludge in construction industry has been suggested by various researchers mostly in the production of bricks and to some extent in the ceramic and glass production. There are around 5,000 operating kilns in Bangladesh which employ about 1 million people and contribute to about 1 % of GDP. The brick kilns consume around 45 million tonnes of agricultural soil and nearly 3.5 million tons of coal and 1.9 million tons of wood annually [43].

The use of sludge in construction industry contributed to the sustainability of limited natural resources and this is also environment friendly. Moreover, sludge with decent heating value also reduce the energy consumption compared to regular brick making process. Lower moisture content is also required for this application. The average dry matter content identified by the Textile Sludge Study in Bangladesh is about 30 to 40 %, which suits for this application. As some heavy metals might remain inside the brick, leachate study can verify the optimum level of sludge mixing. In addition, emission levels from the brick kiln must comply with the national air quality standard. As discussed before, it has been shown that sludge mixed with clay up to a certain level does not affect brick quality and can be a promising utilization option for Bangladesh. As, the brick industries are discouraged to use topsoil for brick production in Bangladesh, utilization of sludge can be beneficial in the soil crisis context as well. This is being promoted for several years in countries like India, China, Taiwan and Egypt.

In a study carried out in Atomic Energy Research Establishment to produce eco-friendly brick from textile sludge after radiation by gamma ray (15 kGy) for detoxification; optimum results were found for 50-50% sludge/clay samples. In the experiment, sludge was mixed with clay and bricks were made in wooden frame. Dried brick samples were then kept at 450°C for 24 hours in furnace. The result showed that when the sludge content (%) in bricks increased, density, weight loss, firing shrinkage and electrical resistivity was reduced whereas the bending strength, bending modules, impact strength and water uptake (%) was increased. After 50-50% ratio, any further increase in the sludge percentage led to loss of strength and compactness of the brick sample. According to the results, the optimum sample showed higher strength than the sample made by pure clay; but showed slightly lower strength than the commercial brick [44].

A new advanced technology, FaL-G Brick technology is claimed to be climate-friendly which produces bricks without using topsoil and coal, and completely eliminates carbon emissions. Institute for Industrial Productivity (IIP) in Bangladesh (http://www.iipinetwork.org/) is focusing on using this technology to support local industry. In addition, it is also planned to make FaL-G bricks in Bangladesh by using textile sludge as a raw material.

As an alternative to currently commercial brick, compressed stabilised earth blocks (CSEB) is recently promoted by Housing and Building Research Institute (HBRI), an organization under the Ministry of Housing and Public Works, Bangladesh. CSEB uses dredged soil, sand others instead of top soil and it is a low-tech product reduces CO_2 emission. There are various commercial organisation such as Building Pioneers (http://building-pioneers.org/) and Auroville Earth Institute is working on CSEB, although it has been reported that these earth blocks are feasible for using as interior wall but not as external wall in flood prone areas [45].

6.6 Incineration

Incineration of sludge can reduce the sludge volume and potentially produce energy depending on the calorific value of the sludge. However, conventional incineration process generally consumes more energy than it produces, mainly because of high moisture content and lower calorific value of the sludge. If there is no recycling option available, incineration could be considered and it is being practiced in different countries such as India and China to reduce the waste volume. There are several gaseous and particulate pollutants that emit from the exhaust of the incineration system such as furans, dioxins. To address the pollution problem, installation of expensive pollutant filters are highly recommended. Scrubbers can be used to capture significant fraction of the pollutants from the exhaust gas.

Depending on the dry matter content in the sludge, a range of incineration chamber can be chosen. It is expected that after at least 3 months of storage onsite, the sludge will be dried (>50% dry solid) and therefore, sludge can be mixed with waste or fed together into the incineration chamber. However, studies have shown that if the sludge ratio is too high (e.g. >10 %.), high fly ash content or unburnt material in bottom ash may occur.

The requirements incineration of textile sludge are:

- The moisture content of should be as low as possible
- Incineration should be carried out with an industrial incinerator with proper emission control system
- The incineration temperature be sufficiently high to avoid generation of toxic chemicals such as dioxin and furan.
- The temperature of incineration chamber should be at least 800°C to avoid noxious smell
- Emission criteria such as SO_2, CO, TOC, HF, NO_x, dioxins and furans, chromium (Cr^{+6}) should be met as per the National emission standard for this kind of industries.

As the incineration is an energy intensive (thus expensive) process, co-firing of sludges with other high calorific wastes could reduce the energy consumption. Another useful modification of sludge incineration can be introducing heat recovery system. As sludge drying is a heat consuming process and sludge incineration produces heat, integrated sludge treatment can be designed where the heat required for drying can be recovered from the heat released by the sludge incineration. In addition, it is also possible to produce electricity from the heat generated from incineration using boiler-turbine combination. The combination of heat and power recovery is known as Cogeneration system. In this process, a waste incinerator produces steam by a steam boiler and the steam goes to a back pressure turbine and produces electrical power. Moreover, the exhaust steam from turbine still contains enough heat to dry the wet sludge to some extent. Adopting any of these approaches can make the incineration process relatively cost effective.

Although there is currently no incinerator for textile sludge to be used in large scale, an example could be found in medical waste management program, operating by PRISM Bangladesh (http://pbf.org.bd/). PRISM has established a medical waste treatment plant at Matuail, outskirt of Dhaka in 2004 with the collaboration of Dhaka City Corporation and Embassy of Japan in Bangladesh and with support from other international organizations. Currently this waste treatment plant is supporting 484 healthcare establishments (HCEs) from Dhaka City Corporation (DCC), both North and South. There are two incinerators in the facility: 135kg/hour and 60 Kg/hour, which is used for toxic waste coming out from medical facility.

6.7 Co-incineration in Cement Industry

Incinerating the sludge alone can be pretty expensive and in case low temperature operation it may contribute to emissions including toxic Dioxins and Furans. Therefore, co-incineration of textile sludge in the cement industry has been getting poplar over the world as one of the potential utilization of the hazardous sludge whereby wastes are destroyed at a higher temperature of around 1400°C and longer residence time. The usage of industrial solid wastes as building materials can be beneficial in several ways such as conservation of natural resources/raw materials, decrease mining activity, reduce landfill capacity, minimize global warming.

Incinerating sludge alone can be expensive. Furthermore in case of low temperature incineration operation, it may contribute to generation of harmful air emissions such as toxic dioxins and furans. However, a sludge co-incineration study (June 2014) in Berger carried out by GIZ-PSES showed that the dioxins and furans concentrations in the stack gases are far below (<0.01 ng/TEQ[2]/Nm^3) the international recommended standard (0.1 ng PCDDs/PCDFs /I-TEQ/Nm^3).

Utilization of textile sludge in the cement industry is one of the possible options that offers all these benefits. Researches have been reported showing the successful application of sludge in the cement production and also as a mixing component in concrete production. India has adopted this option and as of 2010, there were 22 cement manufacturing units in various states has already started co-processing sludge.

The requirements for co-processing sludge are similar to those in brick making:

- Sludge needs to be dry.
- Dust emission needs to meet the particulate matter emission standards during co-processing.

[2] I-TEQ - International-Toxicity Equivalent (I-TEQ). Toxic Equivalents, or TEQs, are used to report the *toxicity-weighted masses* of mixtures of dioxins

- Other emission criteria such as SO_2, CO, TOC, HF, NO_x, Dioxins and Furans, heavy metals and their compounds should be met as per the National emission standard for this kind of industries.

6.8 Controlled Landfilling

Landfilling should be the last option if no other alternative options are suitable. Although controlled landfilling is isolated from the surroundings, even in case of the most careful setting and proper operation, some degree of subsurface pollution might occur. The textile sludge study carried out by EcoMetrix [40] found that in three sampling events, the organic carbon content of textile sludges exceeded European criteria for:

- an inert waste landfill at approximately 75% of facilities due and additionally for chloride, sulphate, fluoride, antimony, lead, cadmium, chromium, copper, molybdenum, nickel, mercury, zinc and DOC;
- a non-hazardous waste landfill at approximately 58% of facilities due to elevated organic carbon in sludge and sludge leachate and occasionally excess of Sulphate, antimony and zinc concentrations
- a hazardous waste landfill at approximately 42% of facilities due to due to elevated organic carbon in sludge and sludge leachate and Zn.

Developed countries have already prioritizing material recycling of sludge and limiting the disposal to landfill (EU Waste Framework Directive 2008/98/EC). Minimization of environmental pollution can be achieved by proper selection of the site, organized disposal of the sludge, proper precautions and maintenance. For example, land filling site should not be covered even temporarily by inland waters, or be located on the area of water bases (aquifers). It is also recommended to develop landfilling site as far as possible from various establishments such as residential areas, public roads, river etc. To establish a controlled landfill site it is necessary to obtain prior approval from the DoE, which is responsible for granting an environmental clearance certificate. A generalized guideline for sludge management has been prepared by DoE that is applicable for textile sludge as well. According to the guideline basic requirements for the location of a landfill site are:

Basic Requirements for the location of a landfill site

- The over flooding level should be of the > 2.0 m of the maximum expected water level of the surrounding water bodies
- > 500 m distance to populated areas
- No construction in protected areas
- No construction in flood plains and areas with a high risk of natural disasters
- The underground has to resist mechanical stresses, has to hold back or prevent leachate and pollutants
- Water impermeability
- Buoyancy safety has to be considered

Construction of a landfill site must be done according to acceptable specifications and standards such as EPA guidelines. To establish a controlled landfill site, it is necessary to obtain prior approval from the DoE, which is responsible for granting an environmental clearance certificate. Some major points to be considered during the design and construction of a landfill site are listed below.

Major points for Design and Construction of a landfill site

- There should be proper leachate barrier system including suitable lining, ground barrier and leachate draining system.
- There should be suitable leachate storage and disposal system near the landfill site.
- There should be adequate monitoring system to assess leachate water quality and gas emission levels.
- Ground water and surface water near the landfilled facility should be tested on a regular basis to detect any failure of the landfill leak protection facilities.
- Emission of nuisance dust and other particulate matter beyond the landfill boundaries must be minimised.
- The landfill must not adversely affect amenity in the locality, in terms of offensive odour, noise etc.
- Landfilled waste must be covered to minimise odour, dust, litter, the presence of scavengers and vermin, the risk of fire, rainwater infiltration into the waste and the emission of landfill gas. The cover material can be natural material like organic or inert waste in the form of soil with a minimum cover depth of 150 mm. However, specialty manufactured covers such as plastic sheets, tarps, foams and fabricated metal landfill lids can also be used unless there is any apparent environmental risk.
- The landfill must continue to be non-polluting and not cause environmental harm after site closure.
- It can take many years after closure for the waste to become physically, chemically and biologically stable, therefore, development on or near closed landfills should be avoided.

At the moment there are two semi-aerobic sanitary landfill available in Matuail and Aminbazar with a capacity of 2,700 to 3,000 tons of waste per day. Matuail sanitary landfill can treat 2400 tons of waste in a day is operating by Dhaka City Corporation (DCC) from October 2007 under Clean Dhaka Master Plan. This landfill was transformed from a dump site and has leachate collection system which is treated in effluent treatment plant designed to clean the water that percolates out of the landfill, and a gas venting system. The waste management operation is modernised through construction of a weigh bridge, a truck-scale to weigh incoming waste; a carwash facility to avoid contamination of roads by vehicles leaving the landfill; and a waste compaction and monitoring facility [46]. Three types of heavy equipment are used; excavator to unload the trucks, tyre dozer to push the waste away from the platform and feed the bull dozers' and bull dozers to spread and compact the dumped wastes [47]. Currently the facility has 100 acres of land and in the process of acquiring further 84 acres of land to extend the activity. The Matuail landfill received Clean Development Mechanism (CDM), financed by a Dutch corporation for methane recovery and utilization, and was projected to reduce 99,000 tons of CO_2-equivalent per year, directly and indirectly, in 2012 [48].

A basic overview of the main issues regarding selection, construction and operation of sanitary landfills in the perspective of Nepal and Thailand supported by GTZ in "Urban Environmental Guidelines' can be found in http://www.bvsde.paho.org/bvsars/i/fulltext/landfill/landfill.pdf. DoE in consultation with other stakeholders can create a similar guideline for landfill for hazardous waste in build–operate–operate (BOO) basis.

7 Name of ETP operators

The following ETP operators, Table 12, are willing to discuss on sludge treatment and some of them are independently working on sludge (e.g. Niagra, Echotex etc.) and some of them are willing to pay a reasonable fee (5 to 10000 BDT per tons of sludge) for sludge disposal (E.g. Denimach)

Table 12 ETP operators for sludge disposal

Name of the factory	Address	Type of ETPs
Tusuka Trousers Ltd	Konabari, Neelnagar	Physico-Chemical
Denimach	kewa Mouja, Gorgoria Masterbari, Gazipur	Physico-Chemical
Masco Industries Ltd.	Khortol, Tongi Pouroshova, Tongi, Gazipur	Physico-Chemical
Zaber and Zuber Fabrics Ltd.	Pagar, Tongi, Gazipur	Biological
Epyllion Knitex and Fabrics	Jangaliapara, Mirzapur, Gazipur	Biological
Niagra Textile	Chandra, Kaliakoir	Combined physico-chemical followed by biological
Echotex Ltd.	Chandora, Kaliakoir, Gazipur	Combined physico-chemical followed by biological
Amber Denim Ltd.	Chanmari, Vowal, Mirzapur, Gazipur	Combined physico-chemical followed by biological
Divine Textile Ltd.	Chandra, Kaliakoir	Combined physico-chemical followed by biological
Apex Tannery	Gazipur	Chemical ETP

8 Results and Discussion

Sludge samples from different textile factories had been analysed by EcoMetrix in three consecutive years since 2009 [40]. Every year more than 20 different textile industries were considered for the study. Table 13 shows the maximum, minimum and average values of the major parameters found during that study.

Table 13 Major sludge parameters from different industries during three independent samplings

PARAMETER	UNIT	2009			2010			2011		
		Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
As	mg/kg	2	15	3.1	2	15	3.3	2	25	4.5
Cd	mg/kg	0.2	7.7	0.6	0.2	0.7	0.4	0.2	8.9	0.9
Cr	mg/kg	6	1200	110	9	200	63	17	140	56

Cu	mg/kg	9.6	1400	191	6.9	980	143	9.2	1100	173
Pb	mg/kg	4	220	30	4	110	26	9	280	32
Ni	mg/kg	7	190	34	3	110	26	8.7	94	25
Zn	mg/kg	82	3100	637	83	8500	927	200	4100	916
Hg	mg/kg	0.05	0.5	0.1	0.05	1.4	0.2	0.05	1.6	0.2
Nitrogen (total)	%	0.1	6.6	1	0.1	3.83	0.9	0.1	4.6	1.1
Phosphorus (P_2O_5)	%	0.12	1.6	0.6	0.11	2.62	0.6	0.145	2.8	0.7
Chlorine leachate	mg/l	4.4	1100	152	2.8	280	87	11	860	207
Sulfur leachate (SO_4)	mg/l	1	3500	726	10	3400	538	1	1600	530
Total organic car-bon	%	0.7	48.1	11.4	0.7	42.3	9.9	1.1	44.7	11

These values are compared with different sludge standards of India, Europe and USA. Average level of heavy metals were within the limits of all three standards. In addition, the maximum values were also within the limits in most of the cases. Only one incident of first phase of sampling was found where Chromium level was higher (1200 mg/kg) than the allowable limit. Apart from that, Zinc level was found to be higher than the allowable limit for only two incidents during all phases of sampling. Total Organic Carbon (TOC) was found to be relatively high for most of the cases during all three phases of sampling. Though heavy metal content disqualified these sludges as *Category A*, higher TOC level limits the use of these sludges for land and agricultural applications.

A comparative perspective of the limits of different sludge parameters recommended by various authorities is show in Table 14.

Table 14 Limits of some major sludge parameters enforced in different countries.

Parameter	**Unit**	**Bangladesh**	**India**	**China** pH<6.5	**China** pH≥6.5	**US EPA**	**EU**
As	mg/kg	75	-	75	75	75	-
Cd	mg/kg	85	50	5	20	85	40
Cr	mg/kg	600	5,000	600	1,000	600	800
Cu	mg/kg	4,300	5,000	800	1,500	4,300	1,750
Pb	mg/kg	840	5,000	300	1,000	840	1,200
Ni	mg/kg	420	5,000	100	200	420	400
Zn	mg/kg	7,500	20,000	2,000	3,000	7,500	4,000

Hg	mg/kg	57	50	5	15	57	25
Nitrogen (total)	%	-	5	-	-	-	-
Phosphorus (P_2O_5)	%	-	2	-	-	-	-
Chlorine	mg/Kg	-	5,000	-	-	-	-
Chlorine leachate	mg/l	1,500	-	-	-	-	1,500
Sulfur (SO_4)	mg/Kg	-	50,000	-	-	-	-
Sulfur leachate (SO_4)	mg/l	5,000	-	-	-	-	2,000
Total Organic Carbon	%	5	5*	-	-	-	5

* Organic carbon is not available but 5% hydrocarbon is the limit

9 Limit for Different Categories of Sludge

As discussed earlier, all sludge types are not suitable for all applications. Selection of the best sludge utilization option depends not only on the sludge quality but also on the socio-economic aspects. Although, some sludge utilization options have been proposed, these applications should only be acceptable for a certain range of sludge quality parameters. The European Waste list shown in Table 1 for textile industry indicates that the sludge from the textile industry effluent treatment plant might be hazardous if organic solvents are present. Moreover, as suggested by the sludge management guideline, it shall be prohibited on agriculturally or horticulturally used soils to apply crude sludge or sludge from waste-water treatment plants other than for the treatment of domestic wastewaters, municipal wastewaters or comparable wastewater classified as category A. The conclusion of the study by EcoMetrix were approximately 18% of textile facilities had excess concentrations of AOX, chromium, copper and zinc compared to German Sewage Sludge Ordinance of 15 April 1992 and 30% of the facilities exceeded on AOX, chromium, copper, nonylphenol and nonylphenol ethoxylates, and zinc European Working Document on Sludge, 3rd draft of 27 April 2000 for any use in agriculture and/or composting fertiliser [40]. Therefore, considering the nature of the sludge and the presence of different types of heavy metals and other inorganic compounds in sludge from different textile industries in Bangladesh, textile sludge should not be considered as *Category A* sludge. Therefore, any kind agricultural application or composting of the textile sludge should completely be restricted.

Although, Sludge Management Guideline [38] divides sludge into three different categories based on presence of specific component or hazardous behaviour, it is not very straight forward to decide about a sludge sample according to this guideline. To simplify the classification approach, an acceptable limit for the major sludge quality parameters have been given in Table 15. The threshold mainly differentiates among *Categories A, B* and *C* and is given. Limits for *Category A* is suggested based on the Sludge Management Guideline limits adopted from German Sewage Sludge Ordinance, July 2002. The limits to distinguish between *Category B* and *C* have been adopted from the US EPA limits recommended for sludge disposal. This could help the stakeholders decide faster which category their sludge belongs to. Only *Category B* sludge is recommended for different utilization options as mentioned before. *Category C* sludge are too hazardous for these application and must fall under controlled landfill and/or thermal incineration following proper procedure.

Table 15 Limits of heavy metal concentration in textile sludge for different sludge category

Parameter	Unit	Category A*	Category B#	Category C
As	mg/kg	≤ 40	41-75	> 75
Cd	mg/kg	≤ 10	11-85	> 85
Cr	mg/kg	<600**	<600	> 600
Cu	mg/kg	≤ 800	801- 4,300	> 4,300
Pb	mg/kg	<840**	<840	> 840
Ni	mg/kg	≤ 200	201-420	> 420
Zn	mg/kg	≤ 2500	2,501-7,500	> 7,500
Hg	mg/kg	≤ 8	9- 57	> 57

*According to the limits imposed in Bangladesh standard and guidelines for sludge managements of sludge for use as compost/fertilizer

#US EPA Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503)

**As the present limits for these parameters are slightly higher than the US EPA values considered for *Category B* and *C*, US EPA limits are considered for consistency.

Based on these proposed category, and due to the hazardous nature of the textile sludge, the sludges that were tested by EcoMetrix from 21 to 25 ETP operators fell into following two categories, Table 16.

Table 16 Sludge category based on the test result

Test year	Category B	Category C
December 2009	100 % (due to Cu, Zn, Cr)	0%
November 2010	95.5% (due to Cu)	4.5% (due to Zn)
April/May 2011	100% (due to Cu, Zn)	0%

10 Some tasks in this TOR is for future

Under the TOR, some pilot studies were supposed to be carried out, however, for various reasons, after making some progresses, those were postponed at the end. These were discussed below:

Responsibilities 1: *Collect representative textile ETP dry sludge samples (5 Kg each) from 9 ETPs, 1 each from the following 'categories' of ETP:-*

The fortnightly update showed that many ETP operators were ready to send sludge for testing.

3rd Fortnight (21st Jan- 3rd Feb 2016)	4th Fortnight (4th Feb- 18th Feb)	5th Fortnight (22nd Feb- 4th March 2016)	April to May 2016
Visited 5 ETP operators: 2 biological, 2 combined, 1 Chemical. Parameters are fixed and a summary of quotations were submitted to giz PSES team.	Waiting for budget approval. Asked to look into Environmental lab of BUET	Waiting for budget approval. Quotation from Environmental lab of BUET, SGS India and Tuv Sud India was received.	Informed by PSES EC team that budget was not approved for testing

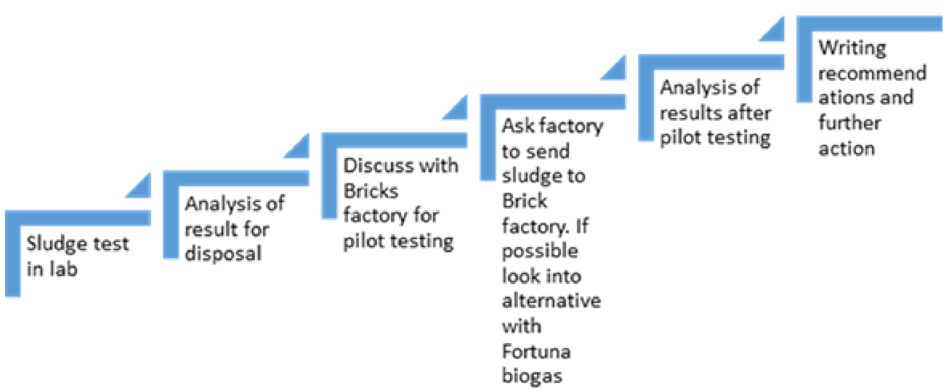
A summary of lab quotations was also collected after many phone and face to face discussion with the different laboratory.

<table>
<tr><th>Parameters</th><th>BV Bangladesh</th><th>SGS (Not locally available but SGS India can do)</th><th>Tuv Sud</th><th>Chem Engg, BUET</th><th>UL Bangladesh</th><th>Environmental Engineering Lab,Civil Engg,BUET</th><th>ICDDRB Microbilogical lab</th></tr>
<tr><td>Pb (Lead)</td><td rowspan="9">BDT 123,050 (VAT inc.)</td><td rowspan="11">BDT 126,500 (VAT inc.)+ Sample sending charge BDT 34500 (VAT inc.)</td><td rowspan="11">laboratory in India can analyze all the parameters. Few of the parameters can also be analysed here in our Mobile Lab like GCV,TOC & Metals but that required little bit more time as our instru-</td><td rowspan="10">BDT 36,000 (VAT inc.)</td><td rowspan="9">BDT 24,130 (VAT inc.)</td><td rowspan="8">14800 (VAT inc.)</td><td>N/A</td></tr>
<tr><td>Cd (Cadmium)</td><td>N/A</td></tr>
<tr><td>Cr (Cromium)</td><td>N/A</td></tr>
<tr><td>Cu</td><td>N/A</td></tr>
<tr><td>Ni</td><td>N/A</td></tr>
<tr><td>Hg (Mercury)</td><td>N/A</td></tr>
<tr><td>Zn</td><td>N/A</td></tr>
<tr><td>Arsenic</td><td>N/A</td></tr>
<tr><td>Moisture of Sludge</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Calorific Value (Kcal/kg)of Sludge</td><td rowspan="2">BDT 27,600 (inc VAT)</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Total Organic Carbon (TOC)</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

Polychlorinated bi-phenyls (PCB)	BDT 48,300 (inc VAT)		ment procure-ment is under process	N/A	N/A	N/A	N/A
Polychlorinat-eddibenzodioxins (PCDD)				N/A	N/A	N/A	N/A
Polychlorinated dibenzofurans (PCDF)				N/A	N/A	N/A	N/A
Nitrogen	N/A	N/A		BDT 21,000 (inc VAT)	N/A	N/A	N/A
Phosphorus	N/A	N/A			N/A	N/A	N/A
Chloride	N/A	N/A			N/A	5200 (VAT inc.)	N/A
Sulphate	N/A	N/A			N/A		N/A
Sulphur	N/A	N/A			N/A	N/A	N/A
Salmonella	N/A	BDT 2,875 (VAT inc.)	N/A	N/A	N/A	N/A	BDT 600 (No VAT)
Helminth Ova	N/A	N/A	N/A	N/A	N/A	N/A	BDT 2,000 (No VAT)
PVC	BDT 13,800 (inc VAT)		N/A		BDT 4,305 (inc VAT)	N/A	N/A

Responsibilities 3: *Identify Bd disposal facilities interested in commercial scale pilots of ETP sludge disposal. Design, conduct, Observe, result analysis and reporting on the piloting of the following opportunities for commercial scale sludge disposal in Bangladesh*

A flow of the piloting sludge disposal for brick manufacturing was given in April 2016, with pending approval from the testing budget. Similarly it was expected to do another piloting in Fortuna group for piloting biogas production. Although due to the funding issues it was not materialised, however, a methodical search to find out commercial brick making with sludge was carried out without much success.



Although pilot study did not carry out but one of the authors (Dr Shoeb Ahmed) assigned a Masters student for brick making with sludge mixture. A maximum 5.25% dry sludge which is equivalent to 15% regular sludge if moisture content is 65% used in this experiment. Calculation is carried out on dry weight basis of sludge as moisture content can be different from time to time, place to place. The summary of the result is given below:

Sludge exhibits wide variations in their properties depending on origin and previous treatment, therefore, needs to be characterized before planning their disposal method and potential applications. The average Gross calorific value was found to be 17.87 MJ/kg. This value is similar to the typical biomass and therefore, possesses very good potential for being used in co-incineration process such as brick and cement manufacturing.

Different sludge/clay mixture (0.5% to 5.25% dry sludge) were used to make bricks, which were evaluated in terms of their compressive strengths and the leaching behavior. The textile sludge incorporated clay fired bricks showed up to 77% more compressive strength compared to average standard bricks. Taking 15 MPa as the average brick strength, sludge incorporated bricks were compared. The maximum average value was 29.01 MPa (0.5% sludge) and the minimum value was 25.75 MPa (3.5% and 5.25%).

The leaching test of clay fired cubes reveal that this textile sludge can be used for brick making purposes without potential threat to human health or environment. From the obtained data of leachability, it was found that rate of leaching increased with increased percentage of sludge. Cd was found to leach the least (0%) while Pb and Zn leached in a range of 1.76 mg/m^2 to 4.57 mg/m^2 and 0.87 mg/m^2 to 4.02 mg/m^2, respectively. Considering all data, it can be seen that concentration of leachate from brick cubes were negligible.

From the cytotoxicity assessment of textile industrial sludge, LC_{50} was found to be at 262 µM concentration of sludge solution. Comparing the heavy metal concentrations in leachate with that found from cytotoxicity analysis, it is safe to say that sludge incorporated bricks can be used as building material without the possibility of heavy metal contamination to surroundings.

Responsibilities 4: *Explore whether there is any market, or use for, 'low strength brick' in Bd– in case bricks made with a small percentage (e.g. 5% or 10%) of ETP sludge are not as strong/presentable as conventional bricks.*

It was possible to analyse the market, if physical sample of brick was available, which then could have been compared against the regular brick.

Responsibilities 7: *Identify an ETP operator/s interested in a commercial scale pilot and arrange for that operator to transport a sufficient quantity of sludge, analysed and considered suitable with* *reference to the DoE 'Standards and Guidelines for Sludge Management', to a disposal facility for a commercial pilot.*

DBL group was interested to commercial piloting on any of the options and would support the logistics if necessary.

11 Conclusion

Textile industry, one of the major producer of wastewater in Bangladesh, performs different types of wastewater treatment processes to treat their wastewater. However, the concentrated waste in the form of sludge is continuously generated, handled and disposed without following any standard and procedure. These sludges come in contact with flood, rain and the surrounding land and water get contaminated. Unfortunately, all the efforts of wastewater treatment therefore go in vain as these pollutants eventually disseminate into the environment. This calls for immediate measures to control random disposal of sludge preferably by safe utilisation in different sectors. It is important to evaluate the sludge in terms of their chemical, physical, and biological characteristics to determine if a specific sludge is suitable for disposal and land application as suggested in the Bangladesh Standards and Guideline for Sludge Management. A proper sludge management method is crucial to ensure that human health and the environment are strictly protected from any negative impacts of sludge management. To facilitate the sludge utilisation, a simple guideline to characterize and categorize textile sludge has been suggested based on current sludge characteristics data of Bangladesh and standards followed in different countries. Considering the potential hazardous content of textile sludge, standard operating procedure for sludge collection and testing has also been recommended. This will help the sludge generating industries to characterize the sludge and select most suitable utilization options from the different suggested applications.

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