CHARACTERIZATION OF FAECAL SLUDGE, DEWATERED AND DRIED SLUDGE FROM SELECT FAECAL SLUDGE AND SEWAGE TREATMENT PLANTS

Research Report

APRIL, 2022

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ABBREVIATIONS

AD	Anaerobic Digestion
ASP	Activated Sludge Process
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
CFU	Colony-Forming Unit
COD	Chemical Oxygen Demand
CPHEEO	Central Public Health and Environmental Engineering Organization
EP	Environment Protection
FS	Faecal Sludge
FSM	Faecal Sludge Management
FSTP	Faecal Sludge Treatment Plants
GoI	Government of India
GPS	Global Positioning System
IIT-R	Indian Institute of Technology - Roorkee
IS	Indian Standards
ISO	International Organization for Standardization
KLD	Kilolitres Per Day
MLD	Million Litres Per Day
MPN	Most Probable Number
NIOSH	National Institute for Occupational Safety and Health
NIUA	National Institute of Urban Affairs
O&M	Operations & Maintenance
OSHA	Occupational Safety and Health Administration
OSS	On Site Sanitation System
PDB	Planted Drying Beds
PPE	Personal Protective Equipment
SBM	Swachh Bharat Mission
SBR	Sequencing Batch Reactor
SOP	Standard Operating Procedure
SRT	Sludge Retention Time
STP	Sewage Treatment Plant
TS	Total Solids
VAR	Vector Attraction Reduction
VS	Volatile Solids
UASB	Up-flow Anaerobic Sludge Blanket
(US) EPA	United States Environmental Protection Agency
WHO	World Health Organization

GLOSSARY

Raw sewage: Sewage consists of wastewater discharged from residences and from commercial, institutional and public facilities that exist in the locality.

Septage: Septage is the liquid and solid material that is pumped from a septic tank, cesspool, or such onsite treatment facility after it has accumulated over a period of time.

Faecal sludge: Faecal sludge is the human waste such as excreta, urine and anal cleansing water/material contained in the pit of the pit latrine or a poorly designed soak pits, lined tanks and septic tanks.

Septic tank: An underground tank that treats sewage by a combination of solids settling and anaerobic digestion.

Sewage treatment plant: A sewage treatment plant is designed to treat raw sewage.

Faecal sludge treatment plant: A Faecal sludge treatment plant is designed to treat Faecal sludge & septage.

Co-treatment of faecal sludge: It is a process where sewage treatment plant, in addition to treating the domestic sewage, if feasible, also treats faecal sludge and septage emptied from various onsite sanitation systems

Co-treated sludge: The sludge produced during co-treatment of faecal sludge with incoming sewage when directly discharged into STP i.e without any prior solid-liquid separation, such sludge produced while treatment process is a mixture of treated faecal sludge and sewage sludge together.

Dewatered co-treated sludge: Sludge having moisture content of 70-80% that is produced after the co-treatment process in Sewage Treatment Plant.

Dried co-treated sludge: Sludge having moisture content of 15-25% that is produced after the co-treatment process in Sewage Treatment Plant.

Dewatered faecal sludge: Sludge having moisture content of 70-80% that is produced after the treatment of Faecal sludge & septage in Faecal sludge treatment plant.

Dried faecal Sludge: Sludge having moisture content of 15-25% that is produced after the treatment of Faecal sludge & septage in Faecal sludge treatment plant.

Sewage sludge: It is residual, semi solid, material that is produced as by-product during sewage treatment

Executive Summary

The launch of the Swachh Bharat Mission (SBM) in 2014 and SBM (2.0) in 2021, revived the national sanitation priorities, bringing forward the unprecedented attention. There is a growing challenge on sanitation in non-sewered areas. Septic tanks are overgrowing, but their desludging system is yet informal and unmanaged. Generally, the frequency of desludging of onsite sanitation systems are significantly less by households and establishments. And also its quite often visual in cities that Faecal Sludge and Septage (FSS) are discharged into storm water drains, creeks, wastelands, and open dumpsites. Recently, the Government of India has recommended in its SBM 2.0 guidelines for scientific treatment of septage in existing and upcoming Sewage Treatment Plants (STPs). Success of faecal sludge treatment plants and co-treatment facility relies on understanding the characteristics of FSS. Similarly, effective utilization of dewatered and dried sludge also depends on the characteristics of sludge with respect to organic matter, pathogens, and heavy metals.

However, there is limited information available on the characteristics of FSS, dewatered, and dried sludge from co-treatment at STPs and stand-alone Faecal sludge treatment plants (FSTPs) in India. The characteristics vary from region to region with respect to geographical and climatic conditions. Hence, this study aims at the characterization of FSS along with dewatered and dried co-treated/faecal sludge in comparison to the existing standards and guidelines such as CPHEEO (2013), USEPA (Class A & B) guidelines, and FCO compost standards (2009). Typical parameters used for the characterization include pH, Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Total solids (TS) and Total Kjeldahl Nitrogen (TKN), Faecal Coliforms (FC), Pathogens (E.coli, Shigella, and Salmonella), and Heavy metals.

Samples for testing were collected from five different STPs/FSTPs and analyzed for the critical parameters. It was observed that for the analyzed FSS, pH ranged from acidic to neutral 6.8 - 7.1, BOD ranged from 18650 - 23223 mg/L, COD varied from 29150 - 36900 mg/L and VS ranged from 17482 - 21812 mg/L. These analyzed values are much higher than the suggested design values for FSS in CPHEEO manual on Sewerage and sewage treatment systems - 2013. FC varied from 9.3x106 - 4.3x107 MPN/100 mL. *Shigella* species are enumerated as 5.1 - 6.3x103 CFU/100 mL. Salmonella species ranged from 6.4 - 7.8x103 MPN/100 mL.

Heavy metals concentration in FSS were within the suggested design values in CPHEEO manual (2013). Still, some metals (Zn & Pb) exceeded the effluent discharge Standards by CPCB - 2005. Although, there are no household industries in the select cities, perhaps, the possible sources of these metals concentration could be health supplements, medicines, food products and household's washing and cleaning products.

The characteristics of dewatered sludge (i.e 70-80% moisture content) from five different STPs/FSTPs are almost similar except for their organic matter content. Due to different degradability of sludge, it varies within 41-45% of organic matter in co-treated sludges compared to 68-70% in untreated/semi-treated dewatered Faecal sludge. The dewatered sludge satisfies Class B guidelines for Faecal Coliforms but fails in *Salmonella* and Helminth numbers. They also meet Class B guidelines for heavy metals but fail to satisfy stringent FCO (2009) compost standards.

Naturally dried (22-48% moisture content) sludge was also examined. It is very interesting to note that all the naturally dried sludge from STPs and FSTPs satisfy the limits of US EPA Class B sludge criteria. Hence, it is recommended to conduct controlled sludge drying experiments to determine safe drying periods and required sludge dryness for the hygienically safe product used in agriculture.

It is inferred from the study that environmental design values for BOD, COD, VS concentrations of Faecal sludge and septage should be revised to higher values, and heavy metal concentrations cannot be ignored for its management. The dewatered co-treated/Faecal sludge should be co-composted with bulking material browns/ sawdust, dry leaves, or dried naturally/thermally/controlled greenhouse conditions to satisfy US EPA Class A or B Guidelines. In addition, the mechanism of pathogen destruction by the naturally drying process needs to be studied scientifically for Indian climatic conditions.

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1 INTRODUCTION

1. INTRODUCTION

1.1. Background

The design of sludge treatment facility along with co-treatment of Faecal Sludge and Septage (FSS) at Sewage Treatment Plants (STP) or individual faecal sludge treatment requires precise data on the characteristics of the influent to determine a suitable facility size and to select appropriate treatment technologies. However, in contrast to wastewater characteristics that are already well known, the data availability on Faecal sludge & septage characterization is limited. The focus of this study is to characterize the Faecal sludge & septage and co-treated sludge, comparing it with existing sludge reuse standards, recommending safe sludge disposal and preparing a standard protocol for the analysis and monitoring. With the recent launch of national level programmes like Swachh Bharat Mission 2.0 and AMRUT 2.0, cities are guided to adopt Faecal Sludge and Septage Management (FSSM) and its co-treatment with sewage at STPs. Capacity of the different STPs in northern India, especially Ganga towns for co-treatment of the Faecal sludge and septage was reported earlier (by NIUA, 2019). Hence, scientific evidence by an influent, effluent and sludge characteristics study on the current practice of co-treatment of Faecal sludge & septage (at STP/FSTP), will be very useful for practitioners and end users to grab all the information regarding disposal and reuse of dried Faecal/co-treated sludge.

1.2. Objective

The main objective of the study is to understand the characteristics of FSS; dewatered and dried co-treated sludge; dewatered and dried sewage sludge from select STPs and FSTPs plants. It is aimed that the study will support in advocacy for formulation of national level standards for utilization of biosolids and treated Faecal sludge.

The scope of the study is limited to:

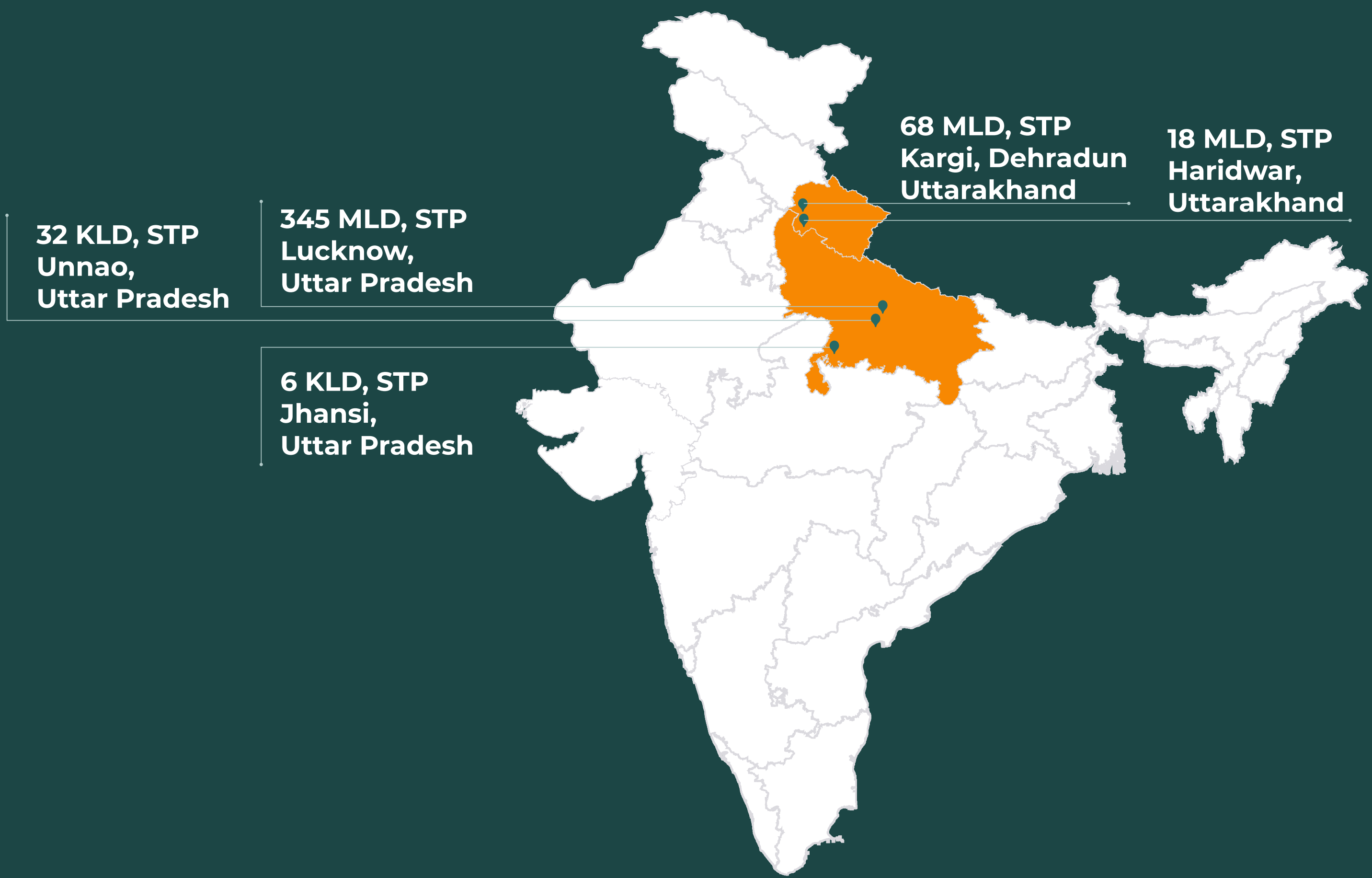
1. The characterization of Faecal sludge and septage and co-treated sludge (dewatered and dried sludge) in terms of Moisture content, Total organic carbon, Total Kjeldahl Nitrogen, Total phosphorus, Heavy metals, Faecal Coliforms, Pathogens (E.coli, Salmonella species and Shigella species) and Helminth eggs from one conventional ASP based STP, two co-treatment plants and two Faecal sludge treatment plants (FSTP).
2. To prepare a standard sampling and analysis protocol.
3. Comparison of the co-treated dried sludge quality with existing standards or guidelines such as CPHEEO (2013), USEPA (Class A & B) guidelines and FCO, 2009.
4. Recommendations on reuse of dried sludge.

1.3. | Study Sites

All the plants selected were from the Class–I cities having a population of more than 1,00,000. The plants are selected based upon the permission granted by STPs and FSTPs authority for sampling at the sites and while considering the limited span of time available with civil restrictions imposed during the pandemic situation of COVID-19. These STPs/FSTPs were selected on the basis of their capacity to treat the FSS within the distance of 300-400 Km from the location of IIT, Roorkee, northern region of India to avoid any delay in the analysis time for the collected samples (APHA, 2017, Methods for Faecal sludge analysis, 2021). A brief on sanitation situation of the city followed by description of the respective STP for the study are explained in the sub sections.

Table 1: Select STPs and FSTPs for study

S. No.	Study sites - STP/FSTP	Types of Sludge
1.	18 MLD Conventional Activated sludge process (ASP) based Sewage Treatment Plant (STP), Haridwar, Uttarakhand	Dewatered and dried sewage sludge
2.	68 MLD Sequencing Batch Reactor (SBR) based STP at Kargi, Dehradun, Uttarakhand (With co-treatment)	FSS, co-treated dewatered and dried sludge
3.	345 MLD Upflow Anaerobic Sludge Blanket reactor (UASB) based STP, Lucknow, Uttar Pradesh (with co-treatment)	FSS, co-treated dewatered and dried sludge
4.	32 KLD Unplanted drying bed based Faecal Sludge Treatment Plant (FSTP), Unnao, Uttar Pradesh	FSS, dewatered and dried FSS
5.	6 KLD Planted Drying Bed based Faecal Sludge Treatment Plant (FSTP), Jhansi, Uttar Pradesh	FSS, dewatered and dried FSS



1.3.1. 18 MLD Activated Sludge Process based STP at Jagjeetpur, Haridwar (Uttarakhand)

Sanitation situation

According to the State Annual Action Plan (SAAP) prepared under AMRUT for the fiscal year 2015-16, the population of Haridwar city is 2,31,338. Out of 47,251 households, about 87% have individual household toilets but recently it has been improved to 100% individual household toilets by the year 2019. Whereas the sewerage has been increased from 52% in 2016 to 80% by 2021. The tankers collect faecal sludge from households and establishments left out from sewerage and sub-urban areas of the city. It is reported by Nagar Nigam that FSS is discharged indiscriminately to any sewer holes by the emptiers. There are 7 STPs in the Haridwar district with an installed capacity of 145 MLD and are operating at a capacity of 120 MLD leading to 100% treatment efficiency of waste water generated. According to key informant interview with XXXX, the plant seldom receives FSS through indiscriminately discharged by emptiers into sewer holes.

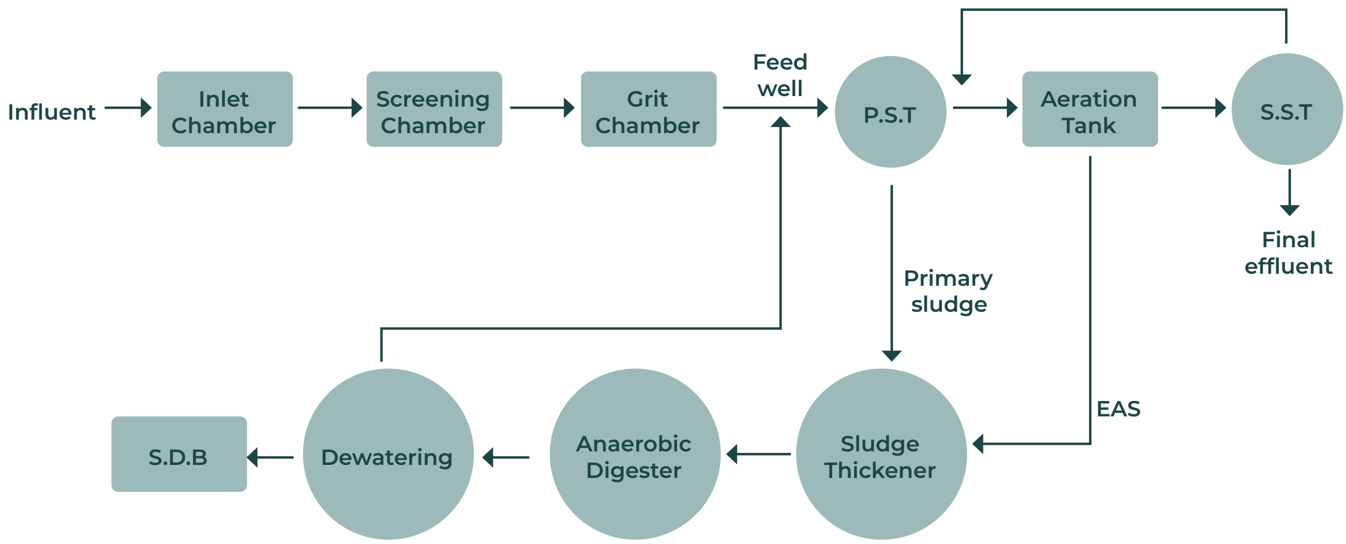
About STP

The 18 MLD ASP based STP was constructed and commissioned by Uttar Pradesh Jal Nigam in 1990. It is based on ASP technology. The STP comprises an inlet chamber, fine screens manual and mechanical both, grit chamber, parshall flume, primary clarifiers, aeration tanks, secondary settling tanks, sludge thickener, anaerobic sludge digesters and sludge drying beds (Figure 1). The reported data was obtained from the plant operator. The process flow diagram of the STP is given in Figure 1.

Table 2: Detail information of the STP

S. No.	Description of the STP	
1	Name and place of treatment plant:	18 MLD ASP, Jagjeetpur, Haridwar, Uttarakhand
2	Commissioned year	1990
3	Running capacity (MLD)	18
4	Designed capacity and year of ultimate design(MLD)	18
5	Dewatered sewage sludge produced (m^3/day)	10
6	Dried sludge being produced (m^3/day)	2
7	Disposal/end use of dried sludge:	Utilization as organic manure

Figure 1: Flowsheet of 18 MLD Activated Sludge Process (ASP) at Haridwar, Uttarakahand



1.3.2. 68 MLD Sequencing Batch Reactor (SBR) based co-treatment STP, Dehradun (Uttarakhand)

Sanitation situation

According to the report 'Urban Faecal Sludge and Septage Management in Uttarakhand' by NIUA in the year 2020, the population of the city is 8,04,379. A total of 1,67,577 households reside in the city with 66% households dependent on Onsite Sanitation System which comprises 12% households dependent on Septic tanks connected to soak pits, 11% households dependent on septic tanks connected to open drains, 10% households dependent on lined tanks with semi permeable walls and open bottom, and 33% households dependent on containment systems that are failed, damaged, collapsed or flooded with no outlet or overflow. Dehradun Nagar Nigam does not have any registered vehicle and around 25 cesspool vehicles privately operate within the city limits. The 68 MLD STP located in Kargi, receives 25-30 trucks septage daily. The emptiers discharge the septage at Kargi STP. Septage is added to STP directly by discharging into a rudimentary designed inlet chamber before the wet well of the STP as septage receiving station at the STP.

About the STP

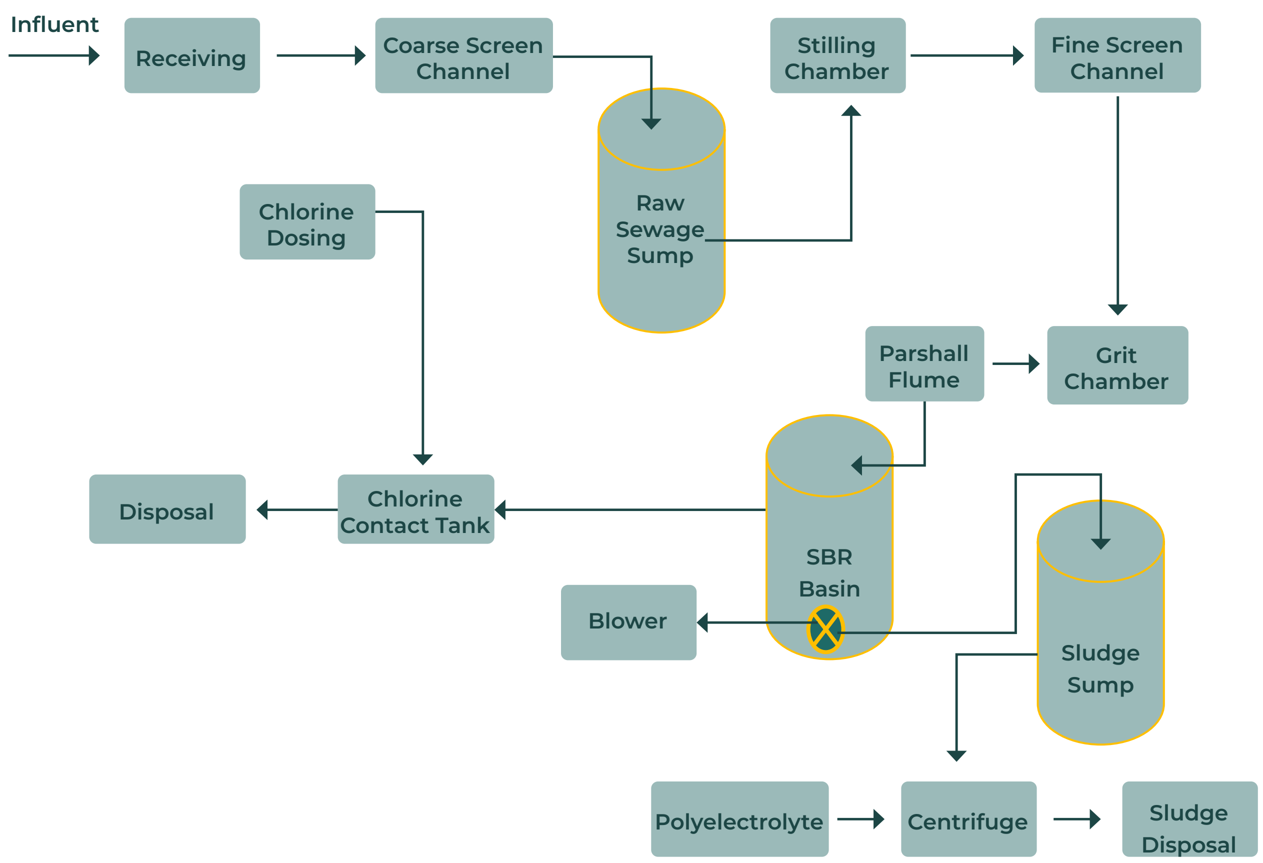
The 68 MLD STP at Kargi, Dehradun is based on the SBR process. It comprises the influent receiving chamber, coarse screen (manual and mechanical), raw sewage sump, pump house, stilling chamber, fine screen (manual and mechanical), grit chamber, parshall flume, SBR basin, chlorine contact tank, sludge sump, and centrifuge. The emptiers discharge collected FSS into a rudimentary designed septage receiving chamber before the wet well, where the FSS is mixed with incoming sewage. The STP is designed for 68 MLD average flow; however, current flow rate is 16-17 MLD. Out of 5 m^3/day of the dewatered sludge, 2-3 m^3/day of dried sludge is produced from the rudimentary designed sludge drying beds cum storage of sludge. The reported data was obtained from the plant operator.

Table 3: Descriptive information of the STP

S. No.	Description of the STP	
1	Name and place of treatment plant	68 MLD SBR, Dehradun, Uttarakhand
2	Commissioned year	2015
3	Running capacity (MLD)	16-17
4	Designed capacity (MLD) and year of ultimate designed	68 and 2015
5	Faecal sludge and septage added (KLD)	~100
6	Dewatered sewage sludge produced (m^3/day)	10
7	Dried sludge being produced (m^3/day)	2-3
8	Disposal/end use of dried sludge	Utilization as organic manure

The typical process flow diagram of STP is provided in Figure 2.

Figure 2: Process flow diagram of 68 MLD STP at Dehradun, Uttarakahand



1.3.3. 345 MLD UASB based Co-treatment STP, Lucknow (Uttar Pradesh)

Sanitation situation

Lucknow, the capital city of the Indian state of Uttar Pradesh, is located in the central region of the state According to SFD report on Lucknow 2020, the population of Lucknow city is 33,91,208. Around 44% of this population attributes to Onsite Sanitation system (OSS) comprising septic tank connected to open drains or storm sewer (35 %), fully lined tank (sealed) connected to open drain or storm sewer (1%), fully lined tank sealed with no outlet or overflow (7%), and lined tank with impermeable walls and open bottom with no outlet or overflow (1%). There are around 60 vacuum tankers plying in the city in which the Lucknow Nagar Nigam (LNN) owns 10 vacuum tankers and private emptiers owns 50 tankers. Only 2% of the FS emptied from OSS reaches to the STP, while the remaining 98% is disposed into the open drains. Total four STPs located at Bharwara, Daulatganj, Vrindavan Pariyojna Sector 10 and Vrindavan 6B have overall capacity of 416.5 MLD. FSS which is conveyed through drains as overflow along with supernatant are intercepted and diverted to the STPs which attributes to 94% treatment of FSS.

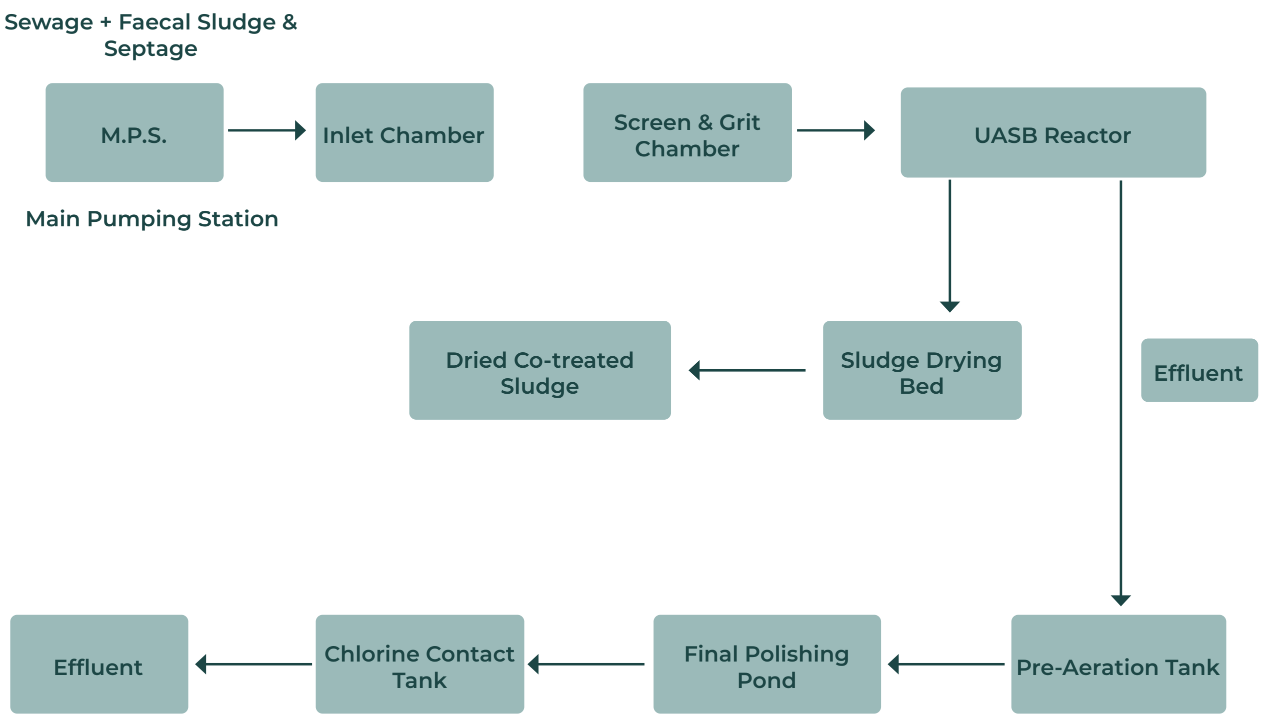
About STP

The Bharwara STP is located at Bharwara area in Gomti Nagar, Lucknow. The STP is based on Up-flow Anaerobic Sludge Blanket (UASB) Reactor technology. From the inlet, the wastewater flows through mechanical screens, and flows to Upflow Anaerobic Sludge Blanket (UASB) reactors of the STP. FSS by emptiers is discharged into nearby sewage pumping station where it is mixed with incoming sewage. The co-treatment of FSS is by direct discharge method without any preliminary treatment. The plant is currently running at its full capacity. The process flow diagram is shown in Figure 3.

Table 4: Detail information of the STP

S. No.	Description of the STP	
1	Name and place of treatment plant	345 MLD SBR, Lucknow, Uttar Pradesh
2	Commissioned year	2005
3	Running capacity (MLD)	345
4	Designed capacity (MLD)	345
5	Dewatered sewage sludge produced (m^3/day)	90
6	Dried sludge being produced (m^3/day)	12-14
7	Disposal/end use of dried sludge	Partial use as organic manure and dumping in low lying areas

Figure 3: Flowsheet of 345 MLD STP at Lucknow, Uttar Pradesh



1.3.4. 32 KLD Faecal Sludge Treatment Plant Unnao, Uttar Pradesh

Sanitation situation

According to SFD Report Published in year 2020, the population of the city is 2,14,128. About 91% of the population is dependent on Onsite Sanitation System (OSS) comprising of Septic tank connected to open drain or storm sewer (41%), Fully lined tank (sealed) connected to open drain or storm sewer (41%), lined tank with impermeable walls and open bottom with no outlet or overflow (4%), and lined tank with impermeable walls and open bottom with no outlet or overflow, where there is significant risk of groundwater pollution (4%) and Unlined pits, no outlet or overflow, where there is significant risk of groundwater pollution (1%). Unnao NPP owns and operates 2 vacuum tankers with 5 private operators functional within the NPP limits leading to an overall emptying efficiency of 75% for the OSS, except lined tank with impermeable walls and open bottom with no outlet or overflow, leading to a significant risk of groundwater pollution and, unlined pits with no outlet or overflow, that cannot be emptied. However, it treats only ~10 KLD of FS due to the low number of tankers decanting at the FSTP.

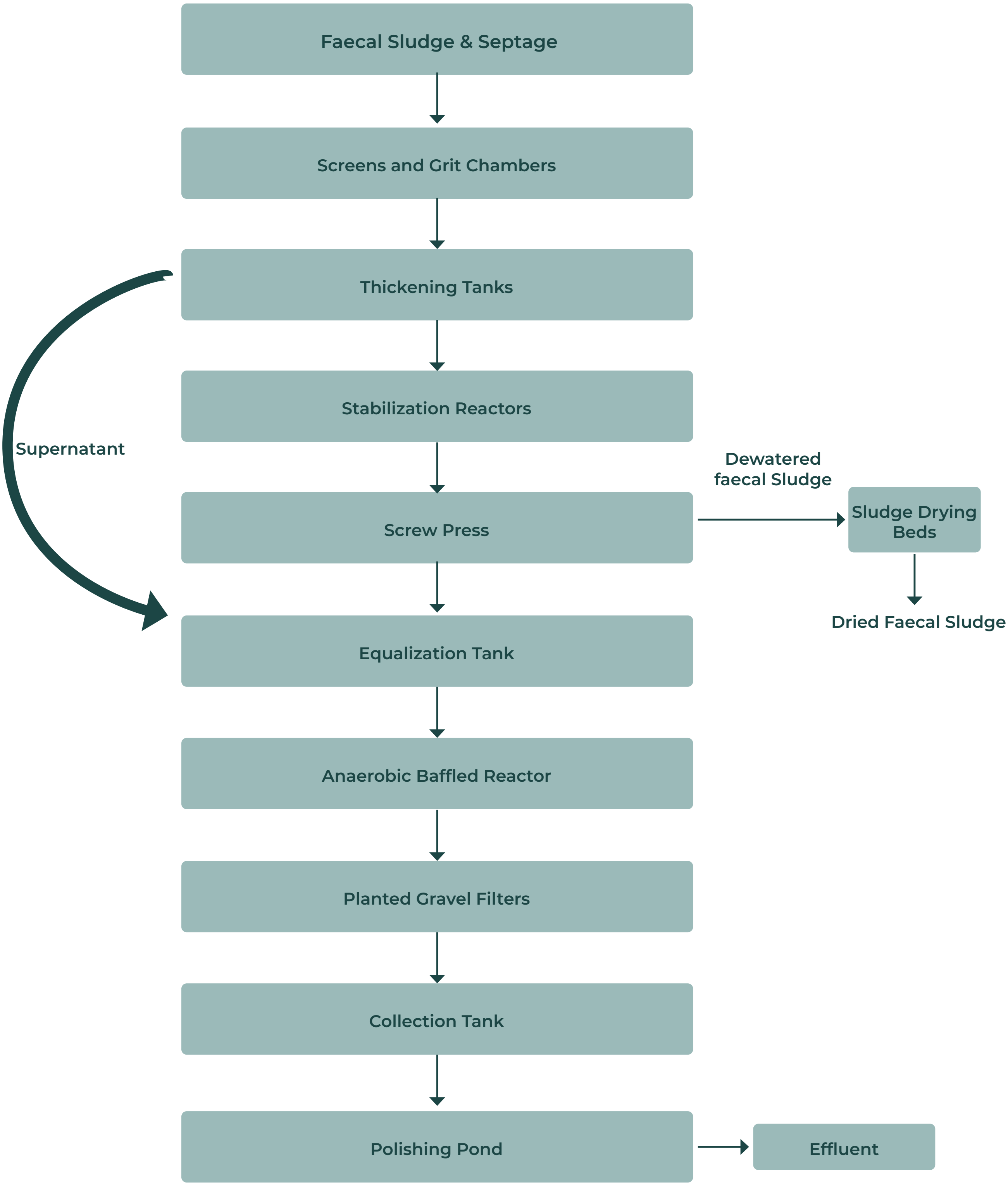
About FSTP

Currently 3-10 KLD of FSS is being discharged by emptiers at FSTP. Dewatered FSS is generated at the rate of 0.040 - 0.050 m3/day. The reported data was obtained from the plant operator. The process flow diagram is given below in Figure 4.

Table 5: Detail information of the FSTP

S. No.	Description of the FSTP	
1	Name and place of treatment plant	32 KLD FSTP at Unnao, Uttar Pradesh
2	Commissioned year	2018
3	Running capacity (KLD)	3 - 10
4	Designed capacity (KLD)	32
5	Dewatered sewage sludge produced (m^3/day)	0.04 – 0.05
6	Dried sludge being produced (m^3/day)	0.01 – 0.02
7	Disposal/end use of dried sludge	Utilization as organic manure

Figure 4: Process flow diagram of 32 KLD FSTP at Unnao, Uttar Pradesh



1.3.5. 6 KLD Faecal Sludge Treatment Plant, Jhansi, Uttar Pradesh

Sanitation situation

According to SFD Report Published in the year 2020, the population of the city is 6,22,180. About 98% of the population is dependent on Onsite Sanitation System (OSS) comprising septic tanks connected to open drain or storm sewer (38%), fully lined tank (sealed) connected to open drain or storm sewer (54%) and lined tank with impermeable walls and open bottom with no outlet or overflow (6%). Jhansi Nagar Nigam has two functional vacuum trucks, which are operated and maintained by private partner via public-private partnership. Jhansi has a dedicated faecal sludge treatment plant (FSTP) located in Bijoli area with a capacity of 6 KLD. The plant is currently running at full capacity and treating influent at an efficiency of 90%.

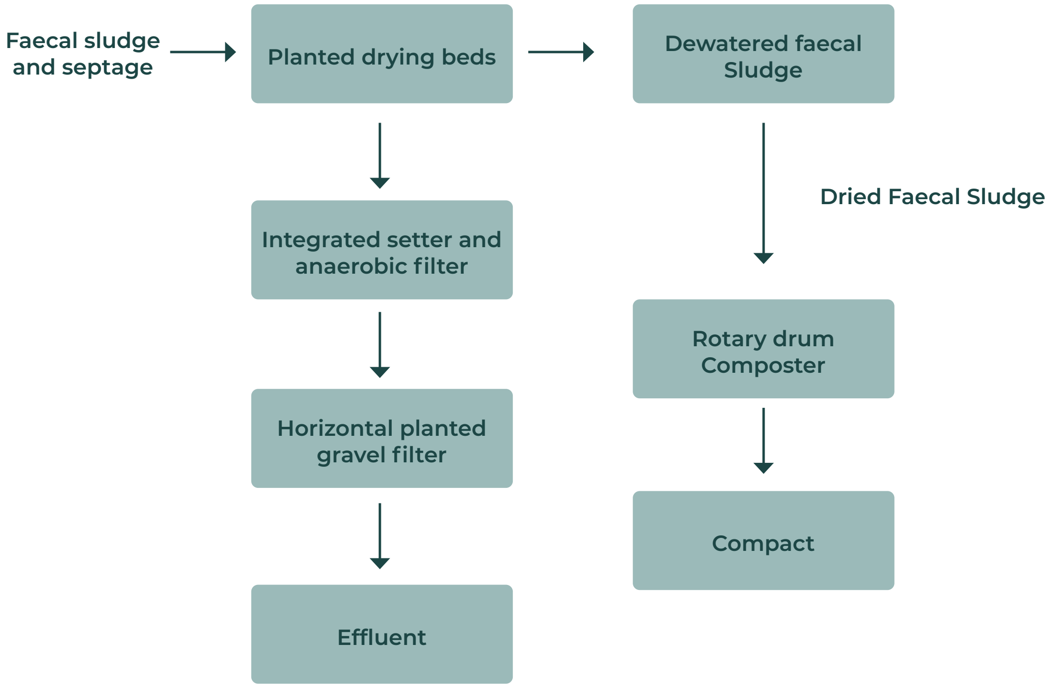
About FSTP

The FSTP comprises planted drying bed (PDB), integrated settler and anaerobic filter (AF), horizontal planted gravel filter, stabilization reactor, sludge drying bed, vertical planted gravel filter, anaerobic filter and settler (Figure 6). The data was obtained from the plant operator.

Table 6: Detail information of the FSTP

S. No.	Description of the FSTP	
1	Name and place of treatment plant	6 KLD FSTP at Jhansi (UP)
2	Commissioned year	2018
3	Running capacity (KLD)	6
4	Designed capacity (KLD)	6
5	Dewatered sewage sludge produced (m^3/day)	0.056
6	Dried sludge being produced (m^3/day)	0.012
7	Disposal/end use of dried sludge	Utilization manure

Figure 5: Process flow diagram of 6 KLD FSTP at Jhansi, Uttar Pradesh



1.4. Limitations of the study

The study period of the project was one year, to study the seasonal effects on the characterization and monitoring of Faecal sludge and septage and co-treated sludge from the select STPs and FSTPs. But due to Covid-19 restrictions imposed in the state during the study period, the selection of few sites were revised. Due to limited time period of the project and the financial resources, the Institution could only conduct the sample collection and analysis once for each site. In lieu of studying seasonal variations, the institution prepared standard operating procedure (SOP) for characterizing the FSS (refer to annexure 1).

Due to the same reason explained earlier, the study could cover only five treatment plants from the northern region, within a distance of 300-400 km from the location of IIT-Roorkee to avoid any delay in transportation of samples.

2 LITERATURE REVIEW

2. Literature Review

According to urban Shit Flow Diagram (SFD) of India, around 63% of India's urban population is dependent on on-site sanitation systems (such as septic tanks, twin pit latrines, etc.), 36% is dependent on off-site systems (such as sewer network etc.) and 1% is still defecating in the open.

Roughly, 60% of the population, dependent on onsite sanitation systems, gets their systems emptied. The rest of the faecal sludge gets discharged into the environment. This indicates that there is a need to advocate around regular emptying amongst the public, and to regulate private emptying service providers to expand emptying services. For 5% of the urban population in India, excreta is managed on-site either through a twin pit system or by abandoning the pit after use, thereby eliminating the need for emptying faecal sludge from such systems. Moreover, safe management of faecal sludge and septage from the households dependent on the onsite sanitation is possible by using the treatment infrastructure of the off-site sanitation.

The launch of the Swachh Bharat Mission in 2014 and SBM (2.0), 2021 reinvigorated the national sanitation priorities, bringing them unprecedented attention. Over these five years, the programme expanded its focus from the construction of toilet facilities to incorporating concerns of wastewater management. In one of its most critical interventions, the government took note of the entrenched reliance on onsite sanitation facilities, like septic tanks and pits and issued the National Policy of Faecal sludge Management in 2017.

With the emerging 'circular economy' model as a lever to drive sustainable development to protect land and water resources globally, the recycled end-products (treated wastewater and biosolids) from these plants are also being endorsed at local level. Wastewater, being pathogenic, is rich in nutrients like nitrogen and phosphorus, and organic matter. Consequently, recycling both the treatment end-products- treated wastewater and biosolids in agriculture, enhances crop yields, reduces the burden of synthetic fertilizers, mitigates risks posed by water scarcity, and brings down the cost of production, thereby boosting the incomes of farmers (WHO, 2006a). The informal markets have flourished as a result, allowing cesspool operators and small-scale farmers in city peripheries and peri-urban areas to establish their linkages (Biome Environmental Trust, 2018; Kvarnström et al., 2012). In fact, according to WHO, 10% of the world's population consume food produced on lands irrigated with wastewater. Nonetheless, its use in agriculture cannot be allowed to continue without treatment, acknowledging the safety of the farmers who are at highest risk of infection, surrounding communities, and the households consuming the produce (Fuhrimann et al., 2014; WHO, 2006b). Balancing the benefits that accrue from its recycling with the risks it poses to public health, therefore, emerges as an imperative for regulatory and policy guidance (Fuhrimann et al., 2014).

The National Policy draws from various existing laws and regulations, including the Water (Prevention and Control of Pollution) Act, 1974, and the Solid Waste Management (SWM) Rules, 2016 under the Environment (Protection) Act, 1986, for its legislative and regulatory authority in ensuring the safe disposal of post-processed Faecal sludge and septage. The Policy states that 'the SWM Rules 2016 will also apply for disposal and treatment of Faecal sludge and septage, before or after processing, at landfills and for use as compost'.

Usage of the word 'sludge' varies and can be confusing, as there are several different types of sludge, and various terminologies are used by different practitioners. For example, types of wastewater sludge include sludge that settles out in the sewer, or sludge that is separated from liquid flows within wastewater treatment plants. Faecal sludge from septic tanks is also commonly called 'septage', and might or might not include sludge, scum or supernatant layers. In addition, septic tanks commonly do not operate as designed, and/or what many people frequently refer to as 'septic tanks' are more like cesspits in reality. Faecal sludge management refers to the storage, collection, transport, treatment, and safe end use or disposal of Faecal sludge (Strande et al., 2014). Faecal sludge and wastewater are composed of excreta, together with additional inputs, and are both designed for the safe management of the resulting waste streams. The main difference between Faecal sludge and wastewater is the respective sanitation service chains, which has very significant ramifications for management, cost, appropriate treatment, and quantities and qualities (Q&Q) (Dodane et al., 2012). Faecal sludge is stored onsite, and is periodically collected and transported to FSTPs, followed by safe disposal or end use.

In India, the competent authorities and regulators recognize the risks associated with recycling of Faecal sludge and septage-derived products. They have attempted to address these issues albeit tangentially by providing SWM, 2016 and National policy (2017). These attempts, however, cannot substitute formal standards directly governing the subject. The standard must consolidate and address various types of quality-related concerns under one governing document for sewage sludge and Faecal sludge considering the Indian environmental and geographical conditions. STP / FSTP operators should adhere to standards and reporting protocols. No foul odour should emanate from the biosolids. The pathogen load in biosolids should be reduced in order to minimize the risk to public health. The treatment facilities shall implement any of the processes listed under (a) to (c) below, or achieve the standards prescribed in (d) using any other process.

(a) Air drying on percolation beds to achieve a moisture content not more than 60% followed by storage in a dry space for at least one year. (or) (b) Co-composting of Faecal sludge solids with organic solid waste to achieve temperatures above 45 °C for at-least 7 consecutive days after every turning or any other time temperature combinations as prescribed in the pathogen kill curve (or) (c) Achieve temperatures homogeneously within the solids as per the pathogen kill curve using any thermal process (or) (d) Demonstrate consistent achievement of 1,000 most probable number (MPN) per gram total dry solids of *E. Coli* or 1,000 colony-forming units (CFU) per gram total dry solids of Faecal Coliforms .The pathogens in Faecal sludge solid poses a risk of transmission through vectors such as insects, rodents and birds. Composting should be done to achieve temperatures above 40°C for at least 14 days with average temperature exceeding 45 °C during that time. The biosolids should not have toxic contaminants in order to reduce risk to the receiving soils. The ceiling limits for heavy metal contamination in biosolids should be less than the limits of FCO (2009), USEPA class A/ B sludges (Quality of FSM report, 2020).

The manual considers three main recycling applications for biosolids, (i) as a material for immobilized bricks (suitable only for chemically precipitated sludge which is fully dried before its use for non-load bearing paver blocks), (ii) as a soil filler, and (iii) as a fuel (Manual on Sewerage and Sewage Treatment Systems, 2013).

CPHEEO has prescribed management protocols for different kinds of sludge. Use of raw sewage sludge directly on land as a soil filler for growing crops is not desirable. For dewatered septage/sludge agricultural application, it should satisfy the Class A biosolids criteria of US EPA either by lime stabilization, solar drying or composting; where the sewage sludge from drying beds should be ploughed into soil before raising the crops. Top dressing of soil with sludge should be prohibited. Dried sludge may be used for lawns and for growing deep-rooted cash crops and fodder grasses, with minimum exposure to the edible ones . Heat-dried sewage sludge is the safest from the public health point of view. Though deficient in humus, it is convenient in handling and distribution. Dried sludge can be used as manure/soil conditioners (Reuse and Recycling of Faecal Sludge-derived Biosolids in Agriculture, 2020).

3 METHODOLOGY

3. METHODOLOGY

3.1. | Collection of FSS samples

An adequate attention was given to representative sample collection in FSS characteristics study. The FSS samples were collected from the tankers itself instead of onsite sanitation facilities at the respective discharge sites of the STP/FSTP. The samples were collected as a composite, by mixing small equal portions at an interval of 2 minutes during disposal from the tanker into the sewage sump of the STP/FSTP.

3.2. | Sludge samples collection

The samples were collected from one conventional ASP plant, two STPs and two FSTPs. The date of sampling is mentioned below in Table 2.

Table 6: Date of sampling

STP/FSTP sites	Date of Sampling
18 MLD STP at Haridwar, Uttarakhand	28th Jan, 2021
68 MLD STP at Dehradun, Uttarakhand	28th Jan, 2021
32 KLD FSTP at Unnao, Uttar Pradesh	12th March, 2021
345 MLD STP at Lucknow, Uttar Pradesh	23rd August, 2021
6 KLD FSTP at Jhansi, Uttar Pradesh	17th August, 2021

Figure 6: Sample collection from select STPs/FSTPs

(a) 68 MLD STP at Dehradun, Uttarakahand

(b) 6 KLD FSTP at Jhansi, Uttar Pradesh

Figure 7: Dewatered sludge collection from select STPs/FSTPs

(a) 32 KLD FSTP at Unnao, Uttar Pradesh

(b) 18 MLD STP at Haridwar, Uttarakahand

(c) 6 KLD FSTP at Jhansi, Uttar Pradesh

(d) 345 MLD STP at Lucknow, Uttar Pradesh

Figure 8: Dried sewage and co-treated sludge collection from select STPs/FSTPs

(a) Dried sewage sludge, 18 MLD STP at Haridwar, Uttarakahand

(b) Dried Co-treated sludge, 68 MLD STP at Dehradun, Uttarakahand

(c) Dried Co-treated sludge, 345 MLD STP at Lucknow, Uttar Pradesh

3.3. | Sample analysis

All the physico-chemical and microbiological parameters were analyzed as per the methods described in Table 3. Preservation measures of physico-chemical and microbiological tests were adopted according to APHA (2017) and WHO method (1996) for helminths. The detailed procedures for physico-chemical and microbiological parameters are given in Annexure 1.

Table 8: Methods adopted for analysis of physico-chemical and microbiological parameters

Physico-chemical parameters	
pH, EC, Total Organic Carbon Total Nitrogen, Ammonia, Nitrate, Phosphorus, Potassium and Heavy metals	CPHEEO Manual on Solid Waste Management (2016). Indian Standards for soil and compost IS 10158 (1982). Laboratory procedures and methods for characterisation of Faecal sludge (Methods for Faecal sludge analysis,2021)
Microbiological parameters	
• Faecal Coliforms, *E. coli* and *Shigella* species • *Salmonella* species • Helminth eggs	Standard Methods (APHA, 2017) USEPA Method 1682: *Salmonella* in sewage Sludge (2006) Modified Bailenger Method (1979): Analysis of Wastewater for Use in Agriculture -A Laboratory Manual of Parasitological and Bacteriological Techniques, WHO (1996)

4 RESULTS

4. RESULTS

4.1. | Characterization of Faecal Sludge & Septage

Faecal sludge & septage was analyzed for physico-chemical and microbiological parameters as illustrated in Table 4. Heavy metals concentration is given in Table 5.

Table 9: Physico-Chemical and Microbiological Characteristics of Faecal sludge & Septage

Physico-Chemical Parameters	Faecal sludge & Septage (68 MLD STP, Dehradun)	Faecal sludge & Septage (345 MLD STP, Lucknow)	Faecal sludge & Septage (32 KLD Unnao FSTP)	Faecal sludge & Septage (6 KLD FSTP, Jhansi)	Faecal sludge & Septage Suggested Design Value for (CPHEEO Manual, 2013)	USEPA (1994)
pH	6.5	6.6	7.1	6.9	6.0	1.5-12.6
TS (mg/L)	28,850	34,568	28,600	35,850	15,000	1132-1,30,475
VS (mg/L)	17,482	20,890	17,790	21,812	10,000	353-71,402
BOD (mg/L)	18,650	21,987	11,567	23,223	7,000	440-78,600
COD (mg/L)	29,150	33,880	18,200	36,900	15,000	1500-7,03,000
TKN (mg/L)	396	387	356	396	700	66-1060
NH4 –N (mg/L)	318	312	326	318	150	3-116
Total Phosphorus as P2O5 (mg/L)	328	347	345	342	250	20-760
Alkalinity (mg/L)	716	879	714	987	1,000	552-4190
Oil & Grease (mg/L)	6,300	6,800	7,100	7,800	8,000	208-23,368
Microbiological Parameters						
FC (MPN/100mL)	9.3×10^6	4.3×10^7	4.3×10^6	9.3×10^6	$10^6 - 10^8$	$10^6 - 10^8$
E.coli (CFU/100mL)	2.5×10^5	4.5×10^6	1.1×10^5	2.9×10^5	-	-
Salmonella species (MPN/100 mL)	7.0×10^3	6.5×10^3	6.4×10^3	7.8×10^3	-	-
Shigella species (CFU/100mL)	6.3×10^3	4.5×10^3	5.6×10^3	5.1×10^3	-	-
Helminth eggs (number/L)	6.0×10^3	6.0×10^3	8.0×10^3	7.0×10^3	-	-

Table 10: Heavy metals concentration in FSS samples

Heavy Metals	Faecal sludge & Septage (68 MLD STP, Dehradun)	Faecal sludge & Septage (345 MLD STP, Lucknow)	Faecal sludge & Septage (32 KLD FSTP, Unnao)	Faecal sludge & Septage (6 KLD FSTP, Jhansi)	Septage & Faecal sludge Characteristics (CPHEEO Manual (2013), adapted from USEPA manual/ handbook)	USEPA (1994)	CPCB effluent standards (2005)
As (mg/L)	N.D.	N.D.	N.D.	N.D.	0.2	0.03-0.5	
Cd (mg/L)	N.D.	N.D.	N.D.	N.D.	0.7	0.03-10.8	
Cr (mg/L)	0.058	0.045	0.034	0.042	1.0	0.60-2.2	
Cu (mg/L)	0.425	0.78	0.345	0.626	8.0	0.30-34	
Hg (mg/L)	N.A.	N.A.	N.D.	N.D.	-	0.0002-4	
Mo (mg/L)	N.D.	N.D.	N.D.	N.D.	-	-	
Se (mg/L)	N.D.	N.D.	N.D.	N.D.	-	0.02-0.3	
Ni (mg/L)	0.352	2.45	0.230	2.89	1.0	0.20-37	
Pb (mg/L)	0.368	0.04	0.314	0.05	10	2.0-8.4	0.1
Zn (mg/L)	21.30	8.12	9.78	7.38	40	2.9-153	5

N.D.- Not Detectable

- Solids

Total Solids (TS) concentration of faecal sludge involves a variety of organic (volatile) and inorganic (fixed) matter, composed of floating material, settleable matter, colloidal material, and matter in solution. TS refers to the material remaining after 24 hours of drying the FS at 103-105°C. Volatile solids (VS) depict the fraction that burns off at a temperature of 500°C, which is also considered to be the organic portion.

The TS concentration here ranged from 35,000 - 39,000 mg/L. Volatile solids concentration ranged from 12,000 - 29,000 mg/L. Higher concentration of solid thus indicates the requirement for solid-liquid separation (dewatering) of the faecal sludge, before the biological treatment.

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

COD is the oxygen equivalent of the organic matter that can be oxidised chemically with dichromate, and BOD is the measure of the oxygen used by microorganisms to degrade organic matter. COD concentrations are usually higher than BOD for faecal sludge, and FS typically has much higher BOD.

The COD of Faecal sludge & septage ranged from 18,000 - 36,000 mg/L and BOD varied from 10,000- 14,000 mg/L. The BOD/COD ratio ranged from 0.39-0.55. Hence, the possibility of toxic components or acclimatized microorganisms required for stabilization are limited. Therefore, it is inferred that the waste cannot be easily treated by biological means without any preliminary treatment.

- ### Nitrogen and Phosphorus

Depending on the pH value, storage length, presence of oxygen and type of faecal sludge, nitrogen in FS is present in the form of ammoniacal nitrogen, nitrates/nitrites and organic forms of nitrogen.Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen and ammoniacal (NH_3-N) nitrogen.Total Kjeldahl Nitrogen (TKN) values were between 350 - 400 mg/L.

Phosphorus in faecal sludge is present as phosphate, either in the acidic or basic form of orthophosphoric acid (H_3PO_4 / PO_4-P), or as organically bound phosphate (e.g. nucleic acids, phospholipids and phosphorylated proteins). Total phosphorus here ranged from 140 - 350 mg/L.

- ### pH and Alkalinity

pH is essential for understanding water chemistry, including acid-base chemistry, alkalinity, neutralization, biological stabilization, precipitation, coagulation, disinfection, and corrosion control. pH of the Faecal sludge & septage samples varied from 8.2 - 8.5. Alkalinity of the samples ranged between 887 - 986 mg/L.

- ### Heavy metals

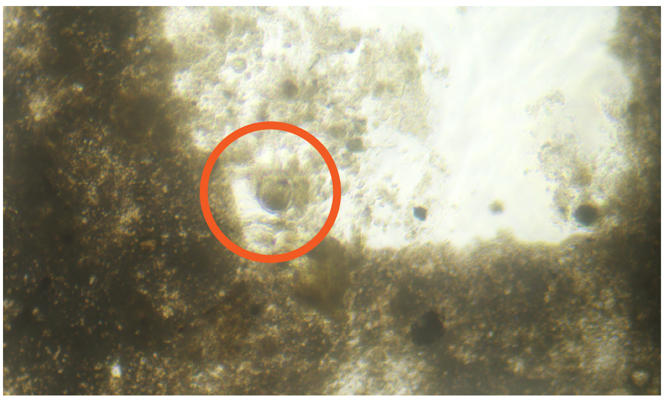
The presence of Heavy metals in the faecal sludge is completely dependent upon the source (domestic or industrial) of collection, as it typically comes from industrial sources, but there might be slight contamination occurring from domestic sources as well.

Even though the Heavy metals were within the range as per the suggested Faecal sludge & septage values as adapted from the CPHEEO manual, 2013; they are not removed during the treatment process, and thus, it is necessary to avoid contamination of the FS by heavy metals, keeping in mind the end use.

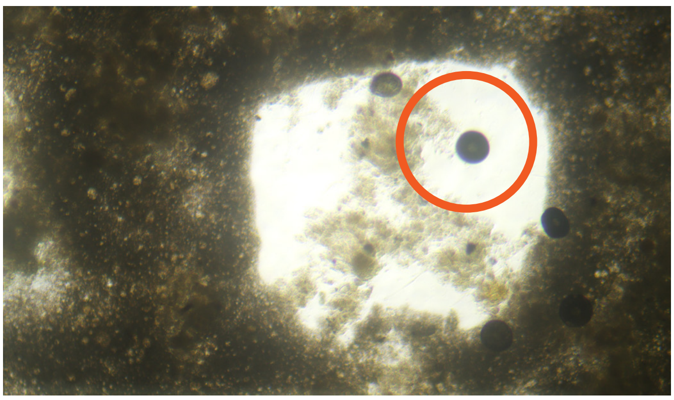
- Faecal Coliforms (FC) and Pathogens (*E. coli, Salmonella, Shigella* and Helminth eggs)

Faecal sludge contains large amounts of microorganisms (pathogens) that actually arise from the sludge itself, due to the feces. Exposure to untreated FS is considered as a pathogenic health risk. Thus, adequate reductions in the pathogenic load needs to be determined, based on the end use or disposal for treated sludge and liquid effluents. The exclusive indicator organisms that are studied here for faecal sludge and environmental contamination are the coliform bacteria (Total & Faecal coliforms) and helminths. The FC range was from 4.3×10^6 to 9.3×10^7 MPN/100 mL. E. coli ranged from 2.5×10^5 to 4.5×10^6 MPN/100 mL. Salmonella species enumerated from 6.500 - 7800 MPN/100 mL. Shigella species varied from 4500 - 5100 CFU/100 mL respectively. Helminth eggs were enumerated as 6000 to 7000 per Litre and species such as Hookworms, *Ascaris*, *Schistosoma* were reported. Protozoans such *Entamoeba histolytica*, Roundworms, *Litonotus*, *Amoeba* were found in the Faecal sludge & septage samples (Figure 10 & 11).

Figure 9: Microscopic images of Helminth eggs in Faecal sludge & septage at 6 KLD FSTP Jhansi, Uttar Pradesh



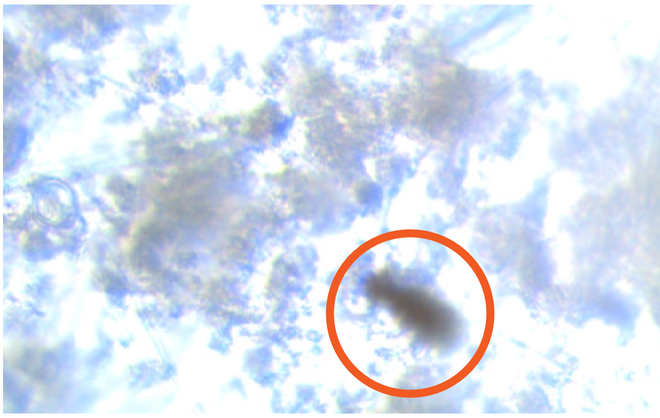
a) *Ascaris* species



b) *Taenia* species

Figure 10: Microscopic images of Protozoans in Faecal sludge & septage at 6 KLD FSTP Jhansi,

Uttar Pradesh



a) *Aspidisca* species

b) *Entamoeba histolytica*

4.2. | Characterization Of Dewatered And Dried Co-Treated/ Faecal Sludge & Septage

4.2.1. 18 MLD ASP (STP) at Haridwar, Uttarakhand

Sewage sludge collected from 18 MLD ASP based STP, Haridwar; was analyzed for physico-chemical and microbiological parameters. The results are summarized in Table 6. Heavy metals concentration is reported in Table 7.

Table 11: Sewage sludge characterization of 18 MLD STP at Haridwar, Uttarakhand

Parameters	Dewatered Sludge	Dried sewage Sludge(Sludge Drying Bed)	FCO Composts Standards (2009)	US EPA Class A Sludges	US EPA Class B Sludges
pH	7.5	7.2	6.5-7.5	-	-
Moisture Content (%)	76.5	22.8	15-25	-	-
Colour	Brown	Black	Dark brown to black	-	-
Odour	No foul odor	No foul odor	Absence of foul odor	-	-
Conductivity (ds/m)	4.5	5.9	4.0	-	-
Organic Matter (%)	41	36	-	-	-
Total Organic Carbon (%)	24	21	16	-	-
Total Kjeldahl Nitrogen (%)	2.4 % (17 mg/L)	3.2 % (22.8 mg/L)	0.5	-	-
Total Phosphorus asP_2O_5 (%) – Min.	1.11 % (27.7 mg/L)	1.66 % (41.5 mg/L)	0.5	-	-

Total Potassium as K_2O (%)-Min.		1.34%			
C/N ratio	10	7			
Faecal Coliforms (MPN/g dry solids)	2.3×10^4	2.1×10^3	-	<1000	$<2\times10^6$
E.coli (CFU/g dry solids)	1.3×10^3	nil	-	-	-
Salmonella species (MPN/ 4g dry solids)	45	-	-	<3	-
Shigella species (CFU/g dry solids)	36	-	-	-	-
Helminth eggs (numbers/L)	3000	-	-	≤1 per 4 g total solids (dry weight basis)	-

Table 12: Heavy metals concentration in sewage sludge of 18 MLD ASP based STP at Haridwar, Uttarakhand

Heavy metals (mg/kg)	Dewatered sewage Sludge	Dried sewage Sludge	FCO Compost standards (2009)	US EPA Class A sludges	USEPA Class Bsludges	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
As	N.D.	N.D.	10	41	75	75
Cd	N.D.	N.D.	5	39	85	85
Cr	N.D.	N.D.	50	-	-	500
Cu	91	78	300	1500	4300	4300
Mo	N.D.	N.D.	100	300	840	840
Mn	N.D.	N.D.	0.15	17	57	57
Ni	N.D.	N.D.	-	-	75	75
Pb	5.6	1.4	50	420	420	420
Se	N.D.	N.D.	-	-	-	-
Zn	844	592	-	36	100	100

**ND- Non Detectable*

- pH

pH of the collected dewatered sludge was 7.9 and dried sludge was 7.3

- **Moisture Content**

Moisture content of the dewatered sludge was 76.5% and dried sludge was 22%.

- **Color and Odor**

Color of the dewatered sludge and dried sludge was black and dark brown, respectively. No foul odor was experienced near the sludge sampling points or in the collected sludge samples.

- **Total Organic Carbon (TOC)**

The concentration of Organic Matter (OM) in sewage is closely related to TOC content.

- **Nutrients**

The concentration of TKN in the dewatered sludge was 2.43% and dried sewage sludge was 3.23%. Total phosphorus was 1.1% in dewatered sludge and 1.66% in dried sewage sludge.

- **Faecal Coliforms (FC)**

The presence of indicator organisms relates to the occurrence of pathogens. FC values in the dewatered and dried sludge were 2.3×10^4 MPN/g dry weight and 2.1×10^3 MPN/g dry weight, respectively.

- ***E. coli***

E. coli enumerated in the dewatered sludge sample was 1300 MPN/g dry weight and 930 MPN/g for dried sludge.

- ***Salmonella* and *Shigella* species**

Salmonella and *Shigella* species were found in the dewatered sludge samples but absent in dried sludge.

- **Helminth eggs**

The helminth eggs were counted as 3000/L in the dewatered sludge. However, the eggs were absent in the dried sludge.

- Heavy Metals

Most of the heavy metals (Pb, Cd, Cu, Cr, Zn,) concentration tested were within the range of FCO compost standards (2009).

4.2.2. 68 MLD (SBR) STP at Dehradun, Uttarakhand

Physico-chemical and microbiological characteristics and heavy metals concentration of the co-treated sludge samples are summarized in Table 8 and 9, respectively.

Table 13: Characteristics of Co-treated (FS+SS) Sludge from 68 MLD SBR at Dehradun, Uttarakhand

Parameters	Dewatered co-treated Sludge	Dried co-treated Sludge	FCO Composts Standards (2009)	US EPA Class A Sludges	USEPA Class B Sludges
pH	8.2	7.6	6.5-7.5	-	-
Moisture (%)	75	22	15-25	-	-
Colour	Brown	Black	Dark brown to black	-	-
Odour	No foul odour	No odour	Absence of foul odor	-	-
Conductivity (ds/m)	5.4	6.5	4	-	-
Organic Matter (%)	43	38	-	-	-
Total Organic Carbon (%)	25	22	16	-	-
Total Kjeldahl Nitrogen (%)	2.7% (19.2 mg/L)	3.4% (24.2 mg/L)	0.5%	-	-
Total Phosphorus as P2O5 (%) – Min.	1.70% (42.5 mg/L)	1.78% (44.5 mg/L)	0.5%	-	-
Total Potassium as K2O (%) –min.	1.23	1.56	-	-	-
C/N ratio	9	6			

Faecal Coliforms (MPN/g dry solids)	4.3×10^4	2.1×10^3	-	<1000	$<2\times10^6$
E.coli (CFU/g dry solids)	1.4×10^3	nil	-	-	-
Salmonella species (MPN/4 g dry weight)	57	-	-	<3	-
Shigella species(CFU/g dry solids)	48	-	-	-	-
HelminthEggs (numbers/L)	4000	-	-	≤1 per 4 g total solids (dry weight basis)	-

Table 14: Heavy metals concentration in co-treated (FS+SS) sludge from 68 MLD SBR at Dehradun, Uttarakhand

Heavy metals (mg/kg)	Dewatered Sludge	Dried Sludge	FCO Compost standards (2009)	US EPA Class A sludges	USEPA Class B sludges	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
As	N.D.	N.D.	10	41	75	75
Cd	N.D.	N.D.	5	39	85	85
Cr	43.6	35	50	-	-	500
Cu	112	64	300	1500	4300	4300
Mo	N.D.	N.D.	100	300	840	840
Mn	N.D.	N.D.	0.15	17	57	57
Ni	N.D.	N.D.		-	75	75
Pb	7.2	6.2	50	420	420	420
Se	N.D.	N.D.				
Zn	996	586	-	36	100	100

- pH

pH of the co-treated dewatered sludge was 8.2 and dried sludge was 7.6.

- Moisture Content

Moisture content of the co-treated dewatered sludge was 75% and dried sludge was 23%.

- Color and Odor

Color of the co-treated dewatered sludge sample was black and dried sludge was grey-brown. No foul odor was found near the sampling point or in the collected sludge samples.

- Total Organic Carbon (TOC)

TOC value for the co-treated dewatered sludge was 25%, which was reduced to 22% for the dried sludge.

- Nitrogen and Phosphorus

Total Nitrogen of the co-treated dewatered sludge was 2.7% which increased to 3.5% for dried sludge. Total phosphorus was 1.70% and 1.78% in the dewatered and dried sludge, respectively.

- Faecal Coliforms (FC)

FC in the co-treated dewatered sewage sludge sample was 4.3×10^4 MPN/g dry weight and for the co-treated dried sewage sludge was 2.1×10^3 MPN/g dry weight. However, as per the coliform standards for biosolids to be disposed of on the irrigated lands should be less than 1000 MPN /g dry solids (USEPA guidelines for class A sludge).

- *E. coli*

E. coli enumerated in the co-treated dewatered sewage sludge was 1400 MPN/g dry weight and the values for the dried sewage sludge was 1000 MPN/g dry weight.

- *Salmonella* and *Shigella* species

Salmonella and *Shigella* species were present in the co-treated dewatered sludge samples but absent in the dried sludge (Table 8).

- ### Helminth eggs

Helminth eggs were enumerated as 4000 Numbers/L in the co-treated dewatered sludge. None of the eggs were found in the dried sludge.

- ### Heavy Metals

Heavy metals such as Zn, Pb, Cd, Cr, Cu, etc. tested in the co-treated sludge sample were within the range of FCO compost standards (2009). STP is working well in terms of physico-chemical and heavy metals parameters.

4.2.3. 345 MLD STP at Lucknow, Uttar Pradesh

Sewage sludge collected from 345 MLD STP, Lucknow was analyzed for physico-chemical and microbiological parameters. The results are summarized in Table 9. Heavy metals concentration is reported in Table 10.

Table 15: Co-treated sewage sludge characterization of 345 MLD STP at Lucknow, Uttar Pradesh

Parameters	UASB Sludge	Dried Sludge (Sludge Drying Beds)	FCO Composts Standards (2009)	USEPA Class A Sludge	USEPA Class B Sludge
pH	8.3	7.9	6.5-7.5	-	-
Moisture Content (%)	89	48	15-25	-	-
Colour	Black	Dark Brown	Dark brown to black	-	-
Odour	No foul odor	No foul odor	Absence of foul odor	-	-
Conductivity (ds/m)	5.8	6.5	4	-	-
Organic Matter (%)	45	28	-	-	-
Total Organic Carbon (%) – Min.	26%	16	16	-	-
Total Kjeldahl Nitrogen (%)- Min.	1.78 % (12.7 mg/L)	2.08 % (14.8 mg/L)	0.5%	-	-

Total Phosphate as P2O5 (%) min	1.13	2.23	0.5 %	-	-
Total Potassium as K2O (%) min	1.98	2.02	-	-	-
C/ N ratio	15	8	-	-	-
Faecal Coliforms (MPN/g dry solids)	2.3×10^{4}	2.3×10^{3}	-	<1000	$<2\times10^{6}$
E.coli (CFU/g dry solids)	9.8×10^{4}	Nil	-	-	-
Salmonella species (MPN/ 4g dry solids)	67	Nil	-	<3	-
Shigella species (CFU/g dry solids)	55	Nil	-	-	-
Helminth eggs (numbers/L)	5000	Nil	-	≤1 per 4 g (dry weight basis)	-

Table 16: Heavy Metals Concentration in Co-treated Sewage Sludge from 345 MLD STP at Lucknow, Uttar Pradesh

Heavy metals (mg/kg)	UASB sludge	Dried Sludge (Sludge Drying Beds)	FCO composts standards (2009)	US EPA Class A sludge	USEPA Class B sludge	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
As	N.D	N.D	10	41	75	75
Cd	N.D	N.D	5	39	85	85
Cr	16.2	12.2	50	-	-	500
Cu	113	N.D.	300	1500	4300	4300
Pb	15.2	14	100	300	840	840
Hg	N.D	N.D	0.15	17	57	57
Mo	N.D	N.D	-	-	75	75
Ni	2.5	1.43	50	420	420	420
Se	N.D	N.D	-	36	100	100
Zn	735	435	1000	2800	7500	7500

- pH

pH of the dewatered sewage sludge sample was 8.3 and dried sludge was 7.9. An increase in the dewatered sludge was collected after the anaerobic technology UASB, pH was slightly higher at the alkaline side.

- Moisture Content

Moisture content of the dewatered sludge was 89% and dried sludge was 48%.

- Color and Odor

Color of the dewatered sludge and dried sludge was black and dark brown, respectively. No foul odor was experienced near the sampling points.

- Total Organic Carbon (TOC)

A reduction in the total carbon content of the dewatered co-treated sludge (45%) was observed. TOC values in the dried co-treated sludge (28%).

- Nutrients

The concentration of TKN in the dewatered sludge was 1.78% and dried sewage sludge was 2.03%. Total phosphorus was high in both the dewatered and dried co-treated sludge (1.1-1.23%).

- Faecal Coliforms (FC)

FC values in the dewatered and dried sludge were 2.3×10^4 MPN/g dry weight and 2.3×10^3 MPN/g dry weight, respectively.

- *E. coli*

E. coli enumerated in the dewatered sludge sample was 9800 MPN/g dry weight and absent in the dried sludge.

- *Salmonella* and *Shigella*

Salmonella and *Shigella* species were found in the dewatered co-treated sludge, but absent in dried sludge (Table 10).

- Helminth eggs

  The helminth eggs numbers were counted as 5000/L in the dewatered sludge. However, the eggs were absent in the dried sludge.

- Heavy Metals

  Most of the heavy metals (Zn, Pb, Cd, Cu, Cr) concentration tested were within the range of FCO compost standards (2009). Hence, the limits of heavy metals in dewatered/dried sludge needs to be measured before its disposal into the soil.

4.2.4. 32 KLD FSTP at Unnao, Uttar Pradesh

Physico-chemical and microbiological characteristics of the Unnao FSTP sludge samples are summarized in Table 12. Heavy metals tested in the samples are given in Table 13.

Table 17: Characterization of Faecal Sludge from 32 KLD FSTP at Unnao, Uttar Pradesh

Parameters	Dewatered Faecal Sludge	Dried Faecal Sludge	FCO Composts Standards (2009)	US EPA Class A Sludge	USEPA Class B sludge
pH	7.9	7.3	6.5-7.5	-	-
Moisture Content (%)	83	28	15-25	-	-
Colour	Dark brown	brown	Dark brown to black	-	-
Odour	No foul odour	No odour	Absence of foul odor	-	-
Conductivity (ds/m)	4.4	5.5	4	-	-
Organic Matter (%)	68	59	-	-	-
Total Organic Carbon (%) –Min.	39	34	16	-	-
Total Kjeldahl Nitrogen (%)- Min.	3.85% (27.5 mg/L)	4.31% (30.7 mg/ L)	0.5	-	-
Total Phosphorus as P2O5(%) – Min.	2.94% (73.5 mg/L)	2.98% (74.5 mg/L)	0.5	-	-

Total Potassium as K2O (%)–min.	2.94	2.98			
C/N ratio	1.78	2.86			
Faecal Coliforms (MPN/g dry solids)	4.3×10^4	nil	-	<1000	$<2\times10^6$
E.coli (CFU/g dry solids)	2.2×10^3	nil	-	-	-
Salmonella species (MPN/4 g dry weight)	69	-	-	<3	-
Shigella species(CFU/g dry solids)	62	-	-	-	-
Helminth eggs (numbers/L)	5000	-	-	≤1 per 4 g (dry weight basis)	-

Table 18: Heavy Metals Concentration in Faecal Sludge from 32 KLD FSTP at Unnao, Uttar Pradesh

Heavy metals (mg/kg)	Dewatered Faecal Sludge	Dried Faecal Sludge	FCO Composts Standards (2009)	US EPA Class A Sludge	USEPA Class B Sludge	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
As	N.D.	N.D.	10	41	75	75
Cd	0.24	N.D.	5	39	85	85
Cr	N.D.	N.D.	50	-	-	500
Cu	47	N.D.	300	1500	4300	4300
Pb	36	N.D.	100	300	840	840
Hg	N.D.	N.D.	0.15	17	57	57
Mo	N.D.	N.D.	-	-	75	75
Ni	N.D.	N.D.	50	420	420	420
Se	N.D.	N.D.	-	36	100	100
Zn	934	457	1000	2800	7500	7500

- pH

pH of the collected dewatered sludge was 7.9 and dried sludge was 7.3.

- Moisture Content

Moisture content of the dewatered Faecal sludge was 83% and dried sludge was 28%.

- Color and Odor

Color of the dewatered Faecal sludge sample and the dried sludge was brown. No foul odor was found near the sampling point or in the collected sludge samples.

- Total Organic Carbon (TOC)

TOC values for the dewatered Faecal sludge was 39%, which was reduced to 34% for the dried sludge.

- Nutrients

The total Nitrogen of the dewatered Faecal sludge was 3.8% which increased to 4.3% for dried sludge. Total phosphorus was 2.94% in dewatered and 2.98% dried Faecal sludge.

- Faecal Coliforms (FC)

FC of the dewatered Faecal sludge sample was 43,000 MPN/g dry weight. Coliforms were absent in the dried Faecal sludge.

- *E. coli* while entering the overview of the Jhansi FSTP

E. coli enumerated in the dewatered Faecal sludge was 2200 MPN/g dry weight but absent in the dried sludge.

- *Salmonella* and *Shigella* species

Salmonella was 69 MPN/4g in the dewatered Faecal sludge samples but absent in the dried sludge. *Shigella* species was 62 CFU/g in the dewatered Faecal sludge (Table 12).

- Helminth Eggs

Helminth eggs were enumerated as 5000 Numbers/L in the dewatered Faecal sludge. Eggs were not found in the dried sludge.

- Heavy Metals

Most of the heavy metals (Pb, Cd, Cu, Cr,Zn) concentration tested were within the range of FCO compost standards (2009).

4.2.5. 6 KLD FSTP, JHANSI

Sewage sludge collected from 6 KLD Jhansi FSTP was analyzed for physico-chemical and microbiological parameters. The results are summarized in Table 14. Heavy metals concentration is reported in Table 15.

Table 19: Faecal Sludge Characterization of 6 KLD FSTP at Jhansi, Uttar Pradesh

Parameters	Dewatered Faecal Sludge	Dried Faecal Sludge	FCO Composts Standards (2009)	USEPA Class A Sludge	USEPA Class B Sludge
pH	7.9	7.4	6.5-7.5	-	-
Moisture Content (%)	52	28	15-25	-	-
Colour	Black	Dark Brown	Dark brown to black	-	-
Odour	No foul odor	No foul odor	Absence of foul odor	-	-
Conductivity (ds/m)	4.9	5.7	4	-	-
Organic Matter (%)	70	58	-	-	-
Total Organic Carbon (%)-Minimum	41	33	16	-	-
Total Kjeldahl Nitrogen (%)-Minimum	1.02% (7.2 mg/L)	2.42% (17.2 mg/L)	0.5	-	-
Total Phosphorus) as P_2O_5 (%) min	3.77% (94.2 mg/L)	4.04% (101 mg/L)	0.5	-	-
Total Potassium as K2O (%) min	2.56	2.98	-	-	-

C/N ratio	20	14	-	-	-
Faecal Coliforms (MPN/g dry solids)	2.3×10^4	9.3×10^2	-	<1000	$<2\times 10^6$
E.coli (CFU/g dry solids)	1.1×10^3	nil	-	-	-
Salmonella species (MPN/ 4g dry solids)	79	nil	-	<3	-
Shigella species (CFU/g dry solids)	65	nil	-	-	-
Helminth eggs (numbers/L)	4000	nil	-	≤1 per 4 g (dry weight basis)	-

TABLE 20: Heavy Metals concentration in Faecal Sludge from 6 KLD FSTP at Jhansi, Uttar Pradesh

Heavy metals (mg/kg)	Dewatered Sludge	Dried Sludge	FCO composts standards (2009)	USEPA Class A Sludge	USEPA Class B Sludge	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
As	N.D.	N.D	10	41	75	75
Cd	N.D.	N.D.	5	39	85	85
Cr	8.8	12.6	50	-	-	500
Cu	146	143	300	1500	4300	4300
Pb	12	10	100	300	840	840
Hg	N.D.	N.D.	0.15	17	57	57
Mo	N.D.	N.D.	-	-	75	75
Ni	6.6	1.42	50	420	420	420
Se	N.D.	N.D.		36	100	100
Zn	292	240	1000	2800	7500	7500

- pH

pH of the dewatered sewage sludge sample was 7.9 and dried sludge was 7.4. A decrease in the pH of the tested materials was caused by nitrate formation that implies H^+ release during nitrification (Bhatia et al., 2012).

- Moisture Content

Moisture content of the dewatered sludge was 52% and dried sludge was 28%. Compost samples contain 17% moisture.

- Color and Odor

Color of the dewatered sludge and dried sludge was black and dark brown, respectively. No foul odor was experienced near the sampling points.

- Total Organic Carbon (TOC)

The concentration of Organic Matter (OM) in sewage sludge was closely related to TOC content. A reduction in the total carbon content of the dewatered Faecal sludge (41%) was observed in comparison to dried sludge (33%).

- Nutrients

The concentration of TKN in the dewatered sludge was 1.03% and dried sewage sludge was 2.05%. Total phosphorus was high in both the dewatered and dried sludge, i.e., 3.5-4.56 %.

- Faecal Coliforms (FC)

FC values in the dewatered and dried sludge were 2.3×10^4 MPN/g dry weight and 9.3×10^2 MPN/g dry weight, respectively.

- *E. coli*

E. coli enumerated in the dewatered sludge sample was 1100 MPN/g dry weight and nil for the dried sludge.

- *Salmonella* and *Shigella*

Salmonella and *Shigella* species were found in the dewatered sludge samples but absent in dried sludge (Table 13).

- ### Helminth eggs

  The helminth eggs were counted as 4000/L in the dewatered sludge. However, the eggs were absent in the dried sludge.

- ### Heavy Metals

  Most of the heavy metals (Pb, Cd, Cu, Cr) concentration tested were within the range of FCO compost standards (2009).

5 DISCUSSION

5. Discussion

Untreated Faecal sludge & septage has a very high oxygen demand due to readily degradable organic matter but is highly infectious due to increased numbers of pathogens such as *Salmonella* species, ***Shigella*** species, protozoans, and helminths. Furthermore, it also has a substantial concentration of nutrients.

It was observed that the collected Faecal sludge & septage from five Class-I cities have similar characteristics. pH ranged from slightly acidic to a neutral 6.8-7.1. BOD went from 18,000 mg/L - 24,000 mg/L, which is much higher than 7000 mg/L (Suggested design BOD value CPHEEO, 2013). COD varied from 29,000 mg/L - 40,000 mg/L, which is also higher than 15,000 mg/L (Suggested design COD value CPHEEO, 2013). Similarly, VS ranged from 17,000 mg/L - 20,000 mg/L, much more than the 10,000 mg/L (Suggested design value CPHEEO, 2013). However, measured TKN and TP values are lower than the values suggested by CPHEEO. In another study, the Faecal sludge & septage characteristics of ten cities are similar to the present study (NIUA, 2019).

Faecal sludge & septage is also host for many disease-causing viruses, bacteria, and parasites. The number of Faecal Coliforms varied from 9.3x106   MPN/100 mL to 4.3x107 MPN/100 mL. *E. coli* and *Shigella* species were reported in the range of 7.0x103 to 5.6x105 CFU/100mL.

Heavy metals Cr, Co, Se, Pb, etc., concentration in Faecal sludge & septage were within the suggested design values for CPHEEO Manual 2013. Still, metals (Zn, and Pb) fail to satisfy Indian Standards for disposal of treated wastewater (CPCB, 2005). Hence, heavy metals concentration in the Faecal sludge & septage cannot be ignored.

Overall, it can be concluded that the design BOD, COD, VS concentrations of Faecal sludge & septage should be revised to higher values. The main reason for higher concentrations is the very low frequency (10-12 years) of cleaning the septic tanks. During the survey, the tanker driver informed that many of the septic tanks were not cleaned for years due to the non-cooperation of the house owner or the facility of collecting the Faecal sludge & septage was not available. Hence, municipal stakeholders of the Indian cities need to reinvent the sanitation services, especially for the septic tanks in the peri-urban areas.

The characteristics of dewatered (70-80% moisture content) sludges from five different STPs/FSTPs are almost similar except for organic matter content. Due to higher degradation efficiencies, it varies within 41-45% in co-treated sludge compared to 68-70% in untreated/semi-treated dewatered Faecal sludge. Total nitrogen and phosphorus in all the dewatered sludge ranged from 1.78 - 3.85% and 1.1 - 3.77% respectively. Faecal Coliforms were found to vary from 2.3x104 - 4.3x104 MPN/g in all kinds of dewatered sludge, i.e., reduction was observed as compared to raw Faecal sludge and septage. Number of pathogens (*E. coli*, *Shigella*, *Salmonella* species) were almost similar in dewatered Faecal sludge, co-treated, and sewage sludge.

The dewatered sludge satisfies the Class B guidelines for Faecal Coliforms but fails in *Salmonella* and Helminths number. They also meet the Class B guidelines for heavy metals but fail to satisfy stringent FCO (2009) compost standards.

In the STPs with co-treatment, the reduction of pathogens is attributed to the aerobic (ASP, SBR based STPs) and anaerobic (UASB) digestion processes. In FSTPs, two factors may be responsible for the reduction in pathogens. Firstly, the mechanical abrasion and dewatering of the Faecal sludge & septage destroys the bacteria's cellular structure (Unnao, FSTP). Secondly, the pathogenic bacteria and protozoa outcompete for the food (organic matter and nutrients) with the cultivated plants, as in Planted Gravel Bed process (Jhansi, FSTP) (Gheeti et al., 2018, Bhatia et al., 2013). Characteristics of naturally dried (22-48% Moisture Content), sewage, co-treated sludge, and Faecal sludge were compared by pH, moisture, organic matter, nutrient, pathogens, and heavy metals. It was observed that the characteristics of all kinds of dried sludge from the STPs and FSTPs were almost similar and found to be satisfying as per US EPA Class B guidelines. This is ascribed to the natural drying process of dewatered sludge, resulting in removal of pathogenic microbes from dried sludge. The results are analogous to the findings, such that the drying reduces the moisture content from 88.99% to 65.48%, and favors microbial decay (Obianyo, 2015).

Furthermore, to enhance the Indian sludge quality to match the USEPA Class A sludge guidelines, it is desirable to co-compost the dewatered sludge by using bulking agents or using other technologies such as solar sludge drying in the greenhouse, thermal drying etc.

6 COMPARISON OF RESULTS

6. COMPARISON OF RESULTS FOR ALL THE MONITORED STPs AND FSTPs

Table 21: Comparison of Data studied from all the STP/FSTP

Parameters	18 MLD ASP based STP, Haridwar (Centrifuge & Sludge drying bed)		68 MLD SBR based STP, Dehradun (Centrifuge & Sludge storage yard)		345 MLD UASB based STP, Lucknow (Sludge sump & Sludge drying bed)	
	Dewatered sludge	Dried sludge	Dewatered sludge	Dried sludge	Dewatered sludge	Dried sludge
pH value	7.5	7.9	7.2	7.9	8.3	7.9
Moisture Content (%)	77	23	75	22	89	48
Color	Brown	Black	Brown	Black	Black	Dark Brown
Odour	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor
Conductivity (ds/m)	4.5	5.9	5.4	6.5	5.8	6.5
Organic Matter (%)	41	36	43	38	45	28
Total Organic Carbon (%)-Min	24	21	25	22	26	16
Total Nitrogen (%)-Min	2.4	3.2	2.7	3.4	1.78	2.08
Total Phosphate as P2O5 (%) min	1.11	1.66	1.7	1.78	1.13	2.23
Total Potassium as K2O (%) min	1.01	1.34	1.23	1.56	1.98	2.02
C/N ratio	10	7	9	6	15	8
Faecal Coliforms (MPN/g dry solids)	2.3×10^4	2.1×10^3	4.3×10^4	2.1×10^3	2.3×10^4	2.3×10^3
Salmonella (MPN/4g dry solids)	45	nil	57	nil	67	nil

32 KLD FSTP, Unnao (Sludge drying bed)		6 KLD FSTP, Jhansi (Sludge drying bed)		FCO Composts Standards (2009)	USEPA Class A Sludges	USEPA Class B Sludge	CPHEEO manual (2013) Adapted from USEPA class B sludge guidelines
Dewatered sludge	Dried sludge	Dewatered sludge	Dried sludge				
7.9	7.3	7.9	7.4	6.5-7.5	-	-	
83	28	52	28	15-25	-	-	
Dark brown	Brown	Black	Dark Brown	Dark brown to black	-	-	
No foul odor	No foul odor	No foul odor	No foul odor	Absence of foul odor	-	-	
4.4	5.5	4.9	5.7	4	-	-	
68	59	70	58	-	-	-	
39	34	41	33	12	-	-	
3.85	4.31	2.03	2.42	0.8	-	-	
2.94	2.98	3.77	4.04	0.4	-	-	
1.78	2.86	2.56	2.98	0.4			
10	8	20	14	<20			
4.3×10^4	nil	2.3×10^4	9.3×10^2	-	<1000	$<2\times 10^6$	
69	nil	79	Nil	-	<3	-	

Helminth eggs (numbers/L)	3000	nil	4000	nil	5000	nil
As (mg/kg)	N.D.	N.D.	N.D.	N.D.	N.D	N.D
Cd (mg/kg)	N.D.	N.D.	N.D.	N.D.	N.D	N.D
Cr (mg/kg)	N.D.	N.D.	43.6	35	16.2	12.2
Cu (mg/kg)	91	78	112	64	113	N.D.
Pb (mg/kg)	N.D.	N.D.	N.D.	N.D.	15.2	14
Hg (mg/kg)	N.D.	N.D.	N.D.	N.D.	N.D	N.D
Mo (mg/Kg)	N.D.	N.D.	N.D.	N.D.	N.D	N.D
Ni (mg/kg)	5.6	1.4	7.2	6.2	2.5	1.43
Se (mg/kg)	N.D.	N.D.	N.D.	N.D.	N.D	N.D
Zn (mg/kg)	844	592	996	586	735	435

5000	nil	4000	Nil	-	≤1 per 4 g	-	-
N.D.	N.D.	N.D.	N.D	10	41	75	75
0.24	0.16	N.D.	N.D.	5	39	85	85
N.D.	N.D.	8.8	12.6	50	-	-	500
47	N.D.	146	143	300	1500	4300	4300
36	-	12	10	100	300	840	840
N.D.	N.D.	N.D.	N.D.	0.15	17	57	57
N.D.	N.D.	N.D.	N.D.	-	-	75	75
N.D.	N.D.	6.6	1.42	50	420	420	420
N.D.	N.D.	N.D.	N.D.	-	36	100	100
934	457	292	240	1000	2800	7500	7500

7 CONCLUSIONS AND RECOMMENDATIONS

7. CONCLUSIONS & RECOMMENDATIONS

Based on sampling and analysis of the FSS, dewatered and dried sewage sludge, dewatered and dried co-treated sludge, following points are concluded:

1. Environmental design values suggested by CPHEEO for BOD, COD, VS concentrations of Faecal sludge & septage should be revised to higher values.

2. Heavy metal concentrations cannot be ignored for Faecal sludge & septage management.

3. Dewatered and dried sludge of sewage, faecal sludge and co-treated i.e., all fails to satisfy Helminth criteria as per the USEPA guidelines for Class B sludge.

4. Dewatered co-treated/Faecal sludge should be co-composted with bulking materials like browns/sawdust, dry leaves, or dried naturally/thermally/ controlled greenhouse conditions to satisfy US EPA Class A or B Guidelines.

5. Dried sludge from conventional STP, Co-treatment STP as well as Faecal Sludge Treatment Plant satisfy USEPA Class B sludge guidelines.

6. The mechanism of pathogen destruction in the natural drying method needs to be studied scientifically for Indian climatic conditions.

7. It is recommended to Co-compost or follow naturally/controlled/thermal drying of dewatered sludge to satisfy US EPA Class B Guidelines for reuse of sludge.

8. Since the quality of the FSS varies, the characterization of FSS produced from different types of onsite facilities and its treatment at STP with dewatering and drying units with or without digestion needs to be studied for adopting efficient co-treatment methods.

As the current study could not capture a large varied data in terms of spatial and temporal manner to dictate Pan India conditions, hence there is a dearth of data in this subject for formulation of National Standards on Biosolids. The way forward obtained from the study is related to the cycle of pathogen destruction, during the drying of sludge needs to be studied. Also, the effect of heavy metals found in the dried sludge on the various crop plants should be considered.

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ANNEXURE

ANNEXURE -1

SAMPLING AND ANALYSIS PROTOCOLS

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled. This objective implies that the relative proportions or concentrations of all pertinent components will be the same in the samples as in the material being sampled, and that the sample will be handled in such a way that no significant changes in composition occur before the tests are done.

A.1. | CRITERIA FOR QUALITY DATA

The basis for any program rests upon the information obtained by sampling. Decisions based upon incorrect data may be made if sampling is performed in a careless and thoughtless manner. The analytical results of a sample are only as accurate as the quality of the sample taken. Obtaining good results will depend to a great extent on the following factors:

1. Ensuring that the samples taken are truly representative of the waste stream.
2. Using proper sampling techniques
3. Careful handling and preservation of the samples
4. Proper analysis and quality assurance

Note: The greatest errors produced in laboratory tests are usually caused by improper sampling, poor preservation, or lack of enough mixing during compositing and testing.

A.2. | SAMPLING DEVICES AND EQUIPMENTS

- Sampling bucket

  Bucket can be attached to an 8 foot length of ½ inch electrical conduit or a wooden broom handle with a ¼ inch diameter spring in a 4-inch loop. A section of thin walled PVC pipe with an appropriate diameter having a cap on one end will be a more durable sampling bucket than a can.

- Sampling bottle

  Glass bottle with rubber stopper equipped with two 3/8 inch glass tubes, one ending near the bottom of the bottle to allow the sample to enter and the other ending at the bottom of the stopper to allow the air into the bottle to escape while the sample is filling the bottle.

- Polythene bags

  Plastic polythene bags of 1 Kg capacity are used to collect the sludge samples.

- Cooler with ice packs – to maintain optimum temperature of samples collected.
- 1000 mL plastic sampling bottles – to collect the fFaecal sludge & septage sample.
- Sterilized glass bottles- to collect the sludge samples for bacteriological and helminth eggs enumeration.
- Water quality meter - optional; to record additional Faecal sludge & septage quality parameters including pH, Dissolved Oxygen, ORP etc. onsite.
- Personal safety/hygiene equipment- gloves, safety vest, hand wipes or hand sanitizers

A.3. | GROUNDWORK FOR SAMPLING

Care must be exercised during the sampling of septage & Faecal sludge to avoid contamination of the sample at the time of collection and during analysis.

Figure A 3: Sampling preparations

A.4. | COLLECTION OF FAECAL SLUDGE & SEPTAGE SAMPLE

The Faecal sludge & septage has been transported using tankers from the neighboring locations of selected sites to treatment plants. The Faecalsamples were collected by the composite sampling procedure, grab samples were collected taken every 2-3 minutes during its disposal from the tanker into the sump. If only a single portion of Faecal sludge & septage sample is collected, there is a chance that the sludge sample may be too thick or too thin, depending on the moment the sample is taken. A composite sample will prevent this possibility.

A.4.1. COLLECTION OF SLUDGE SAMPLES

The dewatered and dried sludge samples were collected from the STP/FSTPs in the polythene bags made of recycled material.

A.5. | SAMPLE PRESERVATION

Sample deterioration starts immediately after collection of the samples. The shorter the time elapses between collection and analysis, the more reliable will be the analytical results. In many instances, however, laboratory analysis cannot be started immediately due to the remoteness of the laboratory or workload. Sample preservation techniques consist of refrigeration, pH adjustment, and chemical fixation. pH adjustment is necessary to stabilize the target analyte (e.g., addition of

NaOH stabilizes cyanide); acidification of total metal samples ensures that metal salts do not precipitate. Refrigeration is the most widely used technique because it has no detrimental effect on the sample composition (i.e., it does not alter the chemistry of the sample), and it does not interfere with most analytical methods.

Table A1: 5 U.S. EPA recommended preservation methods for wastewater samples

Test	Container	Preservation Method	Max. Holding Time
Acidity/Alkalinity	P,G	Store at 4°C	14 days
Ammonia	P,G	Add H_2SO_4 to pH, <2	28 days
BOD	P,G	Store at 4°C	48 hours
COD	P,G	Add H_2SO_4 to pH,<2	28 days
Chloride	P,G	None	28 days
Chlorine, residual	P,G	Det. on Site	No holding
Cyanide	P,G	Add H_2SO_4 to pH,<2	14 days
Dissolved Oxygen	G	Det. On site	No holding
Fluoride	P	None required	28 days
Mercury	P,G	Add HNO_3 to pH,<2	28 days
Metals	P,G	Add HNO_3 to pH,<2	6 months
Nitrite	P,G	Store at 4°C	48 hours
Oil & Grease	G	H_2SO_4 to pH, <2	28 days
Organic carbon	P,G	H_2SO_4 to pH,<2	28 days
pH	P,G	Det. On site	No holding
Phenols	G	H_2SO_4 to pH, <2	28 days
Phosphorus, ortho	P,G	Filter on site	48 hours
Phosphorus, total	P,G	H_2SO_4 to pH,<2	28 days
Solids	P,G	Store at 4°C	7 days
SpecificConductivity	P,G	Store at 4°C	28 days

Sulfate	P,G	Store at 4°C	28 days
Sulfide	P,G	Add 2 mL 1 M zinc	28 days
Temperature	P,G	Det. on site	No holding
T.K.N	P,G	H_2SO_4 to pH < 2	28 days
Turbidity	P,G	Store at 4°C	48 days
*P: Polyethylene; G: Glass			

A.6. | PHYSICO-CHEMICAL ANALYSIS

A.6.1.BOD ANALYSIS

Winkler's method and Azide modification method can be used to determine the Dissolved oxygen.

A.6.1.1. Winkler's method

Principle:

- Winkler's method is applicable to relatively pure water. The Winkler method is subject to interference from many substances like some oxidizing agents such as Nitrate and Fe^{+++} are capable of oxidizing I to I^- producing results too high.
- Reducing agents such as Fe^{++}, SO_3^{--}, S^{--}, reduce to I_2 to I^- producing results too low.
- The Manganous sulphate reacts with the alkali (KOH or NaOH) to form a white precipitate of Manganese hydroxide which in the presence of oxygen, gets oxidized to a brown color compound. In the strong acid medium Manganese ions are reduced by Iodide ions which get converted to Iodine equivalent to the original concentration of oxygen in the sample. The Iodine can be titrated against thiosulphate using Starch as an indicator.

- If no oxygen present in the sample white color precipitate is formed, when $MnSO_4$ and alkai iodide (NaOH + KI) reagents are added to the sample.

  $Mn^{++}+2OH^{-}\rightarrow Mn\ (OH)_2$ ....white precipitates are formed.

- DO determination by modified Winkler method

A.6.1.2. Azide Modification :

Dissolved oxygen removes the interference of such substances especially nitrite ions. Nitrates are of the most frequent interferences encountered in the Dissolved oxygen determination. It oxidizes I to I_2 under acidic conditions and is reduced in N_2O_2 which is oxidized by oxygen that enters the sample during the titration procedure and is converted to NO_{2-} again, establishing a cyclic reaction.

Following reaction is involved in Dissolved oxygen determination

White precipitate of Manganous hydroxide:

$$Mn^{+2} + 2OH^{-} = Mn(OH)_2 \qquad (a)$$

If oxygen is present, the manganous ion is oxidized and brown precipitate of manganese dioxide is formed:

$$Mn^{+2} + 2OH^{-} + 1/2O_2 = MnO_2 + H_2O \qquad (b)$$

Upon addition of concentrated Sulphuric acid, iodine is formed by oxidation of iodide:

$$MnO_2 + 4H^{+} + 2I^{-} = Mn^{+2} + I_2 + 2H_2O \qquad (c)$$

Sodium thiosulphate standard solution is used to titrate iodine

$$2Na_2S_2O_3 + I_2 = Na_2S_4O_6 + 2NaI \qquad (e)$$

If the Nitrites present in the sample cause interference by oxidizing iodide:

$$N_2O_2 + 2I^{-} + 4H^{+} = I_2 + N_2O_2 + 2H_2O \qquad (f)$$

N_2O_2 in turn is oxidized by oxygen entering the sample during titration:

$$N_2O_2 + 1/2O_2 + H_2O = 2NO_2^{-} + 2H^{+} \qquad (g)$$

- When nitrite interference is present, it is impossible to obtain a permanent end point. As soon as the blue color of starch indicator is discharged, the nitrite formed by the above reaction reacts with more I- to produce I2 and the blue color of starch indicator will return (Sawyer, McCarty). Nitrite interferences may be overcome by sodium azide (NaN3). It is convenient to incorporate sodium azide with alkali KI reagent, when H2SO4 is added.

- Sodium azide destroys the nitrite through following reaction :

$NaN_3 + H^+ = HN_3 + Na^+$ **(h)**

$HN_3 + NO_2^- + H^+ = N_2 + N_2O + H_2O$ **(I)**

A.6.2. REAGENTS PREPARATION

(i) $MnSO_4$ Solution

Dissolve 480 g $MnSO_4.4H_20$ in distilled water. Dilute to 1 Lit.

(ii) KI (Alkali –iodide –azide reagent)

Dissolve 500g NaOH (or 700g KOH) +135 g NaI (or 150g KI) in distilled water and dilute to 1 L. Add 10 g NaN_3 dissolve in 40 ml distilled water.

(iii) Conc. H_2SO_4

1 ml H_2SO_4=3 ml alkali –iodide –azide reagent

(iv) Starch indicator

2 g laboratory grade soluble starch + 0.2 g salicylic acid =100 ml hot distilled water

(v) Standard Sodium Thiosulphate

Dissolve 6.025 gm $Na_2S_2O_3.5H_2O$ in distilled water, add 1.5 ml 6N NaOH/4g solid NaOH, dilute to1L.

vi) Standard Glucose-Glutamic Acid

Add 6 ml (2%) glucose-glutamic acid (at room temperature) solution to a 300 ml bod bottle. Record final do at the end of the incubation period. Use calculations for seeded dilution water. The final calculations of BOD on a glucose-glutamic acid control should be equal to 198 mg/l plus or minus 30.5 mg/l to be considered as an acceptable control.

A.6.3. DISSOLVED OXYGEN DETERMINATION OF Faecal SLUDGE & SEPTAGE SAMPLE

Fill three DO bottles of 300 ml capacity with

- Dilute the Faecal sludge & septage sample 50 times. Take 1 mL of diluted sample and add 299 ml of saturated dilution water
- Add 300 ml of dilution water.
- Add 6 mL (2%) glucose-glutamic acid (at room temperature) solution and make up to 300 mL with diluted water.

Incubate the bottles for 3 days at 27 ° C.

After 3 days, add 1 ml $MnSO_4$

Add 1 ml KI (DO fixation)

- Brown flocks are formed; allow the precipitate to settle down
- Add 1 ml conc. H2SO4 shake well, precipitate will disappear

- Take 201 ml sample in flask.
- Volume in flask =
- Capacity of DO bottle × 200/capacity of DO bottle –X)
- Where X= ml reagent used
- (1 ml $MnSO_4$ + 1 ml alkali azide)
- (300×200/300-2 = 201 ml

- Titrate with N/40 $Na_2S_2O_3$
- Titrate it till the blue color turns colorless. Note the consumed N/40 $Na_2S_2O_3$

BOD can be calculated by the following method:

$$BOD_5 = \frac{D_1 - D_2}{P} \quad \text{mg/L}$$

Where:

D1 = DO of diluted sample immediately after preparation, mg/L

D2 = DO of diluted sample after 5 d incubation at 20°C, mg/L

P = decimal volumetric fraction of sample used

B1 = DO of seed control before incubation, mg/L

B2 = DO of seed control after incubation mg/L

f = ratio of seed in diluted sample to seed in seed control

= (% seed in diluted sample) / (% seed in seed control).

If seed material is added directly to sample or to seed control bottles:

f = (volume of seed in diluted sample) / (volume of seed in seed control)

A.7. | CHEMICAL OXYGEN DEMAND (COD)

- COD is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.
- Chemical Oxygen Demand (COD) is defined as the quantity of a specified oxidant that reacts with a sample under controlled conditions. The quantity of oxidant consumed is expressed in terms of its oxygen equivalence and measured as mg/L. The COD test is widely used as a means of measuring the organic strength of domestic and industrial wastewaters.
- The potassium dichromate is used as an oxidizing agent in COD determination in the presence of sulphuric acid. During the digestion both organic and inorganic components of the sample are subjected to oxidation, but in most of the cases the organic component is predominant.
- During two hours of digestion with potassium dichromate, organic matter is converted to carbon dioxide and water regardless of the biological assimilability of substances. For example, glucose and lignin are both oxidized completely as a result COD values are greater than BOD.

- The major advantage of determining the COD is the short duration for its evaluation. The determination can be made in about 3 hours rather than the 5 days required for measurement of BOD and measures can be taken to correct the error on the day they occur. For this reason, COD is used as a substitute for the BOD test in many instances. COD data can often be interpreted in terms of BOD values after sufficient data has been accumulated to establish a reliable correlation between COD and BOD.

A.7.1. LIMITATIONS OF COD DETERMINATION

COD is unable to differentiate between biologically oxidizable and biologically inert organic matter. In addition, it does not provide any evidence of the rate at which the biologically active material would be stabilized under conditions that exist in nature.

A.7.2. COD BY DICHROMATE

Potassium dichromate is a relatively economical compound which can be obtained at a high rate of purity. The dichromate ions become very strong oxidizing agents in solution under strong acidic conditions (acidity is usually achieved by the addition of sulfuric acid).

In the process of oxidizing the organic pollutant found in the wastewater samples, potassium dichromate is reduced forming cr3+. The amount of cr3+ determined after oxidation is complete, and is used as an indirect measure of the organic contents of the water sample. The reaction of potassium dichromate with organic compounds is given by:

$$C_nH_aO_bN_c + dCr_2O_7^{2-} + (8d + c)H^+ \rightarrow nCO_2^- + \frac{(a + 8d - 3c)}{2} H_2O + cNH_4^+ + 2dCr^{3+}$$ where,

D= 2N/3+A/6-B/3-C/2

Inorganic interferences in cod determination

- Certain reduced inorganic ions oxidized under acidic conditions during COD determination and thus caused erroneous results. The straight–chain aliphatic compounds are oxidized more effectively in the presence of silver sulfate catalyst (which is added in the sulphuric acid).

- Chlorides interfere greatly because they react with silver ions to precipitate silver chloride, and thus inhibit the catalytic activity of silver. Bromide, iodide also inactivates silver ion and interfere similarly.

- These ions tend to restrict the oxidizing action of the dichromate ion itself resulting in an error on high side.

$$6Cl^- + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Cl_2 + 2Cr^{3+} + 7H_2O$$

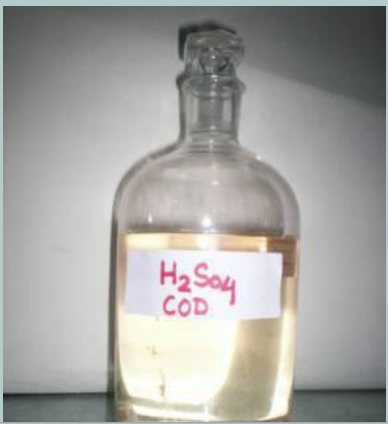
- This interference can be overcome largely, though not completely by adding the $HgSO_4$ in the digestion solution where mercuric ions combine with chloride ions to form a poorly ionized mercuric chloride complex.

$$Hg^{2+} + 2Cl^- \Leftrightarrow HgCl_2$$

- **SOURCES OF ERRORS IN COD DURING DETERMINATION**
- If the test is delayed, the sample should be preserved by acidification to pH <2 with conc. H_2SO_4
- Standard KHP should be prepared weekly

- COD vials should be washed properly with chromic acid and must be dried before use.
- Individual tips should be used for blank and sample as well as for standard KHP solution.
- Anhydrous potassium dichromate should be used for preparation of digestion solution.

A.7.3. COD REAGENTS

	i) 0.1 N $K_2Cr_2O_7$(digestion solution) Add 500 ml distilled water + 10.216 g $K_2Cr_2O_7$ (dried at 150°C for 2 hr) + 167 ml conc.H_2SO_4+ 33.3 g $HgSO_4$. Dissolve, and cool at room temperature, Dilute to 1 L.
	**ii) Sulfuric acid Reagent** 5.5 g silver sulfate (Ag_2SO_4) catalyst + 1 L. Conc.H_2SO_4. Let it stand for 1-2 days to dissolve.
	**iii) KHP standard** 425 mg dry KHP (0.425g) + 1 L Distilled water 0.425 g KHP /l = 500 mg COD

PREPARATION OF CALIBRATION CURVE

	(i) Prepare standard of known concentration of 0 to required range (0-500ppm) from potassium hydrogen phthalate (KHP).
	(ii) Make up to 100 ml with double distilled water
 	(iii) Transfer 1.5 ml of Digestion solution in Borosilicate tube (v) Add 3.5 ml H_2SO_4

Measure absorbance of each sample, blank and standard at 600nm. Use digested blank (zero) no. 1 as reference sample then take absorbance of next standard (lower to higher range)

OBSERVATIONS

mg KHP added	0	0.25	0.5	0.75	1.25
Absorbance					

A.7.4. COD DETERMINATION OF Faecal SLUDGE & SEPTAGE SAMPLE

	i) Take 1.5 ml Digestion solution in COD Vials
	ii) Add 2.5 ml. distilled water for Blank-2.5 ml sample, 2.5 mL KHP of known conc. as Standard and 2.5 mL diluted Faecal sludge & septage sample (50 times diluted)
	iii) Add 3.5 ml conc.H_2SO_4 in each vial

	iv) Digest it for 2 hr in digester at 150°C
	(v) Cool at room temperature
	(vi) Measure concentration (mg/l) of each Sample including Blank and Standard at wavelength of 600nm at previously prepared calibration curve in spectrophotometer.

CALCULATION

COD mg/L = COD (mg) from calibration curve ÷ ml of sample ×1000ml÷L

Result of given sample .... mg/L.

A.8. | pH DETERMINATION

pH in general is a measure of the acidic or alkaline nature of a water sample. pH stands for potential hydrogen and it measures the concentration of hydrogen ions in water, as pH value is expressed as negative log of H^+ concentration.

$$pH = -\log [H^+]$$

Pure distilled water contains equal numbers of H^+ and OH^- ions and is considered neutral i.e. pH = 7. If water contains $H^+ > OH^-$, the water is acidic in nature with pH value less than 7. If water contains $H^+ < OH^-$, the water is basic in nature with a pH value more than 7.

- pH METERS AND ELECTRODES

Temperature compensated pH meters and electrodes have been used to measure the acidic and caustic nature of aqueous samples for decades. These devices are invaluable for process control and monitoring of wastewater processes. Continuous measuring and recording pH meters with protected combination probes should be considered for use at the plant influent sample points and in manholes of the collection system. This type of application will alert operators to sudden changes that might upset biological processes and may possibly locate the contamination source. It also frees the operator from routine grab sample collection and measurement.

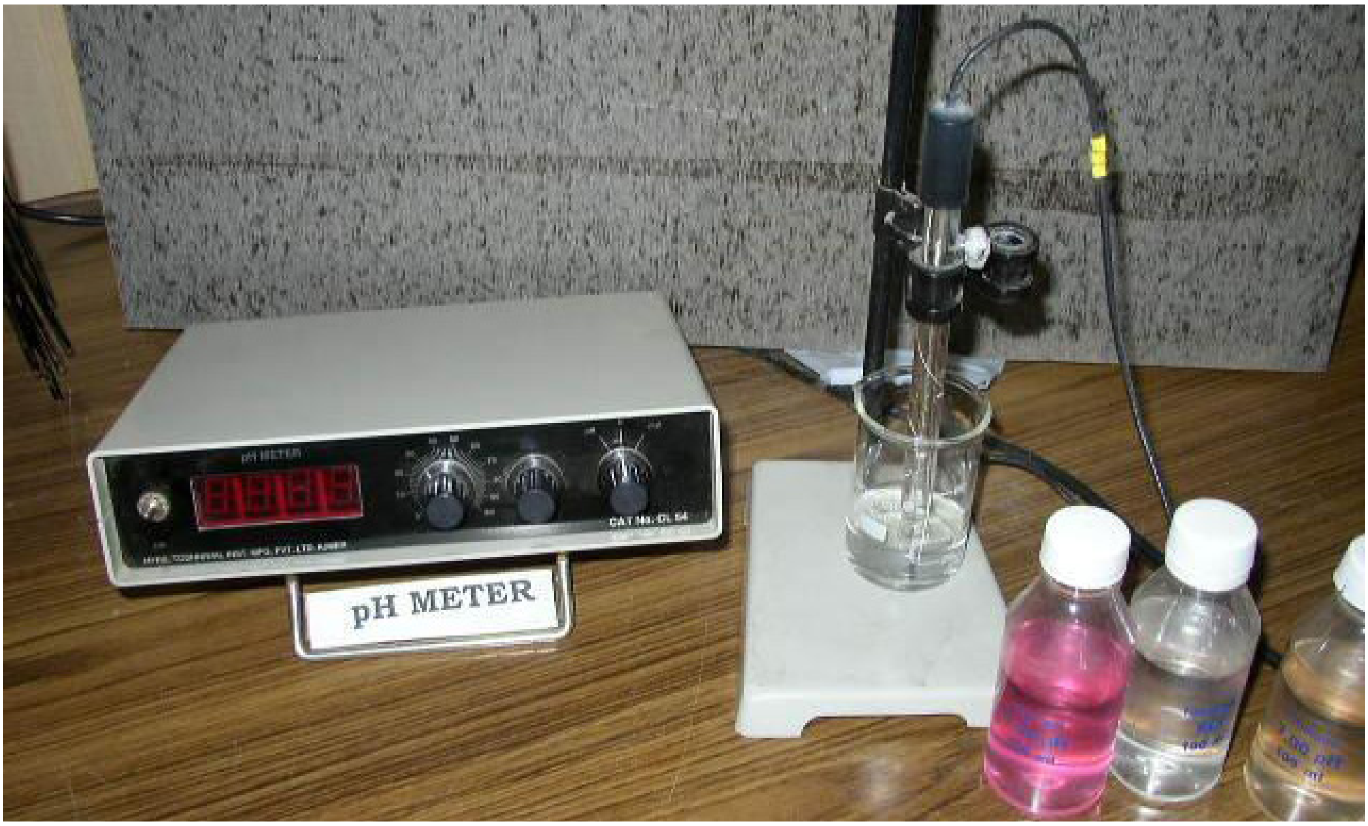
- Apparatus / Instrument Required

1. pH Meter
2. Beakers

- Chemicals Required

1. Buffer solution of pH = 4
2. Buffer solution of pH = 7
3. Buffer solution of pH = 9
4. KCl solution

Figure A8: Photograph View Of Ph Meter



- pH STANDARDS :

5. Use Buffer tablets of pH 4.0, 7.0 and 9.0
6. Use ampule of desired strength
7. Dissolve 1 tablet in 100mL of distilled water

A.9. | TOTAL SOLIDS AND VOLATILE SOLIDS OF Faecal SLUDGE & SEPTAGE SAMPLES

	Take 50 ml of Faecal sludge & septage sample in pre-weighed 100 ml beaker, Keep the beaker in oven at 105°C for 24h
	Weigh the oven dried beaker and note the weight of the sludge sample.
	Crush the sample in mortar and pestle.
	Weigh 2 g of oven dried sample in the pre-weighed crucible and keep in the muffle furnace at 550°C for 2h.
	Weight the crucible from the muffle for the Final weight.

Calculation:

$$\text{Total solids (mg/L)} = \frac{(A - B) \times 1000}{\text{ml. of sample}}$$

Where

A = Final weight of beaker + solid after 105°C

B = initial weight of the beaker

C = Final weight of crucible + solids after 550°C

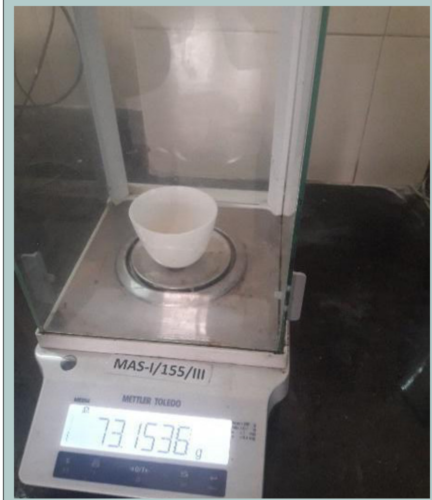
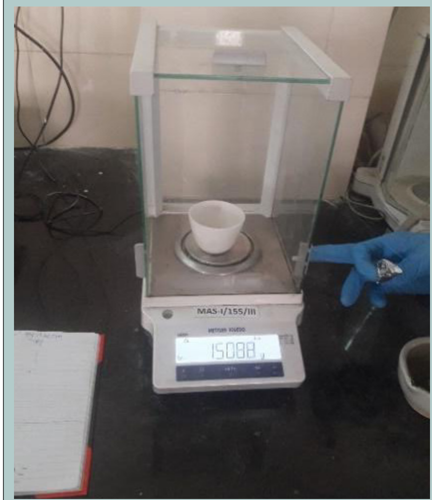
$$\text{Total VS (mg/L)} = \frac{(A - C) \times 1000}{ml.\text{ of sample}}$$

A.9. | SLUDGE SAMPLE ANALYSIS

A.9.1. DETERMINATION OF MOISTURE CONTENT OF SLUDGE SAMPLES

	Take 20 g dewatered and dried sludge in the pre-weighed petri plate. Keep the plates at 105°C for 24h.
	Weigh the oven dried petri plate containing the sample.

A.10. | TOTAL ORGANIC CARBON

	Crush the oven dried sludge sample in mortar and pestle.
	Pre weigh the empty crucible
	Weigh the 1.5 g of sieved sludge sample
	Keep the crucible in muffle furnace at 550°C for 2h. Cool the crucible and weigh it to estimate the TOC

Note : Total Phosphorus, Ammonia, Nitrate and Total Nitrogen of Faecal sludge & septage, dewatered sludge and dried sludge was performed according to Indian Standards for soil and compost IS 10158 (1982). https://www.services.bis.gov.in:8071/php/BIS/bisconnect/pow/is_details?IDS=OTM0

A.11. | HEAVY METALS ANALYSIS

(a) Sample Collection

Septage, dewatered and dried sludge samples were collected from each STP/FSTP. The collected samples were kept in a plastic bag, labeled and then placed in a cold container with ice. Samples were placed in a refrigerator at 4°C until further analysis.

(b) Sample Preparation

The collected sludge samples were air-dried at room temperature for about 96 h, ground for homogeneity, sieved through a mesh of 1.7 mm pore size.

Samples were subjected to nitric acid digestion according to the EPA guidelines. The following procedure was used:

- 2 g of the milled sewage sludge sample was weighed and placed in a conical flask.
- 4-5 mL of HNO_3 was added
- Digested at 90°C - 150°C.
- During heating and boiling, 2-5 mL of H_2O_2 (30% concentration) was added periodically to make sure that the liquid remains until the white fumes were observed.
- The mixture was allowed to cool at room temperature.
- Following the cooling process, the samples were filtered into 100 mL volumetric flasks and filled to the mark with distilled water.

(c) Metal Analysis by ICP-MS

The digested samples were filtered through a 0.45 μm membrane filter into 50 mL plastic bottles and analyzed using ICP-MS (Agilent 8900 Triple Quadrupole instrument, Agilent Technologies Inc., Tokyo, Japan). ICP-MS was employed to analyse for the trace elements which are found at very low concentrations. The Agilent 8900 instrument reported the trace element concentrations in parts per billion (ppb); this instrument is able to measure trace and ultra-trace element concentrations even down to parts per trillion (ppt).

(d) Data Analysis

The data acquisition and processing was controlled by ICP-MS software. The results were expressed as mg/kg as indicated by the following equation, with weight of sludge expressed in kg:

Concentration of heavy metals (mg/kg) = (ppm × 0.1) / weight of sludge

A.12. | MPN METHOD FOR TC AND FC

Multiple tube fermentation test or most probable number (MPN) test is the most used technique for the sanitary analysis of water. The test is used to detect Coliforms (Coliforms are defined as facultatively anaerobic, gram- negative, non-spore forming, rod shaped bacteria that ferment lactose with the production of acid and gas within 24 hours of incubation at 35°C) that make approximately 10% of intestinal microorganisms of humans and other animals and have been found to have widespread use as indicator organisms of Faecal contamination.

MEDIA PREPARATION

Total coliforms

Medium- Lauryl tryptose broth

Reagents

Tryptose	-	20 gm
Lactose	-	5 gm
K2HPO4	-	2.75 gm
KH2PO4	-	2.75 gm
NaCl	-	5 gm
Sodium lauryl sulphate	-	0.1 gm
Bromocresol purple Dye	-	0.01 gm/ L
Distilled Water	-	1 L

Faecal coliforms

Medium- EC Medium

Reagents

Tryptose or Trypticase	-	20 gm
Lactose	-	5 gm
K_2HPO_4	-	4 gm
KH_2PO_4	-	1.5 gm
NaCl	-	5 gm
Bile salt mixture	-	1.5 gm
Distilled Water	-	1 L

Peptone Water or Dilution Water

Bacteriological Peptone	-	1 gm
Distilled water	-	1 L

SLUDGE SAMPLE PREPARATION FOR MICROBIOLOGICAL ANALYSIS

Sludge sample

Prepare 1:10 dilution of sludge sample using sterile distilled water

TOTAL COLIFORMS

(Most Probable Number Method)

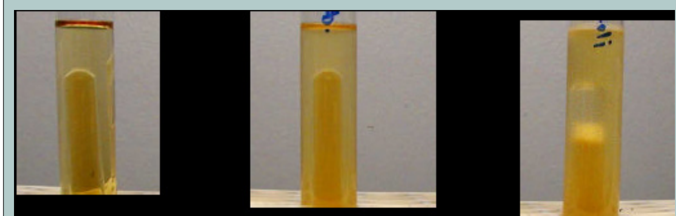
The intestinal tract of humans contain a large population of rod shaped cells known collectively as coliform bacteria. Total coliforms include species of gram-negative rods that may ferment lactose with gas production within 24± 2 h to 48± 3 h incubation on a suitable medium at 35±0.5°C.

	**Preparation of Lauryl Tryptose Broth(LTB)** **Ingredients:** Tryptose (20 g) Lactose (5 g) K_2HPO_4(2.75 g) KH_2PO_4 (2.75 g) NaCl (5 g) Sodium lauryl sulphate (0.1 g) Bromocresol purple dye (0.01 g) Distilled water 1 L
	Fill the broth 10 mL per tube in the MPN stand with the help of an auto-dispenser.
	Preparation of peptone dilution water (1 g/L).

	Sterilize the stands by autoclaving at 15 lbs and 121°C
	Preparation of serial dilutions (10^{-1} to 10^{-8})
	Inoculation of sample (serial dilution) in the lauryl tryptose broth Incubate the inoculated media stand at 35±0.5°C for 24 h
	**Observations:** **i)Purple** color indicates **-ve** results **ii)Yellow** color indicates **+ve** results

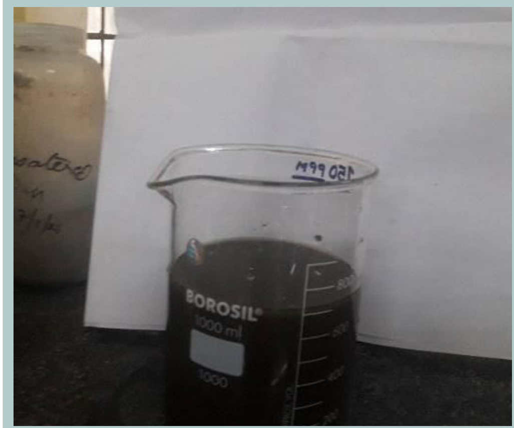
Faecal COLIFORMS

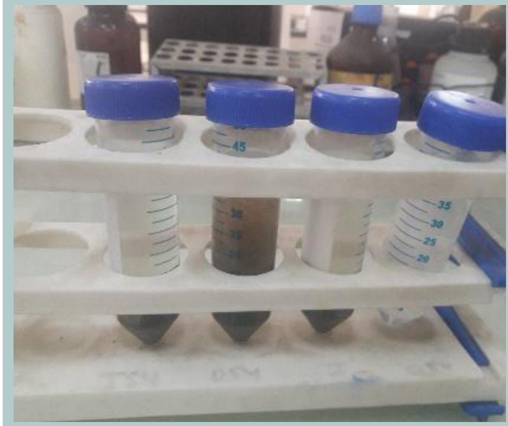
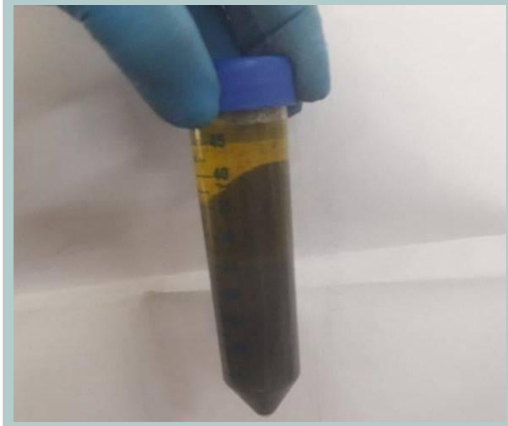
The group of Faecal Coliforms bacteria was established based on the ability to produce gas at an elevated incubation temperature at 44.5 ± 0.2°C for 24 ± 2 h.

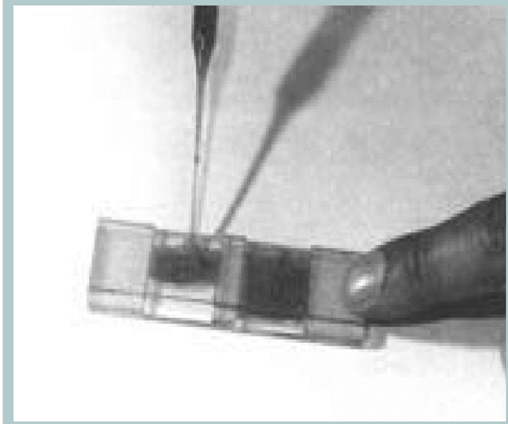
	**Preparation of EC broth** ***Ingredients:*** Tryptose (20 g) Lactose (5 g) $K2HPO4$ (4 g) $KH2PO4$ (1.5 g) NaCl (5 g) Bile salt mixture (1.5 g) Distilled water (1 L)
	Sterilize the stands by autoclaving at 15 lbs and 121°C.
	Incubate inoculated EC broth tubes in an incubator at 44.5 ± 0.2°C for 24 ± 2 h.
	**Observations:** **A) Gas** produced indicates **positive** results **B) No gas** produced shows **negative** results.

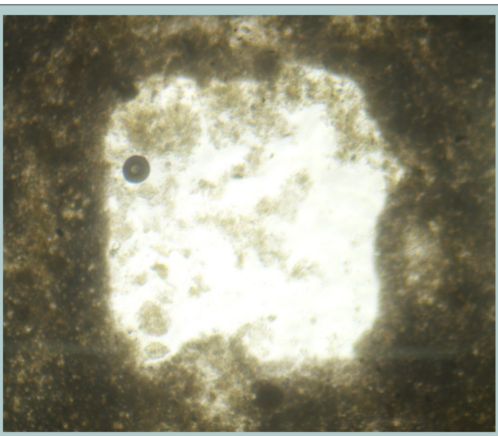
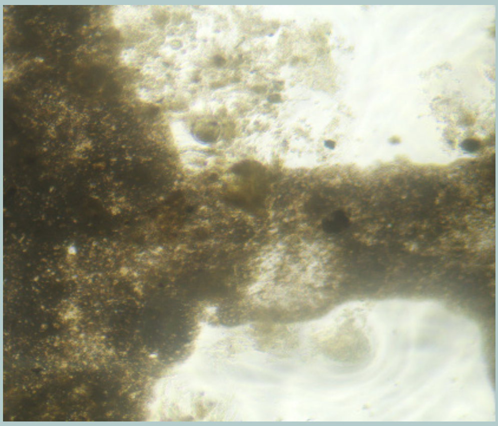
A.13. | HELMINTH EGGS

Helminth eggs are the infective agents for the types of diseases caused due to worms, known as helminthiases. These eggs are microscopic (around 20 to 80 μm for those that are important in the sanitary field) and are contained in variable amounts in wastewater, sludge and excreta. Modified Bailenger method is explained to determine the helminths or presence of their eggs.

	Prepare 1 L of diluted Sludge sample (1:10).
 	Carefully transfer the sample to one or more centrifuge tubes, depending on the volume. Centrifuge at 1000 g for 15 min.

	Remove the supernatant.
	Transfer all the sediments to one tube and re-centrifuge at 1000 g for 15 min.
	Suspend the pellet in an equal volume of acetoacetic buffer, pH 4.5.
	Add two volumes of Ethyl acetate or Ether, and mix the solution thoroughly in a vortex.

	Centrifuge at 1000 g for 15 min. The sample will now separate into three distinct phases. All the non-fatty, heavier debris, including helminth eggs, larvae and protozoa, will be in the bottom layer.
	Record the volume of the pellet containing the eggs (X mL).
	Quickly remove an aliquot with a Pasteur pipette and transfer to a McMaster slide for final examination.

<table>
<tr><td>
</td><td>Place the McMaster slide on the microscope stage and examine under 10X or 40X magnification.
Count all the eggs seen within the grid in both chambers of the McMaster slide.</td></tr>
<tr><td>Calculate the number of eggs per litre from the equation:
where:
N = number of eggs per litre of sample
A = number of eggs counted in the McMaster slide
X = volume of the final product (ml)
P = volume of the McMaster slide (0.3 ml)
V = original sample volume (litres)</td><td>$$N = AX/PV$$</td></tr>
</table>

A.14. | PHYSICO-CHEMICAL PARAMETERS OF SEPTAGE

The tables (Table:A 14.1, 14.2, 14.3, 14.4, and 14.5) represent the data of the physico-chemical parameters of septage at inlet and outlet, obtained from the individual STPs/FSTPs respectively and determined by their in-house laboratory facilities.

Table A14.1. Physico-Chemical Characteristics of Septage and Final Outlet of 6 KLD, FSTP at Jhansi, UP

Physico-chemical Parameters	Unit	Inlet (Septage)	Final Outlet
pH	-	6.9	7.2
TS	mg/L	35850	10
VS	mg/L	21812	4
BOD	mg/L	23223	10
COD	mg/L	36900	52
TKN	mg/L	396	23
NH_4–N	mg/L	318	18
Total Phosphorus as P_2O_5	mg/L	342	27
Alkalinity	mg/L	987	280
Oil & Grease	mg/L	7800	-

Table A14.2. Physico-Chemical Characteristics of Septage and Final Outlet of 32 KLD, FSTP at Unnao, UP

Physico-chemical Parameters	Unit	Inlet (Septage)	Final Outlet
pH	-	7.1	7.0
TS	mg/L	28600	12
VS	mg/L	17790	4
BOD	mg/L	11567	8
COD	mg/L	18200	64
TKN	mg/L	356	43
NH_4–N	mg/L	326	29
Total Phosphorus as P_2O_5	mg/L	345	19
Alkalinity	mg/L	714	325
Oil & Grease	mg/L	7100	-

Table A14.3: Physico-Chemical Characteristics of Inlet and Final Outlet Sample of 18 MLD STP, Jagjeetpur, Haridwar, UK

S. No.	Parameters	Unit	Inlet	Outlet
1	Alkalinity as $CaCO_3$	mg/L	324	250
2	pH	-	7.5	7.7
3	Turbidity	NTU	122	2.1
4	COD	mg/L	301	53
5	BOD	mg/L	185	11
6	TSS	mg/L	158	10
7	NH_4-N	mg/L	20	3
8	NO_3-N	mg/L	0.2	5.7
9	TN	mg/L	24.3	9.8
10	PO_4-P	mg/L	2.1	1.1

Table A14.4: Physico-Chemical Characteristics of Inlet and Final Outlet Sample of 68 MLD Kargi, Dehradun, UK

S. No.	Parameters	Unit	Raw sewage	Outlet
1	Alkalinity as $CaCO_3$	mg/L	420	265
2	pH	-	7.1	7.2
3	Turbidity	NTU	65	1.8
4	BOD	mg/L	298	11
5	COD	mg/L	547	33
6	TSS	mg/L	406	9
7	NH_4-N	mg/L	45.3	1
8	NO_3-N	mg/L	0.1	4.1
9	TN	mg/L	48.6	7.2
10	PO_4-P	mg/L	3.5	1.4

Table A14.5: Physico-Chemical Characteristics of Inlet and Final Outlet Sample of 345 MLD, Lucknow, UP

S. No.	Parameters	Unit	Raw sewage	Outlet
1	Alkalinity as $CaCO_3$	mg/L	390	240
2	pH	-	7.1	7.3
3	Turbidity	NTU	72	6.1
4	BOD	mg/L	225	14
5	COD	mg/L	437	48
6	TSS	mg/L	406	15
7	NH_4-N	mg/L	45.3	28.4
8	NO_3-N	mg/L	0.1	2.1
9	TN	mg/L	48.6	35.2
10	PO_4-P	mg/L	2.9	2.4

Notes:

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