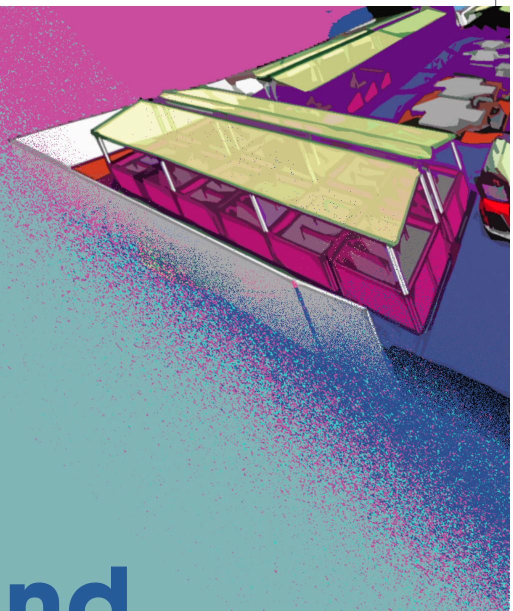
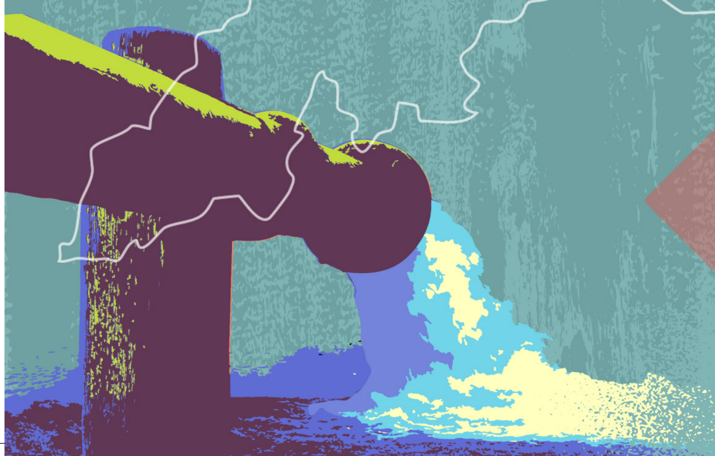
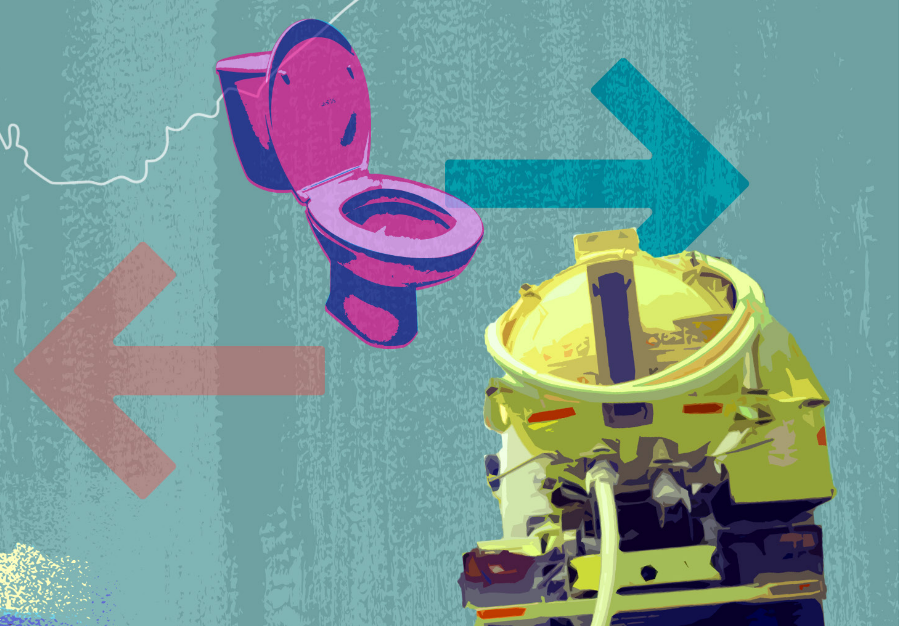


Monitoring and evaluation of FSTPs and STP co-treatment plant in Odisha





Monitoring and evaluation of FSTPs and STP co-treatment plant in Odisha

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Maps in this report are indicative and not to scale.

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ABBREVIATIONS AND ACRONYMS

AAETI	Anil Agarwal Environment Training Institute
ABR	Anaerobic baffled reactor
ACF	Activated carbon filter
AF	Anaerobic filter
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AN	Ammoniacal nitrogen
APHA	American Public Health Association
As	Arsenic
ASF	Sand filter
BMGF	Bill & Melinda Gates Foundation
BOD	Biological Oxygen Demand
BS	Biosolids
C:N ratio	Carbon–to–nitrogen ratio
Ca	Calcium
CapEx	Capital expenditure
Cd	Cadmium
CFU	Colony forming unit
COD	Chemical Oxygen Demand
CPR	Centre for Policy Research
Cr	Chromium
CSE	Centre for Science and Environment
Cu	Copper
CU	Capacity utilization
DEWATS	Decentralized wastewater treatment system
DL	Dry leaves
E. coli	Escherichia coli
EC	Electrical conductivity
EML	Environment Monitoring Laboratory
EY	Ernst & Young
FC	Faecal coliform
FCO	Fertilizer Control Order
FS	Faecal sludge
FSSM	Faecal sludge and septage management
FSTP	Faecal sludge treatment plant
FT	Feeding tank
GHSD	Greenhouse solar drier roof
Gy	Gray
Hg	Mercury
HRT	Hydraulic retention time
HUDD	Housing & Urban Development Department
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
K	Potassium
KL	Kilolitre
KLD	Kilolitres per day
kW	Kilowatt

MBBR	Moving Bed Biofilm Reactor
MCC	Micro-composting centre
Mg	Magnesium
MLD	Megalitres per day
MLD	Million litres per day
MLG	Microbiology Laboratory Guidebook
Mn	Manganese
MoEF&CC	Ministry of Environment, Forest and Climate Change
MPN	Most probable number
Na	Sodium
NGT	National Green Tribunal
NH3-N	Ammoniacal nitrogen
NH4+N	Ammonium nitrogen
Ni	Nickel
O&M	Operations and maintenance
OpEx	Operational expenditure
OUSM	Odisha Urban Septage Management
OUSP	Odisha Urban Sanitation Policy
OWSSB	Odisha Water Supply & Sewerage Board
OWW	Organic wet waste
P	Phosphorus
Pb	Lead
PGF	Planted gravel filter
pH	Potential of hydrogen
PP	Polishing pond
PPE	Personal protective equipment
RMC	Rourkela Municipal Corporation
SBM	Swachh Bharat Mission
SDB	Sludge drying bed
SeTP	Septage treatment plant
SF	Sand filter
SHGs	Self-help groups
SR	Stabilization reactor
SRT	Solids retention time
STP	Sewage treatment plant
STT	Settling-thickening tank
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TP	Total phosphate
TRP	Technical resource person
TS	Total Solids
TSS	Total Suspended Solids
TSU	Technical support unit
ULB	Urban local body
USDA	United States Department of Agriculture
USDB	Unplanted sludge drying bed
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
Zn	Zinc

1. INTRODUCTION

Odisha is a coastal state on the eastern side of India comprising 30 districts. It is the eighth largest state in the country with an area of 1,55,707 km^2 and stands at eleventh position in terms of population size with over 41.9 million people, according to the 2011 census. It is projected to be about 46.66 million as of 1 July 2024, as per the Report of the Technical Group by the National Commission. Since the advent of Swachh Bharat Mission (SBM) in 2014—aimed to address liquid waste management by making appropriate containment unit as an integral part of toilet construction—Odisha has become one of the pioneering states to take quick measures to implement faecal sludge and septage management (FSSM) interventions; considering the preponderance of on-site systems in urban Odisha, the government has recognized the importance and implementation of non-sewered sanitation systems. Among these are the pioneering initiatives taken by the Housing & Urban Development Department (HUDD) such as establishing septage/faecal sludge treatment facilities (SeTPs/FSTPs) in 11 large towns/cities in Odisha. The HUDD initiatives included piloting FSSM followed by implementation of FSTPs in two towns Angul and Dhenkanal by urban local bodies (ULBs) in 2015 and during 2017–18 with the support of the Bill & Melinda Gates Foundation (BMGF) and Arghyam, through Project Nirmal implemented by the Centre for Policy Research (CPR) and Practical Action. Other initiatives executed by HUDD include implementation of FSTPs in nine Atal Mission for Rejuvenation and Urban Transformation (AMRUT) towns/cities during 2017–18, exposure visit to advanced FSSM practices in other countries including Malaysia (2015), and adoption of septage management guidelines and regulations by all the ULBs. Additionally, intensive efforts have been made by HUDD to attract private sector investments for infrastructure development, technological solutions and capacity building, and therefore, has been successful in improving the ULBs. State-mandated policy measures such as the Odisha Urban Sanitation Policy (OUSP) and Odisha Urban Septage Management (OUSM) Guidelines (2016–17), have given a conducive environment for FSSM's implementation in the state.[1]

Decentralized wastewater treatment system (DEWATS) is chosen as a preferred technology in all the FSTPs, given the comparative advantage of technology in terms of its minimum electricity requirement and ease of operations through semi-skilled personnel. All FSTPs are solar plants generating solar power; installed with 10–kilowatt (kW) on-grid solar panel with net-metering system. All plants also have landscaping as an integral part of the design to make them as a public space to increase community's acceptance of waste treatment plants. As of January 2023, a total of 119 FSTPs were planned in 115 ULBs with a total treatment capacity of 2.057 million litres per day (MLD); of these, 110 FSTPs are commissioned with a total treatment capacity of 1.917 MLD and nine FSTPs with a treatment capacity of 0.140 MLD are under construction.[2]

It is worth mentioning that Odisha stands as a model in promoting gender-inclusive sanitation in FSSM by including women self-help groups (SHGs) and sexual and

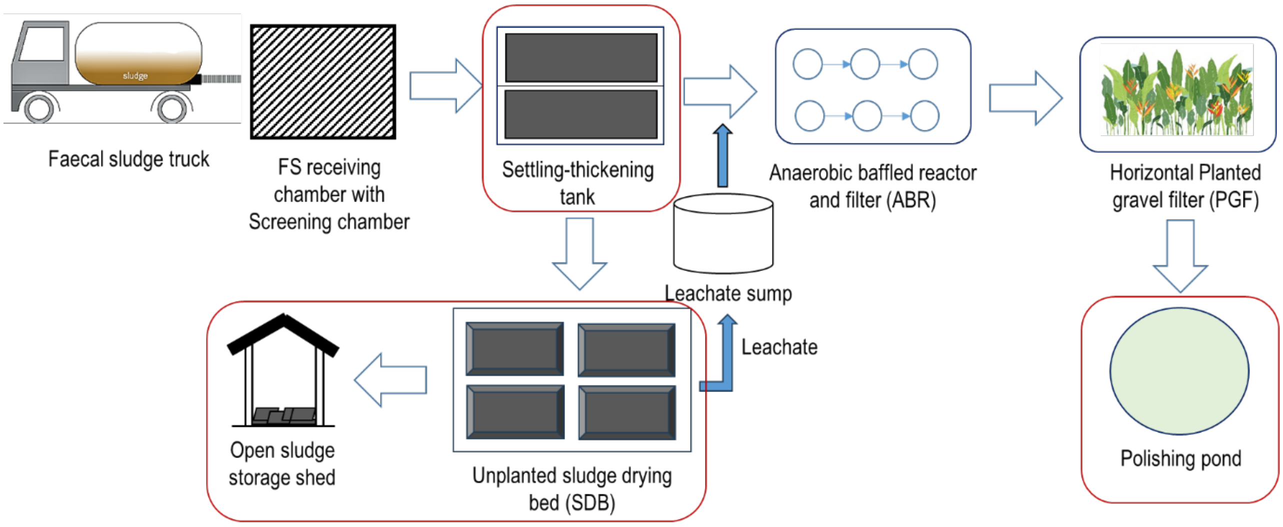
Women self-help groups (SHG) with the CSE team
Source: CSE

Odisha's FSTP laboratory technical resource persons (TRPs) in a training session at EML, AAETI
Source: CSE

gender minority community such as transgender groups as part of their operations and maintenance personnel in several FSTPs. A total of 79 FSTPs are operated by women SHGs, one FSTP is run by specially-abled SHG, and seven FSTPs are run by transgender groups. Each FSTP also has a laboratory to monitor the effluent quality which is run by a woman technical resource person (TRP); 70 labs are being run by woman graduates from the locality engaged by the SHGs who are provided with training and periodic capacity building by the state.[3]

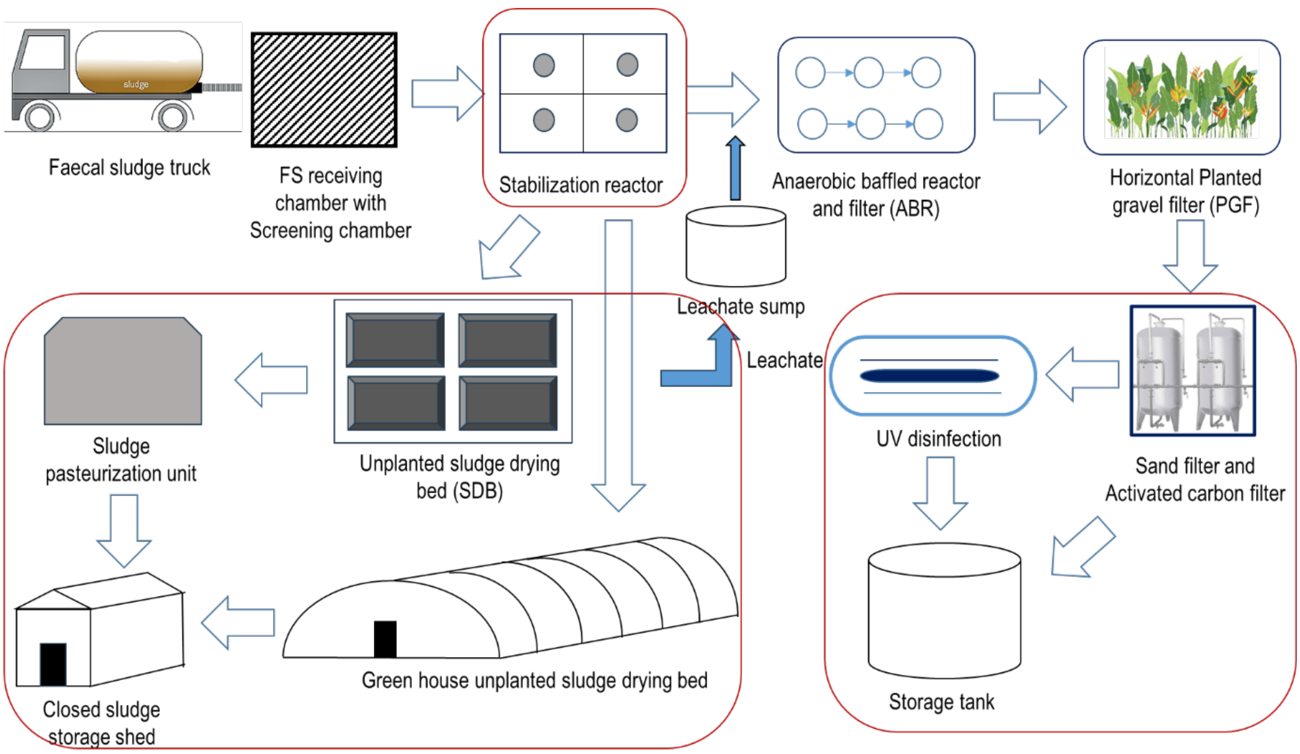
All the evaluated FSTPs in Odisha comprise the same nature-based technology including the DEWATS technology for liquid treatment and sludge drying beds for solid treatment. Within this technology, two variants with minor differences (indicated with coloured boxes in *Figure 1* and *Figure 2*) are seen in the FSTPs which are given as follows:

Figure 1: Schematic representation of the process flow of nature-based technology 1 in Odisha FSTPs



Source: CSE

Figure 2: Schematic representation of the process flow of nature-based technology 2 in Odisha FSTPs



Source: CSE

1. Nature-based technology 1: The process involves screening, settling-thickening tank, unplanted sludge drying beds, anaerobic baffled reactor with anaerobic filter, horizontal planted gravel filter and polishing pond. This is the most common technology observed in majority (13) of the FSTPs.

2. Nature-based technology 2: This involves screening, stabilization reactor, unplanted sludge drying beds, anaerobic baffled reactor with anaerobic filter, horizontal planted gravel filter, collection tank, sand filter, activated carbon filter and UV irradiation. This is observed in two FSTPs.

The STP co-treatment plant in Puri involves screening, settling-thickening tank, unplanted sludge drying beds, followed by waste stabilization ponds/aerated lagoons technology of STP and chlorination for final treatment of effluent.

2. OBJECTIVES OF THE STUDY

1. To evaluate the treatment efficiency of the FSTPs and the STP co-treatment plant in Odisha

2. To check whether the quality of treated effluent generated by the FSTPs and the STP co-treatment plant are meeting the effluent discharge standard limits set by the Ministry of Environment, Forest & Climate Change (MoEF&CC) and the National Green Tribunal (NGT)

3. To determine the potential of biosolids generated in the FSTPs and the STP co-treatment plant for their use in agriculture

4. To determine the quality of co-compost generated by co-composting biosolids from FSTPs and organic wet waste from micro-composting centres (MCCs)

5. Assessment of the long-term performance and sustainability of FSTPs by re-evaluating a few FSTPs for the quality of treated effluent and biosolids

3. SELECTION CRITERIA FOR FSTPs

The FSTPs and STP co-treatment plant in Odisha evaluated in this study were commissioned during 2020–2024. Hence, their capacity utilization is moderate to high.

In this study:

- The selection of the FSTPs and the STP co-treatment plant for evaluation has been done on the basis of capacity utilization.
- FSTPs that utilize ≥ 60 per cent of their treatment capacities have been selected.
- The locations of the selected plants include 11 in eastern Odisha (Rokat, Basudevpur, Paradeep, Basuaghai, Jatni, Khordha, Dhenkanal, Angul, Jagatsinghpur, Balasore and Puri; three in northern Odisha (Barbil, Baripada and Rourkela); and two in western Odisha (Sonepur and Sambalpur).
- A total of 16 plants were selected for the study; out of these, we analyse 15 FSTPs and one STP co-treatment plant situated in Puri.

4. SIGNIFICANCE OF THE STUDY: PARAMETERS MONITORED

This study is critical for its focus on four outcomes– first, it has assessed the performance of FSTPs and STP co-treatment plant in the state; second, it has assessed the biosolids resource recovery potential of the plants; third, it has assessed the co-compost quality; and fourth, it has assessed the long-term performance of the plants.

4.1 ASSESSMENT OF PERFORMANCE OF FSTPs AND STP CO-TREATMENT PLANTS

Faecal sludge (FS) treatment plants and sewage treatment plants play a vital role in removing contaminants from FS/sewage, thereby protecting the environment and public health. Performance analysis involves monitoring key indicators such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and nutrients such as nitrogen and phosphorus. This evaluation helps identify areas for improvement, enabling operators to optimize processes, reduce operating costs, and maintain regulatory compliance. By monitoring FSTP and STP performance, treatment plant operators can ensure efficient and effective treatment of FS, ultimately protecting ecosystem health and human well-being. The following parameters are most commonly adopted for monitoring of the plants.

4.1.1 Potential of hydrogen (pH): pH is a measure of the acidity (<7) or alkalinity (>7) of sludge based on the chemical activity of hydrogen ions in solution. pH also has a strong influence on chemical and biological processes that occurs in wastewater and faecal sludge treatment plants such as precipitation, coagulation and disinfection.

4.1.2 Total Solids (TS): Solids refer to matter suspended or dissolved in water/wastewater/faecal sludge. 'Total Solids' are the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total Solids include Total Suspended Solids (TSS), which is the portion of total solids retained by a filter, and Total Dissolved Solids (TDS), which is the portion that passes through the filter.

4.1.3 Chemical Oxygen Demand (COD): COD is a measure of the oxygen equivalent of the total organic compounds that can be degraded by chemical processes. COD is often used as a measurement of pollutants in water, wastewater, and aqueous hazardous wastes.

The total COD in wastewater is critical for accurate modeling of biotransformation in wastewater treatment processes.

4.1.4 Biochemical Oxygen Demand (BOD): BOD is a measure of oxygen used by micro-organisms to degrade organic matter. The oxygen demand of the discharge water is an important parameter to be monitored, as discharge into the environment can deplete or decrease the oxygen content of water bodies, resulting in the possible death of aquatic fauna. The oxygen demand is reduced through stabilization, and can be achieved by aerobic or anaerobic treatment.

4.1.5 Total Kjeldahl Nitrogen (TKN): Nitrogen is an important parameter to consider in faecal sludge treatment as the total nitrogen concentrations are typically quite high. Total Kjeldahl Nitrogen (TKN) is the USEPA-approved parameter used to measure organic nitrogen and ammonia, which is the sum of organic nitrogen and ammoniacal nitrogen [(NH_3-N)/ammonium (NH_4^+N)]. Excess nitrogen in water can cause eutrophication which promotes luxuriant growth of aquatic plants and algal blooms. This, in turn, reduces oxygen levels as microbes utilize oxygen to degrade large quantities of dead algae and plants and leads to the increase of toxic substances in water thereby making the water unsuitable for aquatic life. Hence, reducing nitrogen content in the effluent from FSTPs/STPs is essential.

4.1.6 Total phosphates (TP): Phosphate concentration must be measured in order to ensure effective FS/sewage treatment in treatment plants. The discharge from these plants in rivers and lakes leading to increased nutrient content in water bodies is a significant concern. Excess nutrients, particularly phosphates, can stimulate unwanted algae growth, depleting oxygen levels in the water. This disruption in the ecological balance can cause long-term harm to the aquatic ecosystem. It is essential to implement measures to control nutrient runoff and promote sustainable water practices.

4.1.7 Faecal coliforms (FC): Faecal sludge contains a large number of micro-organisms, mainly originating from faeces. These micro-organisms can be pathogenic, and exposure to untreated or partially-treated faecal sludge creates a significant health risk to humans, either through direct contact or indirect exposure. Coliforms are a group of bacteria that are predominantly found in the gastrointestinal tract of warm-blooded animals, including humans. Hence, coliform bacteria including FC/*Escherichia coli (E. coli)* are widely used as indicator organisms worldwide to test the sanitary quality (sewage contamination) of water and wastewater.

4.2 ASSESSMENT OF BIOSOLIDS' POTENTIAL FOR RESOURCE RECOVERY

FS-derived biosolids are nutrient-rich organic materials, making them a valuable soil conditioner. Moreover, the rich organic content makes it a resourceful material for harnessing energy, thus, making it a suitable solid fuel. Biosolids can be utilized to improve the physical, chemical, and biological properties of soils, especially degraded or disturbed ones. Organic materials in biosolids serve as a food source for micro-organisms and are the major binding agents for aggregate formation and stabilization, thereby enhancing soil quality. The USEPA guidelines for the land application of biosolids states, "The nutrients in the biosolids offer several advantages over those in inorganic fertilizers because they are organic and are released slowly to growing plants".

Biosolids release nitrogen and other nutrients slowly over several growing seasons through soil bacteria by a process called decomposition. The primary nutrients in biosolids are in organic forms, not as soluble as those in chemical fertilizers, and released more slowly. This allows the nutrients to nourish plants over a longer period of time with higher use efficiency and a lower likelihood of polluting groundwater when the application rate is appropriate. Utilizing biosolids as soil amendments reduces the volume of waste that would otherwise require disposal in landfills, contributing to sustainable waste management practices. This practice promotes a closed-loop system—minimizing waste and promoting ecological balance. The following parameters need to be analysed to check the usability of biosolids as an alternative to chemical fertilizers:

4.2.1 Potential of hydrogen (pH): The pH of biosolids can vary depending on several factors including the origin of the biosolids (such as sewage/faecal sludge treatment plants), the treatment processes they undergo, and any amendments or treatments applied to them before use. Primary biosolids are the solids removed during the initial stages of wastewater treatment. They typically have a pH ranging from neutral to slightly alkaline (pH 7–8.5). Secondary biosolids undergo further treatment processes (such as biological treatment) and can have varying pH levels depending on the specific treatment methods used.

4.2.2 Electrical conductivity: Electrical conductivity (EC) is an important parameter in soil science, which measures the dissolved salts in the soil, fertilizers and biosolids. It is typically measured in deciSiemens per metre (dS/m) and indicates the ability of the soil to conduct electricity. High EC values indicate high levels of dissolved salts, such as sodium, calcium, and magnesium, which can affect soil structure, fertility, and plant growth. Understanding EC is crucial for farmers and researchers to optimize fertilizer/manure/biosolids application rates, ensuring efficient and effective nutrient delivery to crops.

4.2.3 Moisture content: Moisture content or water content refers to the quantity of water present in a material, which is crucial in various fields. Accurate moisture content analysis helps in implementing efficient strategies for dryness control, quality assurance, and environmental sustainability. Moisture content of biosolids is an important parameter as high moisture content promotes microbial growth including pathogens.

4.2.4 Carbon–to–nitrogen (C:N) ratio: The carbon–to–nitrogen (C:N) ratio is a crucial aspect in various biological and ecological processes. In soil science, it determines the nutrient availability for plants and micro-organisms. A balanced C:N ratio from 15:1 to 20:1 enables optimal decomposition as bacteria and fungi work together to break down organic matter. However, an imbalance can lead to inefficient decomposition and potential environmental issues. These two elements are essential for microbial growth and activity. Nitrogen, in particular, supports the synthesis of important biological compounds, such as amino acids, proteins, and nucleic acids, while carbon serves as a structural component and energy source for microbes. Hence, the organic carbon and nitrogen has to be determined.

4.2.5 Heavy metals: Biosolids can contain heavy metals, which are elements with high atomic weights and densities. These metals can come from various sources such as industrial processes, wastewater, disposing chemicals in septic tanks and even natural geological deposits. When organic matter is processed in wastewater treatment plants, heavy metals can accumulate in the resulting biosolids. Heavy metals in biosolids can pose both challenges and potential benefits depending on their concentrations and management practices. They are not biodegradable and can persist in the environment. If biosolids containing elevated levels of heavy metals are applied to land, there is a risk of these metals leaching into the groundwater or adversely affect plants. This can potentially lead to contamination of crops and affect ecosystems.

4.2.6 Faecal coliform (FC) and *E. coli*: Faecal sludge (FS) contains an enormous diversity of pathogenic micro-organisms that fall into four major groups—pathogenic bacteria, viruses, parasitic protozoa and helminths. These pathogens occur in raw FS and septage, and in liquid effluent and biosolids generated from FSTPs, which requires appropriate treatment before they are disposed into the environment or before they are reused particularly for agricultural purposes. When humans come in contact with water or food contaminated with improperly treated FS and its derivatives, the pathogenic organisms present in them can cause several diseases like diarrhoea, hepatitis, and different types of fever, which are a public health concern globally. Coliforms are a group of bacteria that are predominantly found in the gastrointestinal tract of warm-blooded animals including humans, apart from a minor portion in soils and on plant surfaces. Faecal coliforms (FC), also known as thermotolerant coliforms, are a group of coliform bacteria that are exclusively found in the intestines and faeces of humans and other warm-blooded mammals and hence, their presence specifically indicates faecal contamination. The predominant FC is *Escherichia coli (E. coli).* Hence, the coliform bacteria, FC/*E. coli* must be tested in biosolids.

4.2.7 *Salmonella*: *Salmonella* is a ubiquitous and hardy bacterium that can survive several weeks in a dry environment, several months in water and are frequently found in sewage. They actively grow within a wide temperature range (10–54°C). *Salmonella* spp. are resistant micro-organisms that readily adapt to extreme and hostile environmental conditions. There has been a global increase in the number of outbreaks involving *Salmonella* spp. related to the fresh-cut produce industry and the consumption of fresh-cut vegetables. Such outbreaks are caused by a few *Salmonella* serotypes that have the ability to resist to environmental stresses, remaining viable for extended periods on field crops. It has been observed that *Salmonella* can regrow in the soil and remain viable for over two years after soil inoculation.[4] These characteristics make them the indicator of choice for monitoring the effectiveness of biosolids pathogen reduction. Hence, the overall danger posed by *Salmonella* spp. on public health mandates its monitoring and control in the FS-derived biosolids, which is reused particularly for agricultural purposes.

4.2.8 Helminth eggs: Helminth eggs are the primary cause of helminthiases– a group of worm diseases that affect people worldwide. Despite being part of multi-cellular animals, helminth eggs are incredibly small, measuring between 20–80 micrometres in diameter. These microscopic eggs are often found in wastewater, sludge, and excreta, and can be present in varying amounts particularly in areas with inadequate sanitation and waste management. Helminth eggs are the infectious agents of various intestinal worms like hookworm, roundworm, and whipworm which will germinate into larval form inside the human host and cause diseases. Hence, these eggs can pose a risk of infection if ingested, leading to several diseases of intestinal parasites including ascariasis, schistosomiasis etc. Therefore, proper treatment and disposal of faecal sludge are crucial to prevent the spread of infections and maintain public health.

5. SAMPLE COLLECTION AND TESTING PARAMETERS

Environment Monitoring Laboratory (EML) scientists visited each site and collected, properly preserved and transported the samples at the earliest to the lab by adopting standard protocols for sampling, preservation and transportation.[5] Personal protective equipment (PPE) like overalls, gloves, face masks, protective eyewear, and hand sanitizers were included in the sampling kit and used accordingly during the sampling process. The sampling bottles were properly cleaned, sterilized, and attached with appropriate labelling stickers. The sampling location, along with date and time, was accurately stated on each bottle after sampling. The samples were preserved with frozen ice-gel packs and transported in leak-proof ice-boxes.

5.1 SAMPLING INTERVAL AND DURATION OF THE VISIT

Sampling was done at the selected sites every alternate month. The sampling process from each FSTP was carried out for a duration of five months, i.e., April–August 2024.

5.2 FAECAL SLUDGE, INLET AND OUTLET COLLECTION AND TESTING

1. Raw faecal sludge samples were collected from the tanker when the tanker unloads the faecal sludge into the receiving chamber of FSTPs.

2. Around 1 litre of the inlet and outlet of FSTPs was collected to assess the performance of individual FSTPs. Inlet refers to the leachate entering the treatment modules after the solid–liquid separation process and outlet refers to the final discharge water emerging from the final stage of treatment process in the FSTPs. Liquid samples were collected in sterile polypropylene bottles, capped and preserved with ice packs. They were transported to the laboratory thereafter in the shortest possible time for further analysis.

5.3 TESTING PARAMETERS AND METHODS FOR THE ANALYSIS OF FS, INLET AND OUTLET

Physico-chemical parameters such as potential of hydrogen (pH), Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Kjeldahl Nitrogen (TKN), ammoniacal

Women operator emptying desludging truck at FSTP
Source: EML, CSE

Sample collection from inlet of FSTP (left), sample collection from outlet of FSTP
Source: EML, CSE

nitrogen (AN), total phosphate (TP) and microbial parameter Faecal coliform (FC) were analysed for the collected samples using standard methods (see *Table 1: Physico-chemical parameters and standard methods used for testing*).

5.4 BIOSOLIDS

Biosolids (dried faecal sludge) were collected from the drying bed in all the FSTPs and the STP co-treatment plant. Around 1 kilogram (kg) of sample was collected in plastic bags, sealed properly and transported to the lab, and stored in a refrigerator at 4°C until analysis.

Table 1: Physico-chemical parameters and standard methods used for testing[6]

Parameters	Standard methods
pH	APHA 4500-H+B, 24th Ed, 2023[7]
Total Solids (TS)	APHA 2540-B, 24th Ed, 2023
Total Suspended Solids (TSS)	APHA 2540-D, 24th Ed, 2023
Total Dissolved Solids (TDS)	APHA 2540-C, 24th Ed, 2023
Chemical Oxygen Demand (COD)	APHA 5220-D, 24th Ed, 2023
Biological Oxygen Demand (BOD)	Automated BOD Analyzer & APHA 5210-B, 24th Ed, 2023
Total Kjeldahl Nitrogen (TKN)	APHA 4500-Norg C, 24th Ed, 2023
Ammoniacal nitrogen (TN)	APHA 4500-NH3 C, 24th Ed, 2023
Total phosphates (TP)	APHA 4500-P E, 24th Ed, 2023
Faecal coliform (FC)	APHA 9221 E, 24th Ed., 2023; USDA, MLG Appendix 2.05[8]

Source: CSE

Collection of biosolids from sludge storage sheds

Source: CSE

5.4.1 Testing parameters and methods for the analysis of biosolids

Physico-chemical parameters such as pH, electrical conductivity, moisture content, carbon and nitrogen content, and heavy metals were determined along with microbiological parameters including faecal coliforms, *E. coli*, *Salmonella* and helminth eggs. (see *Table 2: Biosolids characterization methods and equipment used*).

Table 2: Biosolids characterization methods and equipment used[9]

Parameters	Standard methods/Equipment used
pH	APHA 4500-H+B, 24th Ed, 2023
Electrical conductivity (dS/m)	Conductivity meter (Cyberscan 200)
Carbon and nitrogen content	CHN elemental analyser (LECO, USA, 828 series)
Heavy metals (Cu, Zn, Hg, As, Cd, Cr, Pb, Ni)	ICP-OES (Perkin Elmer Avio® 200)
Faecal coliforms	USEPA, Method 1680, 2014[10]; USDA, MLG Appendix 2.05, 2014
E. coli	APHA 9221 B, 9221 F, 24th Ed, 2023; USDA, MLG Appendix 2.05, 2014
Salmonella	Pour plate method using HiCrome Salmonella agar
Helminth eggs	Ambic-ZnSO4 method (Merlien Reddy, 2013)[11]
Nutrients (Ca, Mg, Mn, Na, P, K)	ICP-OES (Perkin Elmer Avio® 200)

Source: CSE

6. FSTPs AND STP CO-TREATMENT PLANT IN ODISHA

In this study, 15 FSTPs and one STP co-treatment plant was evaluated. Of the 15 FSTPs, five FSTPs were evaluated for the first time while the rest of the FSTPs and the co-treatment plant had been evaluated by the Centre for Science and Environment (CSE) during 2020–22[12,13] and were re-evaluated in this study to check their long-term performance and sustainability. The consolidated details of all the plants including their year of commissioning, treatment capacity, capacity utilization and treatment technology (modules) are provided in *Table 3*.

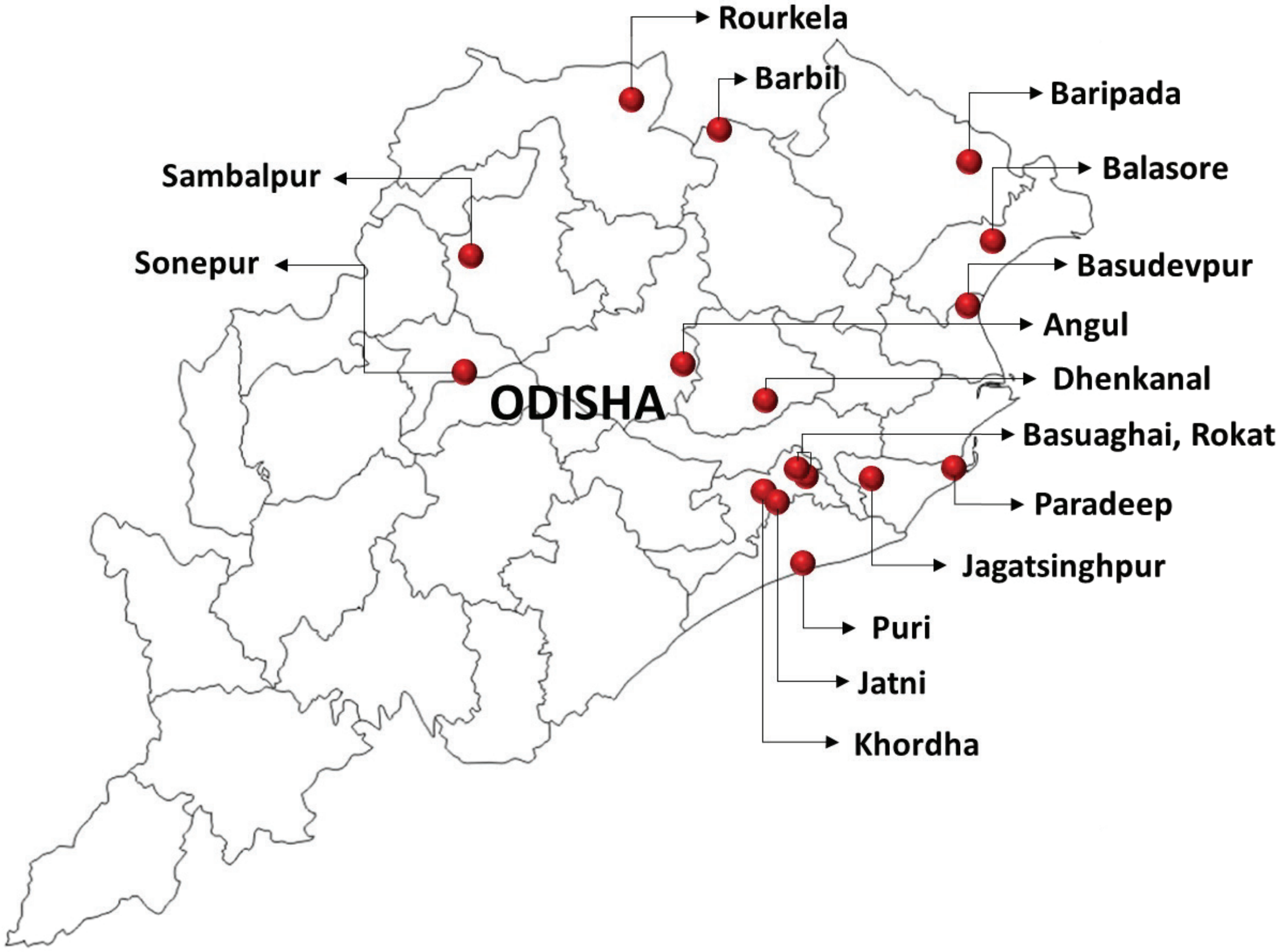
Table 3: FSTPs and STP co-treatment plant evaluated in this study

S. no.	FSTP/STP co-treatment plant location	Year of commissioning	Treatment capacity	Capacity utilization	Solid–liquid separation	Treatment technology	Tertiary treatment	Treated water reuse
Faecal sludge treatment plants								
1	Rokat	2020	75 KLD	52%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Not being used
2	Sonepur	2021	10 KLD	60%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
3	Barbil	2022	20 KLD	53%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
4	Basudevpur	2022	10 KLD	100%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
5	Paradeep	2022	20 KLD	70%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
Re-evaluated faecal sludge treatment plants								
6	Basuaghai, Bhubaneswar	2018	75 KLD	82%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening

S. no.	FSTP/STP co-treatment plant location	Year of commissioning	Treatment capacity	Capacity utilization	Solid–liquid separation	Treatment technology	Tertiary treatment	Treated water reuse
7	Jatni	2021	20 KLD	75%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
8	Khordha	2020	20 KLD	100%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
9	Dhenkanal	2018	27 KLD	63%	Stabilization reactor, SDB	ABR & AF, PGF	ASF, ACF, UV; Solar pasteurization unit for sludge disinfection	Gardening
10	Angul	2020	18 KLD	75%	Stabilization reactor, Greenhouse SDB	ABR & AF, PGF	ASF, ACF	Gardening
11	Jagatsinghpur	2022	20 KLD	80%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
12	Sambalpur	2018	20 KLD	68%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
13	Baripada	2019	50 KLD	70%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
14	Balasore	2020	60 KLD	63%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
15	Rourkela	2018	40 KLD	113%	Settling-thickening tank, SDB	ABR & AF, PGF	Polishing pond	Gardening
Re-evaluated STP co-treatment plant								
16	Puri	2017	50 KLD	60%	Settling-thickening tank, SDB	Aerated lagoons	Chlorine contact tank	Discharge into river

Source: CSE

Map 1: Locations of 15 FSTPs and one STP co-treatment plant evaluated in this study



Source: CSE

7. FAECAL SLUDGE TREATMENT PLANTS

In this study, 15 faecal sludge treatment plants (FSTP) were evaluated, out of which, five FSTPs were evaluated for the first time and the rest were evaluated by CSE during 2020–22. They were re-evaluated to inspect their long-term performance and sustainability. The detailed technology specifications and other relevant information of all the FSTPs observed during sample collection visit are provided in this section. The development and challenges observed in the re-evaluated plants during sampling visits are also included.

7.1 FSTPS EVALUATED IN THIS STUDY

7.1.1 Rokat FSTP

The 75–kilolitres per day (KLD) FSTP has been set up by urban local bodies (ULB) in Rokat village in Bhubaneswar tehsil of Khordha district in Odisha. The FSTP was commissioned in 2020. During the study period, the FSTP was running at 52 per cent capacity by receiving 12–13 trucks of 3,000 litres capacity per day. The faecal sludge (FS) is received from households, community, hospital and public toilets. The FSTP is located near sewage treatment plant (STP) and is operated by eight resource persons. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

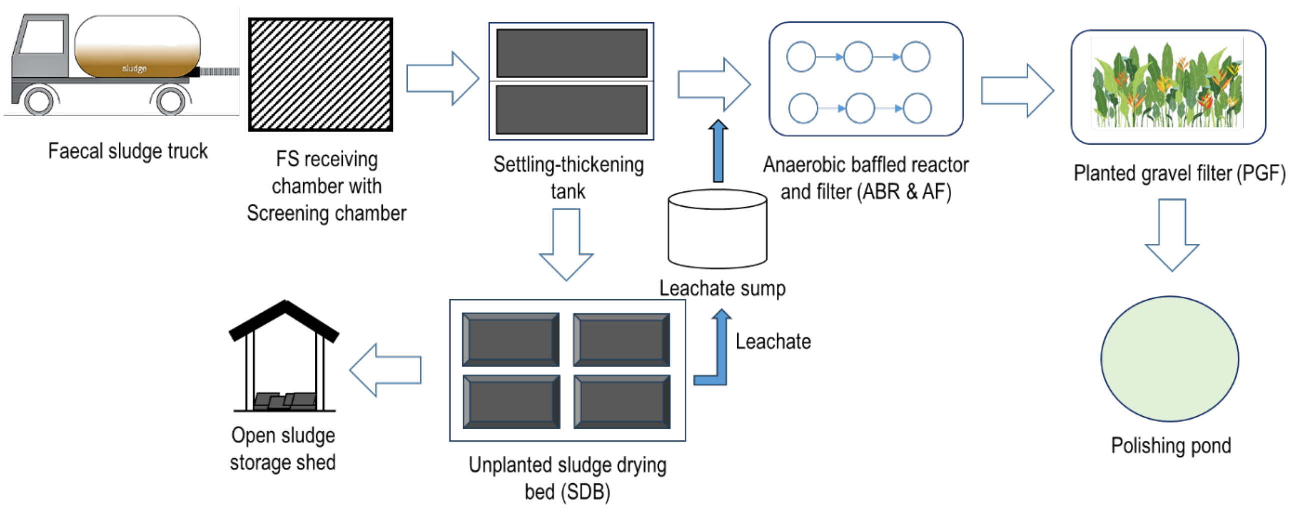
FS from various containments in the village is collected by vacuum trucks, and is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatable material and grit from FS. Then the FS flows into a STT where the solids get settled while the supernatant flows into ABR. There two STTs in Rokat.

The settled sludge from STT is then pumped into SDB for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant from STT undergoes treatment in ABR by anaerobic digestion resulting in the reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, water gets filtered in the anaerobic filter chamber (AF) which contains MBBR beads for filtration, before it reaches the PGF. Then the partially treated water enters the PGF for nutrient removal. There are four PGFs in Rokat. Later, the water enters into a polishing pond for the removal of odour and micro-organisms. The water generated in the FSTP is not used for any purpose and is discharged into a nearby canal. The dried sludge is removed from the SDB and stored in an open sludge storage shed. It has not been reused till date (see *Figure 3: Schematic representation of the process flow in Rokat FSTP*).

Settling thickening tank at Rokat FSTP, Bhubaneswar

Source: CSE

Figure 3: Schematic representation of the process flow in Rokat FSTP



Source: CSE

7.1.2 Sonepur

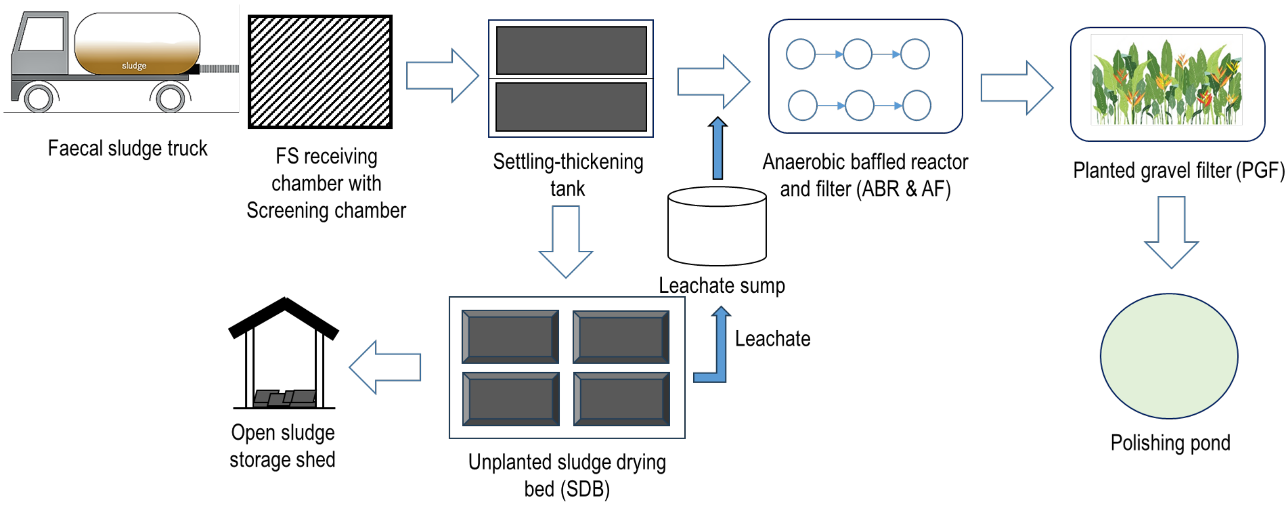
The 10–KLD FSTP has been set up by ULB in Sonepur (also called Subarnapur), a town in Subarnapur district of Odisha. The FSTP was commissioned in 2021. During the study period, the FSTP was running at 60 per cent capacity, by receiving two trucks of 3,000 litres capacity per day. The FS is received from households, community, hospital and public toilets. The FSTP is operated by nine resource persons. The technology adopted is DEWATS with settling-thickening tank (STT), followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS from various containments in the town is collected by vacuum trucks and discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatable material and grit from FS. Then the FS flows into a STT where the solids get settled while the supernatant flows into ABR. There are two STTs in Sonepur. The settled sludge from STT is then pumped into SDB for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant from STT undergoes treatment in ABR by anaerobic digestion, resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, water gets filtered in the anaerobic filter chamber (AF) which contains MBBR beads for filtration, before it reaches the PGF. Then the partially treated water enters the PGF for nutrient removal. There are four PGF beds in Sonepur.

Later, the water enters into a polishing pond for the removal of odour and micro-organisms. The FSTP is located near the Tel River. The water generated in the FSTP is used for gardening purpose within the premises of the FSTP. The dried sludge is removed from the SDB and stored in an open sludge storage shed. It has not been reused till date (see *Figure 4: Schematic representation of the process flow in Sonepur FSTP*).

Settling thickening tank, anaerobic baffled reactors (ABR) and unplanted sludge drying beds at Sonepur FSTP
Source: CSE

Figure 4: Schematic representation of the process flow in Sonepur FSTP



Source: CSE

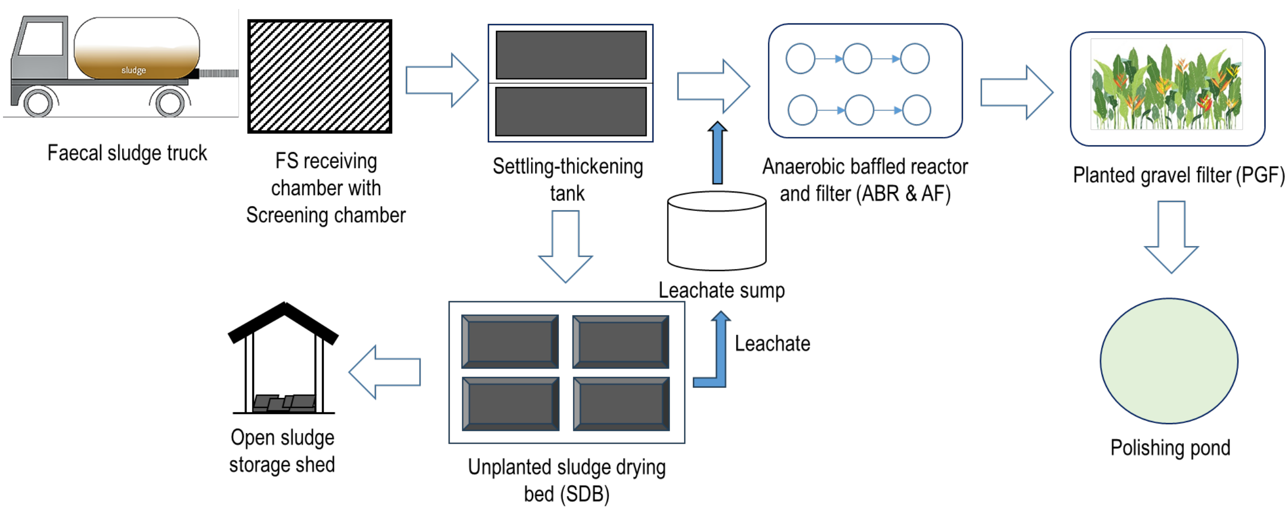
7.1.3 Barbil

The 20–KLD FSTP has been set up in Barbil in the Kendujhar district of Odisha. The FSTP was commissioned in August 2022. During the study period, the FSTP was running at 53 per cent capacity, by receiving three–four trucks of 3,000 litres capacity per day. The FS is received from households, community, hospitals and public toilets. The FSTP is operated by eight resource persons. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS from various containments in the town is collected by vacuum trucks and is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatable material and grit from FS. Then the FS flows into a STT where the solids get settled while the supernatant flows into ABR. There are two STTs in Barbil. The settled sludge from STT is then pumped into the SDB for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant from STT undergoes treatment in ABR by anaerobic digestion, resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, water gets filtered in the anaerobic filter chamber (AF) which contains MBBR beads for filtration, before it reaches the PGF. Then the partially treated water enters the PGF for nutrient removal. There are four PGF in Barbil. Later, the water enters into a polishing pond for the removal of odour and micro-organisms. The FSTP is located near the Karo River. The water generated in the FSTP is used for gardening within the premises. The dried sludge is removed from the SDB and stored in open sludge storage shed. It has not been reused till date (see *Figure 5: Schematic representation of the process flow in Barbil FSTP).*

Anaerobic baffled reactors (ABR) and planted gravel filter beds at Barbil FSTP
Source: CSE

Figure 5: Schematic representation of the process flow in Barbil FSTP



Source: CSE

7.1.4 Basudevpur

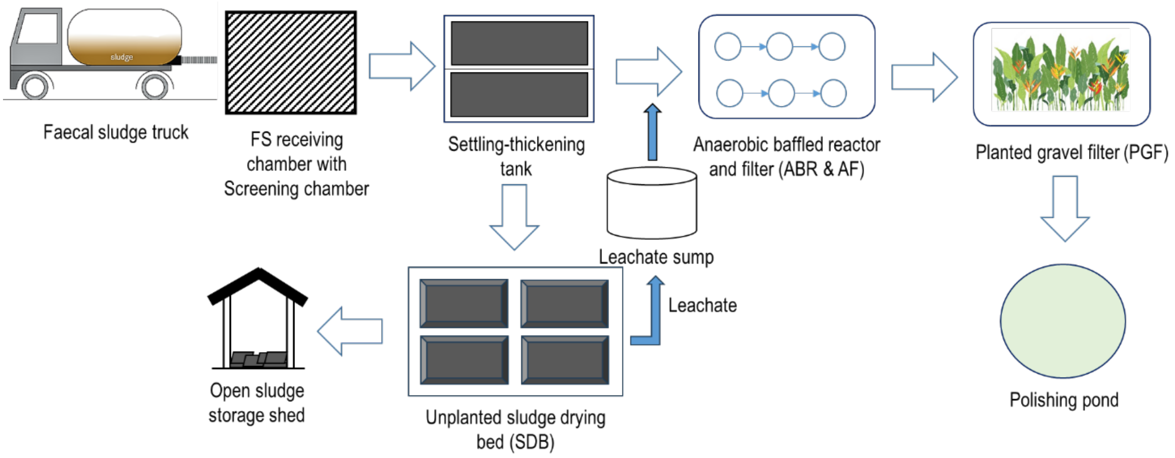
The 10–KLD FSTP has been set up in Basudevpur, which is a town and a municipality in Bhadrak district in Odisha. It is the second most populated (500,000) town in Bhadrak. The FSTP was commissioned in 2022. During the study period, the FSTP was running at 100 per cent capacity, by receiving three–four trucks of 3,000 litres capacity per day. The FS is received from households, community, hospitals and public toilets. The plant is located in an area of 1.5 acres. The CapEx of the plant is Rs 2.49 crore while the OpEx is Rs 88,000 per month. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS from various containments in the village is collected by vacuum trucks and is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatable material and grit from FS. Then the FS flows into a STT where the solids get settled while the supernatant flows into ABR. There are two STTs in Basudevpur. The settled sludge from STT is then pumped into the SDB for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant from STT undergoes treatment in ABR by anaerobic digestion, resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, water gets filtered in the anaerobic filter chamber (AF) which contains MBBR beads for filtration, before it reaches the PGF. Then the partially treated water enters the PGF for nutrient removal. There are four PGF in Basudevpur.

Later, the water enters into a polishing pond for the removal of odour and micro-organisms. A total of 90 per cent of water along with 3 per cent of sludge is generated per day. The water generated in the FSTP is used for gardening within the premises. The dried sludge is removed from the SDB and stored in open sludge storage shed. About 1.3 tonnes of biosolids is generated in a week but it has not been reused till date (see *Figure 6: Schematic representation of the process flow in Basudevpur FSTP*).

Various treatment modules (STT, ABR, PGF, SDB) and sludge storage shed at Basudevpur FSTP
Source: CSE

Figure 6: Schematic representation of the process flow in Basudevpur FSTP



Source: CSE

7.1.5 Paradeep

The 20–KLD FSTP has been set up in Paradeep, a major industrial seaport town and municipality, in the Jagatsinghpur district of Odisha. The FSTP was commissioned in 2022. During the study period, the FSTP was running at 70 per cent capacity, by receiving four trucks of 3,000–4,000 litres capacity per day. The FS is received from septic tanks from households, community and public toilets. The FSTP is located in a 5–acre industrial area in Paradeep. The CapEx of the FSTP is Rs 2.67 crore while the OpEx is Rs 85,000 per month. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

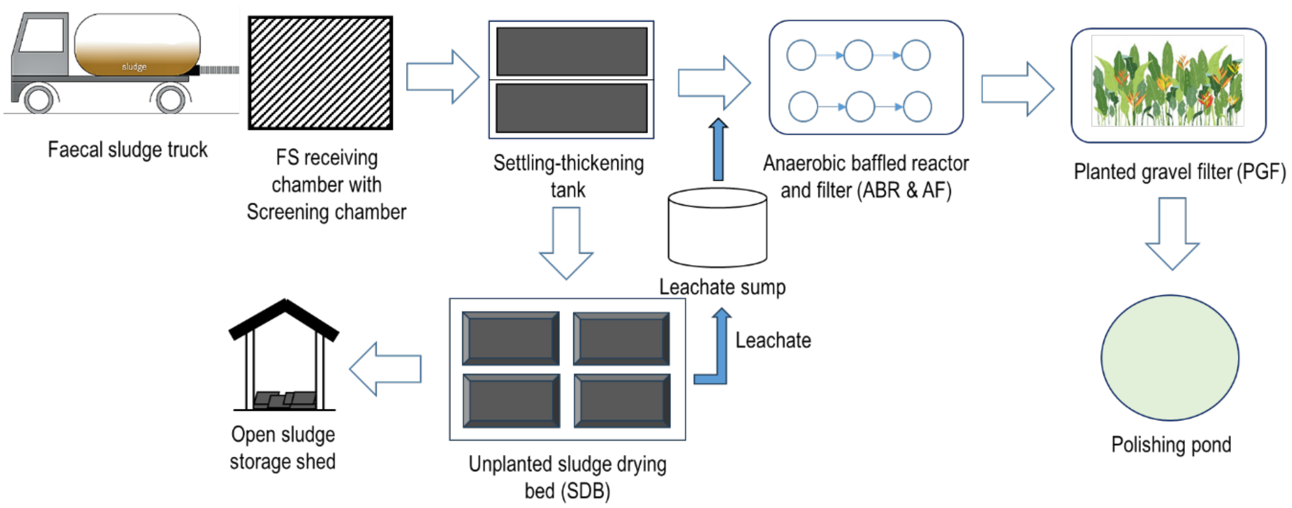
FS is collected from various containments in the village by vacuum trucks and is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatable material and grit from FS. Then the FS flows into a STT where the solids get settled while the supernatant flows into ABR. There are two STTs in Paradeep. The settled sludge from STT is then pumped into SDB for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant from STT undergoes treatment in ABR by anaerobic digestion, resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, water gets filtered in the anaerobic filter chamber (AF) which contains MBBR beads for filtration, before it reaches the PGF. Then the partially treated water enters the PGF for nutrient removal. There are four PGF beds in Paradeep.

Later, the water enters into a polishing pond for the removal of odour and micro-organisms. A total of 2 per cent of sludge is generated. The water generated in the FSTP is used for gardening within the premises. The dried sludge is removed from the SDB and stored in open sludge storage shed. It has not been reused till date (see *Figure 7: Schematic representation of the process flow in Paradeep FSTP*).

PGF beds, unplanted SDBs and sludge storage shed at Paradeep FSTP

Source: CSE

Figure 7: Schematic representation of the process flow in Paradeep FSTP



Source: CSE

7.2 RE-EVALUATED FSTPS

7.2.1 Basuaghai FSTP, Bhubaneswar

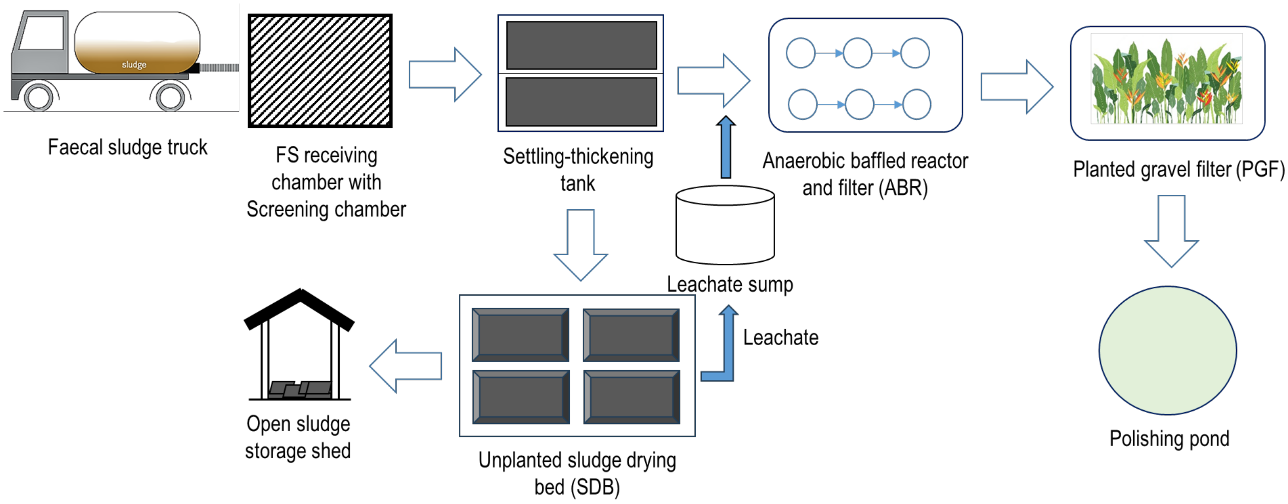
The Basuaghai FSTP is located in the southeastern part of Bhubaneswar—the capital of Odisha. The AMRUT scheme funded the project while the Odisha Water Supply & Sewerage Board (OWSSB) designed and supervised the construction. The FSTP was designed with DEWATS system with a capacity of 75 KLD, and it started operations in June 2018. It is the first and the only FSTP in the city, which mainly relies on onsite sanitation systems. During the study period, the FSTP was running at 82 per cent capacity by receiving 20–21 trucks of 4,000 litres capacity per day. The FS is received from households, community, hospitals, public toilet septic tanks and pit latrines. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

The FS received in the receiving chamber is passed through filter screens to remove grit and inert material. Then the FS flows by gravity to the subsequent treatment unit consisting of two STTs arranged parallelly where solid–liquid separation takes place. The settled and thickened solids/sludge in the STTs are pumped to eight unplanted drying beds operating in tandem. The leachate from the sludge drying beds and the supernatant from the STTs is treated in two parallel series of ABR with anaerobic filters. The next unit is the horizontal flow constructed wetlands (also called PGF beds), where the effluent undergoes further treatment for the removal of nutrients, i.e., nitrogen and phosphorus.

An overview of Basuaghai FSTP showing STT, ABR and sludge storage shed

Source: CSE

Figure 8: Schematic representation of the process flow in Basuaghai FSTP



Source: CSE

This is followed by the final treatment and storage of the effluent in a polishing pond equipped with an aeration pump where odour and pathogens are removed. A total of 95 per cent of water is generated in the FSTP which is used for gardening purposes within the plant premises. The FSTP is located in a populated area without any nearby waterbodies—reducing the chances of water contamination. The biosolids are removed from the drying beds and stored in the (open) storage shed. Around 1 tonne of dried sludge/biosolids is generated in a month which is used for land filling (see *Figure 8: Schematic representation of the process flow in Basuaghai FSTP*).

7.2.2 Jatni FSTP

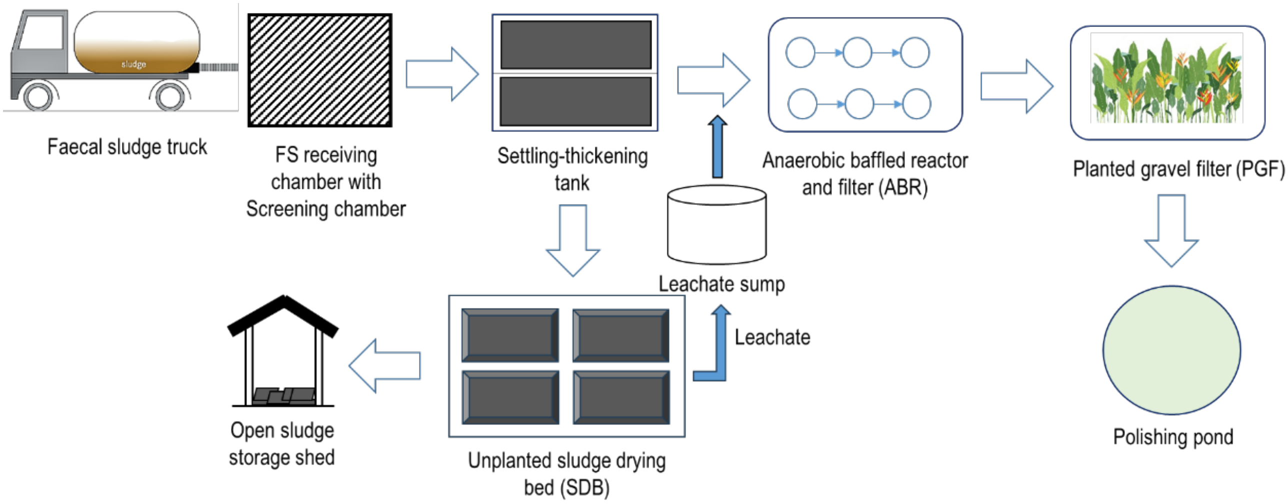
The 20–KLD FSTP has been set up by ULB in the municipal town of Jatni in Khordha district in Odisha. The FSTP was commissioned in May 2021. During the study period, the FSTP was running at 75 per cent capacity by receiving FS of around 15,000 litres from four–five cesspool trucks with capacity of 1,000–5,000 litres per day. The FS is received from households, community, hospitals and public toilet septic tanks. The CapEx of the 1.5–acre plant was Rs 2.6 crore while the OpEx is Rs 70,000 per month. The FSTP is operated with solar power and is located near the mines. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS collected from various containments in the town by vacuum trucks is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatables and grit from FS. Then the FS flows into STT where the solids get settled while the supernatant flows into ABR. The settled sludge from STT is then pumped into SDB and allowed to stay for two–three weeks for drying. Eight SDBs are filled consecutively. Leachate from the SDB enters into ABR; leachate along with FS supernatant undergoes treatment in ABR by anaerobic digestion resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, the partially treated water enters the PGF for nutrient removal. There are four PGF in Jatni.

Later, the water enters a polishing pond for the removal of odour and micro-organisms. The water generated in the FSTP is used for gardening within the plant premises, and for cleaning roads and railway tracks. A total of 60 per cent of water is generated in the FSTP which is used for gardening purposes within the plant premises. The FSTP is located in a forest area without any nearby waterbodies—reducing the chances of water contamination. The biosolids are removed from the drying beds and stored in the (open) storage shed. About 400 kg of biosolids are generated in a month which has not been reused till date (See *Figure 9: Schematic representation of the process flow in Jatni FSTP*).

An overview of Jatni FSTP showing STT, ABR, SDBs and sludge storage shed
Source: CSE

Figure 9: Schematic representation of the process flow in Jatni FSTP



Source: CSE

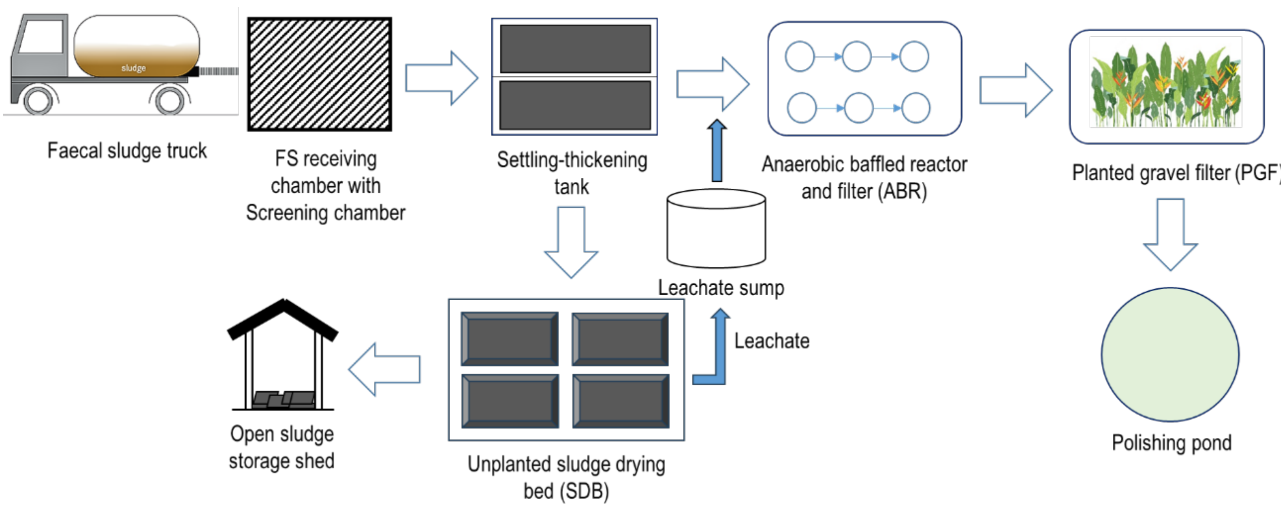
7.2.3 Khordha FSTP

The 20–KLD FSTP has been set up by ULB in the municipal town of Khordha, the headquarters of Khordha district in Odisha. The FSTP was commissioned in November 2020. During the study period, the FSTP was running at full capacity by receiving five–six trucks of 4,000 litres capacity per day. The FS is received from households, community, hospitals, public toilet septic tanks and pit latrines. The plant occupies a total area of one acre and is located near the industrial area. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS collected from various containments in the town by vacuum trucks is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatables and grit from FS. Then the FS flows into STT where the solids settle down while the supernatant flows into ABR. The settled sludge from STT is then pumped into SDB, which is covered with a movable asbestos roof, and allowed to stay for two–three weeks for drying (in each SDB). There are eight STTs in Khordha. Leachate from the SDB enters into ABR; leachate along with FS supernatant undergoes treatment in ABR by anaerobic digestion for the reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, the partially treated water enters the PGF for nutrient removal. There are four PGF in Khordha. Later, the water enters into a polishing pond for the removal of odour and micro-organisms. About 18,000 litres of water is generated per day in the FSTP which is used for landscaping within the plant premises. The dried sludge/biosolids is removed from SDBs and stored in an open storage shed. About 400 kg of biosolids is generated in a month which is not reused until now, except for occasional gardening purposes within the plant premises (see *Figure 10: Schematic representation of the process flow in Khordha FSTP*).

An overview of Khordha FSTP showing STT, ABR and SDBs
Source: CSE

Figure 10: Schematic representation of the process flow in Khordha FSTP



Source: CSE

7.2.4 Dhenkanal FSTP

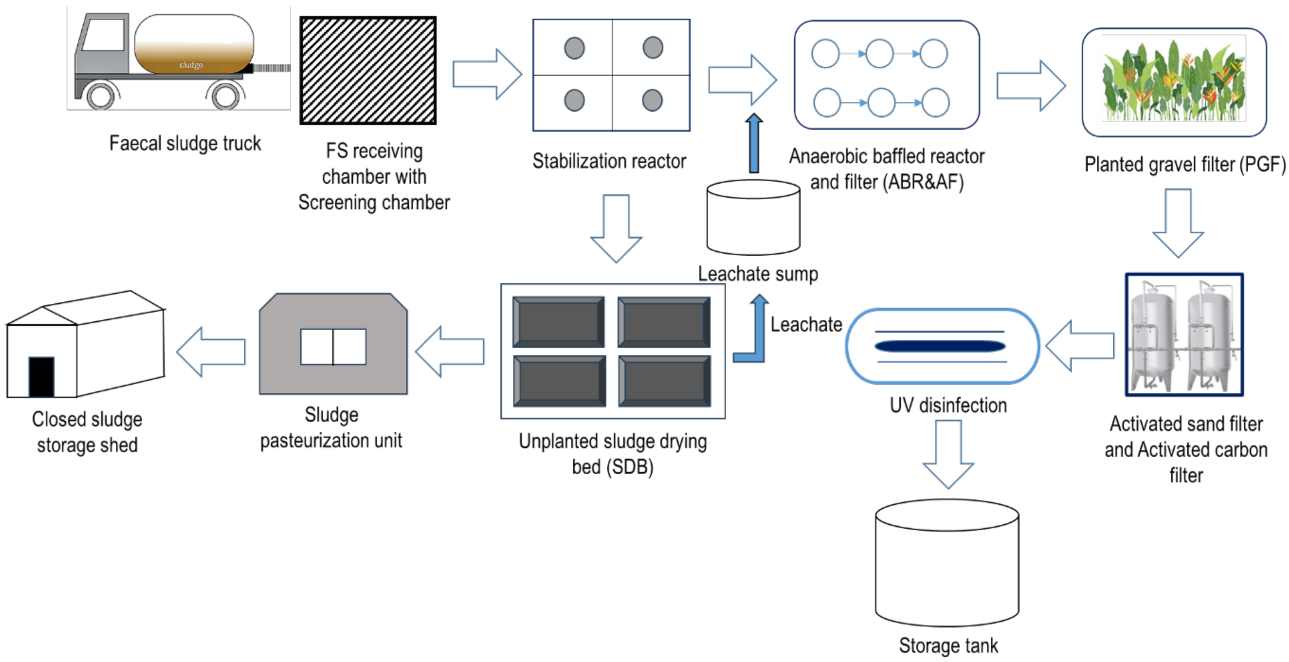
The 27–KLD FSTP in Dhenkanal is the first FSTP in the state to be built by the collective action of sanitation alliances, along with Dhenkanal municipality and the government of Odisha. The FSTP was commissioned in October 2018. During the study period, the FSTP was running at 63 per cent capacity by receiving three–four trucks with a capacity of 17,000 litres of FS per day. The FS is received from households, community, hospitals and public toilets. The plant is located near the MSW dumping area. The main treatment steps followed in this FSTP are stabilization, dewatering/solid–liquid separation and pathogen removal. The FS is conveyed to the FSTP through desludging trucks. The treatment modules for solid components are—feeding tank (FT) with screen chamber, stabilization reactor, and unplanted sludge drying bed (SDB) with green house solar drier roof (GHSD). Treatment modules for liquid components are—integrated anaerobic baffled reactor with filter chambers, planted gravel filter (PGF), sand and carbon filter followed by UV exposure and collection tank. The treatment system also consists of a solar sludge pasteurization unit where the dried sludge from the SDB is subjected to decontamination for the removal of pathogens, for safe usage in agriculture.

FS collected from various containments in the town by vacuum trucks is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatables and grit from FS. Then the FS flows into the three–chambered stabilization reactor where it is allowed to stay for 11 days for homogenization, stabilization and anaerobic degradation of the sludge. Stabilization also improves the dewaterability of the FS.

Then the stabilized FS is pumped into SDBs fitted with GHSD roof and allowed to stay for two–three weeks (in each SDB) for drying, followed by decontamination in solar sludge pasteurization unit, and finally stored in a closed storage room. Leachate from the SDBs enters into the three-chambered ABR where it undergoes treatment by anaerobic digestion for the reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, the partially treated water enters the PGF for nutrient removal. Later, the water passes through sand and carbon filter and into a UV chamber for pathogen removal and finally stored in a collection tank. Around 80 per cent of liquid and 20 per cent of biosolids is generated in the FSTP. The water generated is used for washing vehicles and landscaping within the plant premises. The biosolids generated is sent for co-composting at another site (see *Figure 11: Schematic representation of the process flow in Dhenkanal FSTP)*.

Anaerobic stabilization reactors and series of unplanted SDBs at Dhenkanal FSTP
Source: CSE

Figure 11: Schematic representation of the process flow in Dhenkanal FSTP



Source: CSE

7.2.5 Angul FSTP

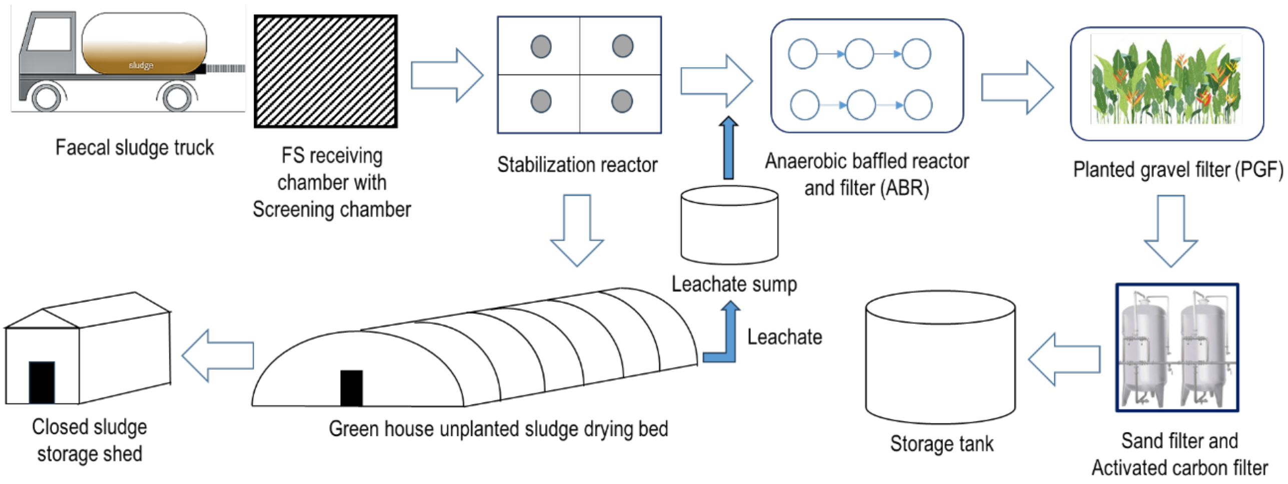
The 18–KLD FSTP is located in Angul, a district headquarters in Odisha. This FSTP is one of the first FSTPs to be established, apart from Dhenkanal, with the collective action of sanitation alliances and the Odisha government. The FSTP was commissioned in January 2020. During the study period, the FSTP was running at about 75 per cent capacity by receiving four–five trucks of 3,000 litres capacity per day. The FS is received from households, community, hospitals, public toilets and other sources. The plant is located near a waste dumping area.

The treatment starts by the removal of coarse particles like sand and grit from the FS received from tankers in the screen and grit chamber, followed by stabilization of sludge in two separate rows of stabilization reactors. Further, the stabilized sludge moves to the two SDB units where solid–liquid separation takes place. Each SDB unit consists of two parallel rows of six drying beds covered with a semi-circular translucent roof to expedite the drying process.

Finally, the dried sludge/biosolids is stored in the closed dry-sludge storage room for subsequent use in soil conditioning. The biosolids is used as a fertilizer within the plant premises for gardening. The liquid portion, after percolating through the SDB units, is collected in respective leachate sumps which in course are connected to a common ABR with anaerobic filter. The effluent from the outlet of the anaerobic filter is passed through planted gravel filter (PGF) followed by sand and carbon filter, and then exposed to UV irradiation. Finally, the treated water is stored in the water collection tank until usage. The water is used for horticulture in the premises (see *Figure 12: Schematic representation of the process flow in Angul FSTP).*

Unplanted sludge drying beds with green house at Angul FSTP
Source: CSE

Figure 12: Schematic representation of the process flow in Angul FSTP

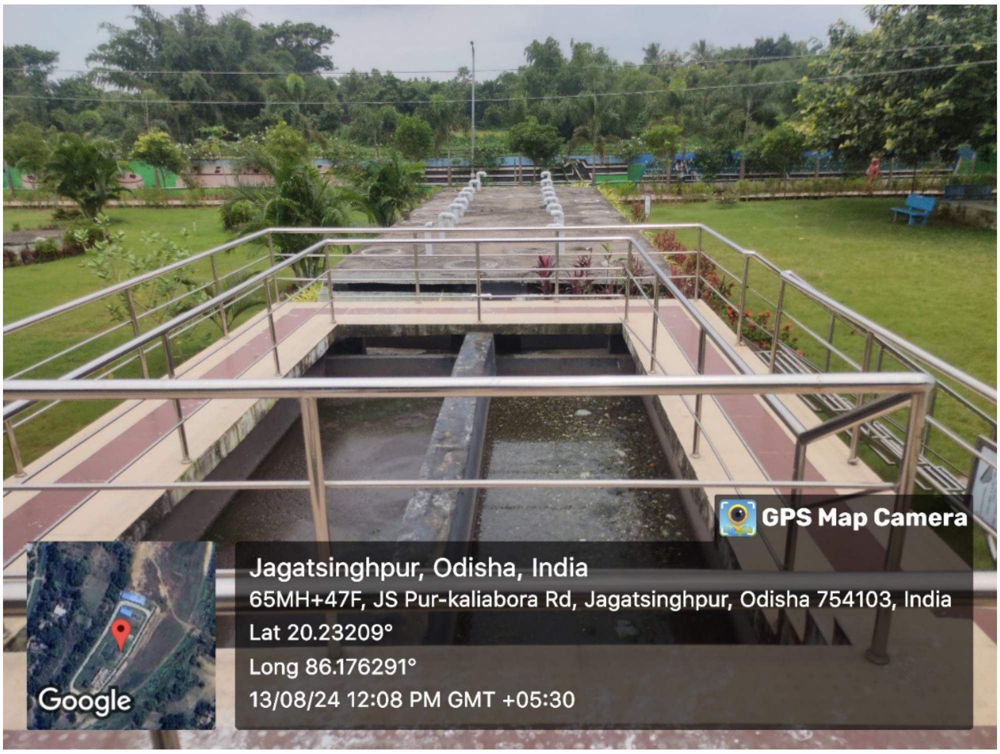


Source: CSE

7.2.6 Jagatsinghpur FSTP

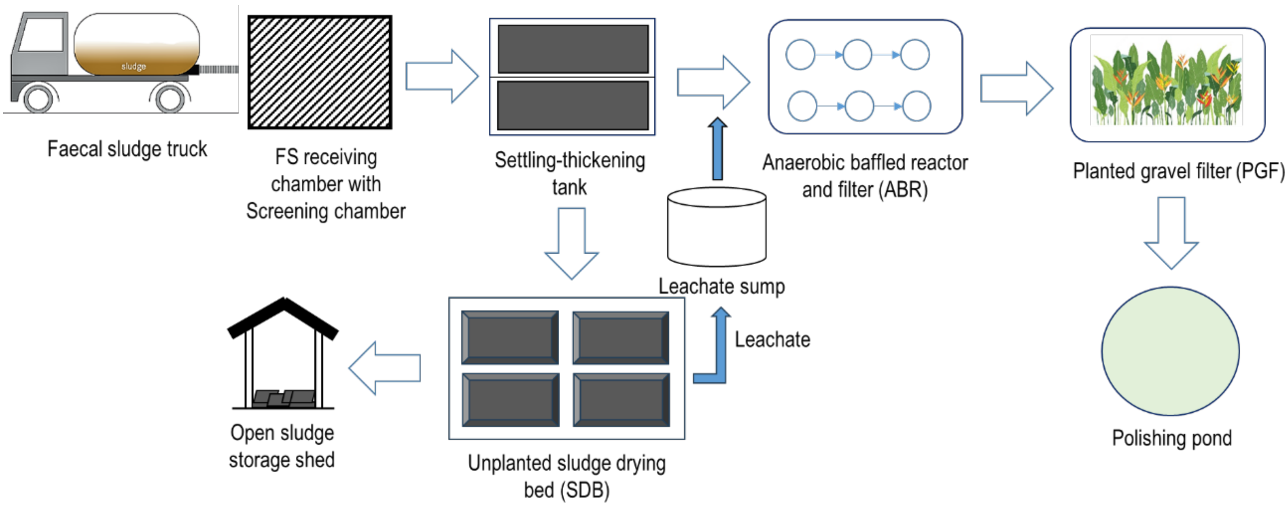
The 20–KLD FSTP has been set up by ULB in the municipal town of Jagatsinghpur, which is the headquarters of Jagatsinghpur district in Odisha. The FSTP was commissioned in 2022. The CapEx of the FSTP is Rs 3.5 crore while the OpEx is Rs 1 lakh per month. During the study period, the FSTP was running at about 80 per cent capacity by receiving FS from five–six trucks of 3,000 litres capacity per day. Occasionally, no FS is received. The FS is received from households, and commercial and public toilets. The plant is located in a well-populated area of the town. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment.

FS collected from various containments in the town by vacuum trucks is discharged at the sludge receiving unit of the plant which is fitted with a screen to remove solid waste, floatables and grit from FS. Then the FS flows into the STT where the solids get settled while the supernatant flows into ABR. The settled sludge from STT is then pumped into eight SDBs, which are covered with a movable asbestos roof, and allowed to stay for two-three for drying. Leachate from the SDB enters into ABR; leachate along with FS supernatant undergoes treatment in ABR by anaerobic digestion, resulting in reduction of Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). From the ABR, the partially treated water enters the PGF for nutrient removal.



An overview of Jagatsinghpur FSTP showing STTs and ABR
Source: CSE

Figure 13: Schematic representation of the process flow in Jagatsinghpur FSTP



Source: CSE

Later, the water enters into a polishing pond for the removal of odour and micro-organisms. The Alaka River flows nearby FSTP, however, the treated water from FSTP is not discharged into it. The treated water is used for gardening purposes within the premises, and also for cleaning and washing the cess pool trucks. The dried sludge is removed from the SDBs and stored in an open sludge storage shed. The biosolids is not used for any purpose except for gardening within the premises occasionally (see *Figure 13: Schematic representation of the process flow in Jagatsinghpur FSTP*).

7.2.7 Sambalpur FSTP

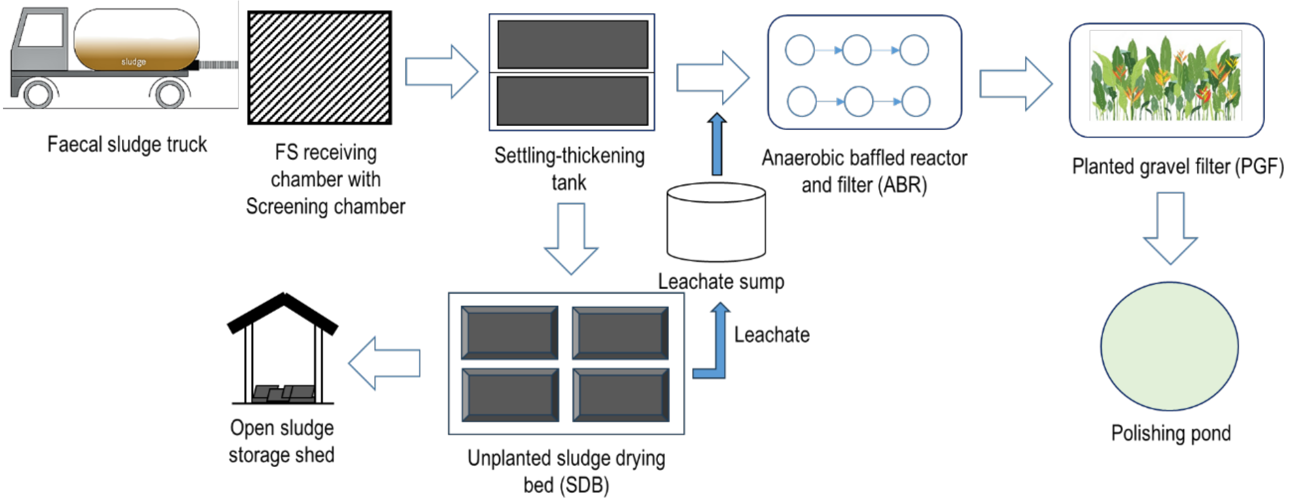
The 20–KLD Sambalpur FSTP is located in Khandual village, Dhanupali tehsil, in Sambalpur district—nearly 10 km away from the main city. The FSTP became operational on 26 October 2018. During the study period, the FSTP was running at about 68 per cent capacity by receiving four-five trucks of about 1,000–4,500 litres capacity (12–15 KL) per day. The FS is received from households, community, hospitals and public toilets. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment. The CapEx of the FSTP is Rs 191.55 lakh. Eight staff are working in each plant.

The treatment consists of a faecal sludge receiving chamber fitted with a screening unit to remove inert material and grit, followed by two parallel STTs for solid–liquid separation and eventually, the ABR. Thickened sludge from the bottom of the STT is pumped to the SDBs covered with a movable roof where the solid part is dried under sunlight and finally stored in the dry sludge (open) storage yard. The supernatant from the top of the STT flows to the ABR; the leachate (liquid) from the bottom of the SDB is collected in the leachate sump and pumped into the ABR inlet periodically where anaerobic digestion of the leachate takes place. The effluent from the outlet of the ABR is passed through two successive beds of PGF and finally stored in the polishing pond.

The Malti River flows nearby FSTP, however, the effluent from FSTP is not discharged into it. The effluent collected in the polishing pond is used for horticulture and watering the plants in the premises. The biosolids generated in the FSTP is given to the forest department to be used as a fertilizer (see *Figure 14: Schematic representation of the process flow in Sambalpur FSTP*).

An overview of Sambalpur FSTP showing SDBs, ABR and PGF beds.
Source: CSE

Figure 14: Schematic representation of the process flow in Sambalpur FSTP



Source: CSE

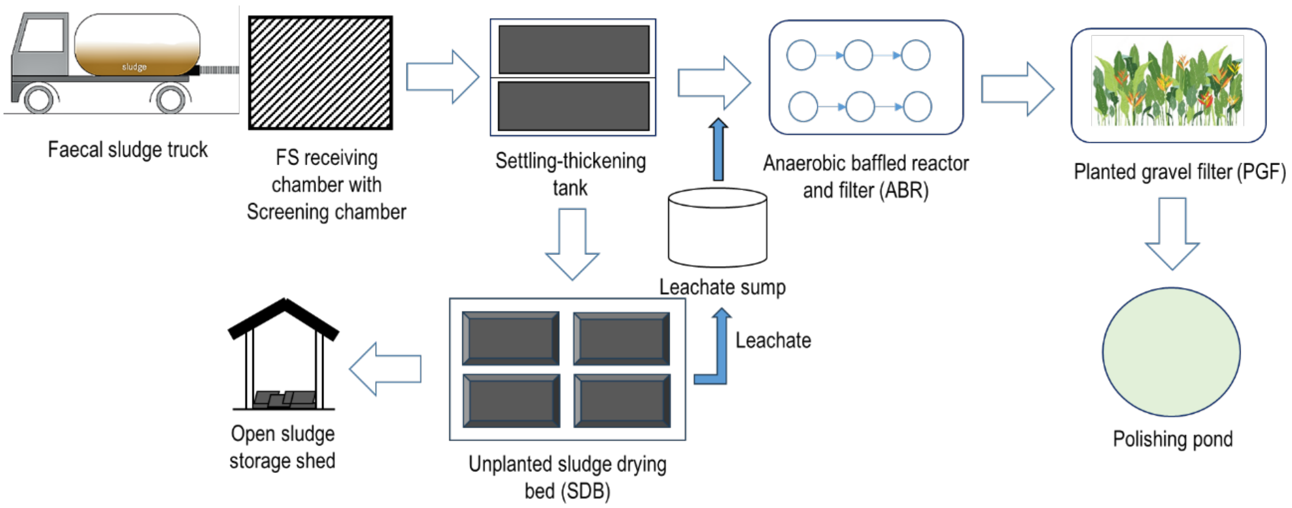
7.2.8 Baripada FSTP

The 50–KLD FSTP in Baripada was commissioned in January 2019 and is operated under the jurisdiction of Baripada municipality in Mayurbhanj district in Odisha. Septage is mainly collected from households and public toilets from the adjacent urban and rural areas by cesspool trucks of 1 kilolitre (KL) and 3 KL capacities. One truck of 1 KL capacity and two trucks of 3 KL capacity are available for delivering faecal sludge to the FSTP. During the study period, the FSTP was running at about 70 per cent capacity by receiving nearly 35 KL of faecal sludge (12 trips of cesspool trucks) in a day. The technology adopted is DEWATS with settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment. The OpEx of the FSTP is Rs 98,500 per month.

The first unit of the treatment plant is a screening chamber to remove inert solid waste from FS, followed by two parallel rows of STTs, and eventually to the ABR with anaerobic filter. Thickened sludge from the bottom of the STT is pumped to the SDBs where the solid part is dried under sunlight and finally stored in the dry-sludge (open) storage yard. The liquid from the bottom of the SDBs is collected in the leachate sump which is pumped into the ABR inlet periodically for treatment. The supernatant from the STT also flows into the ABR where anaerobic treatment takes place.

STTs and ABR at Baripada FSTP
Source: CSE

Figure 15: Schematic representation of the process flow in Baripada FSTP



Source: CSE

The partially treated effluent from the outlet of the anaerobic filter is passed through PGF for nutrient removal, then through sand filter for the reduction of TSS, and finally stored in the polishing pond where odour and pathogen is removed. The water stored in the polishing pond is used for cleaning the cesspool vehicles and horticulture purposes within the premises. About 1 quintal of dry sludge is generated in a month which is used for gardening purposes within the premises (See *Figure 15: Schematic representation of the process flow in Baripada FSTP*).

7.2.9 Balasore FSTP

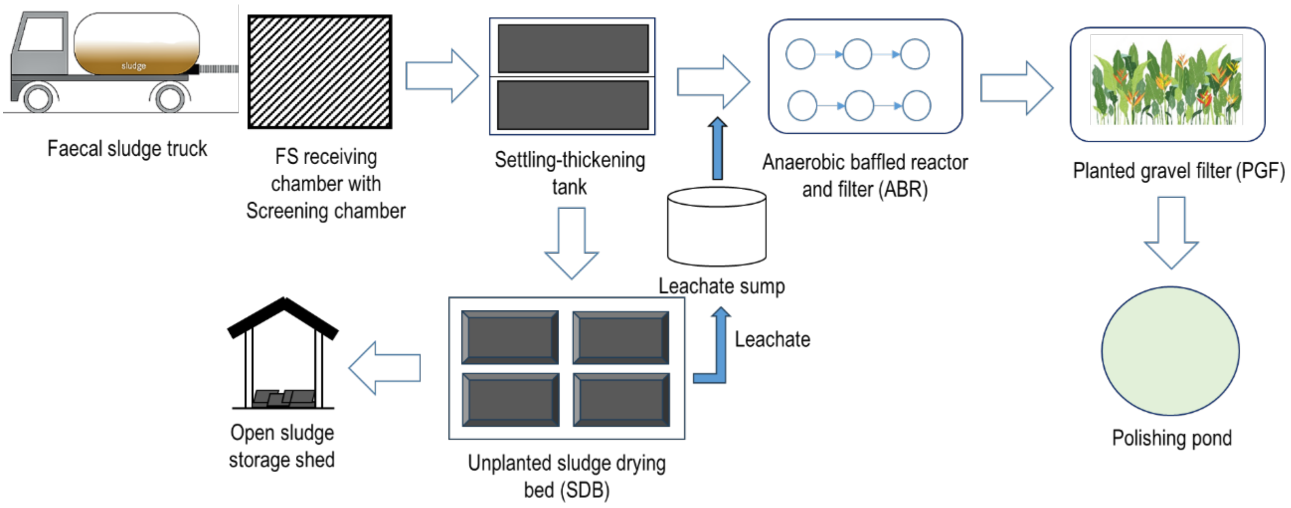
The 60–KLD FSTP in Balasore, the district headquarters of Balasore district in Odisha, was commissioned in January 2020. The septage or faecal sludge (FS) is mainly received from commercial, institutional and public toilets. During the study period, the FSTP was running at about 63 per cent capacity by receiving nearly 18–20 cesspool trucks of 1–3 KL capacity per day. The DEWATS technology consists of settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment. The OpEx of the FSTP is Rs 1.17 lakh per month.

The treatment consists of a screening unit followed by two parallel rows of STT and then ABR with anaerobic filter. FS received in the receiving chamber undergoes screening to remove inert material before it is transferred into STTs. Thickened sludge from the bottom of the STT is pumped to the SDBs where the solid part is dried under sunlight and finally stored in the dry–sludge (open) storage yard. The liquid from the bottom of the SDB is collected in the leachate sump and is later pumped to the ABR inlet periodically for treatment. The supernatant from the STT also flows into the ABR where anaerobic treatment takes place. The effluent from outlet of the anaerobic filter flows to PGF where some of the nutrients are taken up by the plants.

The next unit in the treatment system is a sand filtration set–up used for the removal of any suspended or floatable materials. After filtration, the effluent is collected in the polishing pond from where it is used for cleaning of cesspool trucks, FS receiving chamber and gardening purposes onsite (see *Figure 16: Schematic representation of the process flow of Balasore FSTP*).

The STTs, ABR, PGF beds and SDBs at Balasore FSTP
Source: CSE

Figure 16: Schematic representation of the process flow of Balasore FSTP



Source: CSE

About 45 kg of biosolids is generated in a month which is given free of cost to farmers as it can be used as a soil conditioner or fertilizer for flowering plants and vegetable crops. During the survey, it was observed that the sludge is not properly dried in the SDBs as the sludge is being harvested within eight days from the SDBs. A minimum duration of 15 days is required for proper drying of the sludge in SDBs to reduce moisture and pathogen load. There are eight SDBs onsite which are not sufficient to dry all the FS received in the plant.

7.2.10 Rourkela FSTP

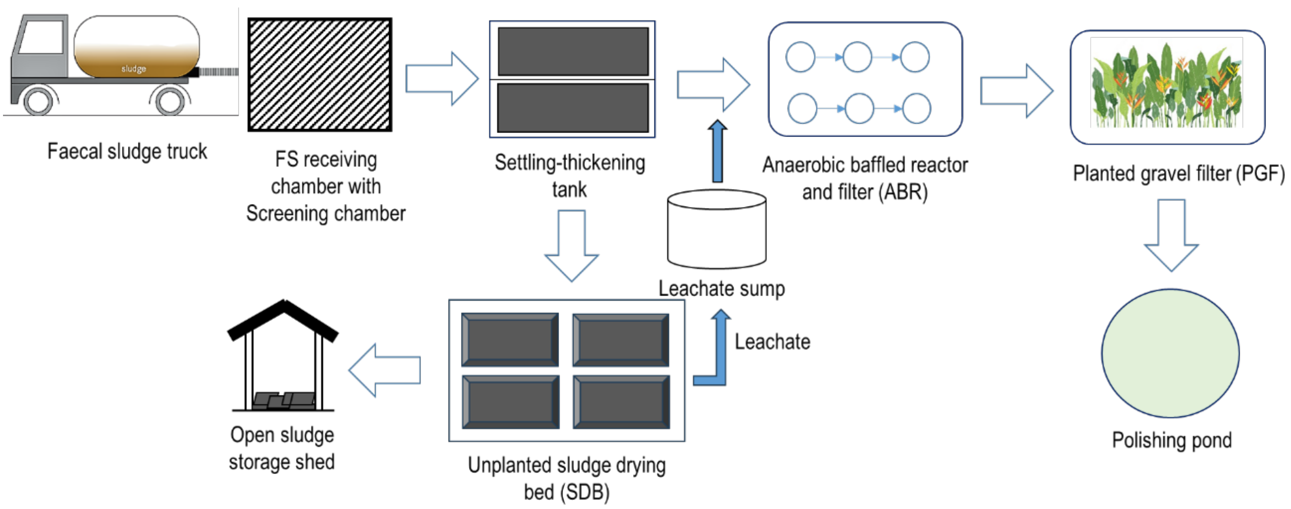
The FSTP was constructed by the Odisha Water Supply and Sewerage Board (OWSSB) at Balughat in Rourkela, planned under the AMRUT programme. The FSTP was commissioned on 25 October 2018 and is currently run by the Rourkela Municipal Corporation (RMC). The plant was designed to process 40 KLD of septage from households, community, hospitals, public toilets and toilets from other sources in cesspool trucks. During the study, FS from around 20 trucks with the capacity of 1 KL, 2KL and 3 KL was received per day, with 3–KL trucks delivering maximum sludge (in 10 trips). As a result, the FSTP was processing faecal sludge more than its capacity—at 113 per cent—during the study period. The technology adapted was DEWATS and consisted of settling-thickening tank (STT) followed by unplanted sludge drying beds (SDBs) for dewatering and drying of sludge, and anaerobic baffled reactors (ABR), horizontal planted gravel filter (PGF) beds and polishing pond for effluent treatment. Seven staff are working in the plant.

The treatment consists of a screening chamber followed by two parallel rows of STT, then ABR with anaerobic filter. FS received in the receiving chamber is fitted with a screen and undergoes screening to remove inert material, followed by its movement into STTs. Thickened sludge from the bottom of the STT is pumped to eight SDBs where the solid part is dried under sunlight and finally stored in the dry-sludge (open) storage yard and crushed. The liquid from the bottom of the SDB is collected in the leachate sump and then pumped to the ABR inlet periodically for treatment. The supernatant from the STT also flows into the ABR where anaerobic treatment takes place. The effluent from the outlet of the anaerobic filter flows to PGF where nutrient removal takes place and then passed through the stone filter. The effluent is finally collected in a polishing pond, which is used for gardening purpose within the FSTP premises (see *Figure 17: Schematic representation of the process flow in Rourkela FSTP*).

The Brahmani River is located near the FSTP; however, the effluent is not discharged into this river. The biosolids generated by the treatment plant is sent to the forest department and the RMC to be used as a soil conditioner or fertilizer.

Sludge receiving area with screen chamber followed by STTs and ABR at Rourkela FSTP
Source: CSE

Figure 17: Schematic representation of the process flow in Rourkela FSTP



Source: CSE

8. STP CO-TREATMENT PLANT EVALUATED IN THIS STUDY

The STP co-treatment plant in Puri was evaluated by CSE during 2020–22 and is re-evaluated in this study to check its long-term performance and sustainability. The detailed technology description and other relevant information of the STP co-treatment plant observed during sample collection visit are provided in this section. The development and challenges observed in the re-evaluated STP co-treatment plant during sampling visit are included as well.

8.1 PURI STP CO-TREATMENT PLANT

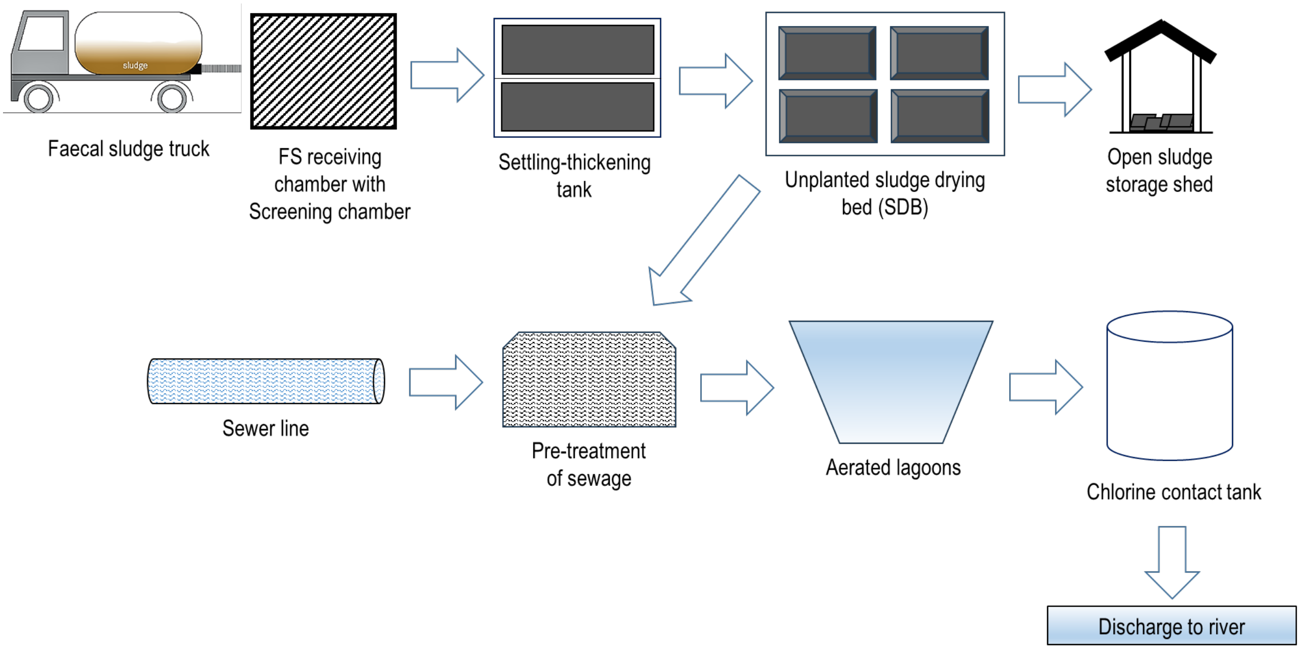
Mangala Ghat STP, with a capacity of 15 megalitres per day (MLD), is located in Puri on the banks of the river Dhaudia since 2013. A 50–KLD faecal sludge treatment plant (FSTP), also called septage treatment plant (SeTP), has been built beside the Mangala Ghat STP. The FSTP leachate gets treated along with the incoming sewage water in the 15–MLD STP. The 25–acre STP co-treatment plant was commissioned in 2017. During the survey, it was observed that the FSTP was running at 60 per cent capacity by receiving about 30 KL of FS from 10–12 trucks of 1– and 3–KL capacity per day. The FS is received from institutional, rural, commercial and household toilets.

The FSTP works on the principle of solid–liquid separation of FS followed by co-treatment of the liquid fraction in the STP. The plant has an elevated unloading platform and FS is discharged from the tankers into the receiving chamber. It is then passed through an inlet channel where a screen is placed at an angle of 45° to remove inert materials. The septage then flows to the settling–cum–thickening tank (STT) where sludge is contained for 10 days. Two STTs are arranged parallelly, which are operated alternately to allow time for sludge settling and thickening. Thickened sludge from the bottom of the STTs is pumped to the unplanted sludge drying beds (SDBs) where the sludge is dried completely under direct sunlight.

The leachate from the bottom of the SDBs is collected into the leachate sump and pumped periodically along with supernatant from STTs to the pre-treatment unit of the STP for subsequent treatment along with sewage water. The combined water stream flows to eight aerated lagoons and finally, the effluent is discharged in the nearby Mangla River after chlorination (see *Figure 18: Schematic representation of the process flow in Puri co-treatment plant*).

The STTs and SDBs at Puri STP co-treatment plant
Source: CSE

Figure 18: Schematic representation of the process flow in Puri co-treatment plant



Source: CSE

9. THE RESULTS OF THE STUDY

The faecal sludge (FS) samples collected from all the FTSPs and STP co-treatment plant were characterized for 10 parameters (as mentioned in section 5.3). The term 'per cent removal' in this section implies 'removal that has occurred from inlet to final outlet'. Biosolids samples collected from FSTPs and STP co-treatment plants are analysed for nine parameters (as mentioned in section 5.4.1). The graphs provided in this section depicts the average data of three months.

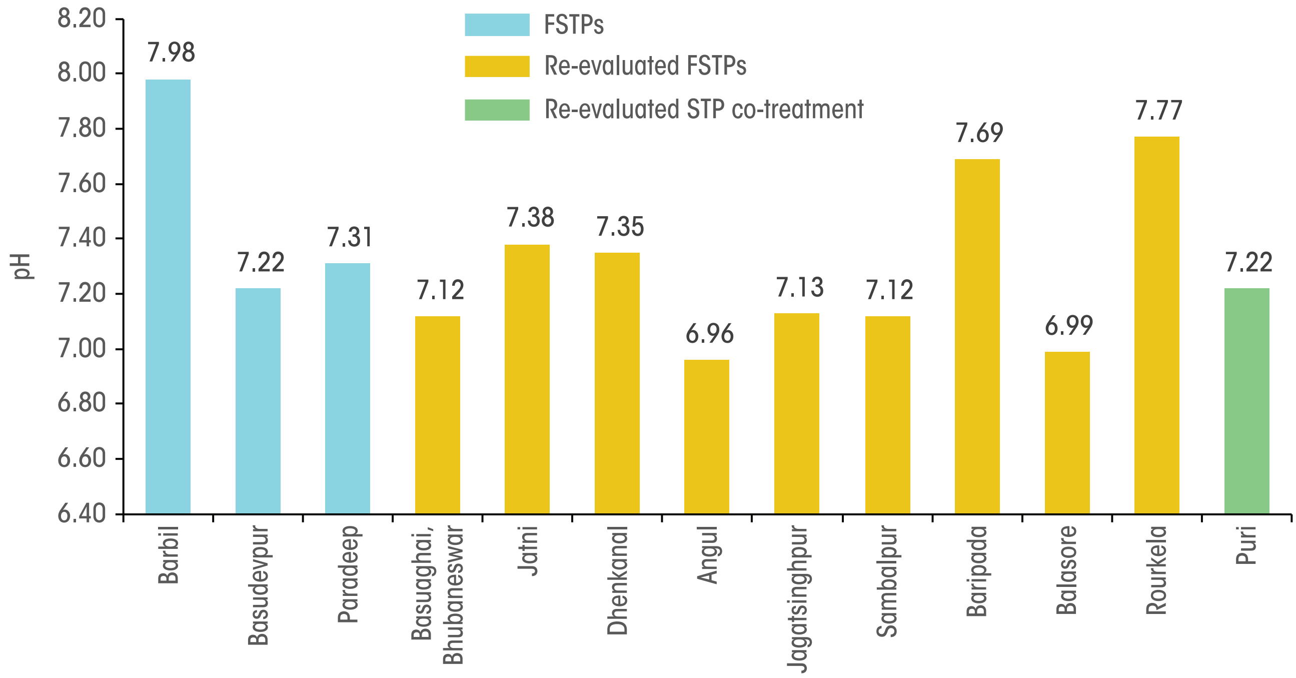
The regulatory standards set by National Green Tribunal (NGT) 2019 and Ministry of Environment, Forest and Climate Change (MoEF&CC) 2017 for the discharge of STP effluent has been followed to assess the performance of FSTPs and co-treatment plants (see *Annexure 1 Table 1*). The physico-chemical parameters in biosolids are compared with Fertilizer Control Order (FCO) 2023 to compare its nutrient value for agricultural applications (see *Annexure 1 Table 2*). To assess the pathogen level in biosolids, this study follows the regulatory limit set by WHO in 2006, and the US Environment Protection Agency (USEPA) for class A biosolids (see *Annexure 1 Table 3*). The consolidated data of all the results is tabulated and depicted in *Annexure 3 Tables 1–5*.

9.1 CHARACTERIZATION OF FAECAL SLUDGE FROM FSTPS AND STP CO-TREATMENT PLANT IN ODISHA

The FS samples collected from the discharge vehicle at the FSTPs in Odisha were analysed for several parameters, of which the important parameters are depicted below. The data provided in this study is the average value of the FS samples collected in three months—April, June and August 2024. The pH of FS ranges from 6.96 to 7.98. Both Total Solids (TS) and Total Suspended Solids (TSS) were found to be the highest in Balasore FSTP (119,633 mg/L and 119,572 mg/L, respectively) followed by Rourkela (70,399 mg/L and 69,269 mg/L, respectively) and Sambalpur (47,001 mg/L and 45,011 mg/L, respectively). The lowest was recorded in Jatni FSTP (1,713 mg/L and 573 mg/L, respectively). The Chemical Oxygen Demand (COD) of the faecal sludge varied widely and ranged from 1,595 mg/L in Paradeep FSTP to 87,600 mg/L in Rourkela FSTP.

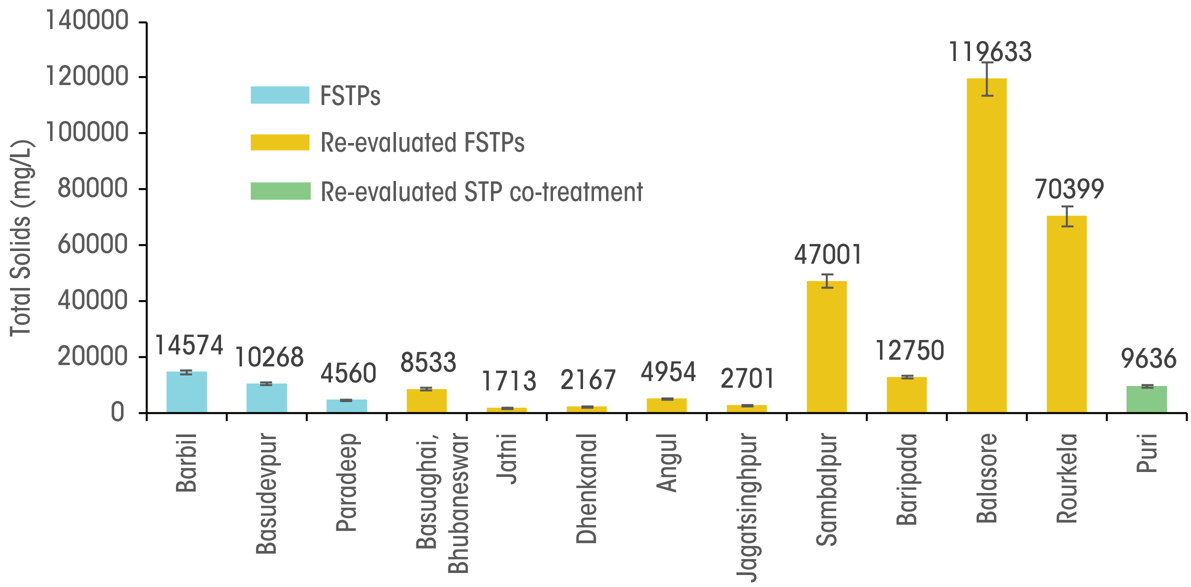
Higher COD in the range similar to Rourkela was also observed in Barbil (82,700 mg/L), Balasore (82,050 mg/L) and Baripada (79,950 mg/L). Biochemical Oxygen Demand (BOD) in the FS samples ranged from 227 mg/L in Paradeep FSTP to 10,210 mg/L in Barbil FSTP. Similar to COD, higher BOD was also observed in Rourkela, Balasore and Baripada FSTPs. The lowest COD and BOD was observed in Jagatsinghpur FSTP and Paradeep FSTP. The Total Kjeldahl Nitrogen (TKN) varied from 167 mg/L in Jagatsinghpur to 3,898 mg/L in Balasore FSTP. Faecal coliforms are in the range of 42,658 (=$\log_{10}$ 4.63) to 10,96,47,820 MPN/100 ml (=$\log_{10}$ 8.04) (see Graphs 1-7).

Graph 1: pH value of the FS



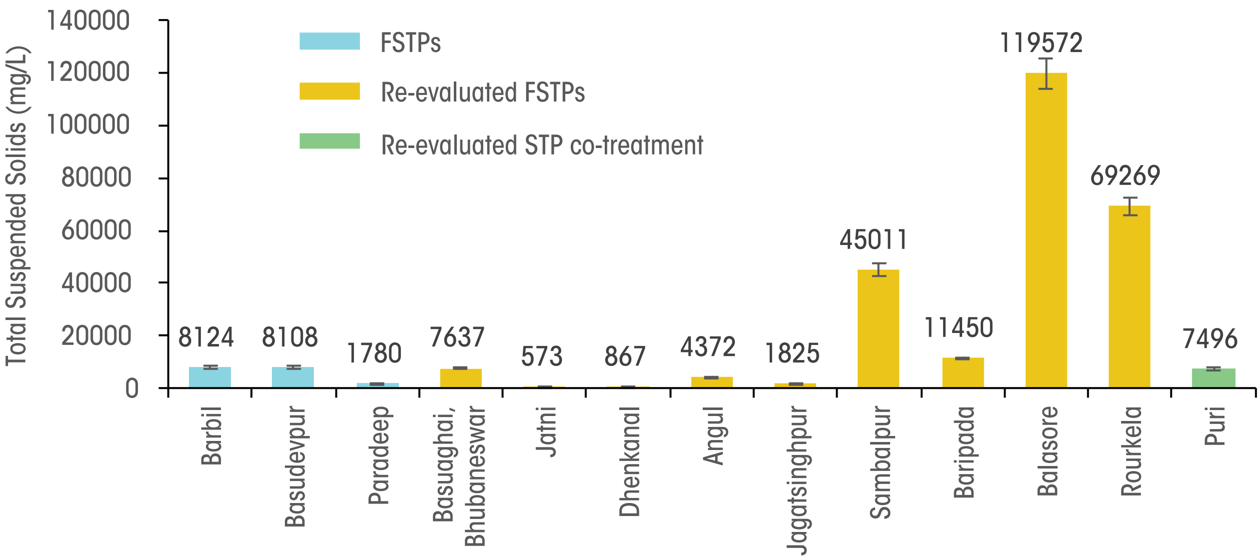
Source: CSE

Graph 2: Total Solids of the FS



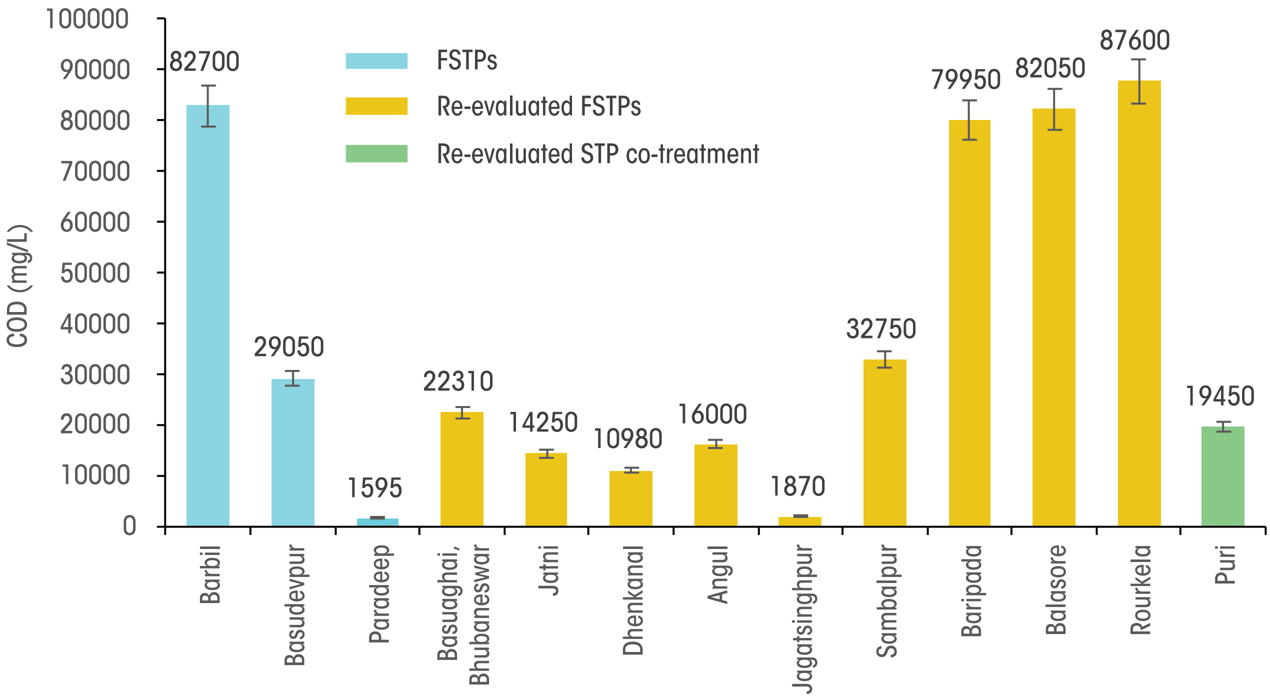
Source: CSE

Graph 3: Total Suspended Solids of the FS



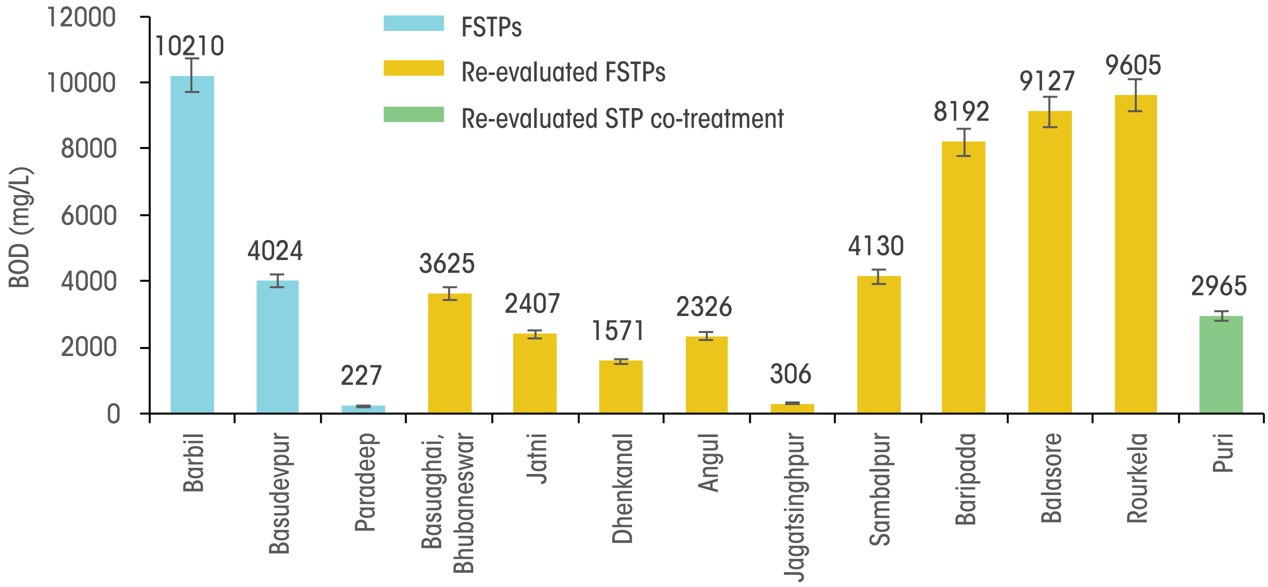
Source: CSE

Graph 4: Chemical Oxygen Demand (COD) of the FS



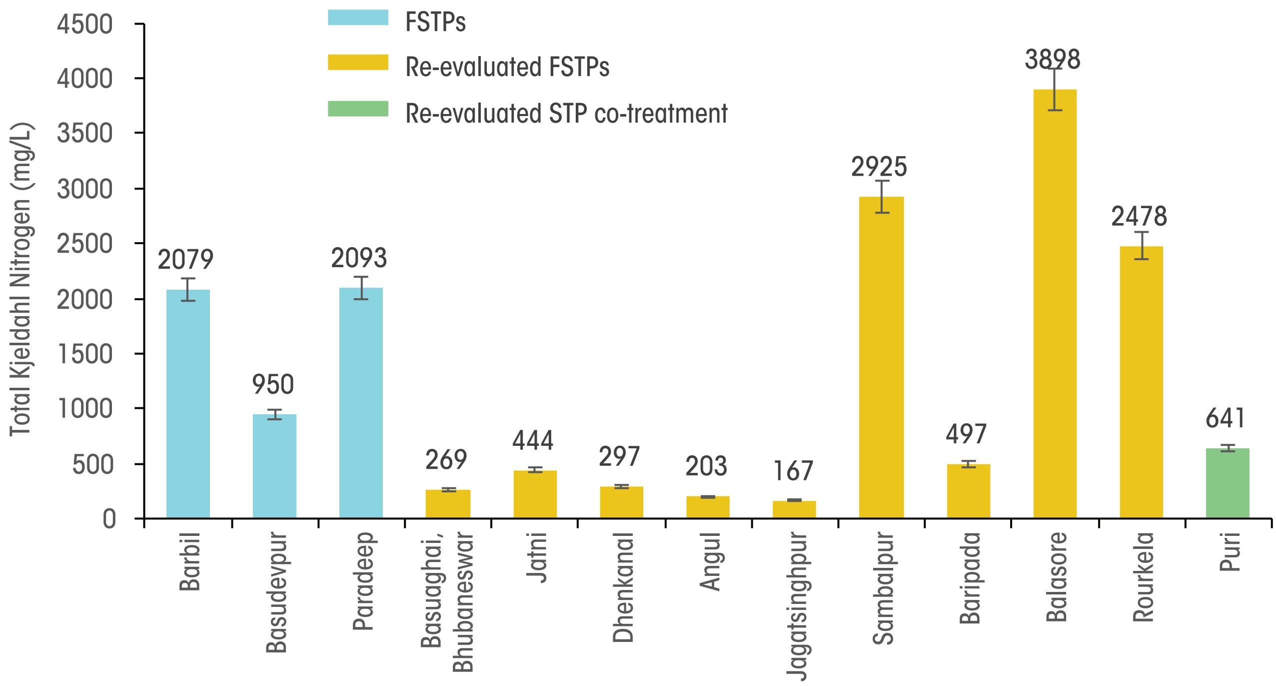
Source: CSE

Graph 5: Biochemical Oxygen Demand (BOD) of the FS



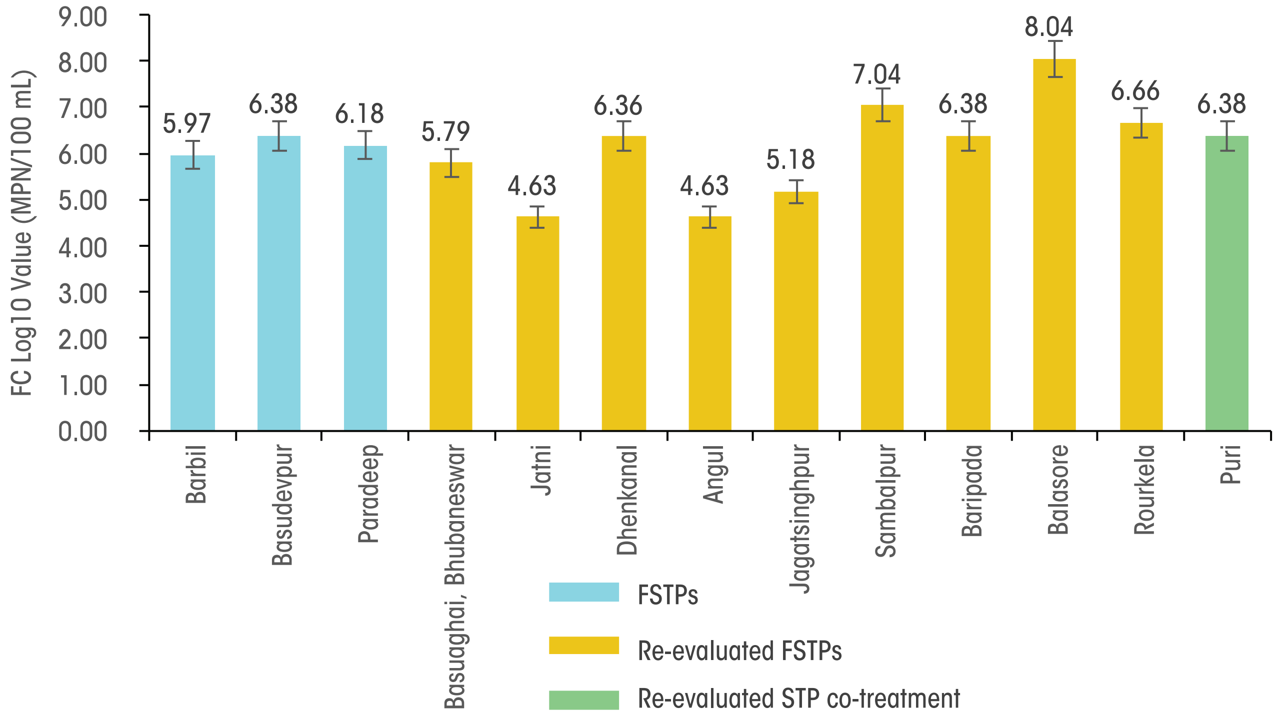
Source: CSE

Graph 6: Total Kjeldahl Nitrogen of the FS



Source: CSE

Graph 7: Faecal coliform (FC) content in the FS



Source: CSE

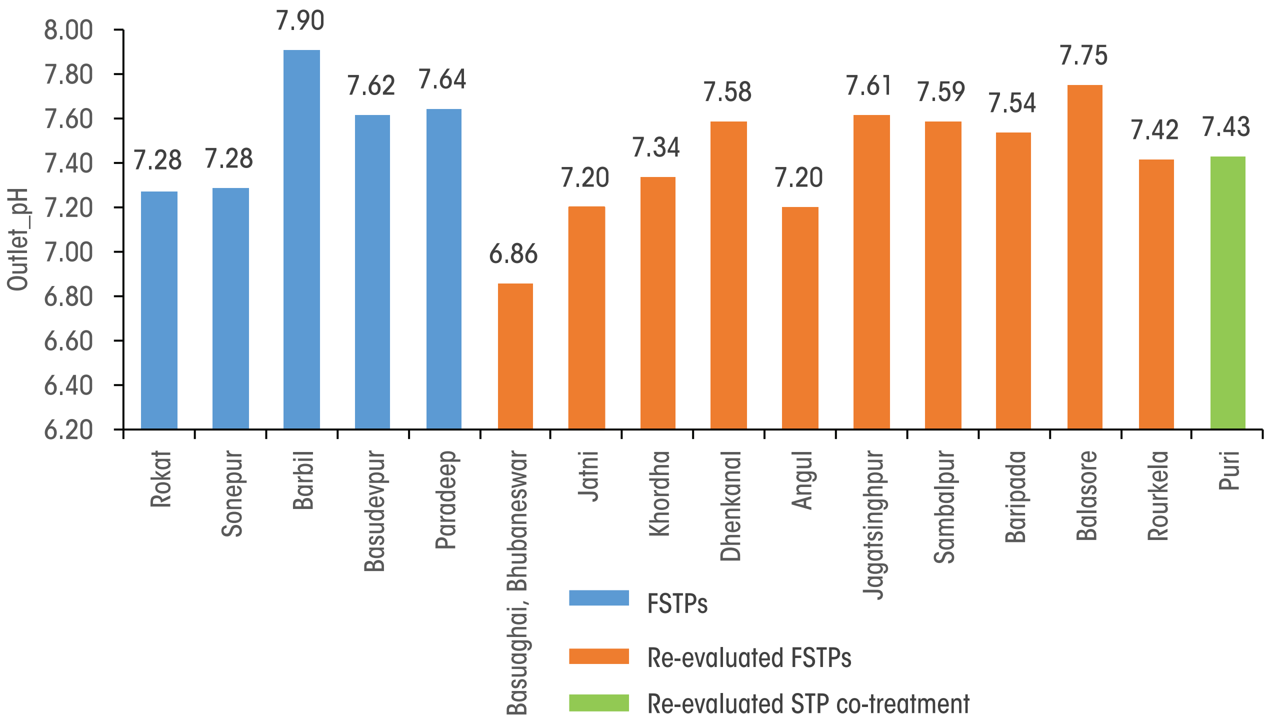
9.2 PERFORMANCE EVALUATION OF FSTPS AND STP CO-TREATMENT PLANT FOR EFFLUENT TREATMENT AND QUALITY

Ten different parameters were selected for the evaluation including pH, Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Kjeldahl Nitrogen (TKN), ammoniacal nitrogen (AN), total phosphate (TP) and faecal coliform (FC). Seven important parameters are represented here to evaluate the performance of FSTPs.

9.2.1 pH

The standard limit of the MoEF&CC for the pH of treated effluent discharged from STPs ranges at 6.5–9 while the NGT ranges at 5.5–9. In this study, the pH of the outlet water from treatment plants in Odisha ranged from 6.86 (Basuaghai) to 7.9 (Angul), which is within the standard limits of both the MoEF&CC and the NGT (see *Graph 8: pH in the outlet of treatment plants*).

Graph 8: pH in the outlet of treatment plants

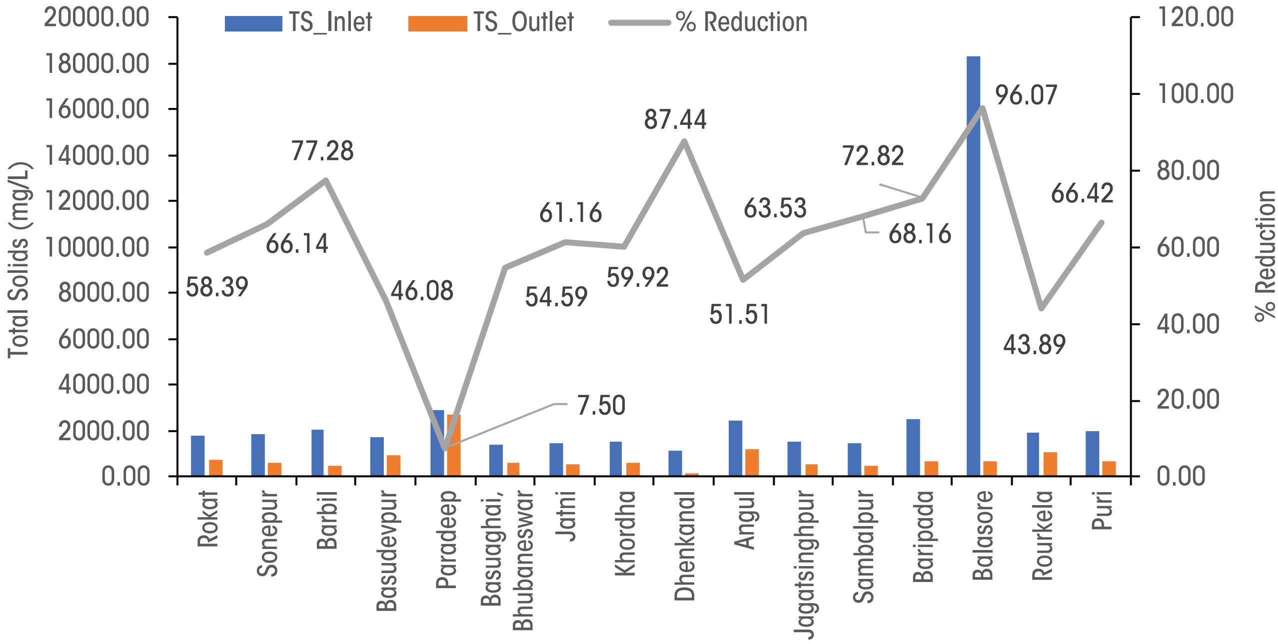


Source: CSE

9.2.2 Total Solids (TS)

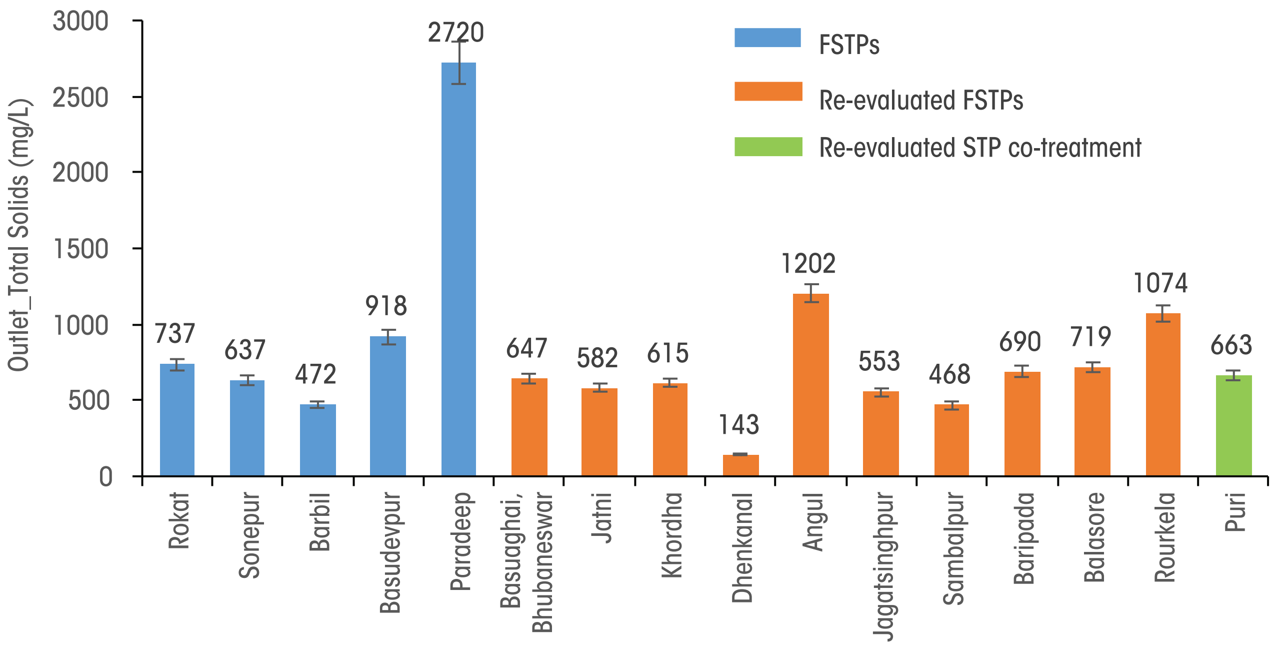
The inlet TS, outlet TS and the 'per cent removal' of TS from the treatment plants in Odisha are shown in *Graph 9: Total Solids in the inlet and outlet of FSTP and 'per cent removal' from inlet to outlet*. The inlet TS was found to be in the range of 1,136 mg/L (Dhenkanal) to 18,307 mg/L (Balasore) whereas in the outlet, TS ranged from 143 mg/L (Dhenkanal) to 2,720 mg/L (Paradeep). Paradeep was recorded with a higher TS which is more than twice as higher than the TS observed in other FSTPs like Angul and Rourkela which ranges at about 1,074–1,202 mg/L (see *Graph 10: Total Solids in the outlet of treatment plants*). The 'per cent removal' of TS varied from 7.5 per cent to 96.07 per cent across the treatment plants. The highest 'per cent removal' of TS was observed in Balasore FSTP whereas the lowest 'per cent removal' was observed in Paradeep FSTP. The lowest 'per cent removal' observed in Paradeep FSTP at 7.5 per cent also correlated with the higher TS observed in the outlet of the FSTP at 2,720 mg/L. The Puri STP co-treatment has an inlet and outlet TS of 1,974 mg/L and 663 mg/L, respectively with a 'per cent removal' at 66.42 per cent.

Graph 9: Total Solids in the inlet and outlet of FSTP and 'per cent removal' from inlet to outlet



Source: CSE

Graph 10: Total Solids in the outlet of treatment plants

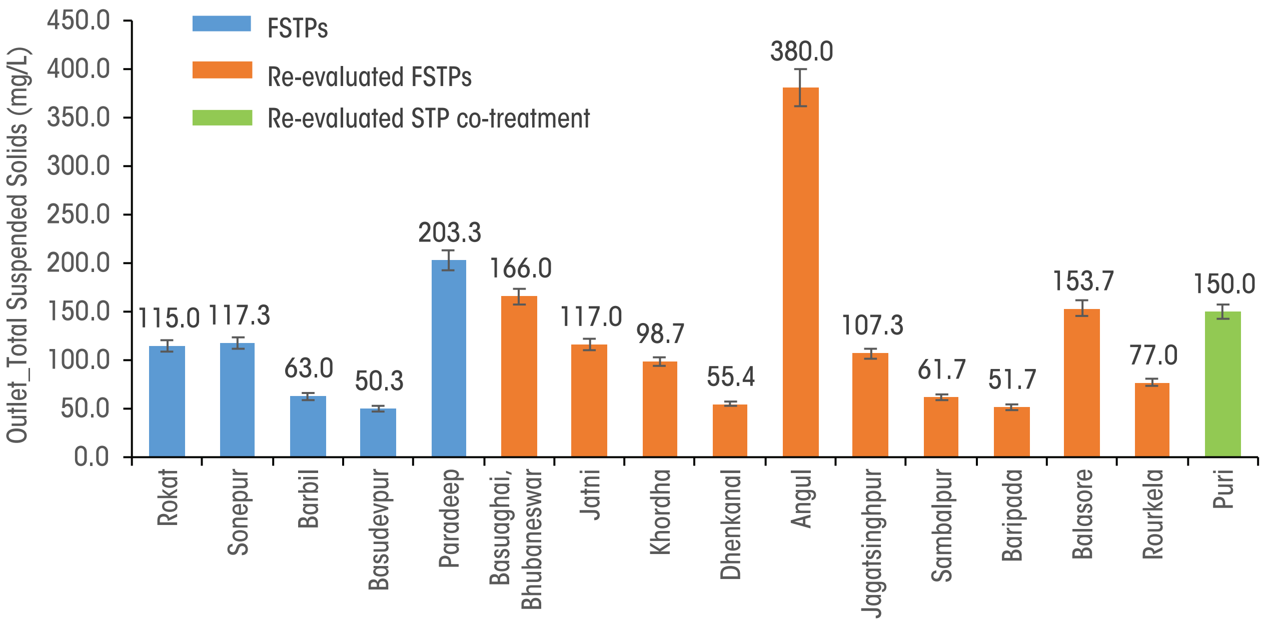


Source:CSE

9.2.3 Total Suspended Solids (TSS)

The TSS in the outlet of the evaluated treatment plants in Odisha is shown in *Graph 11: Total Suspended Solids (TSS) in the outlet of treatment plants*. The TSS in the outlet of FSTPs ranged from 50.3 mg/L (Basudevpur) to 380 mg/L (Angul). The Puri STP co-treatment plant has an outlet TSS of 150 mg/L. Two regulatory limits are set by the MoEF&CC for the TSS of treated effluent discharged from STPs in various cities/towns (see *Annexure 1 Table 1*). The MoEF&CC limits are set at 50 mg/L for metro cities and other cities with over 10 lakh population (referred to as 'Category 1 cities/towns'), and 100 mg/L for other cities with a population below 10 lakh (referred to as 'Category 2 cities/towns'). With the exception of Basuaghai, which is a locality in Bhubaneswar, all the other treatment plant locations evaluated fall under the MoEF&CC's 'Category 2 cities/towns'; hence the plants were compared with the MoEF&CC limits accordingly. Only seven out of the 15 treatment plants ('Category 2 cities/towns') showed an outlet TSS within the MoEF&CC limit of 100 mg/L. Basuaghai, which falls under the MoEF&CC 'Category 1 cities/towns', showed TSS of 166 mg/L. This is above the MoEF&CC limit of 50 mg/L. The higher TSS observed in nine out of the 16 FSTPs and STP indicates the inefficient removal of TSS by the treatment plants. The regulatory limit given by the NGT for TSS of the treated effluent discharged from STPs is 20 mg/L (see *Annexure 1 Table 1*). However, none of the treatment plants had a TSS below the 20 mg/L limit set by the NGT.

Graph 11: Total Suspended Solids (TSS) in the outlet of treatment plants



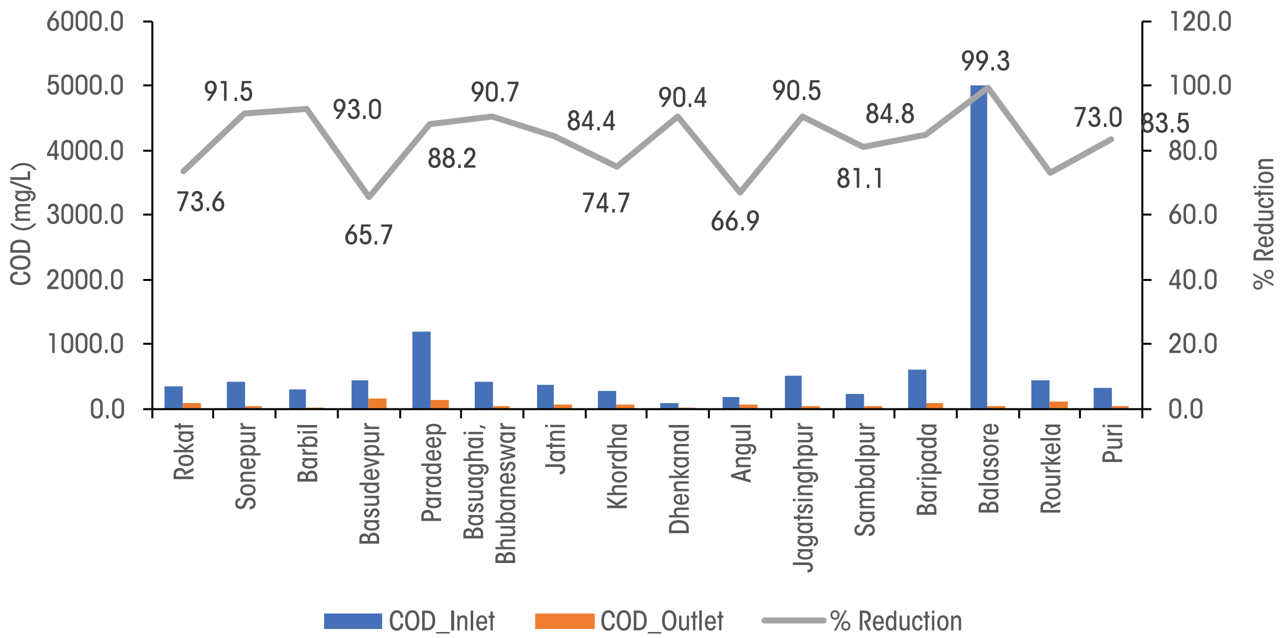
Source: CSE

9.2.4 Chemical Oxygen Demand (COD)

The inlet COD, outlet COD and 'per cent removal' of COD from treatment plants in Odisha are shown in *Graph 12: Inlet COD, outlet COD and 'per cent removal' of COD of the treatment plants*. COD in the inlet of FSTPs ranged from 93.7 mg/L (Dhenkanal) to 5,006.7 mg/L (Balasore) whereas in the outlet, COD ranged from 9.0 mg/L (Dhenkanal) to 153.3 mg/L (Basudevpur). Balasore was recorded with a considerably higher inlet COD which is >4–53 times higher than other treatment plants. The 'per cent removal' of COD varied from 65.7–99.3 per cent across the treatment plants. The highest 'per cent removal' of COD was observed in Balasore FSTP whereas the lowest 'per cent removal' was observed in Basudevpur FSTP. The Puri STP co-treatment plant has an inlet and outlet COD of 322.67 mg/L and 53.33 mg/L, respectively with a 'per cent' removal of COD at 83.5 per cent.

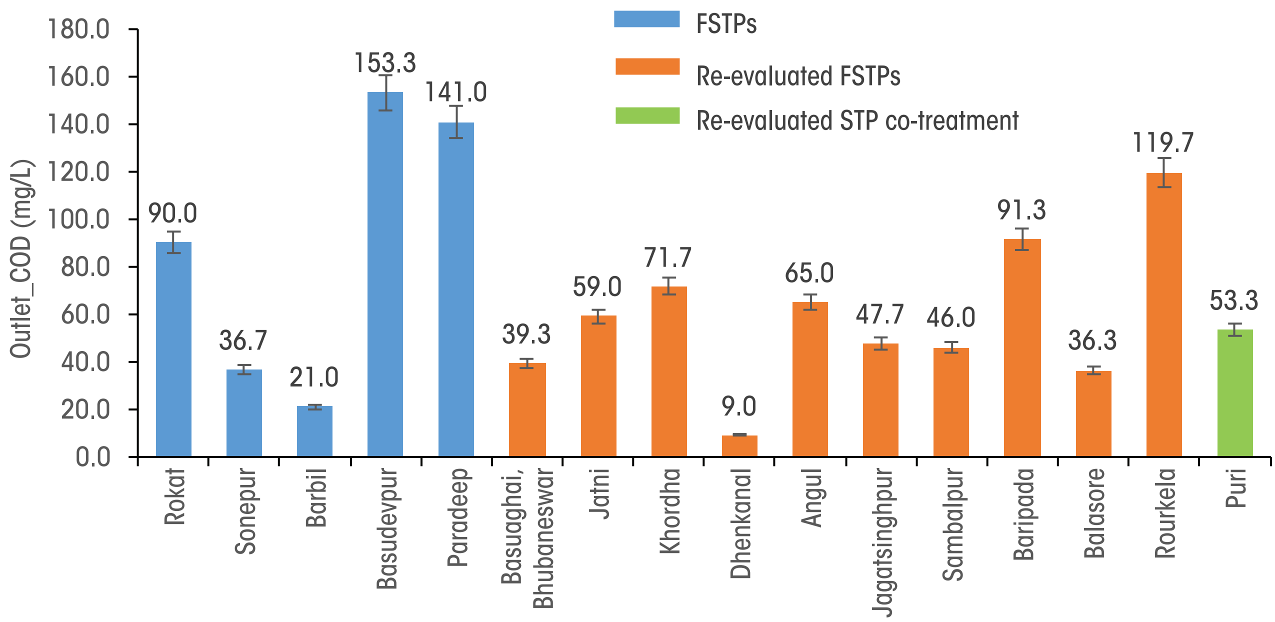
No regulatory limit was given by the MoEF&CC for COD of the treated effluent discharged from STPs. However, a regulatory limit of 50 mg/L for COD of the treated effluent discharged from STPs is given by the NGT (see *Annexure 1 Table 1*). Only seven out of 16 plants remained compliant when compared with the NGT standard of 50 mg/L (see *Graph 13: COD in the outlet water (effluent) of treatment plants*).

Graph 12: Inlet COD, outlet COD and 'per cent removal' of COD of treatment plants



Source: CSE

Graph 13: COD in the outlet water (effluent) of treatment plants



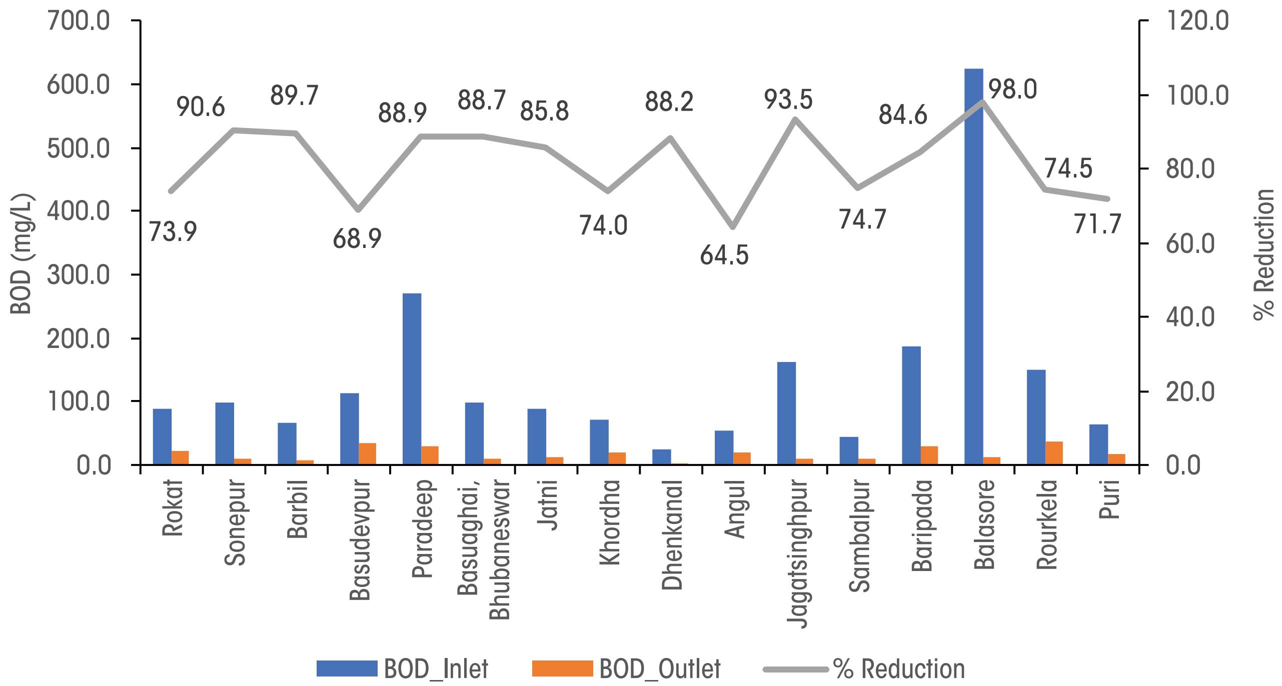
Source: CSE

9.2.5 Biochemical Oxygen Demand (BOD)

The inlet BOD, outlet BOD and 'per cent removal' of BOD from the treatment plants in Odisha are shown in *Graph 14: Inlet BOD, outlet BOD and 'per cent removal' of BOD from the FSTPs*. BOD in the inlet of FSTPs ranged from 25.9 mg/L (Dhenkanal) to 624.1 mg/L (Balasore) whereas in the outlet, BOD ranged from 3.1 mg/L (Dhenkanal) to 38.1 mg/L (Rourkela). Balasore was recorded with a considerably higher inlet BOD which is >2–24 times higher than other treatment plants. The 'per cent removal' of BOD was over 60 per cent and varied from 64.5 per cent to 98 per cent across the treatment plants. The highest 'per cent removal' of BOD was observed in Balasore FSTP whereas the lowest was observed in Angul FSTP. The Puri STP co-treatment plant has an inlet and outlet BOD of 63.1 mg/L and 17.8 mg/L, respectively with a 'per cent removal' of BOD at 71.7 per cent.

Two regulatory limits are given by the MoEF&CC for BOD of the treated effluent discharged from STPs of various cities/towns (see *Annexure 1 Table 1*). The MoEF&CC limits are set at 20 mg/L for metro cities and other cities with over 10 lakh population (Category 1), and 30 mg/L for other cities with population below 10 lakh (Category 2). Except Basuaghai, all the other treatment plant locations evaluated fall under the 'Category 2'; the plants were compared with the MoEF&CC limits accordingly. A total of 13 out of 15 treatment plants (of Category 2) showed an outlet BOD of ≤ 30 mg/L which is within the MoEF&CC standard limit indicating adequate performance of the treatment plants. Only Basudevpur and Rourkela FSTP outlet had a BOD of >30 mg/L but, BOD was <40 mg/L in these locations. Basuaghai FSTP (Category 1) outlet showed a BOD of 11.1 mg/L which is below

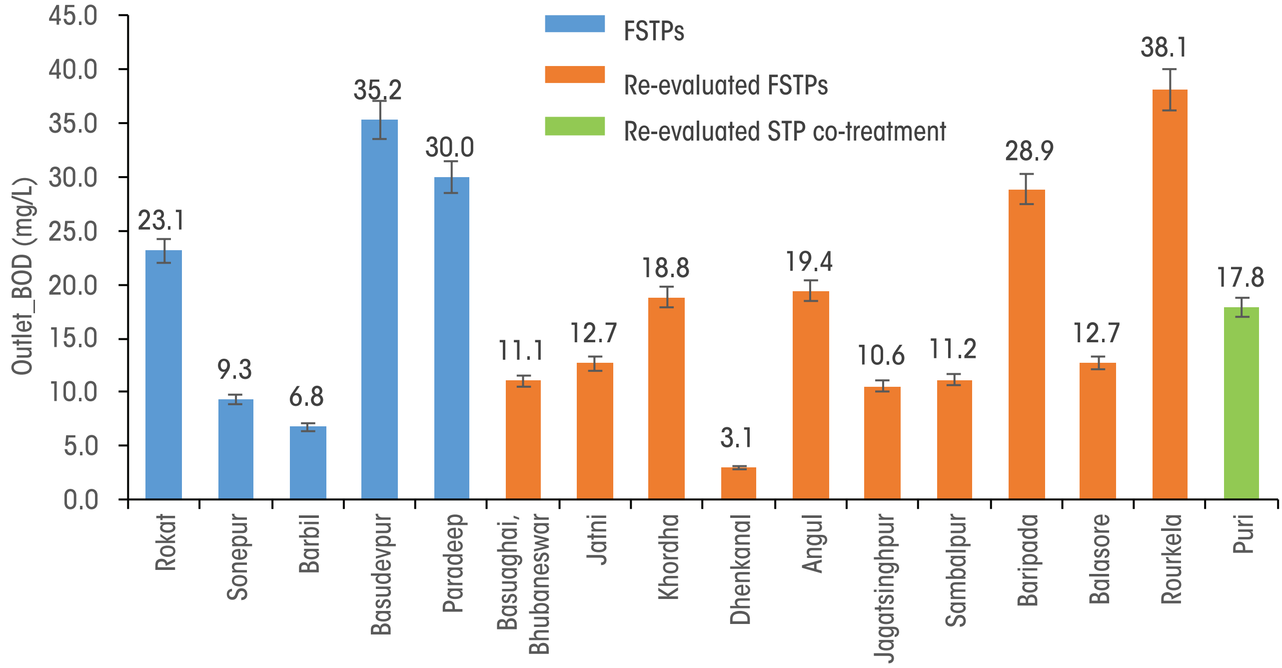
Graph 14: Inlet BOD, outlet BOD and 'per cent removal' of BOD from the FSTPs



Source: CSE

the 20 mg/L limit set by the MoEF&CC indicating better performance (see *Graph 15: BOD of outlet water from the FSTPs*). The regulatory limit set by the NGT for BOD of the treated effluent discharged from STPs is 10 mg/L (see *Annexure 1 Table 1*). Only three plants—Sonepur, Barbil and Dhenkanal—out of the 16 treatment plants had a BOD below the 10 mg/L standard given by the NGT (see *Graph 15: BOD of outlet water from the FSTPs*).

Graph 15: BOD of outlet water from the FSTPs

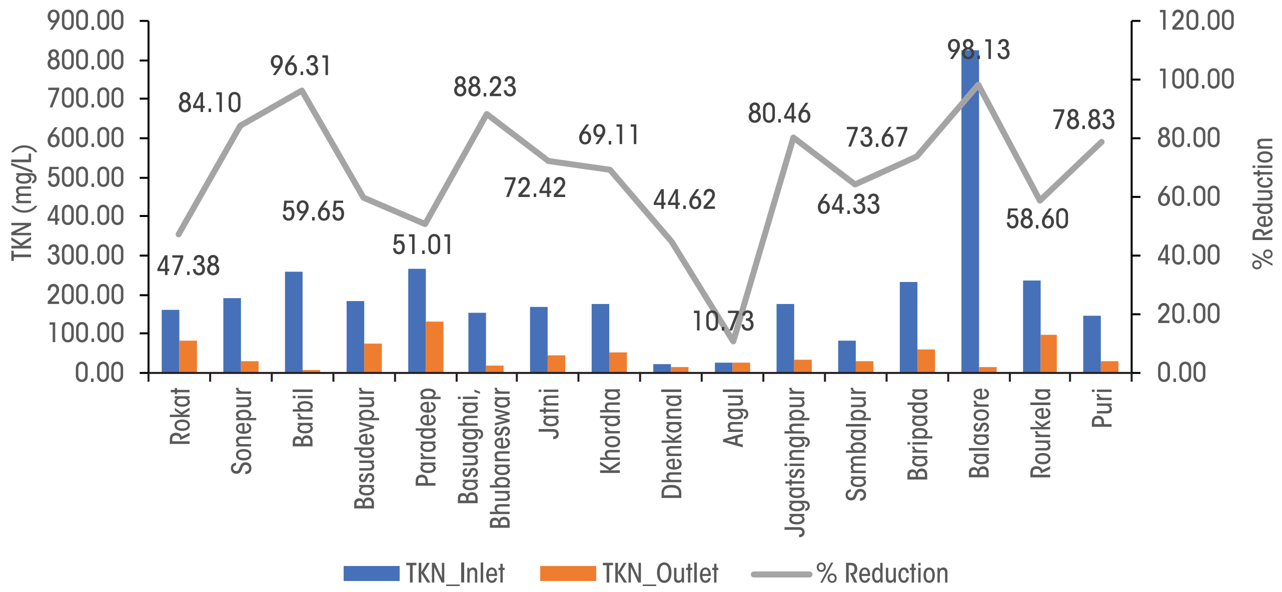


Source: CSE

9.2.6 Total Kjeldahl Nitrogen (TKN)

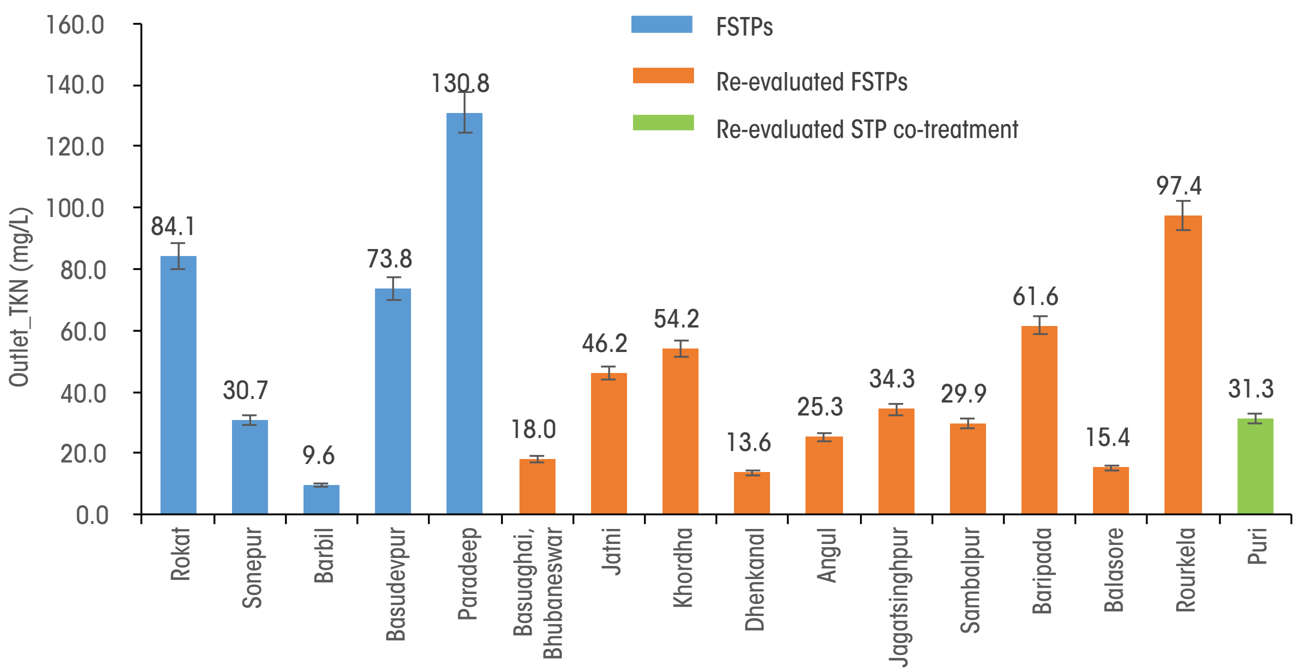
The inlet and outlet TKN and 'per cent removal' of TKN from the treatment plants in Odisha are shown in *Graph 16: Inlet and outlet TKN and 'per cent removal' of TKN from the FSTPs*. TKN in the inlet of FSTPs ranged from 24.6 mg/L (Dhenkanal) to 824.87 mg/L (Balasore) whereas in the outlet, TKN ranged from 9.6 mg/L (Barbil) to 130.8 mg/L (Paradeep). Balasore was recorded with a considerably higher inlet TKN which is >3–33 times higher than other treatment plants. 'Per cent removal' of TKN varied from 10.73–98.13 per cent across the treatment plants with the highest 'per cent removal' of TKN observed in Balasore FSTP and the lowest in Angul FSTP. The Puri STP co-treatment plant has an inlet and outlet TKN of 147.69 mg/L and 31.3 mg/L, respectively with a 'per cent removal' of TKN at 78.83 per cent. A total of 13 out of the 16 treatment plants evaluated showed the 'per cent removal' of TKN at over 50 per cent. Lowest outlet TKN was observed in Barbil FSTP (9.6 mg/L) followed by Dhenkanal (13.6 mg/L) and Balasore (15.4 mg/L) FSTPs (see *Graph 17: Total Kjeldahl Nitrogen (TKN) of outlet water from the FSTPs*).

Graph 16: Inlet and outlet TKN and 'per cent removal' of TKN from the FSTPs



Source: CSE

Graph 17: Total Kjeldahl Nitrogen (TKN) of outlet water from the FSTPs



Source: CSE

9.2.7 Faecal coliform (FC)

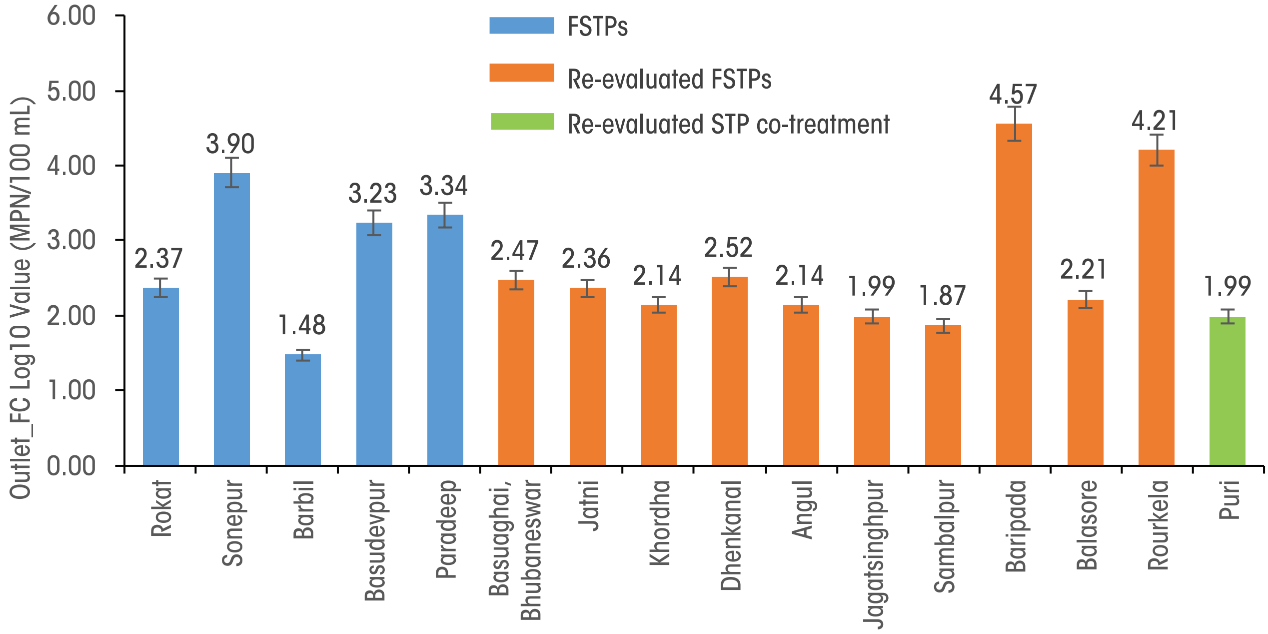
The faecal coliform (FC) content in the outlet of treatment plants in Odisha is shown in *Graph 18: Faecal coliforms (FC) in the outlet water from the FSTPs*. As the microbial populations (FC, *E. coli* etc.) show several-fold variations in their numbers across the samples (30 to >35,000 MPN/100 mL of FC in the outlet in this study), their estimates which are expressed in Most Probable Numbers (MPN) or colony forming units (CFU) are represented in logarithmic ($\log_{10}$) values (see *Graph 18: Faecal coliforms (FC) in the outlet water from the FSTPs)*. This representation of MPN/CFU in logarithmic ($\log_{10}$) values is followed throughout the report for the indicator/pathogenic micro-organisms (FC, *E. coli* and *Salmonella*) to get better visualization of the results.

The regulatory limit given by the Ministry of Environment, Forest & Climate Change (MoEF&CC) for FC in the treated effluent discharged from STPs is 1,000 MPN/100 mL ($\log_{10} 1000 = 3$) for both the MoEF&CC categories of cities/towns—Category 1 with cities with over 10 lakh population, and Category 2 with cities below 10 lakh population (see *Annexure 1 Table 1*). FC in the outlet of FSTPs ranged from 30 MPN/100 mL ($\log_{10} 30 = 1.48$) in Barbil to 36,820 MPN/100 mL ($\log_{10} 36820 = 4.57$) in Baripada. The Puri STP co-treatment plant has an outlet FC of 97 MPN/100 mL ($\log_{10} 97 = 1.99$).

In all the FSTPs evaluated in this study, tertiary treatment through UV radiation, which is one of the disinfection methods to effectively kill the pathogens in the outlet water, is available only in two FSTPs—Dhenkanal and Angul. The Puri STP co-treatment uses chlorination to disinfect the outlet water. These three treatment plants, which use disinfection for pathogen reduction in outlet water, showed FC within the MoEF&CC limit indicating effective functioning of the disinfection methods. The rest of the 13 FSTPs do not contain a disinfection method and only have a polishing pond which functions on solar radiation for pathogen reduction as the final stage of treatment. In spite of the absence of physical/chemical disinfection methods to effectively kill pathogens in the outlet water, eight out of these 13 FSTPs showed FC within the MoEF&CC limit. This indicates that outlet water in the polishing pond of these eight FSTPs is being subjected to solar radiation for adequate time period that has effectively reduced pathogen content to safer levels. This also indicates that solar radiation is indeed effective in reducing pathogen content to safer levels if adequate exposure time is provided. It is recommended that the five FSTPs in Sonepur, Basudevpur, Paradeep, Baripada and Rourkela, which showed FC levels above the MoEF&CC limit (>1,000 MPN/100 mL) can install one of the disinfection methods like UV or chlorination to reduce FC below the limit in the outlet water. This is particularly recommended for Baripada and Rourkela with a much higher FC of 36,820 MPN/100 mL ($\log_{10} 36820 = 4.57$) and 16,227 MPN/100 mL ($\log_{10} 16227 = 4.21$), respectively.

Two regulatory limits are set by the NGT for FC in the treated effluent discharged from STPs. It limits about 100 MPN/100 mL as the desirable limit whereas 230 MPN/100 mL as the permissible limit. When compared to these two NGT standards, only four out of eight plants complied with the desirable and permissible limits respectively. The Puri STP co-treatment complied with both the NGT standards (see *Graph 18: Faecal coliforms (FC) in the outlet water from the FSTPs*).

Graph 18: Faecal coliforms (FC) in the outlet water from the FSTPs



Source: CSE

The compliance and non-compliance of the effluent of the treatment plants with MoEF&CC and NGT regulatory standards for the parameters pH, TSS, COD, BOD and FC are provided in *Annexure 2 Table 1*.

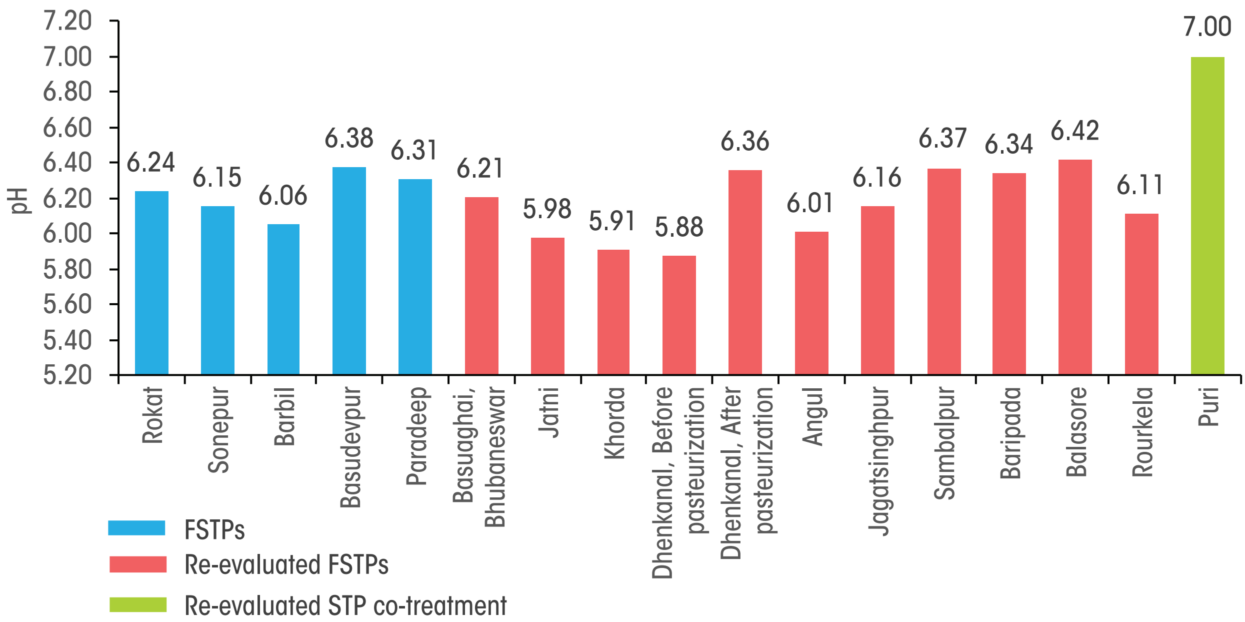
9.3 EVALUATION OF BIOSOLIDS QUALITY FROM FSTPS AND STP CO-TREATMENT PLANT IN ODISHA

Organic manure, a rich source of nutrients, is used in agricultural fields to improve crop yield. However, the physical properties and chemical composition of organic manure must be maintained at optimum levels to prevent the adverse effects on soil, plants and environment. The Fertilizer Control Order (FCO) 2023 provides specifications to monitor the quality of various kinds of fertilizers. To evaluate the reuse potential of biosolids from the treatment plants in Odisha for agricultural purposes, samples were tested for all the parameters set by the FCO 2023. Hence, the results obtained for biosolids were compared with the respective standards given for organic manure in FCO 2023. The parameters and their specifications given in FCO 2023 for organic manure are provided in *Annexure 1 Table 2*.

9.3.1 pH

The pH of the biosolids samples collected from the treatment plants in Odisha is shown in *Graph 19: pH of the biosolids from FSTPs and co-treatment plant*. The standard for pH of the organic manure in FCO 2023 is at 6.0–8.5. In this study, the pH of the biosolids collected from the treatment plants was between 5.88 and 7.0, which is slightly acidic to neutral. Only three FSTPs—Jatni, Khordha and Dhenkanal—had a pH slightly below the

Graph 19: pH of the biosolids from FSTPs and co-treatment plant



Source: CSE

FCO limit, and the rest are within the limit. The pH of biosolids from all the 15 FSTPs was slightly acidic (5.88–6.42), whereas the pH of Puri STP co-treatment was recorded to be neutral at 7.0. No plant had pH in the basic range.

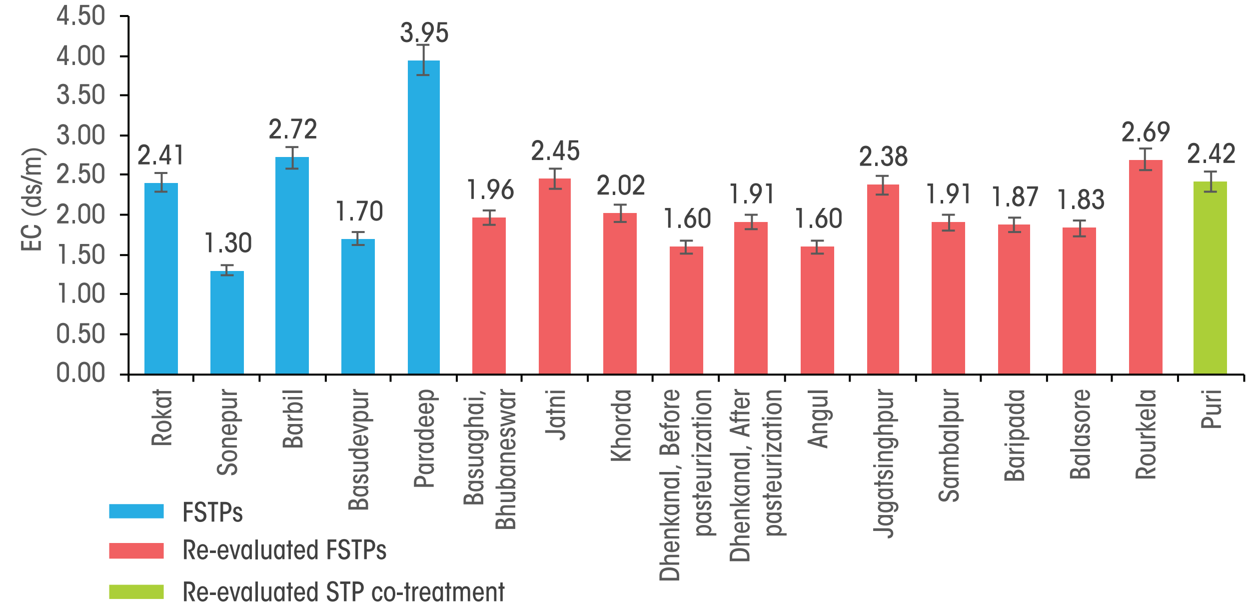
9.3.2 Electrical conductivity (EC)

The electrical conductivity (EC) of the biosolids samples collected from the treatment plants in Odisha is shown in *Graph 20: Electrical conductivity of the biosolids from FSTPs and co-treatment plant*. No standard is given for EC of the organic manure in FCO 2023. However, the FCO has set a standard of ≤6.0 for city compost. We have followed that standard for this study. The EC of the biosolids collected from the treatment plants was between 1.3 ds/m and 3.95 ds/m. The highest EC was recorded in Paradeep FSTP which is slightly higher than all other plants. EC in biosolids samples of all the treatment plants is well below the city compost standard set by the FCO 2023.

9.3.3 Moisture content

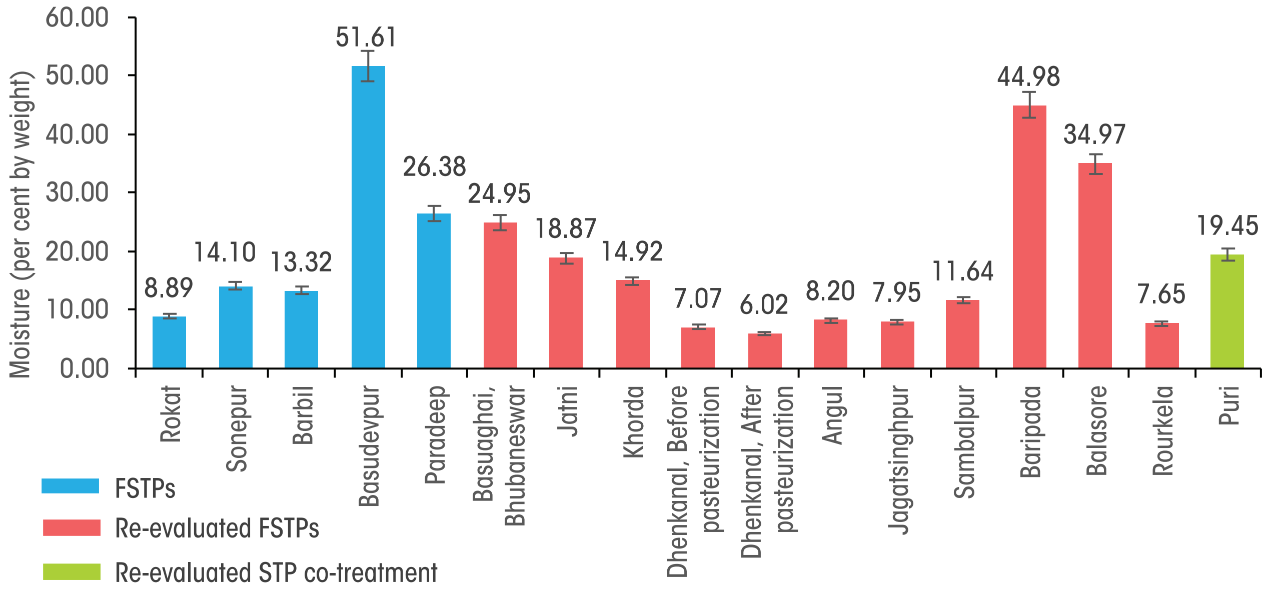
The moisture content of biosolids is an important parameter as it not only affects microbial growth but also acts as a medium for nutrient availability to plants and microbes. The moisture content of biosolids samples collected from the treatment plants in Odisha is shown in *Graph 21: Moisture content in biosolids from FSTPs and co-treatment plant*. The standard for moisture content of the organic manure in FCO 2023 is set at under 25 per cent by weight. In this study, the moisture content of biosolids from the treatment plants varied from 6.02 per cent (in Dhenkanal FTSP biosolids after pasteurization) to 51.61 per cent (in Basudevpur). Only four out of the 16 plants exceeded the FCO limit of

Graph 20: Electrical conductivity of the biosolids from FSTPs and co-treatment plant



Source: CSE

Graph 21: Moisture content in biosolids from FSTPs and co-treatment plants



Source: CSE

25 per cent. Of these, Basudevpur and Baripada FSTPs showed a slightly higher moisture content at 44.98–51.61 per cent. Hence, it is recommended that proper sun drying for a sufficient period of time along with regular turning of the biosolids is done in these plants to reduce moisture content.

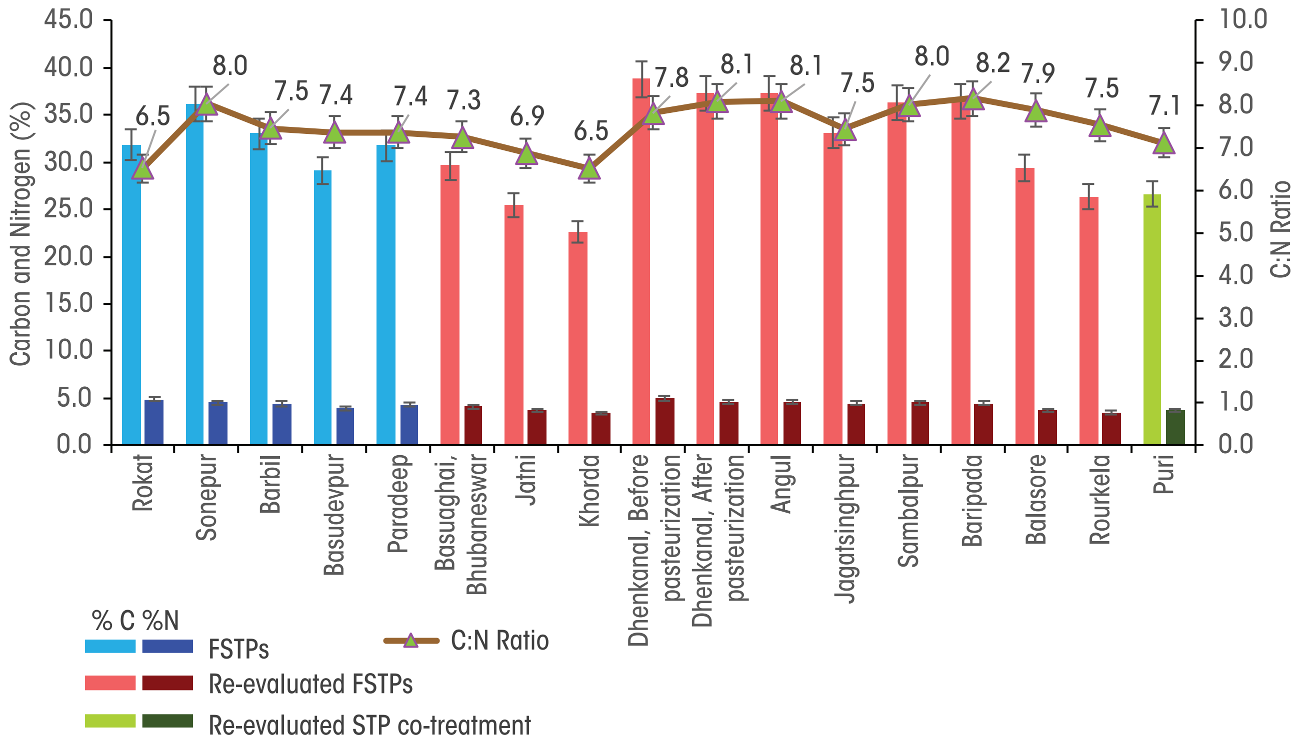
In Dhenkanal FSTP, a pasteurization unit is available for drying and disinfection of biosolids whereas in Angul FSTP, there are greenhouse sludge drying beds to enhance the solar drying of biosolids. As expected, both Dhenkanal and Angul FSTPs were recorded with lower moisture content at 6.02–8.20 per cent in their biosolids (see *Graph 21: Moisture content of biosolids from FSTPs and co-treatment plant*). In the rest of the FSTPs, biosolids are just sun dried. Lower moisture content was observed in most of the samples from the treatment plants that use sun drying for drying the biosolids. Therefore, adequate sun drying and good drying practices like regular turning of the biosolids will accomplish proper drying throughout the samples, and these measures have been practiced in the treatment plants.

9.3.4 Carbon and nitrogen content and Carbon-to-Nitrogen (C:N) ratio

The organic matter (carbon content) of biosolids is an important parameter that must be considered when applied to soil for agricultural purposes. Organic content influences the diversity of soil biota and can affect crop yield. The carbon, nitrogen and Carbon–to–Nitrogen ratio (C:N ratio) of the biosolids samples collected from the treatment plants in Odisha is shown in *Graph 22: Carbon (C), nitrogen (N) and C:N ratio of biosolids from FSTPs and STP co-treatment plant*. The standard given for total organic carbon content of the organic manure in FCO 2023 is ≥ 14 per cent by weight, whereas for total nitrogen (as N), the standard is ≥ 0.5 per cent by weight. In this study, the total carbon content of the biosolids from the treatment plants varied from 22.6 per cent (in Khordha) to 38.8 per cent (in Dhenkanal biosolids before pasteurization). This complies with the recommended standard set by FCO 2023 in all the plants. The total nitrogen content of the biosolids varied from 3.5 per cent (in Khordha and Rourkela) to 5.0 per cent (in Dhenkanal biosolids before pasteurization). Thus, this complies with the recommended standard set by FCO 2023 in all the plants.

However, when the carbon (C) and nitrogen (N) content of soil is considered, the proportion of carbon and nitrogen to each other, the C:N ratio, is more important than individual carbon and nitrogen contents as a balanced C:N ratio (15:1 to 20:1) is essential to provide optimal nutrient (C, N) availability to both plants and soil microbes. This is because a higher C:N ratio of >20 reduces nitrogen utilization by plants by promoting nitrogen immobilization, whereas a low C:N ratio indicates higher mineralization of nitrogen for plant uptake, which results in the loss of nitrogen. Hence, an equilibrium is required between mineralization and immobilization for proper utilization of carbon and nitrogen by plants and microbes—by maintaining the C:N ratio between 15:1 and 20:1.[14] The standard set for C:N ratio of the organic manure in FCO 2023 is <20. In this study, the C:N ratio of the biosolids from the treatment plants ranged from 7.1–9.2 (see *Graph 22: Carbon (C), nitrogen (N) and C:N ratio of biosolids from FSTPs and STP co-treatment plant*). Even though the C:N ratio has been maintained as per the standards set the FCO

Graph 22: Carbon (C), nitrogen (N) and C:N ratio of biosolids from FSTPs and STP co-treatment plant



Source: CSE

in all the treatment plants, it is recommended that a C:N ratio of 15:1 to 20:1 be followed to provide optimal growth of the plants. This can be done by increasing the carbon content in biosolids by co-composting them with materials which are high in carbon such as dry leaves, saw dust etc.

9.3.5 Heavy metals

Faecal sludge (FS) can contain various heavy metals that get accumulated in biosolids. Biosolids, when used for agricultural purposes, can transfer these heavy metals to soil and contaminate the groundwater. Exposure to high levels of heavy metals can be harmful to humans and environmental health. The FCO 2023 has provided specifications for certain heavy metals such as arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc in the organic manure, which in higher quantities can be a public health concern. The concentrations of these heavy metals are evaluated in biosolids from the treatment plants in Odisha (see *Table 4: Heavy metal content in biosolids collected from Odisha FSTPs and STP co-treatment plant*). The standards set by the FCO for each heavy metal are also provided in *Table 4*.

Table 4: Heavy metals content in biosolids collected from Odisha FSTPs and STP co-treatment plant

	Location	Arsenic (mg/kg) max. 10.001	Hg (mg/kg) max. 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1000	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50
1	Rokat	1.84	3.28	1.71	57.45	52.30	1135.00	320.00	45.70
2	Sonepur	1.02	4.96	2.01	54.40	34.30	1396.67	354.00	42.63
3	Barbil	1.13	3.86	3.51	38.43	37.83	1580.00	468.67	40.37
4	Basudevpur	0.32	1.18	1.31	21.57	9.82	661.00	156.33	17.30
5	Paradeep	1.27	1.48	2.03	28.21	16.43	1141.67	255.00	35.70
6	Basuaghai, Bhubaneswar	0.91	3.19	2.02	52.47	41.37	1167.00	298.00	36.97
7	Jatni	1.63	3.81	19.24	130.83	255.07	936.00	337.00	46.13
8	Khorda	0.87	2.72	1.78	71.80	33.63	1052.67	273.00	42.63
9	Dhenkanal, Before pasteurization	0.81	1.73	17.18	48.95	33.55	1289.50	399.50	42.05
10	Dhenkanal, After pasteurization	0.71	3.52	12.13	48.83	29.87	1425.67	395.33	42.97
11	Angul	0.70	2.87	2.35	41.90	79.87	1247.67	289.00	33.40
12	Jagatsinghpur	0.67	2.42	2.35	59.47	50.37	1290.00	356.33	41.63
13	Sambalpur	1.36	4.15	1.90	47.00	40.23	1526.67	323.00	38.30
14	Baripada	0.86	3.57	1.77	48.33	24.73	1184.33	273.00	41.13
15	Balasore	0.69	5.96	3.28	44.57	21.30	965.67	272.67	37.43
16	Rourkela	0.96	3.64	1.25	39.37	27.93	1023.67	218.63	27.90
17	Puri	1.62	5.05	5.21	54.73	58.50	1503.33	581.67	43.50

Source: CSE

In this study, heavy metals like arsenic (<2 mg/kg) and nickel (17.3–46.13 mg/kg) in biosolids were found to be within the FCO limit from all the treatment plants. Lead was well below the FCO limit in almost all the biosolids samples except in Jatni FSTP where lead content is higher at 255.07 mg/kg as compared to the standard limit of 100 mg/kg. Cadmium is above the limit in three locations—Jatni, Dhenkanal and Puri. Chromium is above the limit in seven locations with the highest in Jatni at 130.83 mg/kg as compared to the standard limit of 50 mg/kg. Copper is above the FCO limit in 50 per cent (eight plants) of the treatment plants, with the highest recorded in the Puri STP co-treatment plant at 581.67 mg/kg, followed by Barbil FSTP at 468.67 mg/kg, as compared to the standard limit of 300 mg/kg. The highest non-compliant heavy metals are mercury and zinc. Mercury exceeded the FCO limit of 0.15 mg/kg in all the 16 plants evaluated while zinc exceeded the limit of 1,000 mg/kg in 13 plants. The highest mercury content (>5 mg/

kg) was recorded in Balasore followed by Puri STP co-treatment plant, while the highest zinc content (>1,500 mg/kg) was found in Barbil followed by Sambalpur and Puri.

9.3.6 Faecal coliform and E. coli

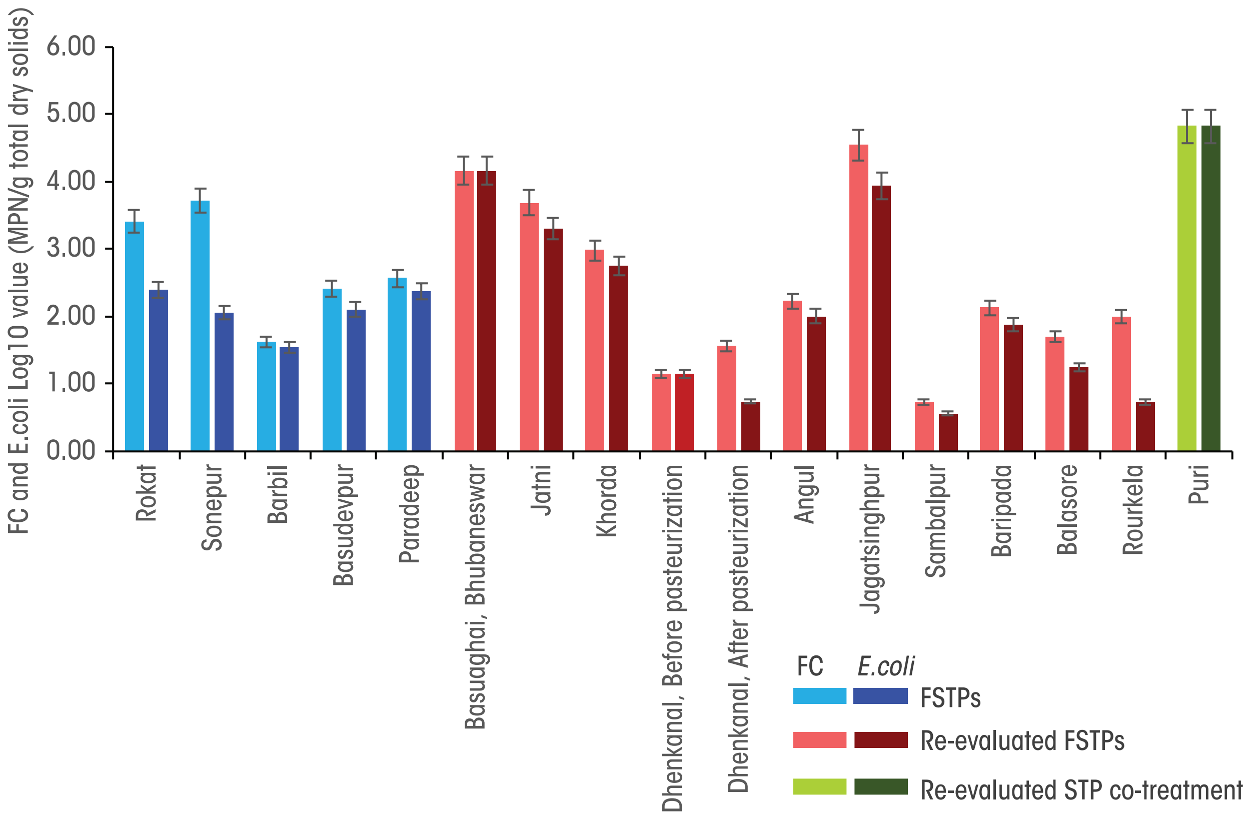
The faecal coliform (FC) and *E. coli*, which are used as a proxy indicator to assess the pathogen content in the biosolids samples collected from the treatment plants in Odisha are shown in *Graph 23: Faecal coliform (FC) and E. coli in the biosolids from FSTPs and STP co-treatment plant*. The regulatory limit given for pathogen content of the organic manure in the FCO 2023 is 'nil'. No biosolids sample from the evaluated treatment plants is free from FC and *E. coli*. The presence and extent of these indicator organisms in the biosolids samples and their suitability for agricultural purposes, are compared with the respective limits set by the USEPA and the WHO (2006). The USEPA (class A biosolids) and WHO (2006) standards for FC and *E. coli* in biosolids to be used for the above-mentioned applications are set at 1,000/g total dry solids ($\log_{10} 1000 = 3$), which are provided in *Annexure 1 Table 3*.

In this study, the FC in the biosolids samples from the treatment plants ranged from 5 MPN/g total dry solids ($\log_{10} 5 = 0.73$) to 66,549 MPN/g total dry solids ($\log_{10} 66549 = 4.82$) whereas *E. coli* in the samples was recorded to be in the range of 4 MPN/g total dry solids ($\log_{10} 4 = 0.56$) to 66,549 MPN/g total dry solids ($\log_{10} 66549 = 4.82$). Both FC and *E. coli* are the lowest in Sambalpur FSTP and the highest in Puri STP co-treatment plant. Biosolids samples from six treatment plants showed FC to be above the USEPA standard whereas four plants exceeded the WHO (2006) standard for *E. coli*. This indicates that adequate drying and storage has not been maintained in these treatment plants.

Adequate drying is essential as high moisture content promotes microbial growth. Improper storage can also contribute to microbial growth. Apart from Dhenkanal and Angul FSTPs, the rest of the treatment plants have an open storage shed for storing the dried biosolids from drying beds. In an open storage shed, there are more chances for biosolids to get wet especially during rainy seasons. Excess water in dried biosolids (which has high nutrient content) will promote the regrowth and multiplication of micro-organisms (pathogens) which are present in low numbers in the dried biosolids.[15] Hence, it is recommended that dried biosolids are preserved in a closed storage room and moisture is avoided. The Dhenkanal and Angul FSTPs have closed storage rooms for storing the dried biosolids and contain low FC and *E. coli* content (see *Graph 23: Faecal coliform (FC) and E. coli in the biosolids from FSTPs and STP co-treatment plant*). The treatment plants with an open storage shed and demonstrably low FC and *E. coli* content in the biosolids samples also reveals that good drying practices are being followed.

The Dhenkanal FSTP is equipped with a pasteurization unit. A slight increase in FC—from 14 MPN/g to 36 MPN/g total dry solids—and a decrease in *E. coli*—from 14 MPN/g to 5 MPN/g total dry solids was observed in the biosolids samples before and after pasteurization, respectively in Dhenkanal. The results show that even though pasteurization seems to be effective in reducing the *E. coli* load, the amount of FC and *E. coli* observed in biosolids before pasteurization itself is very less, indicating that these pathogens were reduced in the sludge drying beds itself.

Graph 23: Faecal coliform (FC) and E. coli in the biosolids from FSTPs and STP co-treatment plant



Source: CSE

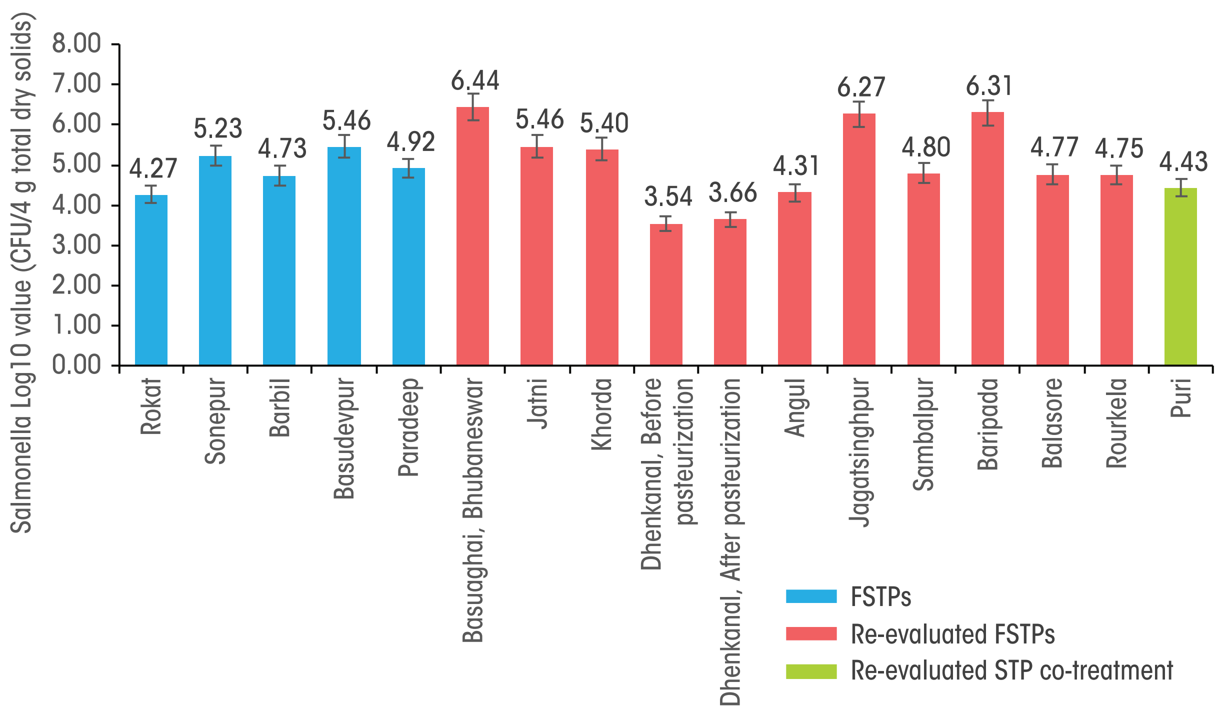
9.3.7 Salmonella

Salmonella is a pathogenic bacterium that causes typhoid fever and salmonellosis, which is found in the faeces of humans and animals infected with *Salmonella*, and hence, also present in FS biosolids. *Salmonella* found in the biosolids samples of the treatment plants in Odisha is depicted in *Graph 24: Salmonella in biosolids from FSTPs and STP co-treatment plant*. The regulatory limit of 'nil' given in the Fertilizer Control Order 2023 (FCO 2023) for pathogen content of the organic manure is also applicable to *Salmonella*. Similar to FC and *E. coli* which are present in all biosolids samples, *Salmonella* too is present in all the samples. Further, the *Salmonella* concentration in the samples is compared with the standards set by the USEPA for class A biosolids (=3 MPN / 4 g total dry solids [$\log_{10} 3 = 0.48$]) which includes all types of biosolids that can be applied to all land types, to assess its suitability for agricultural applications (see *Annexure 1 Table 3*).

In this study, *Salmonella* in the biosolids samples of the treatment plants ranged from 3,484 MPN/4 g total dry solids ($\log_{10}$ 3484 = 3.54) to 27,39,140 MPN/4 g total dry solids ($\log_{10}$ 2739140 = 6.44). All the samples contain high amounts of *Salmonella* which significantly exceeded the USEPA standard. Hence, the biosolids generated in the evaluated treatment plants are not suitable to be used with unrestricted land application. They also cannot be used for other applications like land filling and restricted applications on land free from human exposure as the load is much higher that can lead to contamination. *Salmonella* is resistant to desiccation and drying, and can survive in a wide range of temperatures (2°C to 54°C) and pH (4.0 to 9.5). This may be a reason for the high concentration and consistent occurrence in all of the biosolids samples evaluated in this study. Drying practices described earlier may reduce *Salmonella* to a certain extent but will not completely eliminate them. Hence, disinfection methods such as providing adequate heat treatment including pasteurization, lime treatment, IR radiation etc. are recommended to be adapted in the treatment plants to completely eliminate *Salmonella* from the biosolids.[16]

Although Dhenkanal is equipped with a pasteurization unit, an increase in *Salmonella* (from 3,467 to 4,571 MPN/g total dry solids) was observed in the biosolids samples before and after pasteurization, respectively. This indicates that Dhenkanal's pasteurization unit was ineffective in reducing *Salmonella* in the biosolids.

Graph 24: Salmonella in biosolids from FSTPs and STP co-treatment plant



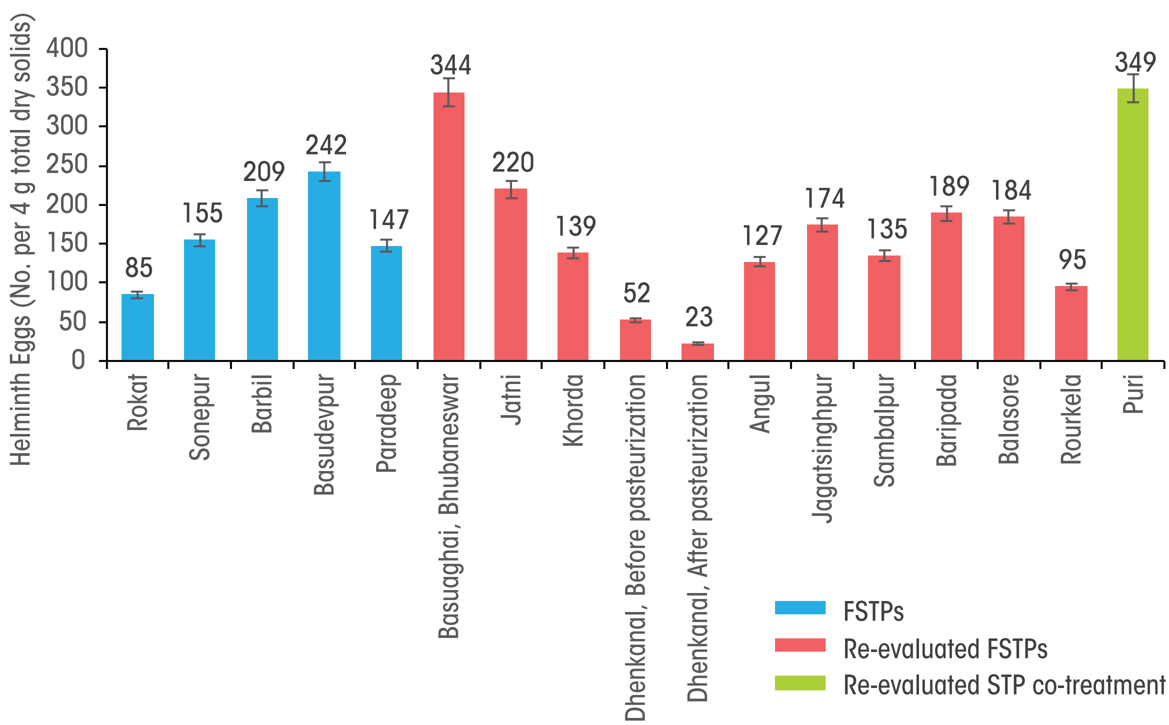
Source: CSE

9.3.8 Helminth eggs

FS biosolids contain helminth eggs upto 10^4 per 4 g (dry weight) depending on the rate of infection in the community. Helminth eggs in the biosolids samples are shown in *Graph 25: Helminth eggs in biosolids from FSTPs and STP co-treatment plant*. The regulatory limit of 'nil' set by the FCO for pathogen content of the organic manure is also applicable to helminth eggs that are used as an indicator to estimate the concentration of parasitic worms (a type of pathogen) present in biosolids. Helminth eggs are also detected in all biosolids samples evaluated in this study. The WHO standard of <1 helminth egg/4 g (dry weight) of FS biosolids that can be used for agriculture, is used to assess the suitability of biosolids for agricultural purposes (see *Annexure 1 Table 3*).

Helminth eggs in the biosolids samples ranged from 23–349 eggs/4 g total dry solids which is above the WHO standards. The highest number of helminth eggs were detected in biosolids from Puri STP co-treatment plant and Basuaghai FSTP (344–349 eggs/4 g total dry solids) as compared to other treatment plants. The lowest number of helminth eggs were detected in Dhenkanal FSTP biosolids which further reduced from 52 to 23 eggs per 4 g (total dry solids) after pasteurization. This indicates that pasteurization (heat treatment for specified temperature and time such as low temperature for longer time period or high temperature for shorter time period) is efficient in reducing helminth eggs

Graph 25: Helminth eggs in biosolids from FSTPs and STP co-treatment plant



Source: CSE

in biosolids. It was observed that the number of helminth eggs were significantly reduced in the biosolids samples when they were subjected to sun drying for a longer duration. Helminth eggs, due to their tougher envelopes, are highly resistant to treatment and hence, difficult to eliminate. They can survive in biosolids from a few months to years. Therefore, a few methods to effectively eliminate helminth eggs in biosolids include heat treatments like pasteurization and sun drying for an extended period of time, and lime treatment.[17]

9.4 EVALUATION OF CO-COMPOST QUALITY FROM JATNI MUNICIPALITY: A CASE STUDY

A pilot study of co-composting biosolids (BS) from the FSTPs with organic wet waste (OWW) from micro-composting centre (MCC) was taken up by the Odisha government in collaboration with Ernst & Young (EY) in Jatni municipality. The aim of this study was to evaluate the quality of co-compost generated by composting varying quantities of BS and OWW. Four batches of co-compost were produced with minor changes in the procedure as described below. The dates of commencement, the composition of BS and OWW, and the mixing ratio used in each batch are provided in *Table 5: Composition of dry leaves, BS, OWW used for various batches of co-composting in Jatni FSTP.*

9.4.1 Procedure used for co-composting in different batches

Batch 1:

The composting process started in the presence of urban local bodies (ULB) officials, state Techinal Support Unit (TSU), self-help group (SHG) members, a technical resource person (TRP) and a Swachh Karmi of the micro-composting centre (MCC). For the first batch of co-composting, tub composting method was used. Initially, a layer of 20 kg dry grass and leaves were uniformly spread on the surface of a concrete bed (Layer 1). Above this layer, 50 kg dried biosolids were spread evenly to form a second layer (Layer 2). This is followed by layering 100 kg shredded raw wet waste from the MCC (Layer 3). The total duration of composting is 90 days, with 60 days of active composting period followed by 30 days of maturation and drying. During the first 60 days, the following are performed at regular intervals for optimal performance of the active composting process—turning of the compost pile once a week which promotes active mixing of components and micro-organisms apart from uniform composting throughout the pile; monitoring the temperature at three points in the compost pile (two corners and at the centre) thrice a day (morning, afternoon and evening) every week to check for temperature gain througout the pile as high temperature accelerates composting process; and sprinkling of water. The temperature in the windrow was recorded using a digital soil thermometer. When a temperature of >65°C is recorded, the compost pile is turned and water is sprinkled over the top layer. When moisture level decreases and the compost pile looks dry, water is sprinkled again to maintain a moisture content of 60 per cent.

Batch 2:

The composting process started in the presence of ULB officials of Jatni municipality, state TSU of Faecal Sludge and Septage Management (TSU-FSSM), SHG members and a

TRP of faecal sludge/septage treatment plant (FSTP/SeTP) facility. Windrow method was used for co-composting process in Batch 2. A total of 5 kg dry leaves, 250 kg dried and sieved biosolids and 750 kg shredded organic wet waste from the MCC were taken and thoroughly mixed outside the bed. The mixture was then transferred to the composting bed and stacked in a heap. Water was sprayed over the mixture and temperature was recorded at five different points in the heap (at the deeper layers of four corners and at the centre). The average temperature was recorded to be at 42°C on the first day of composting. The total duration of composting is 90 days, with 60 days of active composting period followed by 30 days of maturation and drying. Similar to Batch 1, the compost pile was turned and the temperature monitored three times a day. The temperature was recorded at five points—four corners and the centre—and sprinkling of water was done at regular intervals (mostly once in a week) depending on the requirement.

Batch 3:

The composting process started in the presence of ULB officials of Jatni municipality, state TSU-FSSM, SHG members and a TRP of the FSTP/SeTP) facility. Windrow method was used for co-composting process in Batch 3 as well. However, in Batch 3, cow dung was used for building up the inoculum for composting. A total of 10 litres (L) of cow dung slurry is layered throughout the outer surface of the composting bed. About 10 kg dry leaves, 250 kg dried and sieved biosolids and 750 kg shredded organic wet waste from the MCC were taken and thoroughly mixed outside the bed. The mixture was then shifted to the composting bed layered with cow dung and stacked in a heap. Water was sprayed over the mixture and temperature was recorded at five different points in the heap (inner layers of the four corners and at the centre). The average temperature was recorded to be at 42°C on the first day of composting. After 30 days, another 10 L of cow dung slurry is added and mixed with the composting pile. The total duration of composting is 90 days, with 60 days of active composting period followed by 30 days of maturation and drying. Similar to Batch 1 and 2, turning, temperature monitoring and sprinkling of water was done at regular intervals (mostly once in a week) depending on the requirement.

Batch 4:

The process started in the presence of ULB officials of Jatni municipality, state TSU-FSSM, SHG members and a TRP of FSTP/SeTP) facility. Windrow method was used for co-composting process in Batch 4. A total of 500 kg of dried biosolids from sludge drying bed and 1,500 kg of shredded organic wet waste from the MCC were taken and thoroughly mixed outside the bed. In Batch 4, dry leaves were not used. The mixture was then shifted to the composting bed and stacked in a heap. An optimum heap size at a height of 1.2–1.6 meters and a circumference of 6–9 metres was maintained. An initial moisture content of 50–60 per cent and a temperature of 55–60°C was maintained for Batch 4. Water was sprayed over the mixture and temperature was recorded at different points in the heap (inner layers of the four corners and at the centre). The average temperature was recorded to be at 42°C on the first day of composting. The total duration of composting is 90 days, with 60 days of active composting period followed by 30 days of maturation and drying. Similar to other batches, turning and temperature monitoring were performed at regular intervals (mostly once in a week) depending on the requirement. However, in Batch 4,

Table 5: Composition of dry leaves, BS, OWW used for various batches of co-composting in Jatni FSTP

Type of composting	Batch 1	Batch 2	Batch 3	Batch 4
	Tub composting	Windrow composting	Windrow composting	Windrow composting
Commencement date	22-02-2023	03-05-2023	22-06-2023	26-04-2024
Dry leaves (DL) (Kg)	20	5	10	Nil
Biosolids (BS) (Kg)	50	250	250	500
Organic wet waste (OWW) (Kg)	100	750	750	1500
Ratio of DL:BS:OWW	0.4:1:2	0.02:1:3	0.04:1:3	0:1:3

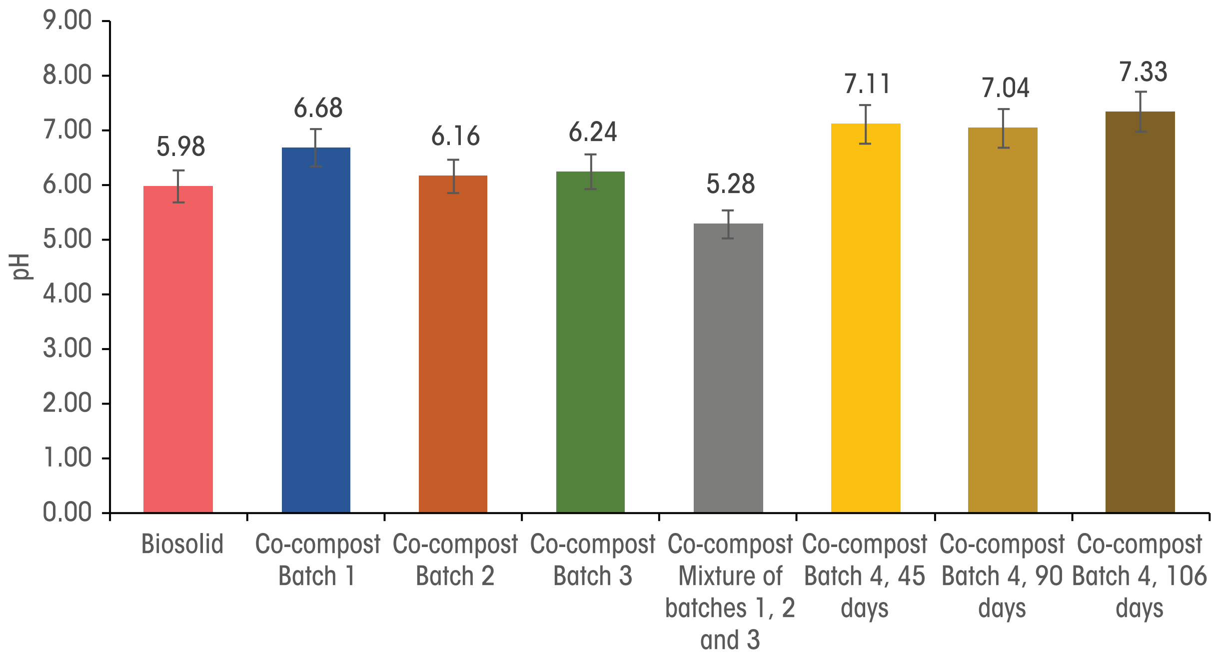
Source: CSE

treated water from polishing pond was used, instead of normal water, to sprinkle on the compost heap depending on its moisture content.

9.4.2 pH

The pH of biosolids and co-compost samples from Jatni FSTP is shown in *Graph 26: pH of biosolids and co-compost samples from Jatni FSTP*. A pH level of 6.0–8.5 of the organic manure must be maintained, as per standards set by the FCO 2023. The pH of the co-compost samples from Jatni varied from 5.28 to 7.33. The lowest pH was observed in the

Graph 26: pH of biosolids and co-compost samples from Jatni FSTP



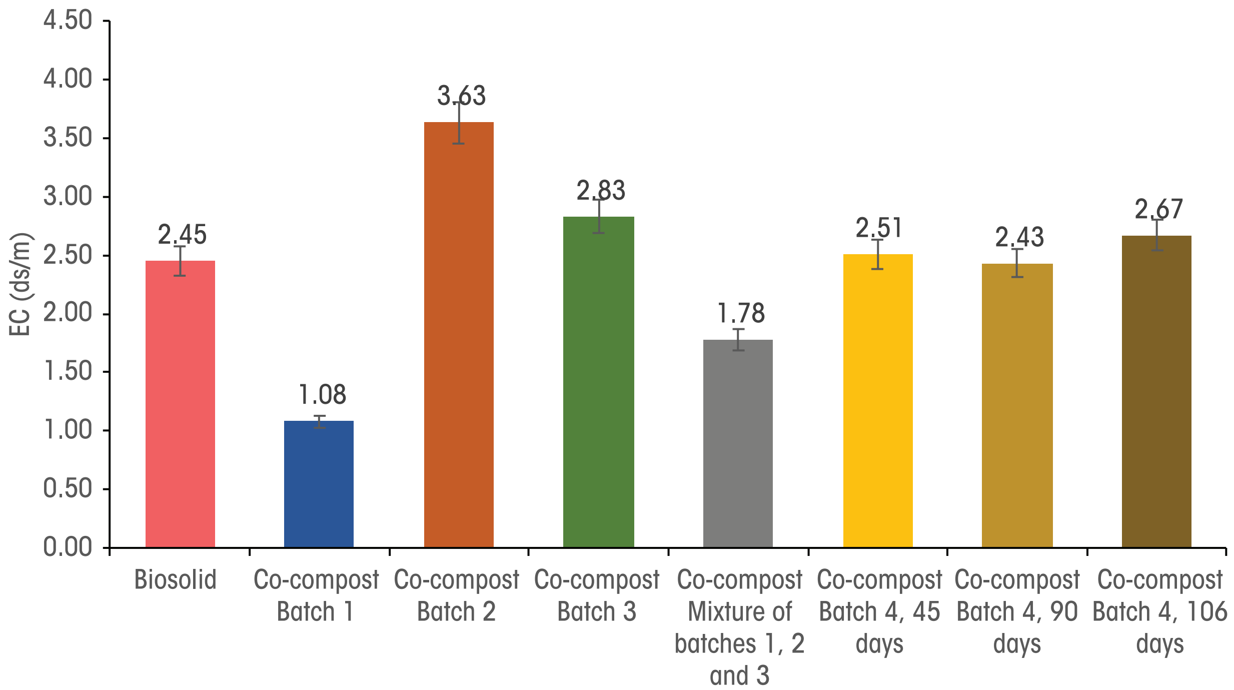
Source: CSE

co-compost mixture of Batches 1, 2 and 3, while the highest was observed in the 106–day sample of co-compost Batch 4. Apart from the co-compost mixture of Batches 1, 2 and 3, all other co-compost samples had a pH higher than that of biosolids (5.98). Hence, they are within the FCO standard limit.

9.4.3 Electrical conductivity (EC)

The electrical conductivity (EC) of biosolids and co-compost samples from the Jatni FSTP is shown in *Graph 27: Electrical conductivity of biosolids and co-compost samples from Jatni FSTP*. No standard is given for EC of the organic manure in the FCO. However, it sets a standard of ≤6.0 ds/m for EC of city compost which was used as a benchmark to evaluate the EC of biosolids. The EC of co-compost samples from Jatni varied from 1.08–3.63 ds/m. The lowest EC was observed in co-compost Batch 1 while the highest was observed in co-compost Batch 2. EC in all the co-compost samples complied with the FCO standard of city compost.

Graph 27: Electrical conductivity of biosolids and co-compost samples from Jatni FSTP

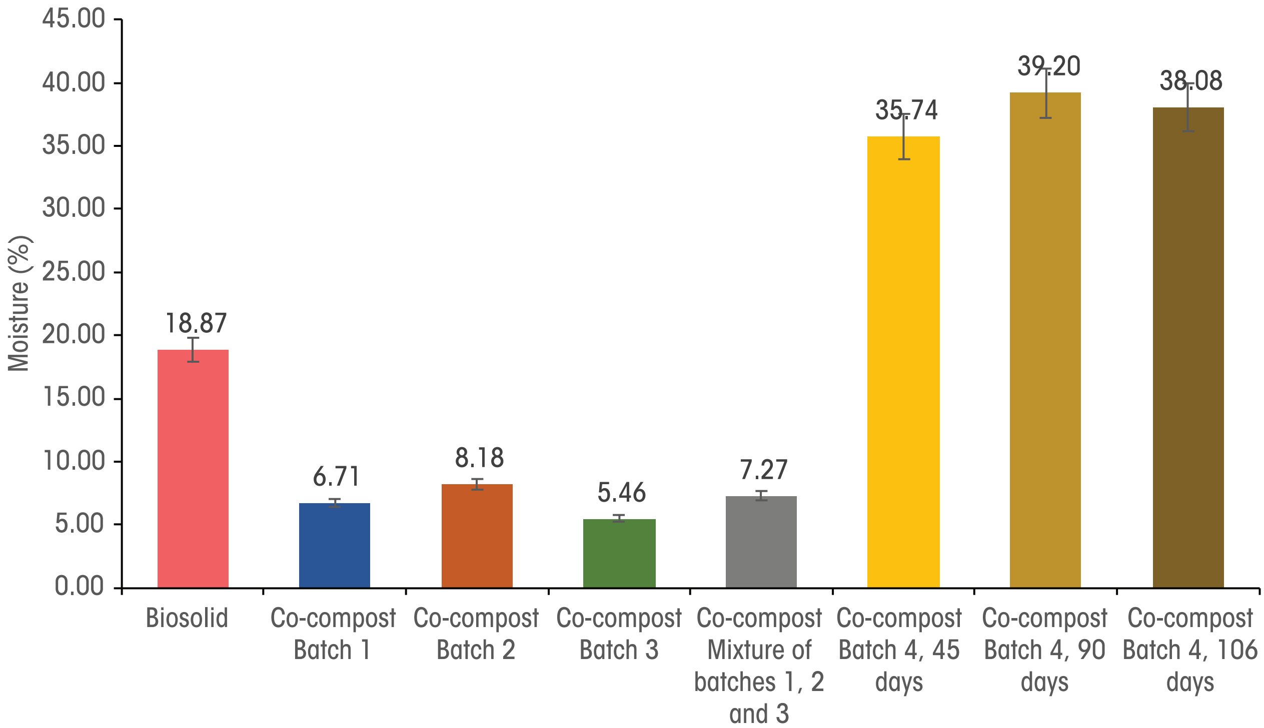


Source: CSE

9.4.4 Moisture content

The moisture content in biosolids and co-compost samples from Jatni FSTP is shown in *Graph 28: Moisture of biosolids and co-compost samples from Jatni FSTP*. The standard set for moisture content of the organic manure is ≤ 25 per cent by weight, as per the FCO 2023. The moisture content of the co-compost samples from Jatni varied from 5.46–39.2 per cent. The lowest per cent moisture was observed in co-compost Batch 3 while the highest was observed in 90–days sample of co-compost Batch 4. Moisture content in Batch 4 samples did not comply with the FCO standard whereas the rest of the batches complied. It was observed that all three samples of co-compost Batch 4 had a moisture content of over four times than that of co-compost Batches 1, 2 and 3. This indicates that more efficient drying is required for Batch 4 co-compost samples that contain 2–10 times more biosolids and 2–15 times more organic wet waste as compared to Batches 1, 2 and 3, in order to attain a moisture content within the FCO limit.

Graph 28: Moisture of biosolids and co-compost samples from Jatni FSTP

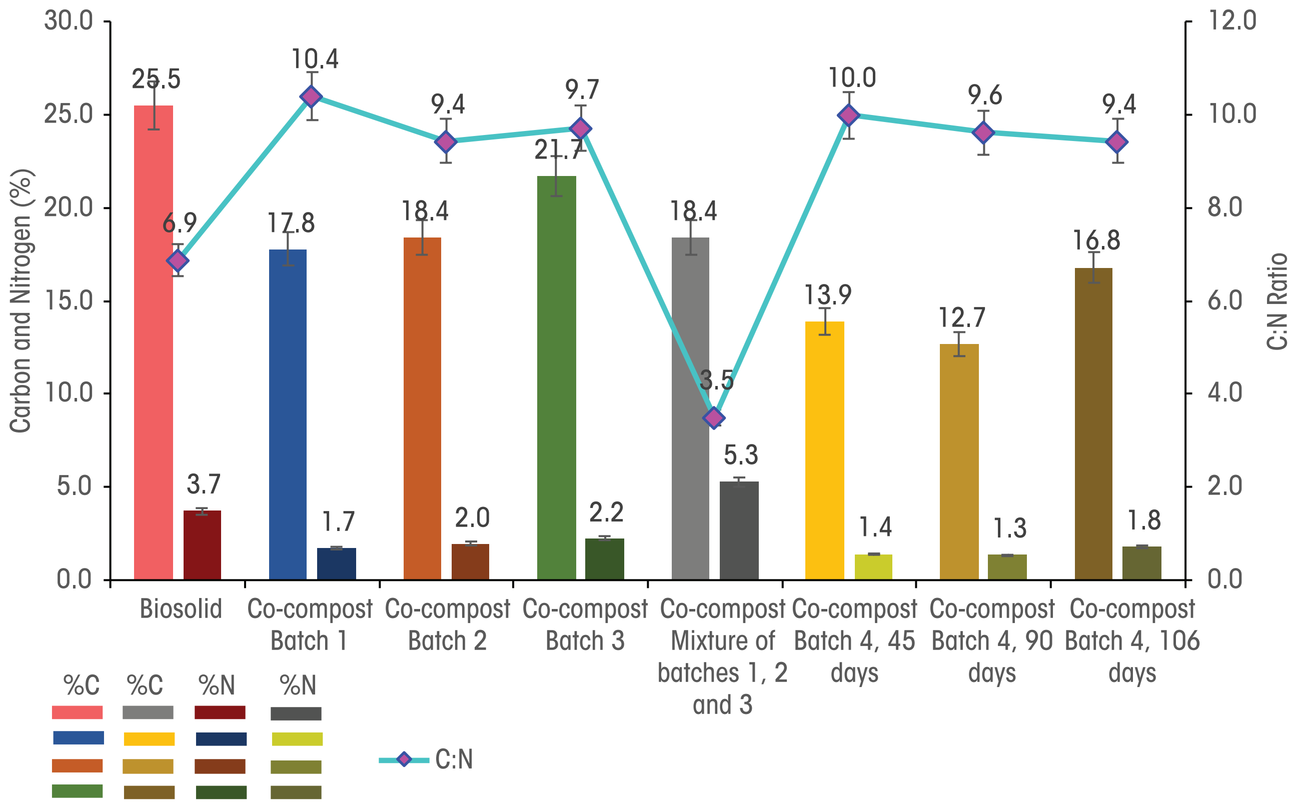


Source: CSE

9.4.5 Carbon and nitrogen content and carbon-to-nitrogen (C:N) ratio

The carbon and nitrogen content and carbon–to–nitrogen (C:N) ratio of biosolids and co-compost samples from the Jatni FSTP is shown in *Graph 29: Carbon, nitrogen and C:N ratio in biosolids and co-compost samples from Jatni FSTP*. Composting/co-composting is usually conducted to improve the quality of final product (compost/co-compost) to improve soil nutrition and promote plant growth and improve crop yield. A good quality compost/co-compost should have a C:N ratio of 15–20. The carbon content in co-compost samples from the Jatni FSTP varied from 12.7–21.7 per cent which is less than the carbon content of biosolids (25.5 per cent) at the co-treatment plant. The nitrogen content in the co-compost samples varied from 1.3–5.3 per cent. Apart from the 45– and 90–days co-compost samples of Batch 4 for carbon, all other co-compost samples complied with the FCO standards of ≥ 14 per cent by weight and ≥ 0.5 per cent by weight for carbon and total nitrogen (as N), respectively. The C:N ratio varied from 3.5 to 10.4, with the lowest observed in mixture of co-compost Batches 1, 2 and 3. All co-compost samples were compliant with the FCO standard of <20 for C:N ratio. Although the C:N ratio increased

Graph 29: Carbon, nitrogen and C:N ratio in biosolids and co-compost samples from Jatni FSTP



Source: CSE

in the co-compost samples (9.4–10.4) as compared to biosolids (6.9), as already discussed earlier (section **4.3**) and mentioned above, it is recommended that a greater C:N ratio of about 15–20 is maintained in the Jatni co-compost samples in order to be used as a good quality compost for improving crop yield. This can be done by further increasing the carbon content by adding more carbon-rich materials such as dry leaves, saw dust etc. during composting.

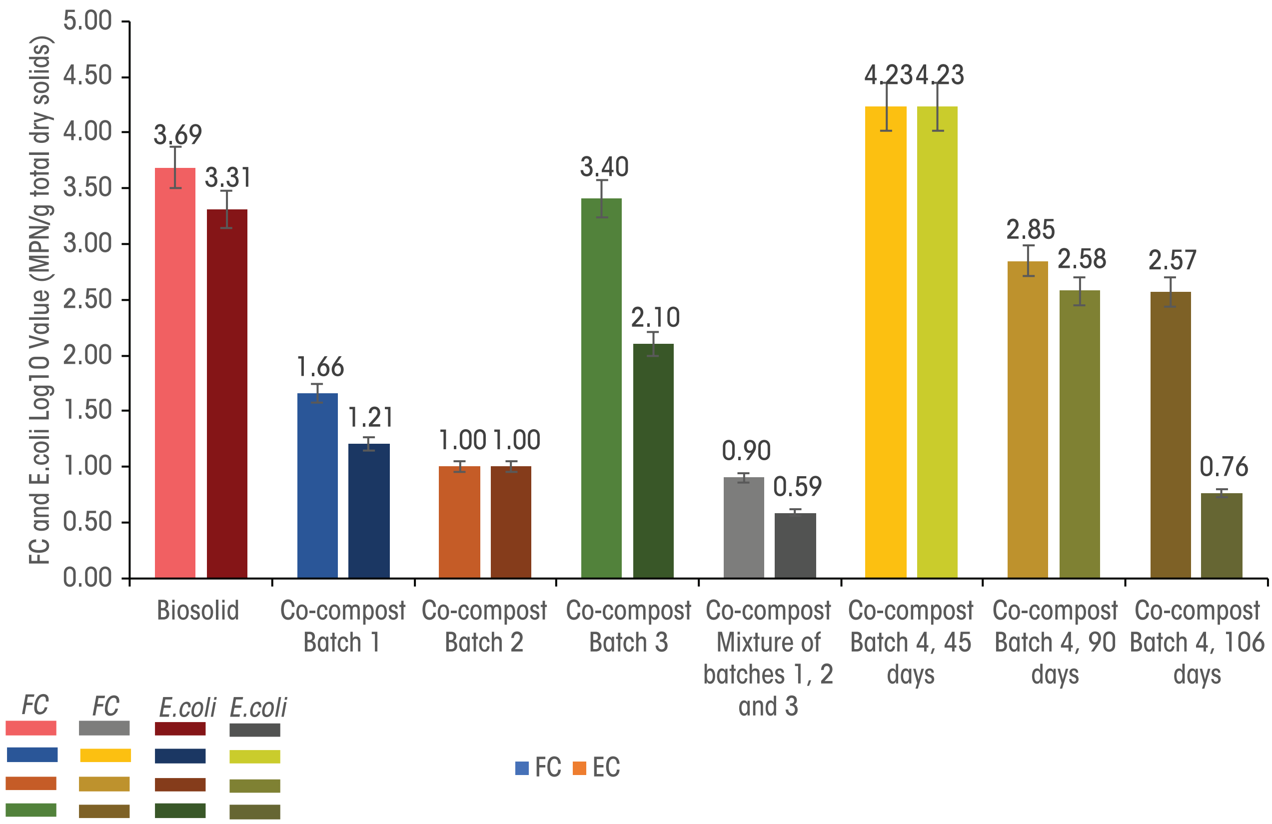
9.4.6 Heavy metals

The heavy metals evaluated in compost samples in this study are provided in *Annexure 3 Table 5*. Heavy metals arsenic (range: 0.61–3.18 mg/kg in this study) and lead (18.7–52.5 mg/kg) were found to be within the FCO limit in all the evaluated compost samples from Jatni. Cadmium (1.14–10.9 mg/kg) was within the FCO limit in all compost samples except in Batch 1 which has the highest cadmium content. Zinc (321–1,680 mg/kg) was within limit in five samples and exceeded in two samples, Batch 3 and Batch 4, 45–days samples with the highest zinc content (1,670–1,680 mg/kg). Copper (135–438 mg/kg) and nickel (23.5–63.7 mg/kg) were both within limit in four compost samples (Batch 2; mixture of Batches 1, 2 and 3; Batch 4, 90–days and 106–days samples) while exceeded the limit in remaining three samples. Chromium (35.2–323 mg/kg) exceeded the FCO limit in all batches of compost except in the mixture of Batches 1, 2 and 3, with the highest recorded in Batch 4, 106–days sample. Mercury (0.24–9.41 mg/kg) exceeded the FCO limit of 0.15 mg/kg in all the batches of compost with the highest recorded in Batch 4, 45–days sample.

9.4.7 Faecal coliform (FC) and *E. coli*

Faecal coliform (FC) and *E. coli* in biosolids and co-compost samples from the Jatni FSTP is shown in *Graph 30: FC and E. coli in biosolids and co-compost samples from Jatni FSTP*. As mentioned above, there is generally a reduction in microbial/pathogen content in co-compost samples due to an increase in temperature during composting. FC and *E. coli* of the co-compost samples from Jatni varied from 4–17,118 MPN/g total dry solids, with the lowest observed in mixture of co-compost Batches 1, 2 and 3 and the highest in 45–days sample of co-compost Batch 4. As expected, it was observed that FC and *E. coli* reduced in all the batches of co-compost samples as compared to biosolids. However, high FC and *E. coli* were observed in 45–days sample of co-compost batch. A possible reason for such a high amount of FC and *E. coli* could be due to an increase in the microbial load during the initial stages of composting as the temperature is optimal for growth and multiplication of microbes. During this stage, the microbial content increases, including those actively involved in composting. It was noted that the FC and *E. coli* content had decreased in the later stages of the composting process (90–days and 106–days samples) in Batch 4 co-compost samples. This reduction in microbial populations helped all the co-compost batches of samples (except Batch 3 for FC) to comply with the USEPA (class A biosolids) and the WHO (2006) standards of 1,000/g total dry solids ($\log_{10} 1000 = 3$) for FC and *E. coli* in biosolids. The use of cow dung for composting in Batch 3 might be a possible reason for increased FC in this sample. It was noted that *Salmonella* increased while FC and *E. coli* decreased from 45 days to 106 days. The difference between *Salmonella*, FC and *E. coli* content during various stages of Batch 4 co-compost samples may be due to the differences in the properties of these two groups of bacteria. *Salmonella* is more resistant than FC and *E. coli*, and has high tolerance for a wide temperature and pH ranges. This

Graph 30: FC and E. coli in biosolids and co-compost samples from Jatni FSTP



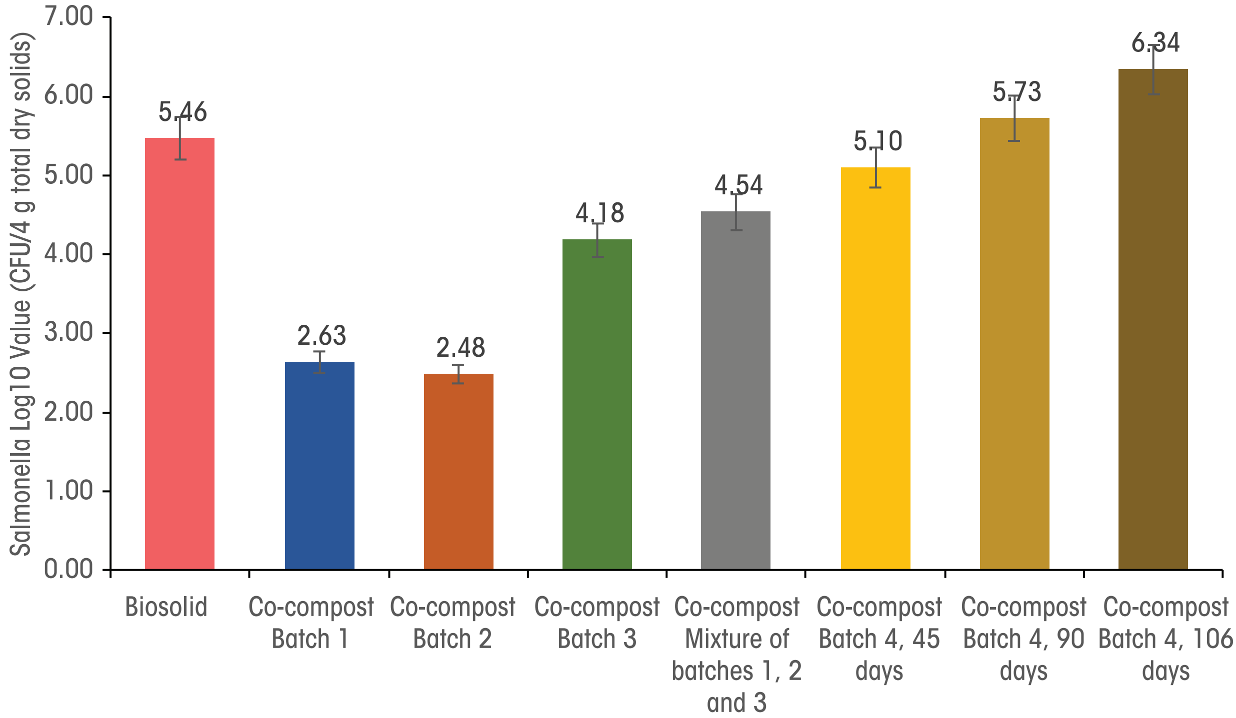
Source: CSE

may allow *Salmonella* to survive in the initial stages and it may increase in numbers later due to the presence of high moisture and nutrients.[18] However, FC and *E. coli* might have decreased gradually due to increase in temperature as they are less resistant.

9.4.8 Salmonella

Salmonella in biosolids and co-compost samples from Jatni FSTP is shown in *Graph 31: Salmonella in biosolids and co-compost samples from Jatni FSTP*. There is usually a reduction in microbial/pathogen content in co-compost samples due to an increase in temperature during composting. *Salmonella* of the co-compost samples from Jatni varied from 305–2,19,64,035 MPN/4 g total dry solids. *Salmonella* was the lowest in co-compost Batch 2 and the highest in 106–days sample of co-compost Batch 4. It was observed that *Salmonella* was >1–4 $\log_{10}$ times less (305–429 MPN/4 g total dry solids) in co-compost Batches 1 and 2 compared to Batches 3 and 4 (15,232–2,19,64,035 MPN/4 g total dry solids). There was lesser amount of *Salmonella* in co-compost Batches 1 and 2 as compared to biosolids which indicates that the co-composting process was performed optimally. This resulted in an increase in temperature, thereby decreasing moisture (see *Graph 41: Salmonella in biosolids and co-compost samples from Jatni FSTP*) and

Graph 31: Salmonella in biosolids and co-compost samples from Jatni FSTP



Source: CSE

microbial content. There was a high amount of *Salmonella* in co-compost Batches 3 and 4 which indicates that the co-composting process was not optimally performed due to which the temperature was not sufficiently high enough to reduce moisture and microbial content. Therefore, it is recommended to do regular turning of the co-composting pile and also regularly monitor its temperature (it should remain at >55°C for at least three consecutive days) to reduce moisture and pathogen load. All the co-compost samples were non-compliant with the USEPA standard limit of 3 MPN/4 g total dry solids ($\log_{10} 3 = 0.48$) of *Salmonella* for class A biosolids.

9.5 RE-EVALUATION OF FSTPS AND STP CO-TREATMENT PLANT FOR LONG-TERM PERFORMANCE AND SUSTAINABILITY

To understand the long-term performance and the sustainability of the treatment plants in Odisha, CSE had evaluated the performance of 11 plants from December 2020 to November 2022, which have been re-evaluated in this study. The re-evaluated plants varied in their treatment capacity (18–75 KLD) and commissioning dates (2017–2022). The treatment plants were compared for capacity utilization, quality of outlet water and biosolids during the two study periods (December 2020–November 2022 and in April 2024) to check for improvement in their performance. The duration between the two study periods of the treatment plants varied from 1.5 years in three plants (Jatni, Khordha and Jagatsingpur) to 3–3.3 years in the other eight plants, which provided a sufficient time period to check for their variation in performance.

9.5.1 Comparison of capacity utilization of FSTPs and STP co-treatment plant during 2020–22 and 2024

The location, treatment capacity, year of commissioning and capacity utilization of the treatment plants during 2020–22 and in 2024 are provided in *Table 6: Comparison of capacity utilization of FSTPs and STP co-treatment plant during 2020–22 and 2024.* Four plants (Jagatsinghpur, Baripada, Balasore and Rourkela) showed an increase, one plant (Khordha) showed no variation, whereas five plants (Jatni, Dhenkanal, Angul, Sambalpur and Puri) showed a decrease in capactiy utilization. The increase in capacity utilization varied from 10 per cent to 53 per cent in the four plants mentioned above with the maximum increase observed in Rourkela at 53 per cent; however, in this plant, the capacity utilization exceeded the plant treatment capacity by 13 per cent. The decrease in capacity utlization varied from 8 per cent to 47 per cent in the five plants mentioned above with the maximum decrease observed in Dhenkanal at 47 per cent.

Table 6: Comparison of capacity utilization of FSTPs and STP co-treatment plant during 2020–22 and 2024

Sl. No.	FSTP / STP co-treatment plant location	Treatment capacity	Date of commissioning	Date of first evaluation	Date of second evaluation	Capacity utilization during first evaluation (December 2020 to November 2022)	Capacity utilization during second evaluation (in April 2024)
FSTPs							
1	Basuaghai, Bhubaneswar	75 KLD	June, 2018	February, 2021	April, 2024	Not available	82%
2	Jatni	20 KLD	May, 2021	November, 2022	April, 2024	100%	75%
3	Khordha	20 KLD	2020	November, 2022	April, 2024	100%	100%
4	Dhenkanal	27 KLD	October, 2018	February, 2021	April, 2024	110%	63%
5	Angul	18 KLD	January, 2020	December, 2020	April, 2024	83%	75%
6	Jagatsinghpur	20 KLD	2022	November, 2022	April, 2024	60%	80%
7	Sambalpur	20 KLD	October, 2018	December, 2020	April, 2024	105%	68%
8	Baripada	50 KLD	January, 2019	December, 2020	April, 2024	60%	70%
9	Balasore	60 KLD	January, 2020	December, 2020	April, 2024	40%	63%
10	Rourkela	40 KLD	October, 2018	December, 2020	April, 2024	60%	113%
STP co-treatment							
11	Puri	50 KLD	October, 2017	December, 2020	April, 2024	70%	60%

Source: CSE

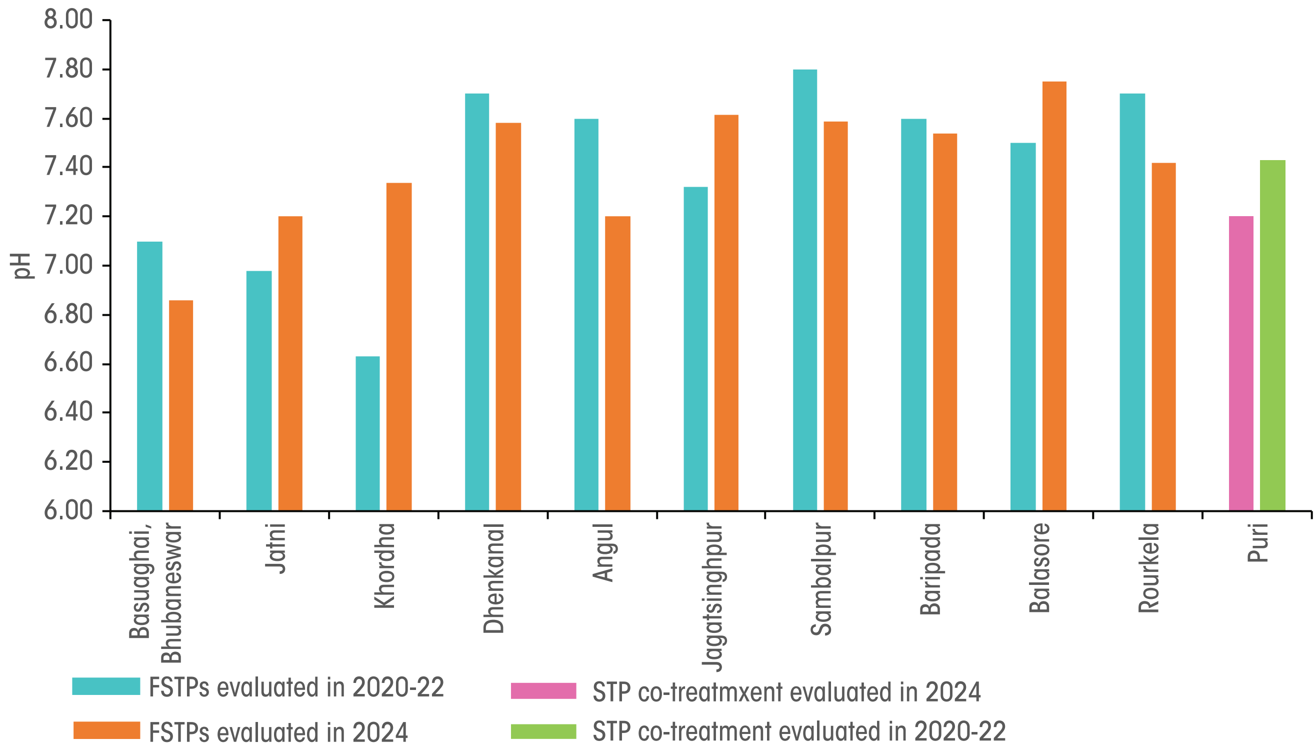
9.5.2 Comparison of outlet water quality from FSTPs and STP co-treatment plant during 2020–22 and 2024

A comparison in the outlet water quality was made on the basis of seven important parameters viz. pH, TS, TSS, COD, BOD, TKN and FC for the 11 Odisha treatment plants during the two study periods 2020–22 and 2024 to check for the improvement in their performance. A decrease in the respective parameters mentioned above, except for pH, in the outlet of a treatment plant indicates an improvement in the treatment capacity/ performance of the plant whereas an increase in the parameter shows a decline in performance.

9.5.2.1 pH:

The comparison of pH in the outlet samples of treatment plants is shown in *Graph 32: Comparison of pH in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A slight variation in pH—decreased in six plants and increased in five plants—was observed in the outlet samples of the treatment plants. However, the pH is within the MoEF&CC and NGT limits set at 6.5–9 and 5.5–9.0, respectively.

Graph 32: Comparison of pH in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024

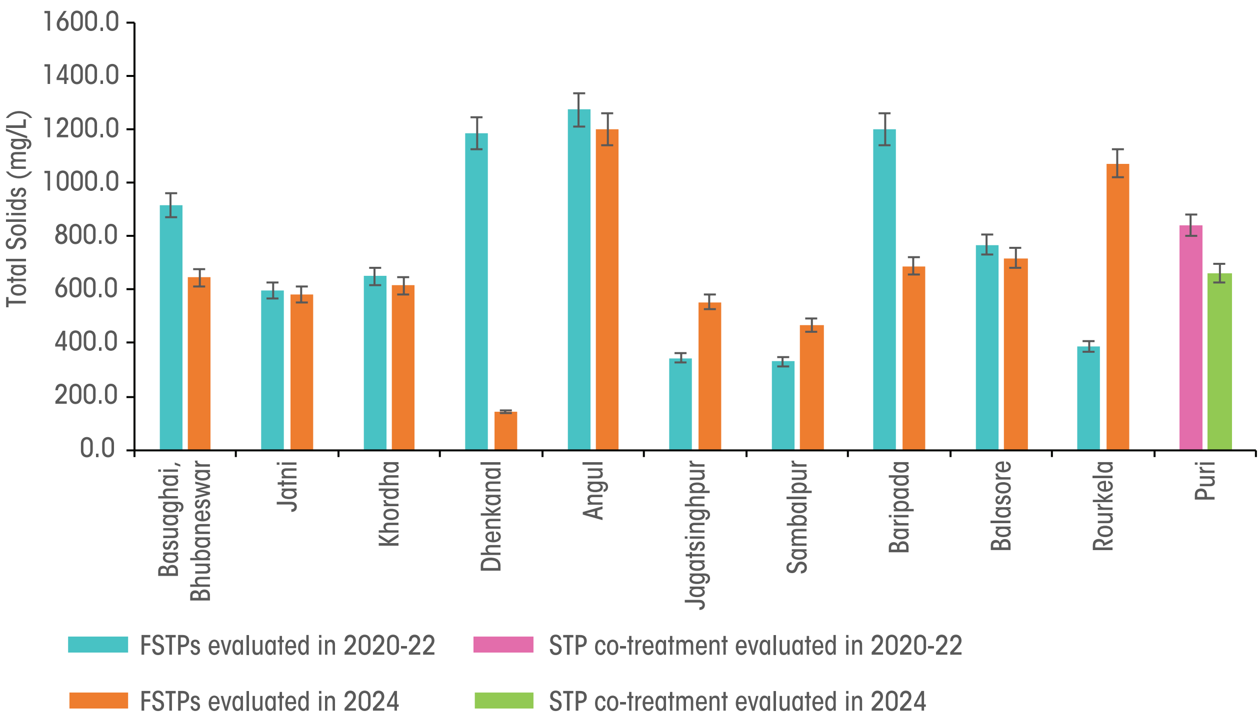


Source: CSE

9.5.2.2 Total Solids (TS):

The comparison of Total Solids (TS) in the outlet samples of treatment plants is shown in *Graph 33: Comparison of TS in outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in outlet TS in eight plants and an increase in three plants was observed during 2020–22 and 2024. The maximum decrease of TS was observed in Dhenkanal (1,187.5 mg/L to 142.7 mg/L) followed by Baripada (1,204.3 mg/L to 689.7 mg/L). This portrays the improvement in their TS removal capacity over time, however, the decrease observed was not significant, as the TS content still remained high at 582–1,202 mg/L in 2024. The highest increase in TS was observed in Rourkela FSTP (389.0 mg/L to 1,073.7 mg/L) which indicates a reduction in the TS removal capacity in this plant. This decline can partially be attributed to the over-utilization of TS removal capacity (113 per cent) observed in 2024. This is one of possible reasons for the increase in outlet TS.

Graph 33: Comparison of TS in outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024

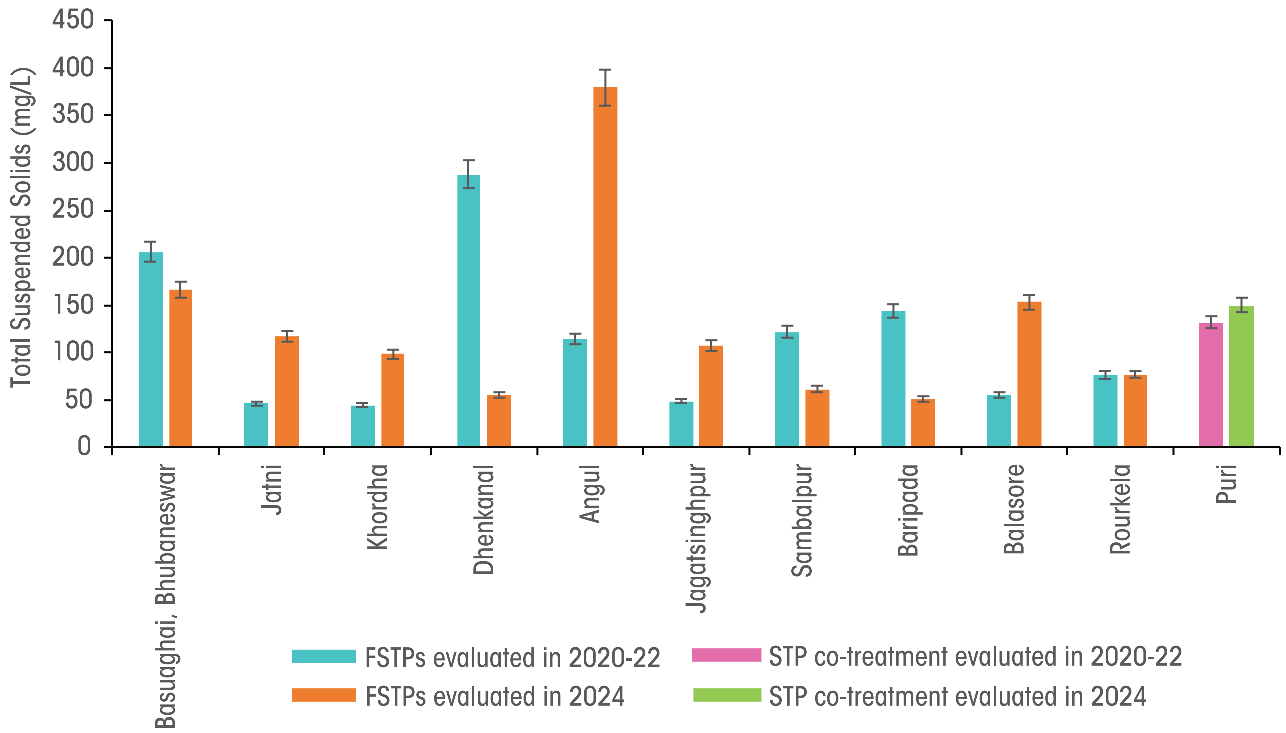


Source: CSE

9.5.2.3 Total Suspended Solids (TSS):

The comparison of Total Suspended Solids (TSS) in the outlet samples of treatment plants is shown in *Graph 34: Comparison of TSS in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in outlet TSS was observed only in four plants whereas TSS increased in the other seven plants from 2020–22 to 2024. Out of the four plants which showed a decrease in outlet TSS, the Dhenkanal, Sambalpur and Baripada FSTPs that were non-compliant with the MoEF&CC standard of 100 mg/L (of non-metro cities) during 2020–22 became compliant in 2024. The fourth plant Basuaghai, which comes under metro city category of the MoEF&CC, showed a decrease in outlet TSS, however, it was still non-compliant with the MoEF&CC standard of 50 mg/L during both periods. Out of the seven plants which showed an increase in TSS, the Khordha and Rourkela FSTPs only showed a slight increase and remained complaint with the MoEF&CC standards in 2024 as well. The other three plants—Jatni, Jagatsinghpur and Balasore—became non-compliant with MoEF&CC standard limit after recording an increase in TSS. Angul and Puri FSTPs, which showed an increase in TSS, remained non-compliant with the MoEF&CC standards in both periods. It was observed that no plant is compliant with the NGT limit of 20 mg/L for TSS in the outlet during both the study periods.

Graph 34: Comparison of TSS in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024

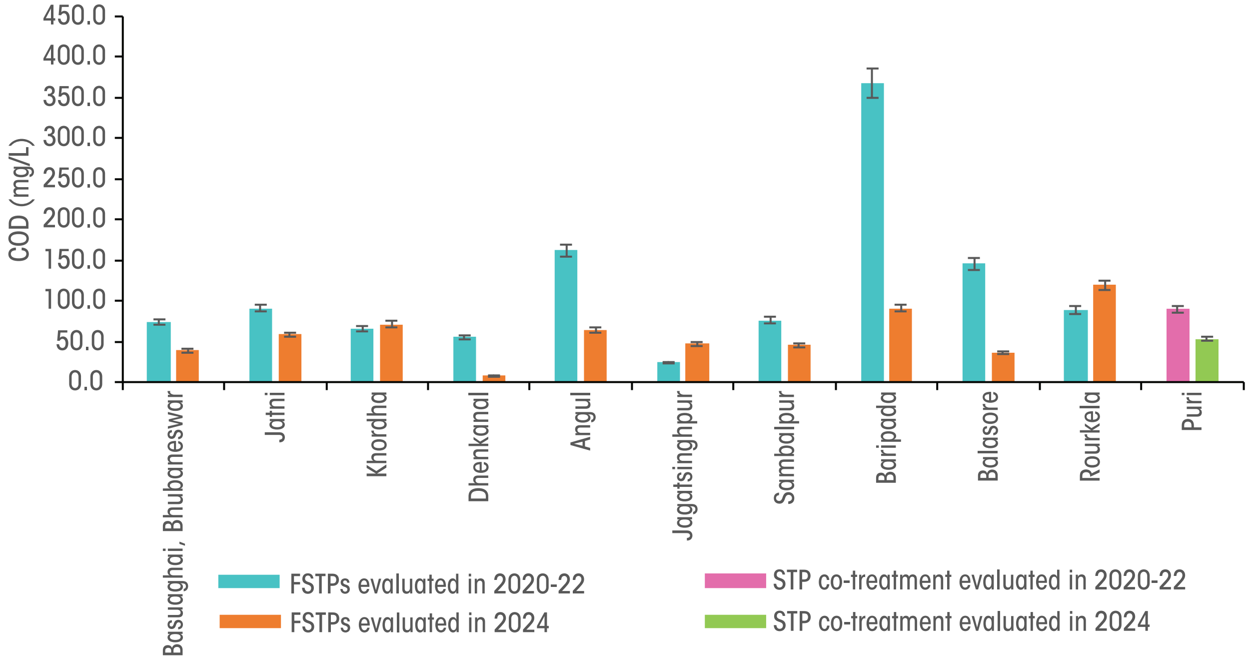


Source: CSE

9.5.2.4 Chemical Oxygen Demand (COD):

The comparison of Chemical Oxygen Demand (COD) in the outlet samples of treatment plants is shown in *Graph 35: Comparison of COD in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in outlet COD was observed in eight plants while an increase was observed in the other three plants from 2020–22 to 2024. Four plants—Basuaghai, Dhenkanal, Sambalpur and Balasore—that showed a decrease in COD from 2020–22 to 2024 and were non-compliant with the NGT standard of 50 mg/L during 2020–22 became compliant in 2024. This shows improvement in the performance of these plants for COD removal. The other four plants—Jatni, Angul, Baripada and Puri—had showed COD levels plummet from 2020–22 to 2024, but they were non-compliant with the NGT standard of 50mg/L during both the study periods. However, these four plants showed improvement in their performance in reducing COD levels. Out of the three plants which showed an increase in COD, the Khordha and Rourkela treatment plants remained non-compliant with the NGT standard during both study periods while the Jagatsinghpur FSTP remained NGT complaint, in spite of showing a slight increase in COD levels.

Graph 35: Comparison of COD in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024

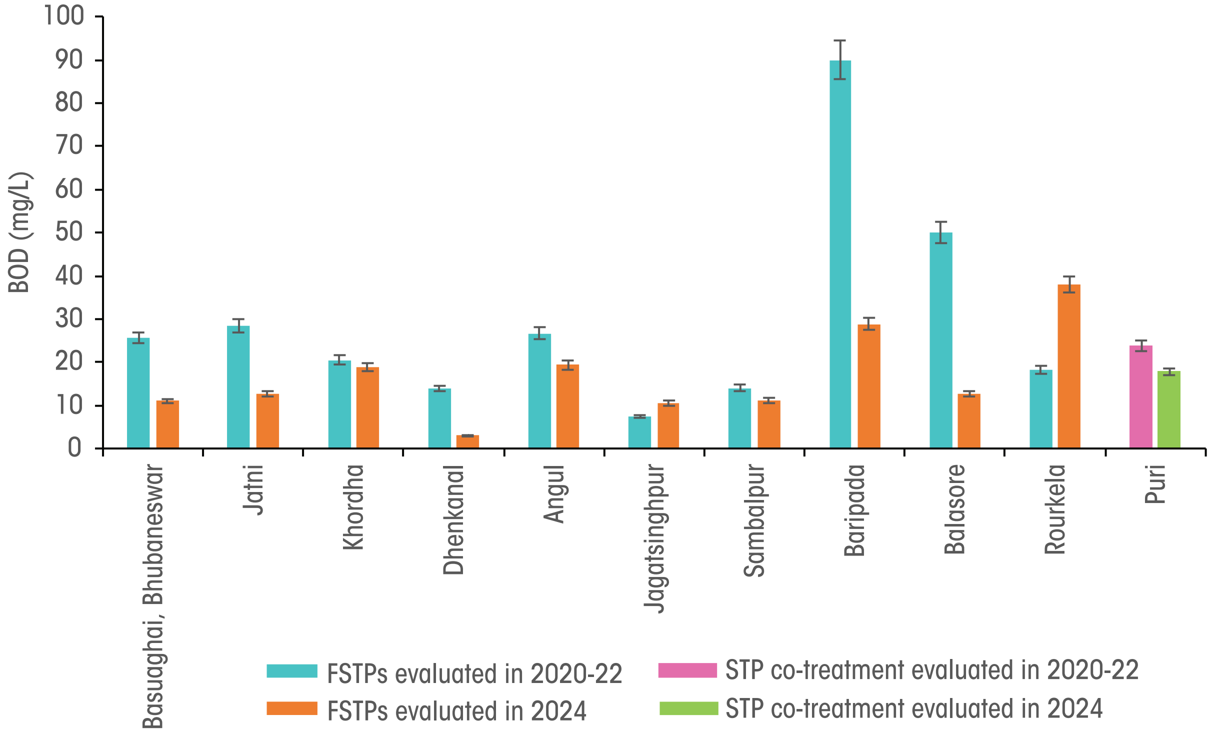


Source: CSE

9.5.2.5 Biological Oxygen Demand (BOD):

The comparison of Biological Oxygen Demand (BOD) in the outlet samples of treatment plants is shown in *Graph 36: Comparison of BOD in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in outlet BOD was observed in nine out of 11 plants whereas an increase was observed in the remaining two plants from 2020–22 to 2024. This indicates an improvement in the performance of the treatment plants in reducing BOD over a period of time. Out of the nine plants which showed a decrease in outlet BOD, six plants were compliant with the MoEF&CC standard during both the study periods. The other three plants—Basuaghai (metro city/Category 1), Baripada and Balasore (non-metro cities/Category 2)—that were non-compliant with the MoEF&CC standard of 20 mg/L and 30 mg/L, respectively during 2020–22 became compliant in 2024. Out of the two plants which showed an increase in outlet BOD, the Jagatsinghpur plant remained compliant in 2024 as well, in spite of showing a slight increase in BOD levels. The remaining Rourkela treatment plant, which showed increase in BOD, became non-compliant with the MoEF&CC limit. It was observed that, except Jagatsinghpur (in 2020–22) and Dhenkanal (2024), no plant is compliant with the NGT limit of 10 mg/L BOD in the outlet during both the study periods.

Graph 36: Comparison of BOD in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024



Source: CSE

Graph 37: Comparison of TKN in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024

Source: CSE

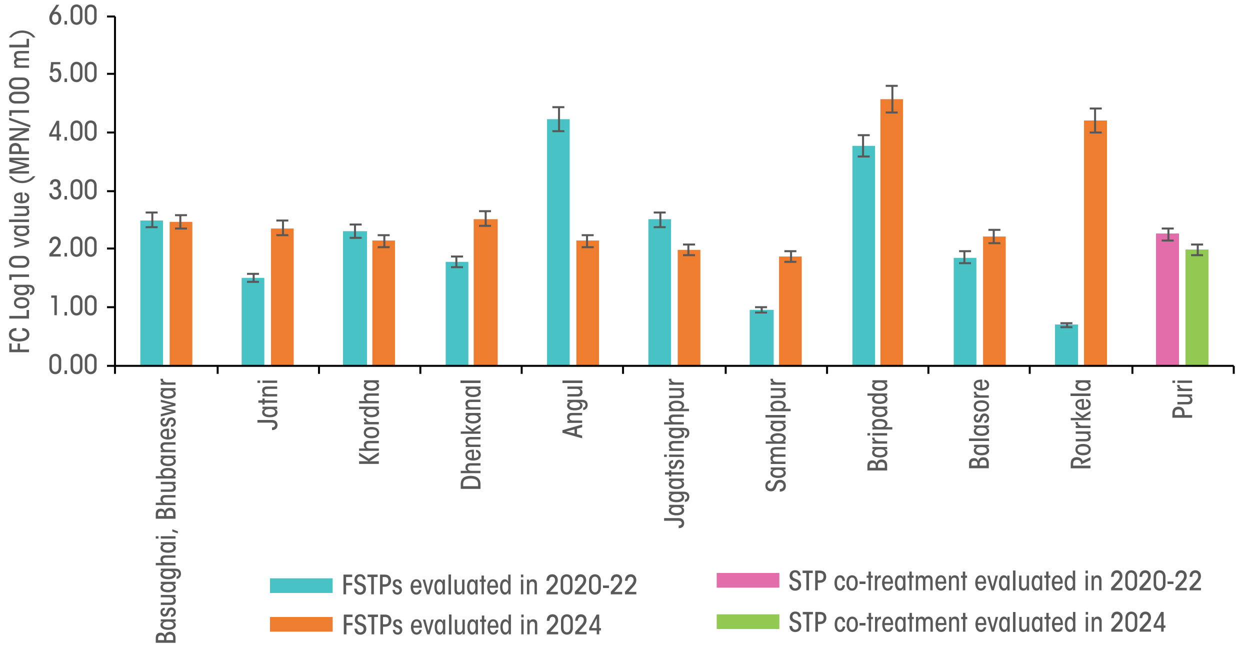
9.5.2.6 Total Kjeldahl Nitrogen (TKN):

The comparison of Total Kjeldahl Nitrogen (TKN) in the outlet samples of treatment plants is shown in *Graph 37: Comparison of TKN in the outlet samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in outlet TKN was observed in five out of 11 plants whereas an increase in TKN was recorded in the remaining six plants from 2020–22 to 2024. Out of the five plants which showed a decrease in outlet TKN, four plants Basuaghai, Dhenkanal, Angul and Balasore had TKN of ≤ 25 mg/L in 2024. However, Baripada plant had a TKN of 61.6 mg/L in 2024. TKN was in the range of 29.9–97.4 mg/L in 2024 in the six treatment plants which showed an increase in TKN.

9.5.2.7 Faecal coliform (FC):

The comparison of faecal coliform (FC) in the outlet samples of treatment plants is shown in *Graph 38: Comparison of FC in the outlet of FSTP and STP co-treatment plants during 2020–22 and 2024*. A decrease in FC of the outlet samples was observed in five out of 11 plants whereas an increase was observed in the remaining six plants from 2020–22 to 2024. Out of the five plants which showed a decrease in outlet FC, four plants—Basuaghai, Khordha, Jagatsinghpur and Puri—were compliant with the MoEF&CC standard in both the study periods; the remaining Angul plant which showed high FC of 16,982 (= 4.23 $\log_{10}$) MPN/100 mL in 2020–22 was non-compliant with the MoEF&CC standard of 1,000 (= 3 $\log_{10}$) MPN/100 mL but became compliant in 2024 with FC of 138 (= 2.14 $\log_{10}$) MPN/100 mL. Out of the six plants which showed an increase in outlet FC, four showed only a little increase in outlet FC and were MoEF&CC compliant in both the study periods.

Graph 38: Comparison of FC in the outlet of FSTP and STP co-treatment plants during 2020–22 and 2024



Source: CSE

Of the remaining two plants which showed an increase in outlet FC, Baripada was non-compliant with the MoEF&CC standard in both the periods whereas Rourkela, which had very less FC (5 [= 0.7 $\log_{10}$] MPN/100 mL) in 2020–22 became non-compliant in 2024 after a large increase in outlet FC to 16,218 [= 4.21 $\log_{10}$] MPN/100 mL. Hence, it is recommended that a tertiary treatment unit must be installed in Baripada and Rourkela treatment plants to keep the FC content levels below the standard limit.

The NGT sets the permissible limit of FC at 230 MPN/100 mL. Of the five plants which showed a decrease in outlet FC from 2020–22 to 2024, the Khordha and Puri plants were compliant in both the study periods; the Angul and Jagatsinghpur plants which were non-compliant in 2020–22 became compliant in 2024 and the remaining Basuaghai plant remained non-compliant in both the periods. Out of the six plants which showed an increase in outlet FC from 2020–22 to 2024, the Jatni, Sambalpur and Balasore plants remained compliant in both the periods; the Dhenkanal and Rourkela plants that were compliant in 2020–22 became non-compliant in 2024 and the remaining Baripada plant was non-compliant in both the study periods.

When compared with the NGT's desirable limit of 100 MPN/100 mL, five plants showed a decrease in outlet FC from 2020–22 to 2024, out of which two plants Jagatsinghpur and Puri which were non-compliant in 2020–22 became compliant in 2024; the remaining three plants Basuaghai, Khordha and Angul remained non-compliant in both the periods. Out of the six plants which showed an increase in outlet FC from 2020–22 to 2024, only the Sambalpur plant remained compliant in both the periods. Four plants—Jatni, Dhenkanal, Balasore and Rourkela—which were compliant in 2020–22 became non-compliant in 2024 and the remaining Baripada plant remained non-compliant in both the periods.

9.5.2.8 Overall performance of the treatment plants during 2020–22 and 2024 in terms of effluent quality

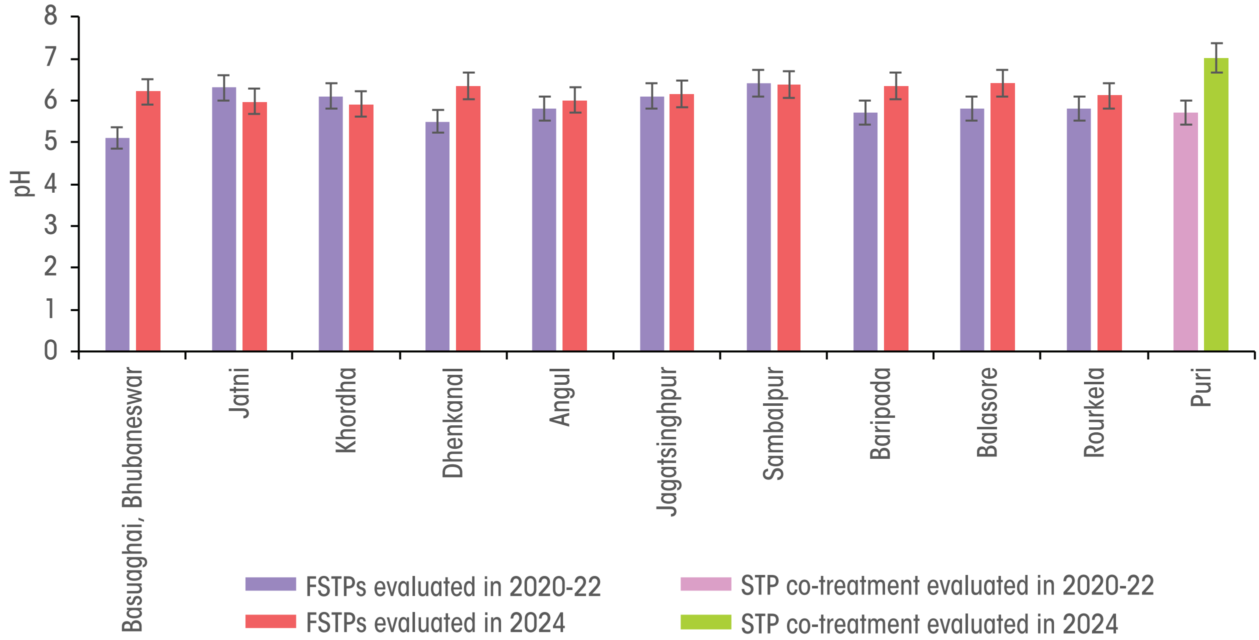
The maximum improvement in the performance of treatment plants during both the study periods was observed in Dhenkenal as its effluent quality became compliant with the MoEF&CC standards for TSS, COD and BOD in 2024. An improvement was also observed in the effluents of Basuaghai and Balasore FSTPs which became compliant for COD and BOD, Sambalpur for TSS and COD, Baripada for TSS and BOD, and Puri, Jagatsinghpur and Angul for FC. A decline in performance from 2020–22 to 2024 was observed in Jatni which became non-compliant with both the MoEF&CC and the NGT standards for TSS and FC in 2024; Jagatsinghpur for TSS and BOD; Balasore for TSS and FC; and Rourkela for BOD and FC. Only the Khordha FSTP did not show any change in performance from 2020–22 to 2024 which was also correlated with the 100 per cent capacity utilization (CU) observed in both the study periods. The performance also correlated with the CU of the treatment plants; the performance improved under two circumstances—when the CU decreased from over-utilization to under capacity (eg. Dhenkanal, Sambalpur), and when there was a slight increase in the CU within the treatment capacity of the plant (eg. Baripada, Balasore). However, when the CU increased from under capacity to over-utilization, the performance declined (eg. Rourkela). This shows the influence of incoming FS on the treatment efficiency of the plant. The compliance and non-compliance of the effluent of the treatment plants with the MoEF&CC and NGT regulatory standards for the parameters pH, TSS, COD, BOD and FC during 2020–22 and 2024 are provided in *Annexure 2 Table 2*.

9.5.3 Comparison of biosolids quality in FSTPs and STP co-treatment plant during 2020–22 and 2024

9.5.3.1 pH:

The comparison of pH in the biosolids samples of treatment plants in Odisha evaluated during 2020–22 and 2024 is shown in *Graph 39: Comparison of pH in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. The pH increased in eight plants, decreased in two plants and remained the same in one plant from 2020–22 to 2024. Of the eight plants that showed an increase, seven were non-compliant for the FCO standards during 2020–22 became compliant in 2024, indicating improvement in pH over time.

Graph 39: Comparison of pH in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024



Source: CSE

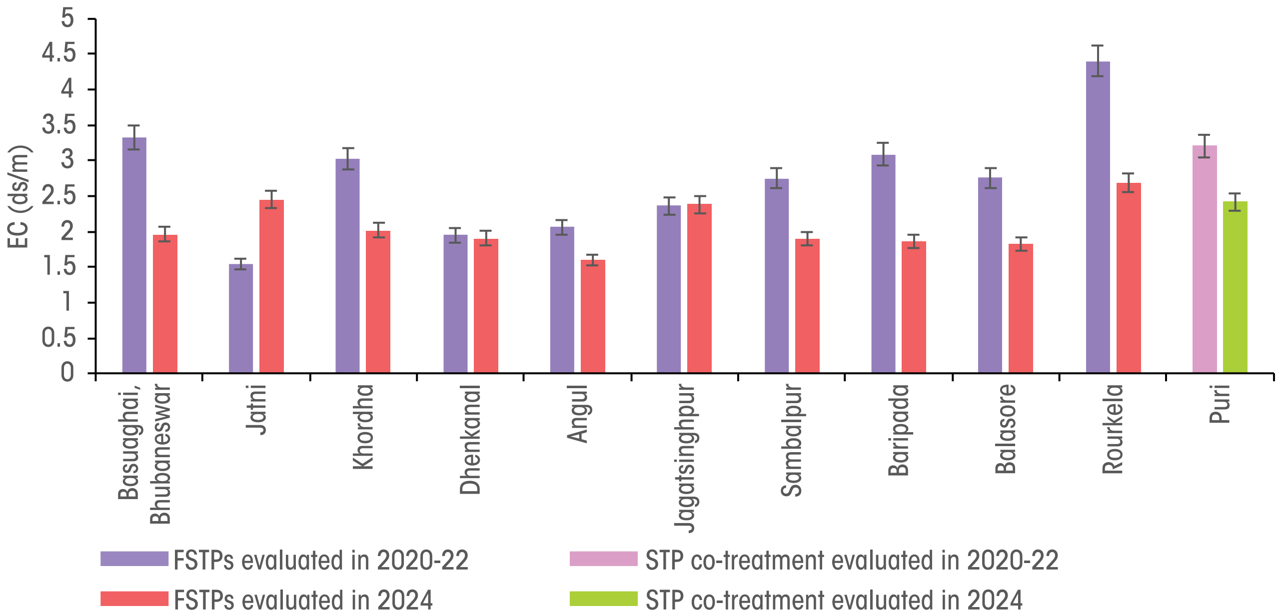
9.5.3.2 Electrical conductivity (EC)

The comparison of electrical conductivity (EC) in biosolids samples of treatment plants is shown in *Graph 40: Comparison of EC in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. Apart from two samples which showed an increase, the EC had decreased in biosolids samples from 2020–22 to 2024. However, biosolids samples from all 11 plants remained compliant with the FCO standard of city compost (≤ 6.0 ds/m) for EC during both the study periods.

9.5.3.3 Moisture content

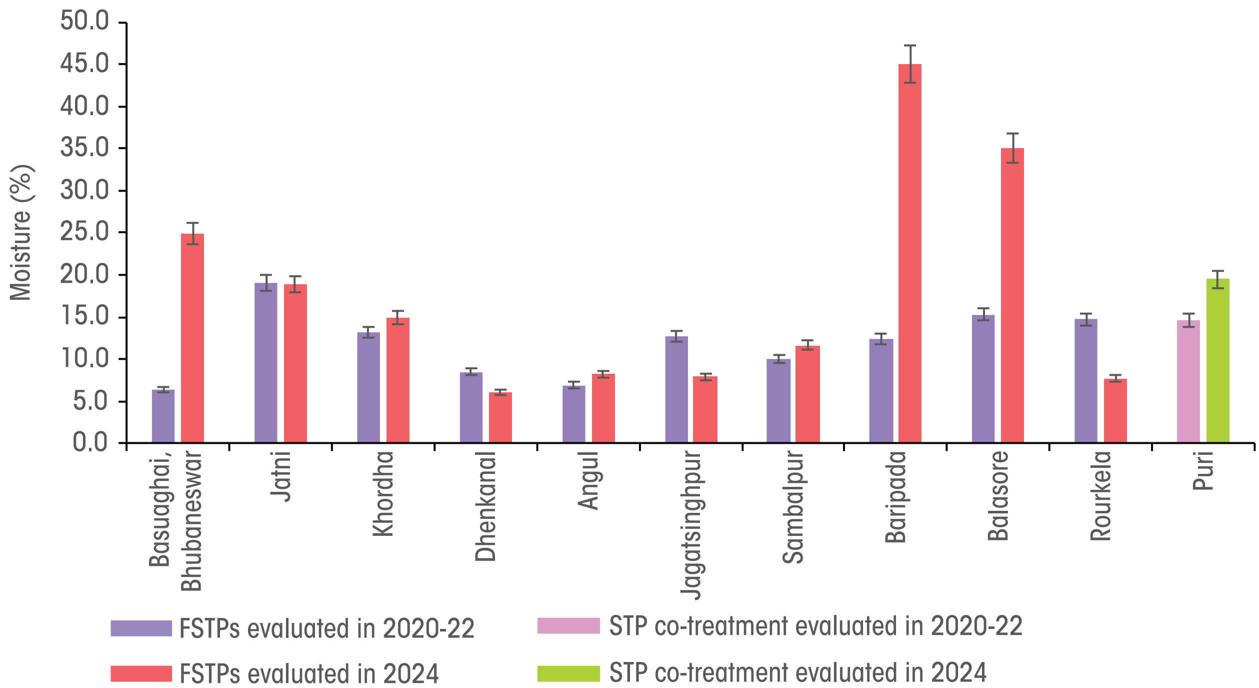
The comparison of moisture content in the biosolids samples of treatment plants is shown in *Graph 41: Comparison of moisture content in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. Biosolids samples from all 11 plants were compliant with the FCO standard (≤ 25 per cent) during 2020–22. An increase in moisture content in biosolids samples was observed in seven plants while a decrease was observed in the rest from 2020–22 to 2024. Of the seven plants that showed an increase, only two plants Baripada and Balasore showed a greater increase in moisture content at 35–45 per cent and, therefore, became non-compliant with the FCO standard. This shows the improper drying of the biosolids in these two plants.

Graph 40: Comparison of EC in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024



Source: CSE

Graph 41: Comparison of moisture content in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024

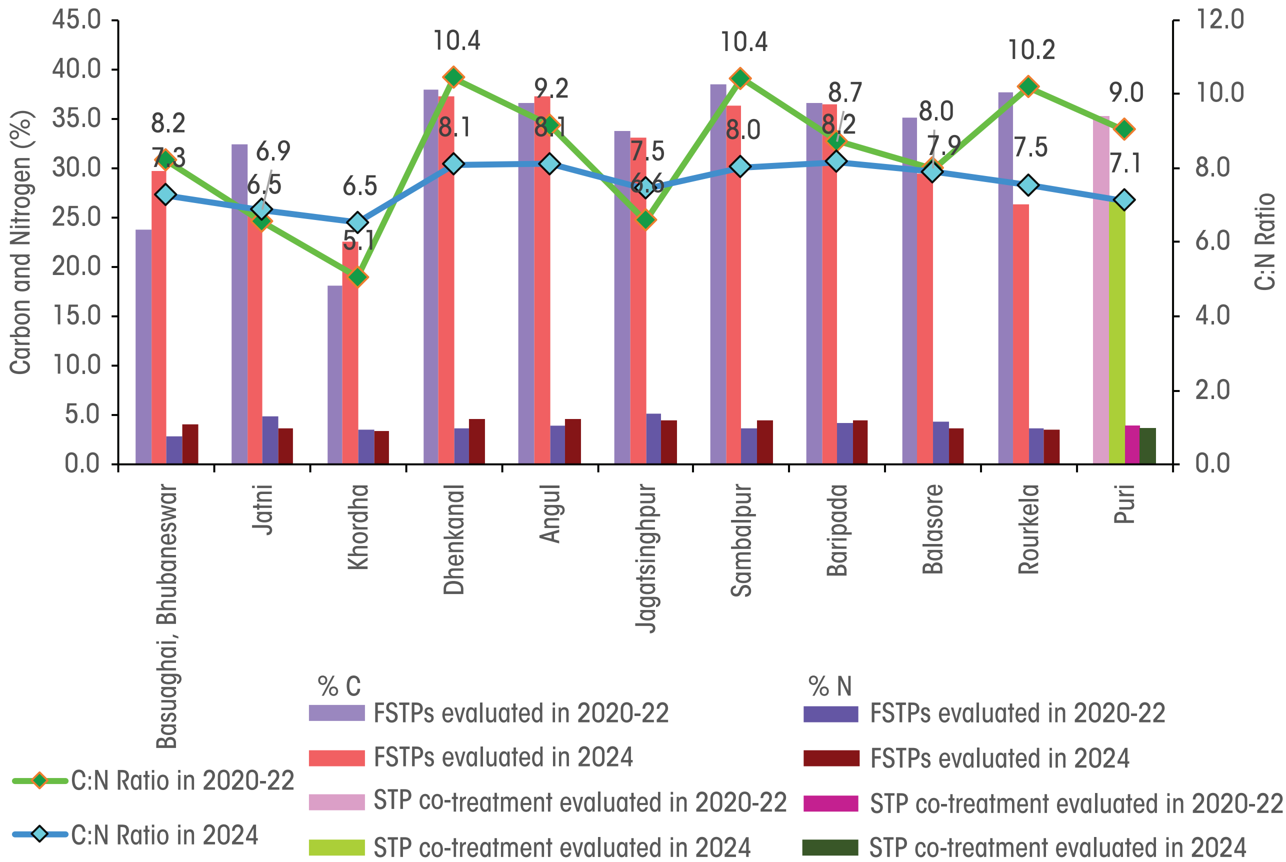


Source: CSE

9.5.3.4 Carbon and nitrogen content and carbon-to-nitrogen (C:N) ratio

The comparison of carbon, nitrogen and carbon-to-nitrogen ratio (C:N ratio) evaluated in the biosolids samples from the treatment plants is shown in *Graph 42: Comparison of carbon, nitrogen and C:N ratio in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. Although the biosolids samples showed an increase in carbon content in three treatment plants and a decrease in eight plants, it showed an increase in nitrogen content in five plants and a decrease in six plants from 2020–22 to 2024. Only a slight variation in carbon (18.1–38.5 per cent in 2020–22 and 22.6–37.3 per cent in 2024) and nitrogen (2.9–5.1 per cent in 2020–22 and 3.5–4.6 per cent in 2024) content was observed between the two study periods. Both carbon and nitrogen were complying with the FCO standard of ≥ 14 per cent by weight and ≥ 0.5 per cent by weight for carbon and total nitrogen (as N), respectively during both the study periods. The C:N ratio in the biosolids samples increased in three treatment plants and decreased in eight plants from 2020–22 to 2024. The C:N ratio in biosolids samples varied from 5.1–10.4 in 2020–22 to 6.5–8.2 in 2024. Although the C:N ratio in biosolids samples meets the recommended FCO standard

Graph 42: Comparison of carbon, nitrogen and C:N ratio in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024



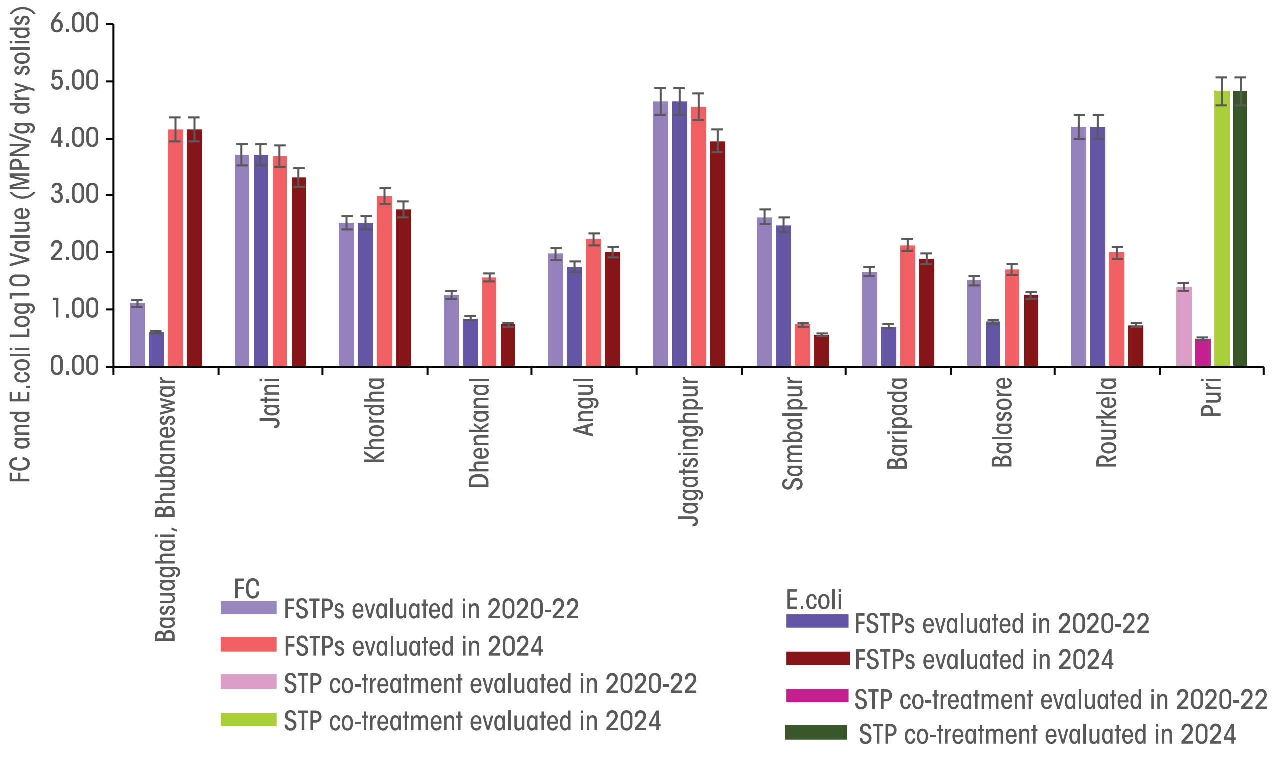
Source: CSE

(<20) in all the treatment plants during both the study periods, it is recommended that a C:N ratio of 15:1 to 20:1 is maintained for optimal growth of the plants. This can be done by increasing the carbon content in the biosolids by co-composting them with dry leaves, saw dust etc.

9.5.3.5 Faecal coliform (FC) and E. coli

The comparison of faecal coliform (FC) and *E. coli* evaluated in the biosolids samples from the treatment plants is shown in *Graph 43: Comparison of FC and E. coli in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. The FC in the biosolids samples increased in seven treatment plants and decreased in four plants, while *E. coli* increased in six plants and decreased in five plants from 2020–22 to 2024. Out of the treatment plants that showed an increase in FC and *E. coli*, the two plants at Basuaghai and Puri were compliant with the USEPA and the WHO standard of 1,000/g total dry solids ($\log_{10}$ 1000 = 3) in 2020–22. However, they became non-compliant in 2024. The Basuaghai and Puri plants showed high FC and *E. coli* content (14,595–66,549 MPN/g total dry solids [$\log_{10}$ 14595 = 4.16; $\log_{10}$ 66549 = 4.82]) in biosolids samples in 2024. This indicates improper drying and maintenance of biosolids in these two plants. Out of

Graph 43: Comparison of FC and E. coli in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024



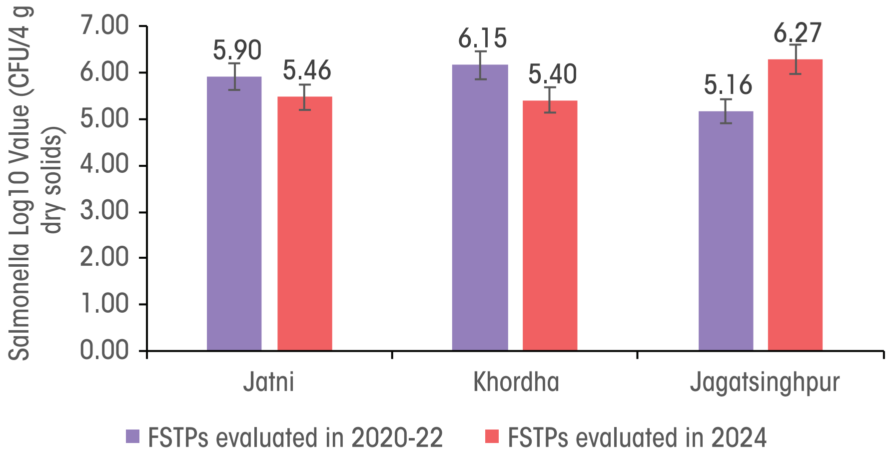
Source: CSE

the treatment plants that showed a decrease in FC and *E. coli* in biosolids, respectively only two plants at Jatni and Jagatsinghpur remained non-compliant with the USEPA/ WHO standard in both the study periods. Rourkela was non-compliant in 2020–22 but became compliant in 2024 for both FC and *E. coli* contents indicating proper drying and maintenance of the biosolids in the plant. The biosolids from six plants—Khordha, Dhenkanal, Angul, Sambalpur, Baripada and Balasore—which showed either decrease or increase in FC and *E. coli* remained compliant with the WHO standards in both the study periods.

9.5.3.6 Salmonella

Salmonella in biosolids samples was analysed from only three treatment plants in Jatni, Khordha and Jagatsinghpur during 2020–22. The comparison of *Salmonella* in biosolids samples from the three FSTPs evaluated during 2020–22 and 2024 is shown in *Graph 44: Comparison of Salmonella in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024*. *Salmonella* showed an increase of >1 $\log_{10}$ in Jagatsinghpur and a decrease of <1 $\log_{10}$ in Jatni and Khordha. However, *Salmonella* in the biosolids samples from all three plants was found to be high (1,43,596–18,61,352 CFU/4 g total dry solids [$\log_{10}$ 143596 = 5.16; $\log_{10}$ 1861352 = 6.27]) and was non-compliant with the USEPA standard of *Salmonella* for class A biosolids (=3 MPN / 4 g total dry solids [$\log_{10}$ 3 = 0.48]) during both the study periods.

Graph 44: Comparison of Salmonella in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024

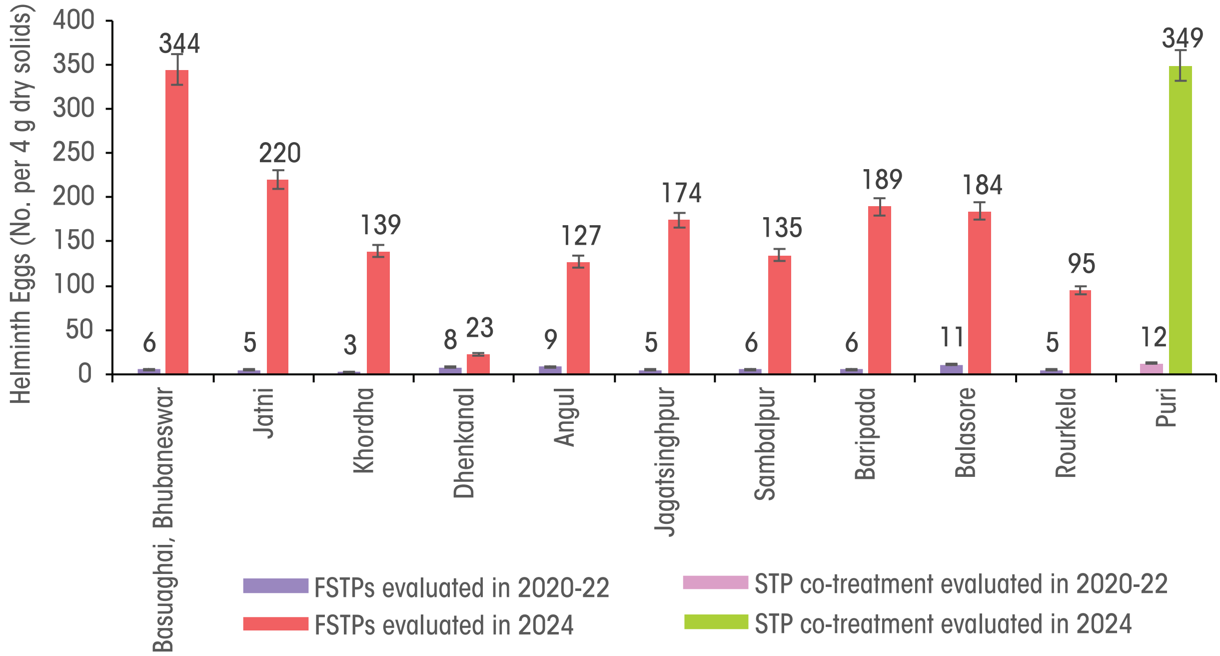


Source: CSE

9.5.3.7 Helminth eggs

The comparison of helminth eggs in biosolids samples of treatment plants is shown in *Graph 45: Comparison of helminth eggs in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024.* Although all plants were non-compliant with

Graph 45: Comparison of helminth eggs in biosolids samples of FSTP and STP co-treatment plants during 2020–22 and 2024



Source: CSE

the WHO standard of <1 helminth egg/4 g dry solids during both the study periods, a large increase was recorded in the biosolids samples from 2020–22 (3–12 eggs/ 4 g dry solids) to 2024 (23–349 eggs/ 4 g dry solids). Effective treatments like heat and lime treatment should be conducted to the biosolids samples for efficient removal of helminth eggs.

9.5.3.8 Overall performance of the treatment plants during 2020–22 and 2024 in terms of biosolids quality

The performance of the treatment plants in terms of biosolids quality from 2020–22 to 2024 was assessed based on their compliance with the FCO/USEPA/WHO standards and improvement in the moisure content and pathogen load in the biosolids. All, except two plants Baripada and Balasore, remained compliant for moisture in both the study periods; these two plants had become non-compliant in 2024. While all plants analysed remained non-compliant for helminths and *Salmonella* in both the study periods, an improvement in FC and *E. coli* compliance was recorded only in the Rourkela plant a decline was observed in two plants Basuaghai and Puri STP co-treatment, and no change was observed in the compliance in the rest of the evaluated plants. The compliance and non-compliance of biosolids measured with the FCO/USEPA/WHO regulatory standards for moisture and pathogens during 2020–22 and 2024 are provided in *Annexure 2 Table 3*.

9.6 THE FINDINGS: A SUMMARY

9.6.1 Treatment technologies

- Out of the 15 FSTPs evaluated in this study, except Dhenkanal and Angul, 13 FSTPs have the same technology which included settling-thickening tanks (STTs) for solid–liquid separation, unplanted sludge drying beds and open storage shed for drying and storage of biosolids respectively, and nature-based DEWATS technology with ABR, planted gravel filter and polishing pond for liquid/effluent treatment.

- Only a slight variation is observed in the technologies adapted at Dhenkanal and Angul FSTPs. The technology in Dhenkanal included a stabilization reactor in place of STTs, unplanted sludge drying beds followed by a sludge pasteurization unit for drying and disinfection of biosolids respectively, and a closed storage room for the storage of treated biosolids. For the liquid/effluent treatment, treatment plants used the nature-based DEWATS technology with ABR and planted gravel filter, followed by tertiary treatment units such as sand filter, carbon filter and UV disinfection, and finally a storage tank. A similar technology is adapted in Angul FSTP, with the only major difference being the presence of a greenhouse unplanted sludge drying bed for drying biosolids. Additionally, disinfection units such as a pasteurization chamber for biosolids and UV for effluent, which are present in Dhenkanal FSTP, are absent in Angul FSTP.

- Only one STP co-treatment plant situated in Puri was evaluated in this study. The technology adapted at Puri STP co-treatment included STTs for solid–liquid separation, unplanted sludge drying beds and open storage shed for drying and storage of biosolids, respectively. For effluent treatment, the effluent and leachate from the STTs and SDBs are mixed with the partially-treated water present in the aerated lagoons of the STP, followed by chlorination in chlorine contact tanks and discharged in nearby river.

9.6.2 Faecal sludge characteristics

- The faecal sludge collected from desludging vehicles at various treatment plants in Odisha showed the following characteristics: the pH was found to be in the range of 6.96–7.98. A huge variation was observed in TS and TSS which varied from 1,713 mg/L to 1,19,633 mg/L and 573 mg/L to 1,19,572 mg/L, respectively. The COD ranged from 1,595 mg/L to 87,600 mg/L whereas BOD was in the range of 227 mg/L to 10,210 mg/L. The TKN varied from 167 mg/L to 3,898 mg/L. The FC was in the range of 42,658-10,96,47,820 MPN/100 mL.

9.6.3 Treatment efficiency and effluent quality

- pH of the outlet water from the evaluated treatment plants in Odisha ranged from 6.86–7.9 which is within the 5.5–9.0 standard limits of the MoEF&CC and the NGT.

- The ‘per cent removal’ of TS varied from 7.5 per cent to 96.07 per cent in the treatment plants, however, the ‘per cent removal’ was >40 per cent in 15 out of the 16 plants. The Puri STP co-treatment has a ‘per cent removal’ of 66.42 per cent. TS in the effluent varied from 143 mg/L to 2,720 mg/L, with 663 mg/L in Puri STP co-treatment. The

TSS in the outlet of FSTPs ranged from 50.3 mg/L to 380 mg/L, with 150 mg/L in Puri. Only seven out of the 16 evaluated treatment plants complied with the MoEF&CC standard of 50–100 mg/L of TSS in their effluent, while none of the plants complied with the NGT standard of 20 mg/L.

- The 'per cent removal' of COD was >65 per cent which varied from 65.7–99.3 per cent in the treatment plants, with 83.5 per cent in the Puri STP-co-treatment. Effluent COD ranged from 9.0 mg/L to 153.3 mg/L, with 53.33 mg/L in Puri. Only seven out of the 16 evaluated treatment plants were compliant with the NGT standard of 50 mg/L COD in their effluent.

- The 'per cent removal' of BOD was >60 per cent which varied from 64.5–98 per cent across the treatment plants, with 71.7 per cent in the Puri STP co-treatment. The BOD in the outlet water ranged from 3.1 mg/L to 38.1 mg/L, with 17.8 mg/L in Puri. A total of 14 out of the 16 evaluated plants complied with the MoEF&CC standard of 20–30 mg/L of BOD in their effluent, while only three plants complied with the NGT standard of 10 mg/L.

- 'Per cent removal' of TKN varied from 10.73 per cent to 98.13 per cent across the treatment plants. However, 13 out of the 16 evaluated plants showed a 'per cent removal' of TKN at >50 per cent. The Puri STP-co-treatment showed 'per cent removal' of TKN at 78.83 per cent. Outlet TKN ranged from 9.6 mg/L to 130.8 mg/L, with 31.3 mg/L at Puri plant. Only one plant has an outlet TKN of <10 mg/L, therefore, meeting the NGT standard for total nitrogen in the treated effluent.

- The FC in the outlet of FSTPs ranged from 30 MPN/100 mL to 36,820 MPN/100 mL. The Puri STP co-treatment plant has an outlet FC of 97 MPN/100 mL. Eleven plants complied with the MoEF&CC standard of 1,000 MPN/100 mL of FC in their effluent. While only four plants complied with the desirable limit of 100 MPN/100 mL of NGT, and eight plants complied with the permissible limit of 230 MPN/100 mL.

- Effluent from only four plants Barbil, Khordha, Dhenkanal and Sambalpur complied with all the MoEF&CC standards that are available for four parameters—pH, TSS, BOD and FC. Effluent from seven plants Rokat, Basuaghai, Jatni, Angul, Jagatsingpur, Balasore and Puri complied with the MoEF&CC standards for three parameters—pH, BOD and FC—except TSS. Out of these 11 MoEF&CC-compliant plants, six plants Barbil, Dhenkenal, Sambalpur, Basuaghai, Jagatsinghpur and Balasore also complied with the only NGT standard available for COD. So, the overall performance of these six treatment plants is considered good in terms of effluent pH and for the removal of COD, BOD and FC from effluent. However, when only the NGT standards are considered, the effluent from none of the plants complied with all the five parameters; effluent from only one plant Barbil complied with four parameters pH, COD, BOD and FC; only the Dhenkanal plant complied with three parameters; and the rest of the plants complied with only two parameters.

9.6.4 Quality of biosolids

- pH of biosolids from the treatment plants in Odisha varied from 5.88–7.0. Out of the 16 evaluated treatment plants, pH in the biosolids of 14 plants complied with the FCO standard of 6.0–8.5 for organic manure.

- EC of biosolids from the treatment plants in Odisha varied from 1.3–3.95 ds/m which is within the FCO limit of ≤6.0 for city compost.

- The moisture content of biosolids from the treatment plants varied from 6.02 per cent to 51.61 per cent. A total of 12 plants complied with the FCO standard of ≤ 25 per cent by weight for organic manure.

- The total carbon content of biosolids from the treatment plants varied from 22.6–38.8 per cent while the total nitrogen content varied from 3.5–5.0 per cent. Both carbon and nitrogen content of the biosolids from all the treatment plants complied with the FCO standard of ≥ 14 per cent and ≥ 0.5 per cent for carbon and nitrogen, respectively. The C:N ratio of biosolids ranged from 7.1–9.2 which is well below the FCO standard of 20. However, a C:N ratio between 15–20 would be optimum for a biosolids sample to be used as organic manure for agricultural purposes.

- Biosolids from all the evaluated treatment plants contained heavy metals arsenic and nickel within the FCO limits. Apart from the Jatni treatment plant, lead was also below the FCO limit in the biosolids. Cadmium was above the FCO limit only at three locations, while chromium and copper were above the FCO limit in seven and eight locations, respectively. Zinc exceeded the FCO limit in 13 treatment plants. Mercury exceeded the FCO limit in all the 16 treatment plants.

- The FC and *E. coli* content in biosolids from the treatment plants varied from 4–-66,549 MPN/g total dry solids. Out of the 16 treatment plants evaluated, biosolids from 10 plants and 12 plants, respectively were compliant with the USEPA/WHO standard limit of 1,000/g dry solids for FC and *E. coli*.

- *Salmonella* in biosolids from the treatment plants ranged from 3,484 MPN/4 g to 27,39,140 MPN/4 g total dry solids which is well above the USEPA standard of <3 MPN/4 g total dry solids for class A biosolids.

- Helminth eggs in biosolids from the treatment plants ranged from 23–349 eggs/4 g total dry solids which is above the WHO standard limit.

- Usually, there will be a positive correlation between mositure content and pathogen load in biosolids samples i.e. as moisture content increases, pathogen load increases and vice versa. However, in this study, no correlation was observed between moisture content and pathogen load in the six biosolids samples with high pathogen load but moisture below the FCO limit. The same was also observed with the four biosolid samples with high moisture content but pathogen content within the FCO limit. This comparison was made between FC, *E. coli* content and moisture but not with

Salmonella and helminth eggs as these two pathogens were much greater than the USEPA/WHO standards in all the biosolids samples.

- It was also observed that pasteurization was effective at reducing the load of helminth eggs in biosolids. The lowest number of helminth eggs (23 eggs/4 g total solids) were observed in the biosolids from Dhenkanal which is equipped with a pasteurization unit.

9.6.5 Quality of co-compost

- A pilot study was initiated at Jatni municipality which consisted of making four batches of co-compost by mixing biosolids from the FSTPs and organic wet waste from MCC in varying quantities. Windrow composting with biosolids and organic wet waste in a ratio of 1:3 was performed for Batches 2, 3 and 4, while tub composting and 1:2 ratio for Batch 1. While small quantities of dry leaves were used for Batches 1, 2 and 3, cow dung was used for only Batch 3.

- pH in the Jatni co-compost samples ranged from 5.28–7.33. Except the mixture of Batches 1, 2 and 3, all the four co-compost batches complied with FCO limit of 6.0–8.5 for pH.

- EC in the Jatni co-compost samples ranged from 1.08–3.63 which is below the FCO limit of <6 ds/m.

- Moisture content in the Jatni co-compost samples ranged from 5.46–39.2. Except in Batch 4, moisture content in all other samples was below the FCO limit of 25 per cent.

- The carbon content in Jatni co-compost samples varied from 12.7–21.7 per cent while the nitrogen content ranged from 1.3–5.3 per cent. Except the 45–days and 90–days co-compost samples of Batch 4 for carbon, all other co-compost samples complied with the FCO standards of ≥ 14 per cent by weight and ≥ 0.5 per cent by weight for carbon and total nitrogen (as N), respectively. The C:N ratio varied from 3.5–10.4 which is compliant with the FCO standard of <20. Apart from the mixture of Batches 1, 2 and 3 sample (which had high nitrogen content and hence low C:N ratio), there was a reduction in carbon and nitrogen and an increase in the C:N ratio (from 6.9 to ≥ 9.4) of co-compost samples as compared to biosolids in Jatni treatment plant. A C:N ratio of 15–20 is beneficial for agricultural purposes.

- The FC and *E. coli* content varied from 4–17,118 MPN/g total dry solids in the Jatni co-compost samples. While the Jatni biosolids did not comply with the USEPA/WHO standard of 1,000/g total dry solids for FC and *E. coli*, except Batch 3 (for FC), and Batch 4, 45–days sample (for both FC and *E.coli*), all other co-compost samples complied with the USEPA/WHO standards indicating that co-composting reduces the microbial and pathogen content. This is because of the increase in temperature during the composting process.

- *Salmonella* in the Jatni co-compost samples varied from 305–21,96,403 MPN/4 g total dry solids which is much above the USEPA standard of <3 MPN/4 g total dry solids for class A biosolids, and hence, they are not suitable for applications listed for class A biosolids.

- The quality of all the four batches of co-compost is good in terms of pH, EC, carbon, nitrogen and C:N ratio. However, an increase in C:N ratio (15–20) is recommended for all batches. Moisture content needs to be reduced in Batch 4 samples. All the four batches of co-compost were also good in terms of FC and *E. coli* but not for *Salmonella*. High moisture content and less storage/drying period might be the reasons for high *Salmonella* content observed in Batch 4 samples as compared to the other three batches.

9.6.6 Evaluation of long-term performance of treatment plants

- Eleven plants—Basuaghai, Jatni, Khordha, Dhenkanal, Angul, Jagatsinghpur, Sambalpur, Baripada, Balasore, Rourkela and Puri—were re-evaluated in this study to understand their long-term performance and sustainability.

9.6.6.1 Capacity utilization

- Four plants Jagatsinghpur, Baripada, Balasore and Rourkela showed an increase, one plant Khordha showed no variation, whereas five plants Jatni, Dhenkanal, Angul, Sambalpur and Puri displayed a decrease in the capactiy utilization from 2020–22 to 2024.

9.6.6.2 Outlet water/effluent quality

- A slight variation in pH (decreased in six plants and increased in five plants) was observed in the outlet water of the treatment plants during 2020–22 and 2024. However, pH remained compliant with both the MoEF&CC and NGT standards in all the treatment plants during both the study periods.

- Effluent TS decreased in eight plants and increased in three plants from 2020–22 to 2024. However, except in Dhenkanal, TS remained high in the treatment plants which showed a decrease in TS levels during the study periods. Rourkela effluent showed a maximum increase in TS which also correlated with its exceeded capacity utilization of 113 per cent.

- TSS in the effluent decreased in four plants and increased in seven plants from 2020–22 to 2024. While the effluent from Dhenkanal, Sambalpur and Baripada plants became compliant with the MoEF&CC standard in 2024 after a decrease in TSS, the effluent from Jatni, Jagatsinghpur and Balasore plants became non-compliant after recording an increase in TSS.

- Outlet COD decreased in eight plants and increased in three plants from 2020–22 to 2024. Effluent from Basuaghai, Dhenkanal, Sambalpur and Balasore treatment plants became compliant with the NGT standard after a decrease.

- Outlet BOD decreased in nine plants and increased in two plants from 2020–22 to 2024. Effluent from Basuaghai, Baripada and Balasore became compliant with the MoEF&CC standard after recording a decrease, while Rourkela became non-compliant after an increase in effluent.

- Outlet TKN decreased in five plants and increased in six plants from 2020–22 to 2024. Outlet TKN reduced to ≤ 25 mg/L in four plants after decrease while it ranged from 29.9 mg/L to 97.4 mg/L after an increase.

- FC in outlet decreased in five plants and increased in six plants from 2020–22 to 2024. FC in the effluent from Angul became compliant with the MoEF&CC standard after a decrease while Rourkela effluent became non-compliant after an increase; FC in the effluent from Angul and Jagatsinghpur treatment plants became compliant with the permissible limit of the NGT after a decrease, while Dhenkanal and Rourkela effluent became non-compliant after an increase; FC in the effluent from Jagatsinghpur and Puri became compliant with the desirable limit of the NGT after a decrease, while Jatni, Dhenkanal, Balasore and Rourkela effluent became non-compliant after an increase.

- When the overall performance of the treatment plants from 2020–22 to 2024 was assessed, the maximum improvement in effluent quality and in terms of becoming compliant with the MoEF&CC/NGT standards for TSS, COD, BOD or FC was observed in Dhenkanal in 2024 (showed improvement in three parameters) followed by Basuaghai, Balasore, Sambalpur and Baripada (showed improvement in two parameters) followed by Puri, Jagatsinghpur and Angul (showed improvement in one parameter). A decline in performance in terms of the effluent becoming non-compliant with MoEF&CC/NGT standards for TSS, BOD or FC was observed in Jatni, Jagatsinghpur, Balasore and Rourkela treatment plants in 2024. The Jagatsinghpur and Balasore plants, apart from showing an improvement in effluent FC, COD or BOD, showed a decline in TSS. Khordha did not show any change in performance. The performance also correlated with the capacity utilzation of the treatment plants indicating the importance of incoming FS load on the treatment efficiency of the plant.

9.6.6.3 Biosolids quality

- pH of the biosolids increased in eight plants, decreased in two plants and remained the same in one plant from 2020–22 to 2024. pH in the biosolids from seven plants Basuaghai, Dhenkanal, Angul, Baripada, Balasore, Rourkela and Puri became compliant with the FCO standards after an increase.

- EC of the biosolids decreased in nine plants and increased in two plants from 2020–22 to 2024 and remained compliant with the FCO standards in both the study periods.

- Moisture content in biosolids decreased in four plants and increased in seven plants from 2020–22 to 2024. Biosolids from Baripada and Balasore recorded an increase in moisture content and thus, became non-compliant with the FCO standards.

- Carbon content in the biosolids increased in three plants and decreased in eight plants; nitrogen content increased in five plants and decreased in six plants from 2020–22 to 2024. However, only a slight variation was observed in the carbon and nitrogen content between the two study periods—and remained compliant with the FCO limits. The C:N ratio in biosolids samples increased in three plants and decreased in eight plants from 2020–22 to 2024, and remained FCO-compliant. Although the C:N ratio was FCO-compliant during both the study periods, it was considerably less (≤ 10) as compared to the recommended C:N ratio of 15–20 required for optimal plant growth.

- FC increased in biosolids samples in seven plants and decreased in four plants while *E. coli* increased in six plants and decreased in five plants from 2020–22 to 2024. Biosolids from Basuaghai and Puri recorded a large increase in FC and *E. coli* and, thus, became non-compliant with the USEPA/WHO standards while that of Rourkela became compliant for both FC and *E. coli* after a decrease.

- *Salmonella* decreased in biosolids at Jatni and Khordha treatment plants, increased in Jagatsinghpur, and remained non-compliant with the USEPA standard for class A biosolids during both the study periods.

- Helminth eggs showed a large increase in biosolids in almost all the plants and remained non-compliant with the WHO standards during both the study periods.

- Performance of the treatment plants in terms of biosolids quality was assessed based on the improvement (compliance with FCO/USEPA/WHO standards) in the moisure content and pathogen load in the biosolids from 2020–22 and 2024. All, except two plants Baripada and Balasore, remained compliant for moisture in both the study periods; these two plants became non-compliant in 2024. While all the analysed treatment plants remained non-compliant for helminths and *Salmonella* in both the study periods, an improvement in FC and *E. coli* compliance was observed only in the Rourkela plant, a decline was observed in Basuaghai and Puri STP co-treatment plant, and no change was recorded in the compliance in all the other plants.

- A few plants showed improvement (in terms of compliance with respective standards) in effluent quality but showed a decline in biosolids quality and vice-versa, from 2020–22 to 2024. The Basuaghai treatment plant (for COD, BOD) and the Puri STP co-treatment plant (for FC) showed an improvement in the effluent quality but a decline in biosolids quality (for FC, *E. coli*); whereas Rourkela showed a decline in effluent quality (BOD, FC) but improvement in biosolids quality for pathogen indicators FC and *E. coli* from 2020–22 to 2024.

9.7 RECOMMENDATIONS

9.7.1 Measures to improve the treatment efficiency and effluent quality

As TSS, COD, TKN and pathogens are found to be in high amounts in majority of the evaluated treatment plants in this study, we have provided several approaches to reduce these parameters in the DEWATS system, which is the only technology used in the FSTPs and the STP co-treatment plant in Odisha.

- **9.7.1.1 Reduce suspended solids content:** In the DEWATS system employed in all the treatment plants to treat FS effluent, the maximum reduction of TSS and TDS occurs in both anaerobic baffled reactors (ABR) with anaerobic filter and the planted gravel filter (PGF). However, several factors play a role for optimal TSS and TDS removal in these units. Managing hydraulic retention time (HRT) and solids retention time (SRT) in ABR, which not only provides sufficient time for biological degradation but also helps maintain a healthy microbial population (by removing excess solids which otherwise mask the microbes), will improve TSS/TDS removal. pH and nutrients such as nitrogen and phosphorus of effluent water also play a major role in TSS/TDS removal by microbes in ABR as the optimal pH and sufficient nutrients are required for efficient microbial activity. The management of water flow will also improve TSS and TDS removal from PGF. It does so by preventing the settling of sediment. Maintaining a healthy and optimal plant growth by providing adequate light and nutrients (overgrown plants should be trimmed to prevent excessive organic matter build-up), and regular removal of accumulated debris such as leaves, plant matter and large particles from the surface of the PGF beds also contribute to TSS and TDS removal from PGF. Additionally, maintaining an optimal pH and ammonia levels in the PGF will also improve TSS/TDS removal by promoting growth of microbes involved in the biodegradation of organic matter.

- **9.7.1.2 Reduce COD levels:** COD and TSS are related parameters comprised of both biodegradable and non-biodegradable components of the organic matter. Hence, similar to TSS reduction, COD reduction in FS effluent also occurs in ABR and PGF of DEWATS where both the physical (to remove non-biodegradable contaminants) and biological (to remove biodegradable contaminants) treatment occurs. Hence, the same approaches which improve TSS removal in ABR and PGF also apply to COD reduction. However, a few additional procedures can also be used to improve COD removal. Some of them include—controlling the organic loading rate to prevent overloading and hindering microbial activity; proper mixing of components in each compartment to ensure even distribution of organic matter for enhanced microbial activity; using media filters to improve biomass retention, and promoting the growth of efficient methanogenic bacteria. Regular monitoring of effluent quality by evaluating parameters such as TSS, COD, ammonia, nitrite, and nitrate should be done to assess the efficiency of ABR and PGF and also to identify any potential issues.

- **9.7.1.3 Reduce nitrogen content:** Nitrogen is primarily removed from wastewater by the processes of nitrification and denitrification which are biological processes.

In nitrification, ammonia is oxidized into nitrite and then into nitrate by autotrophic bacteria (bacteria that use ammonia as an energy source) under aerobic conditions, whereas denitrification involves the conversion of nitrate into nitrogen gas by bacteria under anaerobic conditions. These processes occur in both ABR and PGF and can be optimized to enhance nitrogen removal. To reduce nitrogen in ABR, nitrite and nitrate can be recycled to the inlet of the ABR to reduce them through denitrification. In PGF, apart from the nitrification-denitrification processes, plants can also effectively reduce nitrogen content in the effluent as they use nitrogen as a source of nutrient from the effluent. Hence, maintaining healthy plants in PGF beds will improve nitrogen removal. As nitrification and denitrification processes occur under aerobic and anaerobic conditions respectively, the use of deeper substrate (sand and gravel) layers in the filter bed will enhance nitrogen removal by promoting aerobic conditions in the top layers and anaerobic conditions in the deeper layers. This will promote both the processes in the bed simultaneously for nitrogen removal.

- **9.7.1.4 Reduce pathogen content:**[19] Incorporating a dedicated disinfection step with technologies like ultraviolet (UV) radiation, chlorine, or ozone at the end of the treatment process of the DEWATS system is essential to reduce pathogen load in FS effluents containing high pathogen. These technologies have both advantages and disadvantages, apart from maintenance requirements, which is necessary for optimal performance. Chlorination requires the optimization of chlorine dosage and contact time for effective treatment. Organic content and high ammonia in the effluent reduces chlorine disinfection as organic content utilises free chlorine as well as masks microbes from treatment whereas ammonia results in the formation of undesired less-efficent disinfection products hence, solid content should be minimum before chlorination. The use of sand and carbon filter before the chlorination step will reduce (finer) solids content and prove beneficial. Chlorination is a cost-effective and simple technology, however, it is effective only against bacterial and viral pathogens with normal envelopes. It is not effective against protozoan cysts and helminth eggs which have tougher envelopes. Although ozonation is not cost-effective, it is effective against all kinds of pathogens including protozoan cysts and helminth eggs and thus, it is more effective than chlorination. Like chlorination, ozonation requires optimization of dose and time along with a reduction of solids in the effluent for an effective performance. The optimal ozone dose for disinfection could range from 2–15 mg O_3/L depending on the organic matter of effluent. UV is a physical disinfection process, unlike chlorination and ozonation which are chemical disinfection processes, and does not produce undesirable by-products in the effluent. UV radiation provides effective treatment of bacteria, protozoa, and some viruses. Factors affecting UV (UV–C) include high solids content and microbial biofilms which reduce the treatment efficency by either shielding the microbes or absorbing UV radiation, thereby reducing disinfection. Lamp sleeve fouling and lamp aging can also affect the efficiency of UV against pathogens. Hence, it requires regular monitoring, cleaning and replacement. UV is preferred over chlorination as it is safer to use. Using sand and carbon filter before ozonation and UV will reduce (finer) solids content and prove advantageous for effective disinfection.

9.7.2 Measures to improve biosolids quality

Some measures to reduce moisture, pathogens and heavy metals that are present in high levels in the evaluated biosolids are provided below.

- **9.7.2.1 Adequate drying of biosolids is essential to reduce pathogen load:** FS biosolids generated in the FSTPs are a rich source of both pathogens and nutrients. Adequate drying of biosolids is essential as high moisture content promotes microbial growth; water in biosolids will promote the multiplication of micro-organisms including pathogens, by making the nutrients in a readily utilizable (dissolved) form as compared to dry biosolids.

  Sun drying of FS in sludge drying beds (SDBs) is the most common method used in many FSTPs and was also observed in all the 16 treatment plants in Odisha evaluated in this study. The dried faecal sludge/biosolids removed from the SDBs are in the form of larger-sized flakes which mostly remain dry on their outer layers while the inner layers are wet. This can be reduced by optimizing sludge loading and drying time in the SDBs. The drying period must be extended for a longer period of time along with regular turning of biosolids in the SDBs in order to reduce moisture content in biosolids. Pulverization, a process of breaking down the larger solid material into smaller pieces (powder form) by using mechanical equipment, can be applied to the larger biosolids flakes from SDBs to ensure adequate drying throughout (including the inside portion of) the biosolids. Pulverization, followed by drying or heat treatment, is one of the best methods to reduce pathogen content including helminth eggs in biosolids. As pulverization increases the OpEx of the FSTP, it can only be used in locations where it is highly essential—regions receiving frequent rain and coastal regions.

- **9.7.2.2 Proper storage of dried biosolids is required to prevent pathogen regrowth:** Biosolids are a rich source of nutrients that can promote luxuriant growth of microbes including pathogens when they are exposed to moisture and subjected to contamination. Hence, appropriate storage of dried biosolids—specifically from contamination through storm water run-off and exposure to animal faeces—is crucial to prevent pathogen regrowth. Microbial/pathogen regrowth is reported in several studies especially for FC, *E. coli* and *Salmonella*. From the studies, it was found that while the regrowth of FC and *E. coli* mainly occurs from indigenous sources, the regrowth of *Salmonella* is expected to occur exclusively from external sources such as contamination with animal faeces.[20] Hence, the use of a closed storage room to preserve biosolids (as observed in Dhenkanal and Angul) is highly recommended in the FSTPs in a coastal state like Odisha to prevent from pathogen re-inoculation and multiplication. It was also noted that long term storage (>one year) of biosolids also reduces pathogens such as *Salmonella* and helminth eggs.

- **9.7.2.3 Treatment of biosolids is indispensable if complete elimination of pathogens is required:** Solar drying employed in SDBs in all the evaluated FSTPs can cause maximum reduction of pathogen content, if ideally performed. However, due to the practical difficulty for optimally providing solar drying for all the FS received, a complete pathogen removal cannot be ensured. Treatments involving use of certain chemicals or thermal treatment might be required for a complete removal. Chemicals like lime and acids are commonly employed for this purpose. Lime doses of 20–40 per cent dry weight basis can inactivate 6–8 log_{10} faecal coliforms, 5–7 log_{10} *Salmonella* and 4–5 log bacteriophages in post-stabilized and dewatered sludge by increasing pH to >12. Using 550 ppm of peracetic acid in sludge with high pathogen content has shown an inactivation of 5–6 log_{10} faecal coliform and 4–5_{10} log *Salmonella* in just 10 minutes. Unlike bacterial pathogens which are effectively inactivated using chemical treatments described above, helminth eggs are highly resistant to treatment as they have hard envelopes. Hence, their inactivation levels are decreased; the same doses/duration of lime and peracetic acid described above can cause inactivation of only 0.5–2 log_{10} and 2–3 log_{10} helminth ova, respectively. Thermal treatment at 108°C, irradiation at 3500 Gy and pasteurization at 70°C are some of the most effective technologies for inactivating helminth eggs in sewage sludge and can also be applied to FS biosolids. Additionally, solar drying can remove a considerable amount of helminth eggs.[21]

- **9.7.2.4 Keep heavy metals in safe limits:** FS biosolids are rich in organic matter and nutrients required for plant growth. They also contain heavy metals. To ensure that the FS biosolids are safe as an organic fertilizer or soil conditioner, it is important to comply with the FCO standards for organic manure. Heavy metals are essential. However, when present in excessive amounts it can be highly toxic to plants, animals, and humans. Several methods are available to remove heavy metals from biosolids including chemical precipitation, adsorption, ion exchange, membrane filtration, electrodialysis, biosorption, bioremediation, and electrochemical treatment. The most suitable method depends on the type and amount of heavy metals present, the desired level of removal, cost and operational feasibility and its environmental impact. In this study, zinc, copper and chromium were found to be high in biosolids from several locations, while cadmium and lead were high in others. Zinc can be removed from biosolids using sulfuric acid/acetic acid and hydrogen peroxide extraction, precipitation, etc.[22] Lead can be removed from biosolids using microwave irradiation, photocatalysis, and bioleaching.

In conclusion, the FSTPs and the co-treatment plant in Odisha are working fairly well. Of the 16 FSTPs we analysed, there were 10 FSTPs whose evaluation had been done in 2022–2024 and accordingly, recommendations have been provided in this study. When we re-evaluated them, we found a variation in their performance. Some of the FSTPs in Dhenkanal, Basuaghai, Balasore, Sambhalpur, Baripada, Jagatsinghpur and Angul had, in fact, implemented the recommendations and had improved their performance. The other three FSTPs, which were non-compliant to national standards with respect to performance output, was mainly due to poor operation and maintenance. The non-compliance was based on certain parameters (TSS, BOD, COD, FC) and it was not due to any major design, mechanical or civil issues but was mainly of ignorance in operation and management. The observations indicate that the units in the treatment process are not maintained in accordance with the standard operating procedures. For example, the hydraulic retention time (HRT) of the PGF is not optimally followed or the backwashing of the sand filters is not done periodically. Additionally, the optimal retention time of the treated water in the polishing pond is not carried out. Regarding biosolids, the issues were mainly seen in terms of moisture content and consequently in the pathogen load. Moisture content and pathogen load are directly related to the retention time within the SDB (13 days, as mandated by the USEPA) or the pasteurization unit (as mandated by the contractor). These are minor operation and management issues which can be addressed with skill improvement and training of the plant operators. It is recommended that a customized hands-on training for plant operators be arranged to train and mitigate these issues. This will surely enhance the performance of the FSTPs in Odisha.

REFERENCES

1. Anon. 2018. *Odisha's Journey of Faecal Sludge and Septage Management: Towards sustainable sanitation goals* 2018. Ernst & Young LLP.

2. Anon. 2023. *O.A. No. 606 of 2018, Compliance of Solid Waste Management Rules, 2016, Sewage & Septage Management of the State of Odisha*, Government of Odisha.

3. Ibid.

4. Zaleski K.J., Josephson K.L., Gerba C.P., Pepper I.L. 2005. *Potential regrowth and recolonization of salmonellae and indicators in biosolids and biosolid-amended soil*, Applied and Environmental Microbiology. DOI: 10.1128/AEM.71.7.3701-3708.2005.

5. Vinod Vijayan, Kalyana Chakravarthy Sama, Arvind Singh Senger, Ashitha Gopinath, Megha Tyagi and Saumya 2024, *Standard Operating Procedure for Testing Wastewater, Faecal Sludge and Biosolids*, Centre for Science and Environment, New Delhi.

6. Ibid.

7. American Public Health Association, American Water Works Association and Water Environment Federation 24th Edition 2023. *Standard methods for the examination of water and wastewater*. Washington, DC, USA.

8. Food Safety and Inspection Service, United States Department of Agriculture 2024. *Microbiology Laboratory Guidebook*, 1-8. Appendix 2.05: Most Probable Number Procedure and Tables.

9. Vinod Vijayan, Kalyana Chakravarthy Sama, Arvind Singh Senger, Ashitha Gopinath, Megha Tyagi and Saumya 2024, *Standard Operating Procedure for Testing Wastewater, Faecal Sludge and Biosolids*, Centre for Science and Environment, New Delhi.

10. Anon. 2014. Method 1680: Fecal coliforms in sewage sludge (biosolids) by multiple tube fermentation using Lauryl Tryptose Broth (LTB) and EC Medium, *United States Environment Protection Agency*, Washington DC, USA.

11. P. Moodley, C. Archer, D. Hawksworth, L. Leibach 2008, Standard methods for the recovery and enumeration of helminth ova in wastewater, sludge, compost and urine-diversion waste in South Africa: Report to the Water Research Commission, Water Research Commission.

12. Sunita Narain, Vinod Vijayan and others 2023, *Evaluation of FSTPs and STP Co-treatment Systems across India: An insight into technology and performance*, Centre for Science and Environment, New Delhi.

13. Sunita Narain, Vinod Vijayan and others 2023, *Biosolids: A Report*, Centre for Science and Environment, New Delhi.

14. Sunita Narain, Arvind Singh Senger, Sama Kalyana Chakravarthy, Megha Tyagi, Ashitha Gopinath and Vinod Vijayan 2023, *Quality Assessment of Compost Produced In Different Locations of Haryana, Uttar Pradesh and Odisha*, Centre for Science and Environment, New Delhi.

15. Zaleski K.J., Josephson K.L., Gerba C.P., Pepper I.L. 2005. *Potential regrowth and recolonization of salmonellae and indicators in biosolids and biosolid-amended soil*, Applied and Environmental Microbiology. DOI: 10.1128/AEM.71.7.3701-3708.2005.

16. Kalyana Chakravarthy Sama and Vinod Vijayan 2023. *Streamlining pathogen management in FSTPs: Effective technologies and operational guidelines*, Centre for Science and Environment, New Delhi.

17. Sunita Narain, Ashitha Gopinath and others 2024, *Monitoring and Evaluation of FSTPs and STP Co-treatment Plants in Uttar Pradesh*, Centre for Science and Environment, New Delhi.

18. Zaleski K.J., Josephson K.L., Gerba C.P., Pepper I.L. 2005. *Potential regrowth and recolonization of salmonellae and indicators in biosolids and biosolid-amended soil*, Applied and Environmental Microbiology. DOI: 10.1128/AEM.71.7.3701-3708.2005.

19. Kalyana Chakravarthy Sama and Vinod Vijayan 2023. *Streamlining pathogen management in FSTPs: Effective technologies and operational guidelines*, Centre for Science and Environment, New Delhi.

20. Zaleski K.J., Josephson K.L., Gerba C.P., Pepper I.L. 2005. *Potential regrowth and recolonization of salmonellae and indicators in biosolids and biosolid-amended soil*, Applied and Environmental Microbiology. DOI: 10.1128/AEM.71.7.3701-3708.2005.

21. B.E. Jimenez-Cisneros 2007. *Helminth ova control in wastewater and sludge for agricultural reuse*, Water and Health [Ed.W.O.K. Grabow], Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK. Available at http://www.eolss.net.

22. Driss Barraoui, Jean-François Blais, Michel Labrecque 2021. Cleanup of sewage sludge spiked with Cd, Cu, and Zn: Sludge quality and distribution of metals in the "soil-plant-water" system, *Chemosphere*.Available at https://doi.org/10.1016/j.chemosphere.2020.129223.

23. CPCB 2024, Guidelines for reuse of treated sewage in reference to item of circular economy.

ANNEXURES

ANNEXURE 1

Table 1: Effluent Discharge standards for treated effluent of STPs[23]

Sl. No.	Parameters	Norms as per NGT direction dated 30/04/2019 in the matter of OA No 1069 of 2018	MoEF&CC Notification dated October 2017	
			Cities (more than 10 lakh population)	Areas/ regions other than mentioned above
1	pH	5.5–9.0	6.5–9.0	
2	BOD, mg/L	10	20	30
3	COD, mg/L	50	-	-
4	TSS, mg/L	20	50	100
5	NH4-N, mg/L	-	-	-
6	N-Total, mg/L	10	-	-
7	Faecal coliforms, MPN/100 ml	100– Desirable 230– Permissible	1000	

Note: Metro cities*, all state capitals except in Arunachal Pradesh, Assam, Manipur, Meghalaya Mizoram, Nagaland, Tripura Sikkim, Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Union territory of Andaman and Nicobar Islands, Dadar and Nagar Haveli Daman and Diu and Lakshadweep

*Metro cities are Mumbai, Delhi, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad and Pune

Table 2: Fertilizer Control Order standards for organic manure 2023

Sl. No.	Parameters	Standard
1	Moisture per cent by weight, maximum	25
2	Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
3	Bulk density (g/cm3)	<1.0
4	Total organic carbon per cent by weight, minimum	14
5	Total nitrogen (as N) per cent by weight, minimum	0.5
6	Total phosphates (as P2O5) per cent by weight, minimum	0.5
7	Total potash (as K2O) per cent by weight, minimum	0.5
8	NPK nutrients– Total N, P2O5 and K2O nutrient should not be less than 3%	
9	C:N ratio	<20
10	pH	6.0-8.5
11	Pathogen	Nil
12	Heavy metal content, (as mg/kg), maximum	
	Arsenic (as As2O3)	10
	Cadmium (as Cd)	5
	Chromium (as Cr)	50
	Copper (as Cu)	300
	Mercury (as Hg)	0.15
	Nickel (as Ni)	50
	Lead (as Pb)	100
	Zinc (as Zn)	1000

*The term electrical conductivity and its limit is not mentioned in FCO 2023 for organic manure; however, it is mentioned in FCO 2013 for organic manure as <4 dS/m.

Table 3: Global standards for pathogens in biosolids

Sl. No.	Type of organism	Standard	Regulatory body	Remarks
1.	Faecal coliform	1000 MPN per gram total dry solids	USEPA	Pathogen Class A (ceiling concentration limits for all biosolids applied to land). For all biosolids applied to all land types: agricultural land, forests, reclamation sites, and lawns and home gardens
2.	E. coli	1000 per gram total dry solids	WHO (2006)	Faecal sludge reuse in agriculture
3.	Salmonella	3 MPN per 4 grams of total dry solids	USEPA	Pathogen Class A (ceiling concentration limits for all biosolids applied to land). For all biosolids applied to all land types: agricultural land, forests, reclamation sites, and lawns and home gardens
4.	Helminth eggs	<1 egg per 4 grams of total dry solids	WHO	Faecal sludge reuse in agriculture

ANNEXURE 2

Table 1: Compliance and non-compliance of the effluent with MoEF&CC and NGT regulatory limits of various parameters (NA – Not applicable)

Parameter	pH		TSS (mg/L)			COD (mg/L)	BOD (mg/L)			Faecal coliform (MPN/100 mL)		
Regulatory authority	MoEF&CC	NGT	MoEF&CC		NGT	NGT	MoEF&CC		NGT	MoEF&CC	NGT	
			(Cities >10 lakh population)	(Regions <10 lakh population)			(Cities >10 lakh population)	(Regions <10 lakh population)			Desirable	Permi-ssible
Limit	6.5-9.0	5.5-9.0	50	100	20	50	20	30	10	1000 (=Log10 3)	100 (=Log10 2)	230 (=Log10 2.36)
Rokat	Compliant	Compliant	NA	Non-compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Non-compliant
Sonepur	Compliant	Compliant	NA	Non-compliant	Non-compliant	Compliant	NA	Compliant	Compliant	Non-compliant	Non-compliant	Non-compliant
Barbil	Compliant	Compliant	NA	Compliant	Non-compliant	Compliant	NA	Compliant	Compliant	Compliant	Compliant	Compliant
Basudevpur	Compliant	Compliant	NA	Compliant	Non-compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Paradeep	Compliant	Compliant	NA	Non-compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Basuaghai	Compliant	Compliant	Non-compliant		Non-compliant	Compliant	Compliant		Non-compliant	Compliant	Non-compliant	Non-compliant
Jatni	Compliant	Compliant	NA	Non-compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant
Khordha	Compliant	Compliant	NA	Compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant
Dhenkanal	Compliant	Compliant	NA	Compliant	Non-compliant	Compliant	NA	Compliant	Compliant	Compliant	Non-compliant	Non-compliant
Angul	Compliant	Compliant	NA	Non-compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant
Jagat-singhpur	Compliant	Compliant	NA	Non-compliant	Non-compliant	Compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant
Sambalpur	Compliant	Compliant	NA	Compliant	Non-compliant	Compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant
Baripada	Compliant	Compliant	NA	Compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Balasore	Compliant	Compliant	NA	Non-compliant	Non-compliant	Compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant
Rourkela	Compliant	Compliant	NA	Compliant	Non-compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Puri	Compliant	Compliant	NA	Non-compliant	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant
Total plants compliant	16	16	0	7	0	7	1	13	3	11	4	8
Total plants non-compliant	0	0	1	8	16	9	0	2	13	5	12	8

Table 2: Compliance and non-compliance of the effluent with MoEF&CC and NGT regulatory limits of various parameters during 2020–22 and 2024 (NA- Not Applicable)

Parameter	pH				TSS (mg/L)						COD (mg/L)	
Period of study	2020-22		2024		2020-22			2024			2020-22	2024
Regulatory authority	MoEF&CC	NGT	MoEF&CC	NGT	MoEF&CC		NGT	MoEF&CC		NGT	NGT	NGT
					(Cities >10 lakh population)	(Regions <10 lakh population)		(Cities >10 lakh population)	(Regions <10 lakh population)			
Limit	6.5-9.0	5.5-9.0	6.5-9.0	5.5-9.0	50	100	20	50	100	20	50	50
Basuaghai	Compliant	Compliant	Compliant	Compliant	Non-compliant	NA	Non-compliant	Non-compliant	NA	Non-compliant	Non-compliant	Compliant
Jatni	Compliant	Compliant	Compliant	Compliant	NA	Compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Khordha	Compliant	Compliant	Compliant	Compliant	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant
Dhenkanal	Compliant	Compliant	Compliant	Compliant	NA	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Compliant
Angul	Compliant	Compliant	Compliant	Compliant	NA	Non-compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Jagat-singhpur	Compliant	Compliant	Compliant	Compliant	NA	Compliant	Non-compliant	NA	Non-compliant	Non-compliant	Compliant	Compliant
Sambalpur	Compliant	Compliant	Compliant	Compliant	NA	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Compliant
Baripada	Compliant	Compliant	Compliant	Compliant	NA	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant
Balasore	Compliant	Compliant	Compliant	Compliant	NA	Compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Compliant
Rourkela	Compliant	Compliant	Compliant	Compliant	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant
Puri	Compliant	Compliant	Compliant	Compliant	NA	Non-compliant	Non-compliant	NA	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Total plants compliant	11	11	11	11	0	5	0	0	5	0	1	5
Total plants non-compliant	0	0	0	0	1	5	11	1	5	11	10	6

Parameter	BOD (mg/L)						Faecal Coliform (MPN/100 mL)					
Period of study	2020-22			2024			2020-22			2024		
Regulatory Authority	MoEF&CC		NGT	MoEF&CC		NGT	MoEF&CC	NGT		MoEF&CC	NGT	
	(Cities > 10 Lakh Population)	(Regions < 10 Lakh Population)		(Cities > 10 Lakh Population)	(Regions < 10 Lakh Population)			Desirable	Permissible		Desirable	Permi-ssible
Limit	20	30	10	20	30	10	1000 (=Log10 3)	100 (=Log10 2)	230 (=Log10 2.36)	1000 (=Log10 3)	100 (=Log10 2)	230 (=Log10 2.36)
Basuaghai	Non-compliant	NA	Non-compliant	Compliant	NA	Non-compliant	Compliant	Non-compliant	Non-compliant	Compliant	Non-compliant	Non-compliant
Jatni	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant	Non-compliant	Compliant
Khordha	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant	Compliant	Non-compliant	Compliant
Dhenkanal	NA	Compliant	Non-compliant	NA	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Non-compliant	Non-compliant
Angul	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Compliant	Non-compliant	Compliant
Jagat-singhpur	NA	Compliant	Compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Non-compliant	Compliant	Compliant	Compliant
Sambalpur	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant
Baripada	NA	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Balasore	NA	Non-compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant	Non-compliant	Compliant
Rourkela	NA	Compliant	Non-compliant	NA	Non-compliant	Non-compliant	Compliant	Compliant	Compliant	Non-compliant	Non-compliant	Non-compliant
Puri	NA	Compliant	Non-compliant	NA	Compliant	Non-compliant	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant
Total plants compliant	0	8	1	1	9	1	9	5	7	9	3	7
Total plants non-compliant	1	2	10	0	1	10	2	6	4	2	8	4

Table 3: Compliance and non-compliance of biosolids with FCO/USEPA/WHO regulatory limits for moisture and pathogens during 2020–22 and 2024

Parameter	Moisture (Per cent by wt.)		Faecal coliform (MPN per g total dry solids)		E. coli (per g total dry solids)		Salmonella (MPN per 4 g total dry solids)		Helminths (Eggs per 4 g total dry solids)	
Period of study	2020-22	2024	2020-22	2024	2020-22	2024	2020-22	2024	2020-22	2024
Regulatory authority	FCO	FCO	USEPA Class A	USEPA Class A	WHO	WHO	USEPA Class A	USEPA Class A	WHO	WHO
Limit	25	25	1000 (=Log10 3)	1000 (=Log10 3)	1000 (=Log10 3)	1000 (=Log10 3)	3 (=Log10 0.48)	3 (=Log10 0.48)	< 1	< 1
Basuaghai	Compliant	Compliant	Compliant	Non-compliant	Compliant	Non-compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Jatni	Compliant	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Khordha	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Dhenkanal	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Angul	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Jagatsinghpur	Compliant	Compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant	Non-compliant
Sambalpur	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Baripada	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Balasore	Compliant	Non-compliant	Compliant	Compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Rourkela	Compliant	Compliant	Non-compliant	Non-compliant	Compliant	Compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Puri	Compliant	Compliant	Compliant	Non-compliant	Compliant	Non-compliant	Not analysed	Non-compliant	Non-compliant	Non-compliant
Total plants compliant	11	9	8	6	9	7	0	0	0	0
Total plants non-compliant	0	2	3	5	2	4	3	11	11	11

ANNEXURE 3

Table 1: Consolidated three-month data of physico-chemical parameters and pathogen content in FS, inlet and outlet samples collected from FSTPs and STP co-treatment plant

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Newly-evaluated FSTPs													
Rokat	April 2024	Inlet	7.30	1960	999	961	346.0	89.0	158.76	35.30	12.36	240000	5.38
		Outlet	7.28	736	116	620	115.0	28.0	113.19	52.97	6.70	36	1.56
	June 2024	Inlet	7.38	1580	618	962	336.0	88.2	160.82	127.89	14.80	23000	4.36
		Outlet	7.27	737	114	623	65.0	18.3	54.98	44.79	6.84	430	2.63
		Mean Inlet	7.34	1770	809	962	341.0	88.6	159.79	81.59	13.58	131500	5.12
		Mean Outlet	7.28	737	115	622	90.0	23.1	84.08	48.88	6.77	233	2.37
Sonepur	April 2024	Inlet	7.50	2510	1370	1140	464.0	110.0	161.41	115.78	17.68	210000	5.32
		Outlet	7.33	309	48	261	46.0	11.0	22.93	6.31	1.62	30	1.48
	June 2024	Inlet	7.39	1870	790	1080	602.0	145.1	230.79	136.30	40.40	75000	4.88
		Outlet	7.46	1075	258	817	55.0	13.6	17.05	5.34	1.06	36	1.56
	August 2024	Inlet	7.52	1261	181	1080	222.0	43.4	186.69	138.29	16.56	460000	5.66
		Outlet	7.06	526	46	480	9.0	3.4	52.04	25.58	7.08	24000	4.38
		Mean Inlet	7.47	1880	780	1100	429.3	99.5	192.96	130.13	24.88	248333	5.40
		Mean Outlet	7.28	637	117	519	36.7	9.3	30.67	12.41	3.25	8022	3.90
Barbil	April 2024	FS	7.98	14574	8124	6450	82700.0	10210.0	2078.58	1189.66	308.00	930000	5.97
		Inlet	8.01	2660	1040	1620	422.0	95.0	265.48	187.69	8.68	30	1.48
		Outlet	7.65	623	68	555	52.0	16.0	5.00	3.58	0.05	30	1.48
	June 2024	Inlet	7.87	2250	700	1550	198.0	41.7	282.53	219.46	6.90	920	2.96
		Outlet	8.77	615	59	556	2.0	0.6	14.99	10.74	0.10	30	1.48
	August 2024	Inlet	7.57	1318	168	1150	280.0	60.2	231.97	157.73	12.60	460000	5.66
		Outlet	7.29	177	62	115	9.0	3.8	8.82	2.90	0.08	30	1.48
		Mean FS	7.98	14574	8124	6450	82700.0	10210.0	2078.58	1189.66	308.00	930000	5.97
		Mean Inlet	7.82	2076	636	1440	300.0	65.6	259.99	188.29	9.39	153650	5.19
		Mean Outlet	7.90	472	63	409	21.0	6.8	9.60	5.74	0.08	30	1.48

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Basudevpur	April 2024	Inlet	7.61	2280	750	1530	624.0	161.0	219.91	160.35	13.72	11000000	7.04
		Outlet	7.59	890	48	842	270.0	63.0	66.44	46.38	10.32	430	2.63
	June 2024	FS	7.22	10268	8108	2160	29050.0	4023.5	949.62	29.61	118.00	2400000	6.38
		Inlet	7.59	1456	252	1204	506.0	122.8	148.76	103.56	11.32	150000	5.18
		Outlet	7.50	1050	40	1010	105.0	23.0	95.26	70.25	9.20	4300	3.63
	August 2024	Inlet	7.80	1373	163	1210	210.0	56.3	179.93	128.00	11.48	2400000	6.38
		Outlet	7.76	815	63	752	85.0	19.7	59.68	37.86	9.48	380	2.58
		Mean FS	7.22	10268	8108	2160	29050.0	4023.5	949.62	29.61	118.00	2400000	6.38
		Mean Inlet	7.67	1703	388	1315	446.7	113.4	182.87	130.64	12.17	4516667	6.65
		Mean Outlet	7.62	918	50	868	153.3	35.2	73.79	51.50	9.67	1703	3.23
Paradeep	April 2024	Inlet	7.33	3880	1300	2580	1162.0	296.0	202.86	148.13	16.24	43000	4.63
		Outlet	7.28	2950	70	2880	130.0	27.0	137.89	116.81	5.76	430	2.63
	June 2024	FS	7.31	4560	1780	2780	1595.0	227.2	2093.28	222.36	41.00	1500000	6.18
		Inlet	7.62	2760	260	2500	992.0	231.8	345.45	267.15	26.56	240000	5.38
		Outlet	7.79	2570	100	2470	161.0	34.9	133.77	121.64	13.48	1500	3.18
	August 2024	Inlet	7.34	2182	632	1550	1424.0	283.7	252.84	169.95	30.80	2400000	6.38
		Outlet	7.85	2640	440	2200	132.0	28.1	120.83	97.99	5.52	4600	3.66
		Mean FS	7.31	4560	1780	2780	1595.0	227.2	2093.28	222.36	41.00	1500000	6.18
		Mean Inlet	7.43	2941	731	2210	1192.7	270.5	267.05	195.07	24.53	894333	5.95
		Mean Outlet	7.64	2720	203	2517	141.0	30.0	130.83	112.15	8.25	2177	3.34
Re-evaluated FSTPs													
Basugai Bhubaneshwar	April 2024	FS	7.3	11500	10631	869	8580.0	2860.0	239.32	62.41	18.60	930000	5.97
		Inlet	7.45	1800	710	1090	178.0	68.0	160.52	27.91	13.40	9300	3.97
		Outlet	6.33	684	348	336	63.0	15.0	13.52	1.36	5.50	92	1.96
	June 2024	FS	6.98	2760	1710	1050	38650.0	4843.4	191.10	159.15	21.00	9200	3.96
		Inlet	7.11	1319	368	951	492.0	101.7	139.94	96.57	12.08	93000	4.97
		Outlet	7.06	797	91	706	39.0	13.4	24.40	11.31	4.62	750	2.88
	August 2024	FS	7.07	11338	10571	767	19700.0	3172.3	376.32	117.09	75.00	930000	5.97
		Inlet	7.26	1155	135	1020	594.0	123.2	159.05	108.56	12.92	1100000	6.04
		Outlet	7.19	460	59	401	16.0	4.8	16.17	4.77	4.52	36	1.56
		Mean FS	7.12	8533	7637	895	22310	3625	269	112.88	38.20	623067	5.79
		Mean Inlet	7.27	1425	404	1020	421.3	97.6	153.17	77.68	12.80	400767	5.60
		Mean Outlet	6.86	647	166	481	39.3	11.1	18.03	5.82	4.88	293	2.47

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Jatni	April 2024	Inlet	7.92	2410	740	1670	542.0	115.0	250.19	146.14	24.16	9300	3.97
		Outlet	7.24	643	258	385	154.0	30.0	32.93	14.04	10.22	30	1.48
	June 2024	FS	7.38	1713	573	1140	14250.0	2407.1	443.94	207.47	37.00	43000	4.63
		Inlet	7.44	1507	387	1120	572.0	145.9	214.91	156.54	20.00	460000	5.66
		Outlet	7.35	804	73	731	14.0	5.0	91.14	30.86	5.04	230	2.36
	August 2024	Inlet	7.09	581	78	503	20.0	6.4	37.04	27.91	6.10	30	1.48
		Outlet	7.02	300	20	280	9.0	3.1	14.41	13.41	4.89	430	2.63
		Mean FS	7.38	1713	573	1140	14250.0	2407.1	443.94	207.47	37.00	43000	4.63
		Mean Inlet	7.48	1499	402	1098	378.0	89.1	167.38	110.19	16.75	156443	5.19
		Mean Outlet	7.20	582	117	465	59.0	12.7	46.16	19.44	6.72	230	2.36
Khorda	April 2024	Inlet	7.72	2130	850	1280	390.0	105.0	197.57	140.62	12.48	93000	4.97
		Outlet	7.19	621	203	418	100.0	23.0	59.98	40.87	5.72	92	1.96
	June 2024	Inlet	7.89	1335	325	1010	300.0	82.9	165.82	131.58	14.72	38000	4.58
		Outlet	7.41	815	39	776	73.0	18.9	67.91	44.79	10.08	230	2.36
	August 2024	Inlet	8.21	1141	141	1000	160.0	28.8	162.88	121.24	13.08	430	2.63
		Outlet	7.41	410	54	356	42.0	14.5	34.69	20.86	9.12	92	1.96
		Mean Inlet	7.94	1535	439	1097	283.3	72.2	175.42	131.15	13.43	43810	4.64
		Mean Outlet	7.34	615	99	517	71.7	18.8	54.19	35.51	8.31	138	2.14
Dhenkanal	April 2024	Inlet	7.25	1210	665	545	34.0	8.0	20.29	4.32	4.48	30	1.48
		Outlet	7.28	103	30	73	9.0	4.0	16.17	5.51	0.28	930	2.97
	June 2024	FS	7.31	2158	568	1590	5010.0	790.2	241.08	144.09	27.00	4600000	6.66
		Inlet	7.17	1172	425	747	148.0	39.5	26.46	10.34	7.28	230	2.36
		Outlet	7.68	166	47	119	9.0	2.9	14.99	6.31	0.38	30	1.48
	August 2024	FS	7.39	2176	1166	1010	16950.0	2350.9	352.80	150.06	38.00	3600	3.56
		Inlet	7.28	1026	164	862	99.0	30.4	27.05	15.69	4.94	30	1.48
		Outlet	7.79	159	89	70	9.0	2.3	9.70	2.79	0.27	30	1.48
		Mean FS	7.35	2167	867	1300	10980	1571	297	147.07	32.50	2301800	6.36
		Mean Inlet	7.23	1136	418	718	93.7	25.9	24.60	10.12	5.57	97	1.99
		Mean Outlet	7.58	143	55	87	9.0	3.1	13.62	4.87	0.31	330	2.52

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Angul	April 2024	Inlet	7.39	2135	805	1330	78.0	28.0	17.05	11.20	7.94	30	1.48
		Outlet	7.27	1166	602	564	84.0	23.0	20.58	8.07	5.01	92	1.96
	June 2024	Inlet	7.25	1664	354	1310	122.0	36.3	59.09	52.80	6.42	4300	3.63
		Outlet	7.30	1024	24	1000	59.0	17.1	47.63	20.80	4.84	92	1.96
	August 2024	FS	6.96	4954	4372	582	16000.0	2325.6	202.86	63.09	15.00	43000	4.63
		Inlet	6.89	3636	946	2690	390.0	99.7	8.82	2.10	0.50	92	1.96
		Outlet	7.03	1415	514	901	52.0	18.1	7.64	1.14	2.81	230	2.36
		Mean FS	6.96	4954	4372	582	16000.0	2325.6	202.86	63.09	15.00	43000	4.63
		Mean Inlet	7.18	2478	702	1777	196.7	54.7	28.32	22.03	4.95	1474	3.17
		Mean Outlet	7.20	1202	380	822	65.0	19.4	25.28	10.00	4.22	138	2.14
Jagatsinghpur	April 2024	Inlet	7.2	2090	840	1250	970.0	323.0	220.50	133.06	19.68	7200	3.86
		Outlet	6.85	342	130	212	57.0	12.0	18.52	4.77	2.02	230	2.36
	June 2024	FS	7.13	2701	1825	876	1870.0	305.6	167.29	116.07	18.30	150000	5.18
		Inlet	6.96	1376	366	1010	250.0	80.1	160.82	124.59	14.96	43000	4.63
		Outlet	8.46	765	131	634	77.0	17.3	43.81	27.28	5.68	30	1.48
	August 2024	Inlet	7.55	1086	157	929	292.0	86.9	145.24	108.91	16.36	43000	4.63
		Outlet	7.53	553	61	492	9.0	2.4	40.57	23.82	5.66	30	1.48
		Mean FS	7.13	2701	1825	876	1870.0	305.6	167.29	116.07	18.30	150000	5.18
		Mean Inlet	7.24	1517	454	1063	504.0	163.3	175.52	122.19	17.00	31067	4.49
		Mean Outlet	7.61	553	107	446	47.7	10.6	34.30	18.62	4.45	97	1.99
Sambalpur	April 2024	Inlet	7.74	1860	780	1080	446.0	79.0	78.20	57.69	9.88	360	2.56
		Outlet	8.57	224	35	189	52.0	12.0	17.05	3.01	0.42	36	1.56
	June 2024	Inlet	7.11	1650	570	1080	184.0	33.1	155.82	117.72	7.02	4300	3.63
		Outlet	6.57	854	117	737	78.0	18.9	58.51	31.83	3.68	92	1.96
	August 2024	FS	7.12	47001	45011	1990	32750.0	4129.9	2925.30	151.19	230.00	11000000	7.04
		Inlet	7.46	900	161	739	99.0	20.5	17.35	7.39	4.32	430	2.63
		Outlet	7.62	326	33	293	8.0	2.6	14.11	7.73	2.94	92	1.96
		Mean FS	7.12	47001	45011	1990	32750.0	4129.9	2925.30	151.19	230.00	11000000	7.04
		Mean Inlet	7.44	1470	504	966	243.0	44.2	83.79	60.93	7.07	1697	3.23
		Mean Outlet	7.59	468	62	406	46.0	11.2	29.89	14.19	2.35	73	1.87

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Baripada	April 2024	FS	7.69	12750	11450	1300	79950.0	8192.0	496.86	138.12	40.00	2400000	6.38
		Inlet	7.49	2560	1120	1440	548.0	203.0	187.57	141.82	12.20	460000	5.66
		Outlet	7.41	980	47	933	218.0	67.0	126.13	92.82	12.12	110000	5.04
	June 2024	Inlet	7.12	3190	1930	1260	812.0	234.7	251.37	171.09	21.92	460000	5.66
		Outlet	6.98	887	28	859	47.0	16.9	48.51	31.83	4.64	430	2.63
	August 2024	Inlet	7.82	1862	322	1540	442.0	124.9	263.42	182.06	10.28	2300	3.36
		Outlet	8.22	202	80	122	9.0	2.6	10.29	2.50	7.06	30	1.48
		Mean FS	7.69	12750	11450	1300	79950.0	8192.0	496.86	138.12	40.00	2400000	6.38
		Mean Inlet	7.48	2537	1124	1413	600.7	187.5	234.12	164.99	14.80	307433	5.49
		Mean Outlet	7.54	690	52	638	91.3	28.9	61.64	42.38	7.94	36820	4.57
Balasore	April 2024	Inlet	7.31	3147	1617	1530	1884.0	278.0	354.86	173.31	45.90	460000	5.66
		Outlet	8.17	990	283	707	59.0	21.0	23.23	21.60	1.41	30	1.48
	June 2024	FS	6.99	119633	119572	61	82050.0	9126.8	3898.44	298.98	443.00	110000000	8.04
		Inlet	6.63	46049	44859	1190	10360.0	1221.7	1443.54	242.71	161.20	23000	4.36
		Outlet	7.66	751	100	651	20.0	6.7	15.29	5.29	0.84	30	1.48
	August 2024	Inlet	7.54	5726	4646	1080	2776.0	372.6	676.20	138.41	42.90	750	2.88
		Outlet	7.42	416	78	338	30.0	10.4	7.64	6.48	1.07	430	2.63
		Mean FS	6.99	119633	119572	61	82050.0	9126.8	3898.44	298.98	443.00	110000000	8.04
		Mean Inlet	7.16	18307	17041	1267	5006.7	624.1	824.87	184.81	83.33	161250	5.21
		Mean Outlet	7.75	719	154	565	36.3	12.7	15.39	11.12	1.11	163	2.21
Rourkela	April 2024	Inlet	7.2	2350	830	1520	548.0	224.0	245.49	180.81	20.12	2400000	6.38
		Outlet	7.21	1280	80	1200	163.0	55.0	118.78	84.63	6.76	2300	3.36
	June 2024	FS	7.77	70399	69269	1130	87600.0	9605.3	2478.42	447.90	385.00	4600000	6.66
		Inlet	7.43	1560	400	1160	394.0	115.2	216.09	150.46	13.12	150000	5.18
		Outlet	7.71	1250	80	1170	98.0	30.4	105.55	77.08	7.54	380	2.58
	August 2024	Inlet	7.61	1830	280	1550	386.0	109.0	244.31	179.10	11.80	430000	5.63
		Outlet	7.33	691	71	620	98.0	28.9	67.91	45.53	5.70	46000	4.66
		Mean FS	7.77	70399	69269	1130	87600.0	9605.3	2478.42	447.90	385.00	4600000	6.66
		Mean Inlet	7.41	1913	503	1410	442.7	149.4	235.30	170.12	15.01	993333	6.00
		Mean Outlet	7.42	1074	77	997	119.7	38.1	97.41	69.08	6.67	16227	4.21

FSTP location		Type of	Physico-chemical parameters									Pathogen content	
			pH	TS (mg/L)	TSS	TDS	COD (mg/L)	BOD (mg/L)	TKN (mg/L)	AN (mg/L)	TP	FC (MPN/ 100 mL)	FC Log10 value (MPN/ 100 mL)
Re-evaluated STP co-treatment plant													
Puri	April 2024	FSTP Inlet	7.52	2410	1190	1220	454.0	76.0	171.11	130.50	12.68	46000	4.66
		STP Inlet	6.81	1105	633	472	420.0	93.0	46.75	18.42	3.92	150000	5.18
		STP Outlet	7.41	810	317	493	81.0	26.0	35.28	21.71	3.57	230	2.36
	June 2024	FS	7.22	9636	7496	2140	19450.0	2964.9	640.92	130.73	81.00	2400000	6.38
		FSTP Inlet	7.26	2370	1350	1020	334.0	66.9	142.59	111.75	15.04	43000	4.63
		FSTP outlet	7.70	876	212	664	98.0	25.2	72.91	59.00	6.20	24000	4.38
		STP Outlet	7.50	675	91	584	31.0	10.4	29.99	18.25	3.38	30	1.48
	August 2024	FSTP Inlet	7.66	1143	172	971	180.0	46.4	129.36	79.18	12.36	4300	3.63
		STP Outlet	7.37	504	42	462	48.0	17.1	28.52	12.96	3.08	30	1.48
		Mean FS	7.22	9636	7496	2140	19450.0	2964.9	640.92	130.73	81.00	2400000	6.38
		Mean FSTP Inlet	7.48	1974	904	1070	322.7	63.1	147.69	107.14	13.36	31100	4.49
		Mean FSTP outlet	7.70	876	212	664	98.0	25.2	72.91	59.00	6.20	24000	4.38
		Mean STP Inlet	6.81	1105	633	472	420.0	93.0	46.75	18.42	3.92	150000	5.18
		Mean STP Outlet	7.43	663	150	513	53.3	17.8	31.26	17.64	3.34	97	1.99

Table 2: Consolidated three-month data of physico-chemical parameters and pathogen content in biosolids samples from FSTPs and STP co-treatment plant

Location	Month	Physico-chemical parameters					Pathogen content						
		pH	EC (dS/m)	Mois-ture (%)	Organic Carbon (% by weight)	Total Nitro-gen (% by weight)	Hel-minth Eggs (No. of eggs per 4 g total dry solids)	FC (MPN/g total dry solids)	FC Log10 value (MPN/g total dry solids)	E. coli (MPN/g total dry solids)	E. coli Log10 value (MPN/g total dry solids)	Salmo-nella (MPN/4 g total dry solids)	Salmo-nella Log10 value (MPN/4 g total dry solids)
Newly-evaluated FSTPs													
Rokat	April 2024	5.97	2.20	6.66	29.80	6.09	17	3	0.51	3	0.51	8142	3.91
	June 2024	6.51	2.61	11.11	33.90	3.67	153	5175	3.71	484	2.68	28800	4.46
	Mean	6.24	2.41	8.89	31.85	4.88	85	2589	3.41	243	2.39	18471	4.27
Sonepur	April 2024	5.35	1.53	4.96	37.20	6.59	126	4	0.58	3	0.50	180970	5.26
	June 2024	6.67	1.45	7.76	39.80	3.86	43	228	2.36	38	1.58	138768	5.14
	August 2024	6.44	0.92	29.59	31.60	3.05	295	15622	4.19	298	2.47	193147	5.29
	Mean	6.15	1.30	14.10	36.20	4.50	155	5285	3.72	113	2.05	170962	5.23
Barbil	April 2024	6.02	2.43	5.57	28.10	5.94	102	98	1.99	98	1.99	118603	5.07
	June 2024	6.11	2.41	12.99	34.80	3.79	46	24	1.38	4	0.62	31125	4.49
	August 2024	6.04	3.31	21.38	36.20	3.55	478	4	0.58	4	0.58	13229	4.12
	Mean	6.06	2.72	13.32	33.03	4.43	209	42	1.62	35	1.55	54319	4.73
Basudevpur	April 2024	5.79	3.01	22.28	28.80	6.10	82	309	2.49	309	2.49	73601	4.87
	June 2024	6.54	1.14	69.32	28.10	2.86	469	36	1.55	12	1.07	156451	5.19
	August 2024	6.81	0.95	63.22	30.40	2.88	174	435	2.64	63	1.80	630750	5.80
	Mean	6.38	1.70	51.61	29.10	3.95	242	260	2.41	128	2.11	286934	5.46
Paradeep	April 2024	6.11	5.61	11.46	34.40	6.51	126	520	2.72	520	2.72	6776	3.83
	June 2024	6.72	1.75	25.71	30.50	3.08	151	511	2.71	125	2.10	21536	4.33
	August 2024	6.09	4.48	41.98	30.30	3.31	165	74	1.87	74	1.87	220611	5.34
	Mean	6.31	3.95	26.38	31.73	4.30	147	368	2.57	240	2.38	82974	4.92
Re-evaluated FSTPs													
Basuaghai, Bhubaneswar	April 2024	6.03	1.78	47.43	33.50	6.33	533	43754	4.64	43754	4.64	5996201	6.78
	June 2024	6.09	1.66	15.05	25.40	2.73	198	27	1.43	27	1.43	1582096	6.20
	August 2024	6.50	2.45	12.38	30.10	3.2	301	3	0.53	3	0.53	639123	5.81
	Mean	6.21	1.96	24.95	29.67	4.09	344	14595	4.16	14595	4.16	2739140	6.44

Location	Month	Physico-chemical parameters					Pathogen content						
		pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (No. of eggs per 4 g total dry solids)	FC (MPN/g total dry solids)	FC Log10 value (MPN/g total dry solids)	E. coli (MPN/g total dry solids)	E. coli Log10 value (MPN/g total dry solids)	Salmonella (MPN/4 g total dry solids)	Salmonella Log10 value (MPN/4 g total dry solids)
Jatni	April 2024	5.62	2.93	2.75	33.10	6.63	173	247	2.39	96	1.98	246776	5.39
	June 2024	6.23	1.59	23.28	29.40	2.96	83	14338	4.16	5996	3.78	437971	5.64
	August 2024	6.08	2.83	30.59	14.00	1.53	403	4	0.64	4	0.64	190179	5.28
	Mean	5.98	2.45	18.87	25.50	3.71	220	4863	3.69	2032	3.31	291642	5.46
Khorda	April 2024	5.56	2.27	6.59	21.10	5.57	69	16	1.21	16	1.21	71510	4.85
	June 2024	5.46	0.98	27.09	20.00	2.11	33	2880	3.46	1646	3.22	36210	4.56
	August 2024	6.71	2.81	11.07	26.60	2.69	315	4	0.61	4	0.61	638734	5.81
	Mean	5.91	2.02	14.92	22.57	3.46	139	967	2.99	555	2.74	248818	5.40
Dhenkanal, Before pasteurization	April 2024	5.19	2.30	5.09	40.60	6.43	8	3	0.50	3	0.50	2571	3.41
	June 2024	6.56	0.90	9.05	37.00	3.49	97	25	1.40	25	1.40	4398	3.64
	Mean	5.88	1.60	7.07	38.80	4.96	52	14	1.15	14	1.15	3484	3.54
Dhenkanal, After pasteurization	April 2024	6.25	2.27	4.53	38.10	6.47	0	3	0.50	3	0.50	42	1.62
	June 2024	6.34	1.59	3.16	37.80	3.78	50	3	0.49	3	0.49	207	2.31
	August 2024	6.49	1.87	10.38	36.00	3.57	18	104	2.02	10	1.01	13390	4.13
	Mean	6.36	1.91	6.02	37.30	4.61	23	37	1.56	6	0.74	4546	3.66
Angul	April 2024	4.69	1.63	6.02	35.70	6.37	230	255	2.41	255	2.41	8087	3.91
	June 2024	6.78	1.22	8.25	38.00	3.74	26	251	2.40	47	1.67	52316	4.72
	August 2024	6.56	1.95	10.34	38.20	3.68	125	3	0.52	3	0.52	446	2.65
	Mean	6.01	1.60	8.20	37.30	4.60	127	170	2.23	102	2.01	20283	4.31
Jagatsinghpur	April 2024	6.07	1.75	1.31	36.00	6.53	178	15	1.18	7	0.87	324234	5.51
	June 2024	6.60	0.87	9.77	35.70	3.88	115	477	2.68	255	2.41	398997	5.60
	August 2024	5.81	4.52	12.77	27.70	2.93	229	106617	5.03	26368	4.42	4860824	6.69
	Mean	6.16	2.38	7.95	33.13	4.45	174	35703	4.55	8877	3.95	1861352	6.27
Sambalpur	April 2024	5.75	2.52	9.88	38.00	6.53	284	3	0.52	3	0.52	54148	4.73
	June 2024	6.31	1.98	7.80	34.80	3.57	52	4	0.59	3	0.51	22561	4.35
	August 2024	7.06	1.22	17.25	36.20	3.49	68	9	0.95	4	0.64	111172	5.05
	Mean	6.37	1.91	11.64	36.33	4.53	135	5	0.73	4	0.56	62627	4.80
Baripada	April 2024	5.87	2.28	43.03	37.50	5.98	56	163	2.21	163	2.21	2696040	6.43
	June 2024	6.52	2.56	14.80	34.90	3.65	197	141	2.15	50	1.70	3028166	6.48
	August 2024	6.64	0.77	77.12	36.90	3.75	315	101	2.00	13	1.12	349684	5.54
	Mean	6.34	1.87	44.98	36.43	4.46	189	135	2.13	76	1.88	2024630	6.31

Location	Month	Physico-chemical parameters					Pathogen content						
		pH	EC (dS/m)	Mois-ture (%)	Organic Carbon (% by weight)	Total Nitro-gen (% by weight)	Hel-minth Eggs (No. of eggs per 4 g total dry solids)	FC (MPN/g total dry solids)	FC Log10 value (MPN/g total dry solids)	E. coli (MPN/g total dry solids)	E. coli Log10 value (MPN/g total dry solids)	Salmo-nella (MPN/4 g total dry solids)	Salmo-nella Log10 value (MPN/4 g total dry solids)
Balasore	April 2024	6.21	1.85	15.56	30.00	5.83	180	24	1.37	24	1.37	57318	4.76
	June 2024	6.46	1.05	71.29	29.30	2.62	334	122	2.09	26	1.41	69657	4.84
	August 2024	6.58	2.59	18.07	28.90	2.73	39	4	0.64	4	0.56	48819	4.69
	Mean	6.42	1.83	34.97	29.40	3.73	184	50	1.70	18	1.25	58598	4.77
Rourkela	April 2024	5.97	5.04	0.01	37.30	6.36	160	9	0.96	9	0.96	23603	4.37
	June 2024	6.39	1.58	5.00	35.00	3.55	67	10	0.99	3	0.50	33683	4.53
	August 2024	5.98	1.46	17.94	6.71	0.56	58	280	2.45	4	0.56	112113	5.05
	Mean	6.11	2.69	7.65	26.34	3.49	95	100	2.00	5	0.73	56466	4.75
Re-evaluated STP co-treatment plant													
Puri	April 2024	6.97	4.30	5.94	30.90	6.41	51	3	0.50	3	0.50	8080	3.91
	June 2024	7.26	1.07	44.90	31.80	3.05	944	199639	5.30	199639	5.30	72596	4.86
	August 2024	6.78	1.89	7.51	17.20	1.75	52	3	0.51	3	0.51	865	2.94
	Mean	7.00	2.42	19.45	26.63	3.74	349	66549	4.82	66549	4.82	27180	4.43

Table 3: Consolidated three-month data of heavy metals and nutrients in biosolids samples collected from FSTPs and STP co-treatment plant

Location	Month	Heavy metals								Nutrients					
		As (mg/kg) max. 10.0 as As2O3	Hg (mg/kg) max. 0.15	Cd (mg/kg) max. 5.0	Cr (mg/kg) max. 50.0	Pb (mg/kg) max. 100.0	Zn (mg/kg) max. 1000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0	Total Phos-phates (asP2O5), per cent by weight, min. 0.5	Total Potash (as K2O), per cent by weight, min. 0.5	Ca per cent by weight	Mg per cent by weight	Mn per cent by weight	Na per cent by weight
FSTPs															
Rokat	April 2024	0.88	1.43	2.91	65.30	72.20	1190.00	354.00	49.00	1.85	0.31	1.48	0.33	0.04	0.05
	June 2024	2.81	5.13	0.50	49.60	32.40	1080.00	286.00	42.40	2.23	1.03	3.94	0.53	0.05	0.27
	Mean	1.84	3.28	1.71	57.45	52.30	1135.00	320.00	45.70	2.04	0.67	2.71	0.43	0.04	0.16
Sonepur	April 2024	1.28	5.74	1.90	21.40	24.60	1170.00	255.00	24.30	3.60	0.24	4.35	0.37	0.04	0.13
	June 2024	1.34	4.54	2.09	118.00	54.10	1740.00	443.00	70.10	1.98	0.89	5.14	0.76	0.10	0.17
	August 2024	0.43	4.60	2.04	23.80	24.20	1280.00	364.00	33.50	3.23	0.19	3.24	0.39	0.05	0.03
	Mean	1.02	4.96	2.01	54.40	34.30	1396.67	354.00	42.63	2.94	0.44	4.24	0.50	0.06	0.11

Location	Month	Heavy metals								Nutrients					
		As (mg/kg) max. 10.0 as As2O3	Hg (mg/kg) max. 0.15	Cd (mg/kg) max. 5.0	Cr (mg/kg) max. 50.0	Pb (mg/kg) max. 100.0	Zn (mg/kg) max. 1000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0	Total Phosphates (asP2O5), per cent by weight, min. 0.5	Total Potash (as K2O), per cent by weight, min. 0.5	Ca per cent by weight	Mg per cent by weight	Mn per cent by weight	Na per cent by weight
Barbil	April 2024	1.76	3.78	6.47	36.60	45.00	1610.00	583.00	35.50	3.09	0.26	2.82	0.36	0.05	0.09
	June 2024	1.11	2.95	1.77	52.50	34.40	1670.00	462.00	52.90	0.47	0.54	4.24	0.77	0.09	0.28
	August 2024	0.51	4.84	2.29	26.20	34.10	1460.00	361.00	32.70	1.48	0.14	1.95	0.37	0.05	0.09
	Mean	1.13	3.86	3.51	38.43	37.83	1580.00	468.67	40.37	1.68	0.31	3.00	0.50	0.06	0.15
Basudevpur	April 2024	0.46	0.99	1.96	31.20	13.90	774.00	170.00	21.20	3.55	0.26	3.72	0.31	0.04	0.08
	June 2024	0.17	0.54	0.55	23.10	8.42	700.00	160.00	17.10	4.31	0.25	4.79	0.32	0.05	0.09
	August 2024	0.32	2.02	1.41	10.40	7.15	509.00	139.00	13.60	1.75	0.08	2.14	0.18	0.03	0.04
	Mean	0.32	1.18	1.31	21.57	9.82	661.00	156.33	17.30	3.20	0.19	3.55	0.27	0.04	0.07
Paradeep	April 2024	0.86	1.22	2.58	33.30	16.30	1090.00	249.00	26.60	2.73	0.20	3.08	0.69	0.04	0.42
	June 2024	2.57	0.78	2.37	42.20	24.60	1780.00	385.00	67.20	1.71	0.35	3.93	0.63	0.07	0.24
	August 2024	0.38	2.43	1.13	9.14	8.38	555.00	131.00	13.30	1.18	0.10	1.31	0.23	0.02	0.19
	Mean	1.27	1.48	2.03	28.21	16.43	1141.67	255.00	35.70	1.87	0.22	2.77	0.52	0.04	0.28
Re-evaluated FSTPs															
Basuaghai, Bhubaneswar	April 2024	0.86	1.75	2.32	49.80	58.20	941.00	248.00	32.00	1.76	0.28	2.60	0.50	0.03	0.08
	June 2024	1.39	4.13	1.14	65.50	40.30	1260.00	323.00	46.10	3.14	0.95	3.91	0.66	0.06	0.20
	August 2024	0.47	3.69	2.61	42.10	25.60	1300.00	323.00	32.80	1.96	0.29	2.55	0.43	0.04	0.08
	Mean	0.91	3.19	2.02	52.47	41.37	1167.00	298.00	36.97	2.29	0.51	3.02	0.53	0.05	0.12
Jatni	April 2024	0.80	1.54	2.32	43.50	33.30	1200.00	248.00	42.10	1.87	0.25	2.40	0.41	0.04	0.09
	June 2024	NIL	NIL	53.20	76.00	693.00	568.00	424.00	40.10	3.57	5.75	7.87	1.73	0.07	3.75
	August 2024	2.46	6.07	2.21	273.00	38.90	1040.00	339.00	56.20	1.69	0.33	2.42	0.43	0.05	0.11
	Mean	1.63	3.81	19.24	130.83	255.07	936.00	337.00	46.13	2.38	2.11	4.23	0.86	0.05	1.32

Location	Month	Heavy metals								Nutrients					
		As (mg/kg) max. 10.0 as As_2O_3	Hg (mg/kg) max. 0.15	Cd (mg/kg) max. 5.0	Cr (mg/kg) max. 50.0	Pb (mg/kg) max. 100.0	Zn (mg/kg) max. 1000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0	Total Phosphates (asP_2O_5), per cent by weight, min. 0.5	Total Potash (as K_2O), per cent by weight, min. 0.5	Ca per cent by weight	Mg per cent by weight	Mn per cent by weight	Na per cent by weight
Khordha	April 2024	0.73	1.17	1.58	47.40	19.40	811.00	167.00	28.70	1.29	0.20	2.57	0.30	0.04	0.05
	June 2024	1.66	4.92	2.30	117.00	61.80	1610.00	449.00	67.70	2.04	1.14	4.84	0.80	0.10	0.16
	August 2024	0.22	2.07	1.45	51.00	19.70	737.00	203.00	31.50	1.27	0.19	1.41	0.21	0.04	0.07
	Mean	0.87	2.72	1.78	71.80	33.63	1052.67	273.00	42.63	1.53	0.51	2.94	0.43	0.06	0.09
Dhenkanal, Before pasteurization	April 2024	0.81	3.29	2.48	29.40	22.50	1710.00	338.00	39.00	2.40	0.30	2.92	0.45	0.04	0.18
	June 2024	NIL	0.17	31.87	68.50	44.60	869.00	461.00	45.10	2.77	3.04	7.93	1.35	0.06	2.06
	Mean	0.81	1.73	17.18	48.95	33.55	1289.50	399.50	42.05	2.59	1.67	5.43	0.90	0.05	1.12
Dhenkanal, After pasteurization	April 2024	0.73	3.41	2.36	30.60	21.70	1640.00	314.00	40.30	3.05	0.24	3.36	0.41	0.05	0.11
	June 2024	NIL	3.66	30.90	70.60	41.40	907.00	428.00	41.60	3.11	3.38	7.95	1.27	0.06	2.16
	August 2024	0.68	3.49	3.13	45.30	26.50	1730.00	444.00	47.00	2.56	0.42	3.31	0.63	0.05	0.17
	Mean	0.71	3.52	12.13	48.83	29.87	1425.67	395.33	42.97	2.91	1.34	4.87	0.77	0.05	0.81
Angul	April 2024	0.69	1.96	2.04	28.30	18.80	1430.00	254.00	27.70	4.21	0.21	4.97	0.52	0.04	0.15
	June 2024	0.87	2.22	2.57	54.80	200.00	773.00	264.00	39.80	3.18	2.46	5.45	1.14	0.06	0.76
	August 2024	0.52	4.44	2.45	42.60	20.80	1540.00	349.00	32.70	3.09	0.28	4.03	0.63	0.04	0.21
	Mean	0.70	2.87	2.35	41.90	79.87	1247.67	289.00	33.40	3.50	0.98	4.82	0.76	0.05	0.37
Jagatsinghpur	April 2024	0.60	1.72	2.42	39.30	20.70	1250.00	257.00	28.80	1.79	0.23	2.14	0.34	0.04	0.06
	June 2024	0.96	3.14	1.07	70.50	39.10	1320.00	357.00	50.30	2.68	0.34	2.33	0.33	0.05	0.09
	August 2024	0.44	2.41	3.57	68.60	91.30	1300.00	455.00	45.80	1.89	0.42	2.24	0.56	0.04	0.08
	Mean	0.67	2.42	2.35	59.47	50.37	1290.00	356.33	41.63	2.12	0.33	2.24	0.41	0.04	0.08
Sambalpur	April 2024	1.85	2.02	1.83	20.60	16.50	1540.00	240.00	22.50	2.86	0.20	2.97	0.37	0.04	0.10
	June 2024	1.69	5.28	1.80	106.00	49.60	1720.00	436.00	66.80	2.31	0.73	4.89	0.69	0.09	0.15
	August 2024	0.53	5.15	2.08	14.40	54.60	1320.00	293.00	25.60	1.74	0.08	2.25	0.31	0.04	0.05
	Mean	1.36	4.15	1.90	47.00	40.23	1526.67	323.00	38.30	2.31	0.34	3.37	0.46	0.05	0.10

Location	Month	Heavy metals								Nutrients					
		As (mg/kg) max. 10.0 as As2O3	Hg (mg/kg) max. 0.15	Cd (mg/kg) max. 5.0	Cr (mg/kg) max. 50.0	Pb (mg/kg) max. 100.0	Zn (mg/kg) max. 1000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0	Total Phosphates (asP2O5), per cent by weight, min. 0.5	Total Potash (as K2O), per cent by weight, min. 0.5	Ca per cent by weight	Mg per cent by weight	Mn per cent by weight	Na per cent by weight
Baripada	April 2024	0.70	2.17	1.99	33.40	12.90	1100.00	200.00	32.70	2.21	0.20	2.44	0.27	0.03	0.11
	June 2024	1.45	6.32	1.23	76.40	44.00	1480.00	381.00	54.20	2.89	0.62	3.85	0.54	0.07	0.11
	August 2024	0.43	2.21	2.08	35.20	17.30	973.00	238.00	36.50	2.75	0.21	3.25	0.35	0.04	0.08
	Mean	0.86	3.57	1.77	48.33	24.73	1184.33	273.00	41.13	2.62	0.35	3.18	0.38	0.05	0.10
Balasore	April 2024	0.60	2.03	1.81	44.20	14.40	776.00	147.00	23.60	2.07	0.15	2.32	0.23	0.04	0.06
	June 2024	1.34	2.95	4.84	63.00	31.70	761.00	345.00	45.80	2.70	2.99	7.67	1.14	0.07	1.70
	August 2024	0.13	12.90	3.19	26.50	17.80	1360.00	326.00	42.90	2.68	0.13	3.09	0.30	0.05	0.07
	Mean	0.69	5.96	3.28	44.57	21.30	965.67	272.67	37.43	2.48	1.09	4.36	0.56	0.05	0.61
Rourkela	April 2024	0.73	2.84	1.01	13.00	12.40	678.00	139.00	13.90	1.88	0.13	2.31	0.21	0.03	0.08
	June 2024	0.68	2.07	2.09	93.50	51.90	1950.00	423.00	57.10	1.17	0.58	4.40	0.81	0.07	0.15
	August 2024	1.48	6.02	0.64	11.60	19.50	443.00	93.90	12.70	1.36	0.08	1.66	0.18	0.02	0.03
	Mean	0.96	3.64	1.25	39.37	27.93	1023.67	218.63	27.90	1.47	0.26	2.79	0.40	0.04	0.08
Re-evaluated STP co-treatment plant															
Puri	April 2024	2.03	5.67	11.40	53.20	74.50	1680.00	954.00	48.70	3.32	0.32	2.71	0.35	0.05	0.07
	June 2024	1.12	2.25	1.45	71.10	65.00	1500.00	482.00	49.20	2.73	0.39	3.79	0.70	0.05	0.11
	August 2024	1.71	7.22	2.78	39.90	36.00	1330.00	309.00	32.60	3.14	0.34	3.45	0.56	0.08	0.39
	Mean	1.62	5.05	5.21	54.73	58.50	1503.33	581.67	43.50	3.06	0.35	3.32	0.54	0.06	0.19

Table 4: Consolidated data of physico-chemical parameters and pathogen content in the co-compost samples collected from Jatni FSTP

Co-compost	Month	Physico-chemical Parameters					Pathogen content					
		pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	FC (MPN/g total dry solids)	FC Log10 value (MPN/g total dry solids)	E. coli (MPN/g total dry solids)	E. coli Log10 value (MPN/g total dry solids)	Salmonella (MPN/4 g total dry solids)	Salmonella Log10 value (MPN/4 g total dry solids)
Batch 1	June 2024	6.68	1.08	6.71	17.8	1.71	46	1.66	16	1.21	429	2.63
Batch 2	June 2024	6.16	3.63	8.18	18.4	1.95	10	1.00	10	1.00	305	2.48
Batch 3	June 2024	6.24	2.83	5.46	21.7	2.23	2539	3.40	127	2.10	15232	4.18
Mixture of batches 1, 2 and 3	April 2024	5.28	1.78	7.27	18.4	5.27	8	0.90	4	0.59	34509	4.54
Batch 4, 45 days	June 2024	7.11	2.51	35.74	13.9	1.39	17118	4.23	17118	4.23	124496	5.10
Batch 4, 90 days	August 2024	7.04	2.43	39.20	12.7	1.32	707	2.85	378	2.58	532913	5.73
Batch 4, 106 days	August 2024	7.33	2.67	38.08	16.8	1.78	371	2.57	6	0.76	2196403	6.34

Table 5: Consolidated data of heavy metals and nutrients in the co-compost samples collected from Jatni FSTP

Co-compost	Month	Heavy metals								Nutrients					
		As (mg/kg) max. 10.0 as As2O3	Hg (mg/kg) max. 0.15	Cd (mg/kg) max. 5.0	Cr (mg/kg) max. 50.0	Pb (mg/kg) max. 100.0	Zn (mg/kg) max. 1000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0	Total Phosphates (as P2O5), per cent by weight, min. 0.5	Total Potash (as K2O), per cent by weight, min. 0.5	Ca per cent by weight	Mg per cent by weight	Mn per cent by weight	Na per cent by weight
Batch 1	June 2024	NIL	NIL	10.90	82.30	52.50	378.00	438.00	52.20	3.41	5.81	7.94	1.89	0.11	3.71
Batch 2	June 2024	NIL	0.24	2.15	54.40	19.90	321.00	237.00	41.90	3.96	5.14	8.01	1.98	0.08	1.65
Batch 3	June 2024	1.14	4.64	1.65	104.00	39.70	1670.00	378.00	63.70	1.57	0.51	4.79	0.61	0.07	0.16
Mixture of batches 1, 2 and 3	April 2024	0.96	1.05	1.17	35.20	20.10	619.00	135.00	23.50	1.39	0.36	1.93	0.29	0.04	0.06
Batch 4, 45 days	June 2024	3.18	9.41	1.50	87.60	51.50	1680.00	434.00	62.30	3.14	0.96	5.53	0.86	0.09	0.14
Batch 4, 90 days	August 2024	0.34	4.59	1.89	65.60	26.90	807.00	249.00	39.90	1.66	1.12	2.26	0.49	0.03	0.25
Batch 4, 106 days	August 2024	0.61	2.42	1.14	323.00	18.70	427.00	201.00	38.20	0.99	0.55	1.20	0.22	0.08	0.15

Centre for Science and Environment (CSE) has been actively working in faecal sludge and septage management (FSSM) in India by monitoring and evaluating the performance of FSTPs across the country. In this study, 16 treatment plants were evaluated in Odisha, a state actively involved in the sanitation sector, including FSSM, since the advent of Swachh Bharat Mission (SBM) in 2014. The study also involves the re-evaluation of 11 plants in the state with an aim to understand the long-term performance and sustainability. Evaluation of a STP co-treatment plant in Puri and an assessment of co-compost quality in Jatni were also part of the study.

Re-evaluation of the FSTPs showed both improvement as well as decline in the performance of the plants in terms of effluent and biosolids quality, as the results were compared with the national standards during both the study periods.

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