



EVALUATION OF BIOCHAR FROM FSTPs IN RAJASTHAN



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ABBREVIATIONS AND ACRONYMS

AAETI	Anil Agarwal Environment Training Institute
ACF	Activated carbon filter
AN	Ammoniacal nitrogen
APHA	American Public Health Association
As	Arsenic
BMGF	Bill & Melinda Gates Foundation
BOD	Biological oxygen demand
BS	Biosolid
C	Carbon
C:N ratio	Carbon-to-nitrogen ratio
Ca	Calcium
Cd	Cadmium
COD	Chemical oxygen demand
Cr	Chromium
CSE	Centre for Science and Environment
Cu	Copper
CU	Capacity utilization
DO	Dissolved oxygen
<i>E. coli</i>	<i>Escherichia coli</i>
EC	Electrical conductivity
EML	Environment Monitoring Laboratory
FC	Faecal coliform
FCO	Fertilizer Control Order
FS	Faecal sludge
FSTP	Faecal sludge treatment plant
Gy	Gray
Hg	Mercury
HRT	Hydraulic retention time

ICP-OES	Inductively Coupled Plasma Optical Emission spectroscopy
K	Potassium
KL	Kilolitre
KLD	Kilolitres per day
kW	Kilowatt
MBBR	Moving Bed Biofilm Reactor
MeOH	Methanol
Mg	Magnesium
MLD	Million litres per day
MLG	Microbiology Laboratory Guidebook
Mn	Manganese
MoEF&CC	Ministry of Environment, Forest and Climate Change
MPN	Most probable number
N	Nitrogen
Na	Sodium
NGT	National Green Tribunal
NH₃-N	Ammoniacal nitrogen
NH₄+N	Ammonium nitrogen
Ni	Nickel
NPK	Nitrogen, phosphorus and potassium
OD	Open defecation
ODF	Open defecation free
O&M	Operation and maintenance
OP	Omni Processor
OSS	On-site sanitation systems
P	Phosphorus
PAOs	Phosphorus-accumulating organisms
Pb	Lead
pH	Potential of hydrogen

PHA	Polyhydroxyalkanoates
POP	Pyrolysis-based Omni Processor
PPE	Personal protective equipment
PSF	Pressure sand filter
PU	Polyurethane
SBM	Swachh Bharat Mission
SCWO OP	Supercritical water oxidation Omni Processor
SND	Simultaneous Nitrification and Denitrification
SR	Stabilization reactor
SRT	Solids retention time
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphate
TS	Total solids
TSS	Total suspended solids
ULB	Urban local body
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VFAs	Volatile fatty acids
Zn	Zinc

1. Introduction

Biochar is a charcoal-like substance produced by heating organic biomass—such as agricultural waste, wood chips or faecal sludge—in a high-temperature, low-oxygen environment, a process known as pyrolysis. Unlike common charcoal, which is primarily used as fuel, biochar is engineered specifically for environmental management and soil enhancement. Biochar acts as a powerful tool for climate change mitigation by transforming the short-term carbon cycle into a long-term carbon sink. When organic waste decomposes naturally, it releases carbon dioxide and methane back into the atmosphere; however, the pyrolysis process used to create biochar ‘locks’ this carbon into a stable, solid form that can remain sequestered in the soil for hundreds or even thousands of years. Beyond simple storage, applying biochar to agricultural land improves soil health and water retention, which reduces the need for chemical fertilizers whose production and application are major sources of greenhouse gas emissions. By lowering nitrous oxide emissions from soil and providing a carbon-negative waste-management solution, biochar directly offsets industrial emissions while simultaneously building more resilient ecosystems.

Rajasthan, India’s largest and most arid state, faces a significant sanitation paradox. Despite achieving Open Defecation Free (ODF) status through the Swachh Bharat Mission (SBM), behavioural challenges persist, and approximately 70 per cent of urban households remain dependent on on-site sanitation systems (OSS) such as septic tanks and pits due to a lack of sewer networks. This has created a massive management gap, as current infrastructure only treats a fraction of the nearly 3,870 kilolitres of faecal sludge generated daily. With over half of Rajasthan’s Urban Local Bodies (ULBs) destined to remain reliant on decentralized systems, the state has pioneered faecal sludge treatment plants (FSTPs) and holistic management policies to address untreated waste.^{1,2}

To modernize this effort, innovative thermal technologies known as Omni Processors (OP) are being explored to convert human waste into valuable commodities like potable water, electricity and biochar. These self-sustaining systems operate outside traditional sewer grids and include three primary models: combustion-based OPs, which incinerate dried sludge to produce energy and water; pyrolysis-based OPs, which heat sludge in low-oxygen environments to create carbon-rich biochar and syngas; and supercritical water oxidation (SCWO), which uses extreme pressure and heat to rapidly oxidize organics into clean water

and minerals. By shifting from simple disposal to resource recovery, these modular technologies offer a scalable business case for local entrepreneurs to solve the sanitation crisis while protecting the environment.³

This report evaluates 39 pyrolysis-based Omni Processor (POP)-based FSTPs in Rajasthan that were commissioned in 2023–24 and are operated by MVR Technology. Funded by the Bill & Melinda Gates Foundation (BMGF) and conducted by the Environment Monitoring Laboratory (EML) at the Centre for Science and Environment (CSE), the study assesses the efficiency of these systems in recovering treated water, biosolids, and biochar from faecal sludge. By benchmarking the facilities against rigorous health and environmental standards, the analysis provides a detailed look at the operational performance of POP technology. Ultimately, the report highlights both the strengths and challenges of these sites, offering a roadmap for their role in advancing India’s circular economy through sustainable sanitation and the agricultural reuse of recovered byproducts.

2. Objectives of the study

1. To evaluate the treatment efficiency of the POP-based FSTPs in Rajasthan;
2. To check whether the quality of treated effluent generated by the FSTPs is meeting the effluent discharge standard limits set by the Ministry of Environment, Forest & Climate Change (MoEF&CC) and the National Green Tribunal (NGT); and
3. To determine the potential of biosolids and biochar generated in the FSTPs for their use in agriculture.

3. Selection criteria for FSTPs

The FSTPs evaluated in this study were commissioned in 2023–24. Hence, their capacity utilization is low to moderate.

In this study:

- The selection of the FSTPs for evaluation has been done on the basis of technology and treatment capacity.
- FSTPs with pyrolysis-based Omni Processor (POP) generating biochar were selected.
- Five FSTPs with 10-KLD treatment capacity, nine with 15 KLD, eleven with 20 KLD, six with 25 KLD and eight with 35 KLD located in central and eastern Rajasthan were selected for the study.

4. Significance of the study— Parameters monitored

This study is vital for its evaluation of three key areas: first, the operational performance of Rajasthan’s pyrolysis-based FSTPs; second, the systems’ capacity for biosolid resource recovery; and third, the viability of using the resulting biochar as a sustainable agricultural amendment.

4.1 Assessment of performance of FSTPs

Faecal sludge treatment plants (FSTPs) play a vital role in environmental and public health by neutralizing contaminants within human waste. Their performance is typically evaluated by tracking key metrics such as chemical oxygen demand (COD), biological oxygen demand (BOD) and nutrient levels, including nitrogen and phosphorus. By consistently monitoring these indicators, operators can pinpoint system inefficiencies, streamline treatment processes and lower operational costs. Ultimately, this rigorous oversight ensures that the facilities meet regulatory standards and successfully protect local ecosystems and communities from pollution.

The most commonly adopted parameters for FSTP monitoring include:

4.1.1 Potential of hydrogen (pH)

pH indicates the acidity or alkalinity of sludge by measuring hydrogen ion activity. It is a critical operational parameter that governs essential treatment processes, including biological stabilization, chemical precipitation, coagulation and effective disinfection.

4.1.2 Total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS)

Total solids (TS) represent the entire residue left after evaporation, comprising total suspended solids (TSS)—particles trapped by a filter—and total dissolved solids (TDS)—matter that passes through. High concentrations of these solids degrade water quality by reducing light penetration and dissolved oxygen levels, harming aquatic life and facilitating the transport of pathogens.

4.1.3 Chemical oxygen demand (COD)

COD quantifies the total oxygen required to chemically oxidize all organic and inorganic pollutants. It serves as a primary metric for assessing the overall pollutant load and for modelling how substances transform during the treatment process.

4.1.4 Biochemical oxygen demand (BOD)

BOD measures the oxygen consumed by microorganisms as they break down biodegradable organic matter. Monitoring BOD is vital to prevent effluent from depleting oxygen in receiving waterbodies, a condition that can lead to ‘dead zones’ where aquatic life cannot survive.

4.1.5 Total Kjeldahl nitrogen (TKN) and ammoniacal nitrogen (AN)

TKN measures the sum of organic and ammoniacal nitrogen, both of which are highly concentrated in faecal sludge. Reducing nitrogen is essential to prevent eutrophication—the process where excess nutrients trigger algal blooms that deplete oxygen and release toxins into the water.

4.1.6 Total phosphate (TP)

Total phosphate is monitored to control nutrient enrichment in the environment. Similar to nitrogen, excessive phosphorus discharge disrupts ecological balances by fuelling unwanted plant and algal growth, leading to oxygen depletion in aquatic habitats.

4.1.7 Faecal coliforms (FC)

Faecal coliforms, including *E. coli*, serve as universal indicators of sanitary quality. Because faecal sludge is dense with pathogens, testing for these bacteria is the standard method for detecting faecal contamination and assessing the public health risk associated with treated effluent.

4.2 Assessment of biosolids and biochar

Biosolids derived from faecal sludge are nutrient-dense organic materials that serve as effective soil conditioners and solid fuel sources. By providing a vital food source for microorganisms and acting as binding agents for soil stabilization, they significantly enhance the physical and biological properties of degraded land. When these biosolids undergo pyrolysis—a process of heating biomass in a low-oxygen environment—they produce biochar, a stable, carbon-rich material.

Biochar is exceptionally efficient at sequestering carbon for long-term climate mitigation while simultaneously improving soil fertility through superior water

and nutrient retention. According to USEPA guidelines, these organic biosolids offer a distinct advantage over inorganic fertilizers; their nutrients are released slowly via microbial decomposition, matching the needs of crops over multiple growing seasons. This synchronized release boosts nutrient efficiency and prevents the leaching that causes groundwater pollution. Ultimately, transforming waste into these valuable resources minimizes landfill volumes and fosters a sustainable, closed-loop ecological system.

The following parameters must be analysed to confirm the usability of biosolids and biochar as an alternative to chemical fertilizers:

4.2.1 Potential of hydrogen (pH)

The pH of biosolids is determined by their source and treatment history. While primary biosolids are generally neutral to slightly alkaline, the pH of secondary biosolids varies significantly depending on the specific biological treatment methods employed.

4.2.2 Electrical conductivity (EC)

EC measures the concentration of dissolved salts like sodium and magnesium. High EC levels can damage soil structure and inhibit plant growth; therefore, monitoring EC is essential for determining safe and effective application rates.

4.2.3 Moisture content

Moisture levels regulate microbial activity. Excessive moisture can trigger the regrowth of pathogens, while insufficient moisture stalls the decomposition of organic matter. Maintaining an ideal balance is key to both safety and soil integration.

4.2.4 Carbon-to-nitrogen (C:N) ratio

A balanced C:N ratio (ideally 15:1 to 20:1) is vital for decomposition. If the ratio exceeds 20:1, nitrogen becomes 'immobilized' and unavailable to plants. If it is too low, rapid mineralization can lead to significant nitrogen loss.

4.2.5 Heavy metals

Heavy metals are non-biodegradable elements that can accumulate in biosolids from industrial or agricultural runoff. Monitoring these is critical to prevent soil contamination, groundwater leaching and the entry of toxins into the food chain.

4.2.6 Nitrogen, phosphorus and potassium (NPK)

These primary macronutrients support distinct plant functions: Nitrogen drives vegetative growth, Phosphorus facilitates root development and energy transfer, and potassium regulates overall health and stress tolerance. A proper NPK balance is necessary to maximize crop yield and quality.

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

Since faecal sludge contains a wide array of pathogens, FC and *E. coli* serve as primary indicators of contamination. Testing ensures that treatment has sufficiently neutralized bacteria, viruses and protozoa that cause diseases like diarrhoea and fever.

4.2.8 *Salmonella*

Salmonella is a highly resilient bacterium that can survive and even regrow in soil.⁴ It is used as a benchmark for pathogen reduction; its absence signifies that the biosolids have been treated thoroughly enough to be safe for agricultural reuse.

4.2.9 Helminth eggs

Helminth eggs (intestinal worm eggs) are extremely hardy and represent a major infection risk in developing regions. Effective treatment must ensure the complete destruction of these microscopic agents to prevent parasitic diseases like ascariasis.

5. Sample collection and testing parameters

To ensure high-quality data and scientific integrity, Environment Monitoring Laboratory (EML) scientists visited each site and implemented rigorous protocols for sample collection, preservation, and transport. The team utilized comprehensive personal protective equipment (PPE)—including overalls, gloves, masks, and protective eyewear—to maintain safety and prevent cross-contamination. Samples were collected in sterilized bottles and plastic bags, each clearly labelled with precise location, date, and time coordinates. To maintain biological and chemical stability during transit, all specimens were secured with frozen ice-gel packs and transported in specialized, leak-proof ice-boxes, adhering strictly to established laboratory standards.

5.1 Sampling interval and duration of the visit

Samples were collected from the FSTPs during January–February 2026.

5.2 Inlet and outlet collection

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.



Collection of treated water from FSTP



Collection of inlet sample from FSTP

5.3 Testing parameters and methods for the analysis of inlet and outlet

Physicochemical 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 nitrogen (AN) and total phosphate (TP) and, microbial parameter faecal coliform (FC) were analysed for the collected samples using standard methods (see *Table 1: Testing parameters and standard methods used for the analysis of FS, inlet and outlet*).

Table 1: Testing parameters and standard methods used for the analysis of FS, inlet and outlet⁵

Parameters	Standard methods
pH	APHA 4500-H+B, 24 th ed., 2023 ⁶
Total solids (TS)	APHA 2540-B, 24 th ed., 2023
Total suspended solids (TSS)	APHA 2540-D, 24 th ed., 2023
Total dissolved solids (TDS)	APHA 2540-C, 24 th ed., 2023
Chemical oxygen demand (COD)	APHA 5220-D, 24 th ed., 2023
Biological oxygen demand (BOD)	Automated BOD analyser (Lovibond, BD 600) & APHA 5210-B, 24 th ed., 2023
Total Kjeldahl nitrogen (TKN)	APHA 4500-Norg C, 24 th ed., 2023
Ammoniacal nitrogen (AN)	APHA 4500-NH ₃ C, 24 th ed., 2023
Total phosphate (TP)	APHA 4500-P E, 24 th ed., 2023
Faecal coliform (FC)	APHA 9221 E, 24 th ed., 2023; USDA-FSIS, MLG Appendix 2.05, 2014 ⁷

Source: EML, CSE

5.4 Collection of biosolids and biochar

Biosolids and biochar were collected from all the locations except Niwai and Kuchera; biosolids were not collected from these two locations due to unavailability of biosolids at the time of sampling. Two biosolid samples were collected from each FSTP—after screw press and after belt drying, along with biochar. 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.



Collection of biosolids after screw press



Collection of biosolids after belt dryer



Collection of biochar from pyrolyzer

5.5 Testing parameters and methods used for the analysis of biosolids and biochar

Physicochemical parameters such as pH, electrical conductivity, moisture content, carbon and nitrogen content, heavy metals and nutrients were determined along with microbiological parameters such as faecal coliform, *E. coli*, *Salmonella* and helminth eggs using standard methods (see *Table 2: Testing parameters and standard methods/equipment used for the analysis of soil, biosolids and biochar*).

Table 2: Testing parameters and standard methods/equipment used for the analysis of biosolids and biochar⁸

Parameters	Standard methods/equipment used
pH	FCO, 2023 (pH meter, Eutech, pH 700)
Electrical conductivity	FCO, 2023 (Conductivity meter, Cyberscan 200)
Moisture content	FCO, 2023
Bulk density	FCO, 2023
Carbon and nitrogen content	CHN elemental analyser (LECO, USA, 828 series)
Heavy metals (Cu, Zn, Hg, As, Cd, Cr, Pb, Ni) and nutrients (Ca, Mg, Mn, Na, P, K)	ICP-OES (Perkin Elmer, Avio 200)
Faecal coliform and <i>E. coli</i>	APHA 9221 B, 9221 F, 24th ed., 2023; USDA-FSIS, MLG Appendix 2.05, 2014
<i>Salmonella</i>	USEPA, Method 1682, 2006; USDA-FSIS, MLG Appendix 2.05, 2014
Helminth eggs	Ambic-ZnSO ₄ method (Merlien Reddy, 2013) ⁹

Source: EML, CSE

6. FSTPs evaluated in this study

In this study, 39 FSTPs with pyrolysis-based Omni Processor (POP) technology were evaluated. All the FSTPs were commissioned during 2023–24 and operated by MVR technology with screw press for solid separation; MBBR and pyrolysis for effluent and biosolids treatment respectively. The consolidated details of the FSTPs including population of the FSTP location, treatment capacity, amount of byproducts generated and their reuse are provided in *Table 3*.

Table 3: FSTPs evaluated in this study

S. no	FSTP location	Population		Capacity of the plant (KLD)	Amount of FS received (litres)	Amount of treated water generated (Litres per day)	End use of treated water	Dried sludge generated (kg/month)
		2011 Census (official)	2026 estimated population*					
1	Baggar	14,238	21,200	10	4,000 per day	3,000	Used within the premises	2-3% of the received FS
2	Khatu Shyam Ji	11,374	16,900	15	4,000-8,000 per week	500-700	Gardening/ plant cleaning	150
3	Kishangarhbas	9,154	13,600	10	Used within the premises	2-3% of the received FS
4	Mundwa	16,871	25,100	10	8,000–16,000 per month	4,000– 10,000	Used within the premises	2-3% of the received FS
5	Pirawa	13,192	19,600	10	32,000–40,000 per month	..	Not used until now	2-3% of the received FS
6	Uniara	12,551	18,700	10	16,000 received until now	..	Used within the premises	2-3% of the received FS
7	Bhusawar	19,946	29,700	15	16,000–20,000 per week	..	Gardening, greenbelt within the premises	2-3% of the received FS
8	Deoli	22,065	32,800	15	20,000–24,000 per month	..	Gardening, greenbelt within the premises	2-3% of the received FS
9	Deshnok	18,470	27,600	15	16,000–20,000 per week	1,000	Green belt	200
10	Mukundgarh	18,469	27,600	15	4,000 per day	3,000	Used within the premises	2-3% of the received FS

S. no	FSTP location	Population		Capacity of the plant (KLD)	Amount of FS received (litres)	Amount of treated water generated (Litres per day)	End use of treated water	Dried sludge generated (kg/month)
		2011 Census (official)	2026 estimated population*					
11	Nawa	22,088	33,000	15	4,000–8,000 per day	4,000–5,000	Used within the premises	2-3% of the received FS
12	Viratnagar	20,568	30,700	15	10,000–14,000 per day	4,000–5,000	Gardening/ plant cleaning	500
13	Weir	19,385	28,900	15	8,000–12,000 per week	..	Gardening, greenbelt	2-3% of the received FS
14	Sarwar	20,372	30,300	15	4,000–8,000 per week	2,000–3,000	Used within the premises	2–3% of the received FS
15	Lakheri	29,572	43,000	20	4,000–8,000 per week	..	Gardening, Greenbelt within the premises	2–3% of the received FS
16	Bijainagar	32,124	46,000	20	80,000–100,000 per month	..	Gardening, greenbelt within the premises	2–3% of the received FS
17	Gulabpura	24,349	35,000	20	40,000–48,000 per week		Gardening, greenbelt within the premises	2–3% of the received FS
18	Losal	28,504	41,000	20	4,000 per day	3,000–4,000	Gardening, greenbelt within the premises	2–3% of the received FS
19	Bissau	22,762	33,000	20	4,000–8,000 per day	3,000–6,000	Used within the premises	2–3% of the received FS
20	Malpura	31,028	45,000	20	80,000–100,000 per month	2,000–3,000	Used within the premises	2–3% of the received FS
21	Kuchera	24,843	36,000	20	4,000 received until now	2–3% of the received FS
22	Kishangarh Renwal	29,201	42,500	20	16,000-20000 per day	4,000	Used within the premises	2–3% of the received FS
23	Thodaraisingh	23,559	34,000	20	16,000–20,000 per month	8,000–10,000	Used within the premises	2–3% of the received FS
24	Reengus	26,139	38,000	20	4,000–8,000 per day	1,000–1,500	Gardening, greenbelt within the premises	150-300

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

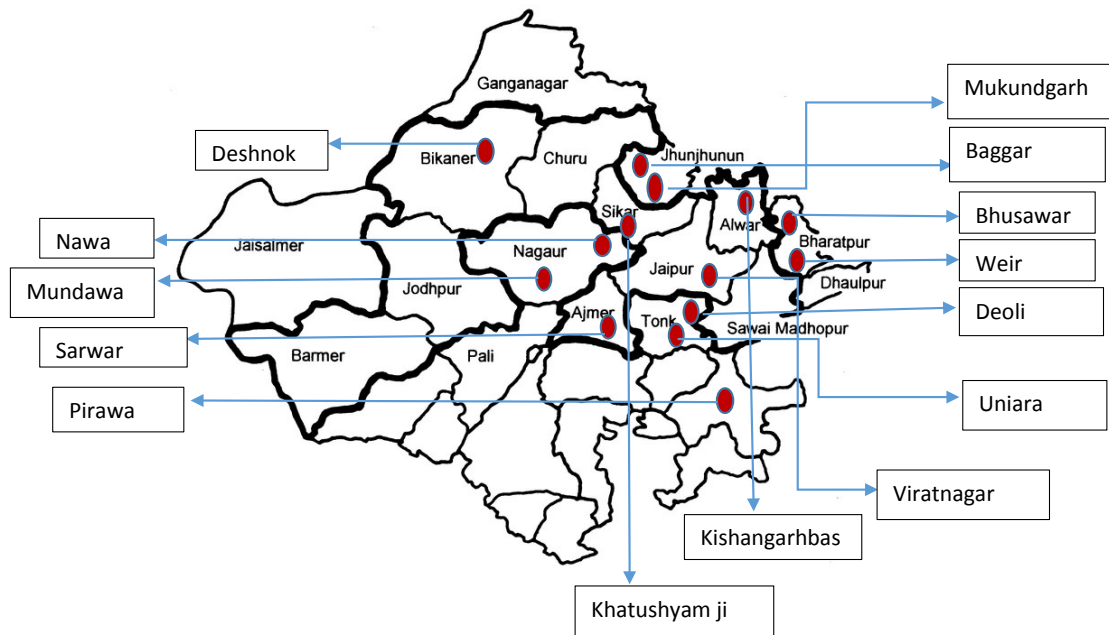
S. no	FSTP location	Population		Capacity of the plant (KLD)	Amount of FS received (litres)	Amount of treated water generated (Litres per day)	End use of treated water	Dried sludge generated (kg/month)
		2011 Census (official)	2026 estimated population*					
25	Rajaldesar	27,419	40,000	20	16,000-20,000 per month	3,000-4,000	Gardening, greenbelt within the premises	4-5
26	Chhabra	32,285	47,000	25	12,000 per week	..	Not used until now	15
27	Taranagar	32,640	47,500	25	4,000-8,000 per day	3,000-5,000	Used within the premises	2-3% of the received FS
28	Chaksu	33,432	48,000	25	12,000-20,000 per day	4,000-6,000	Gardening, greenbelt within the premises	90
29	Niwai	37,765	55,000	25	4,000 per week	3,000	Gardening, greenbelt within the premises	80
30	Bidasar	32,546	47,000	25	12,000-16,000 per day	1,500	Machine maintenance and greenbelt	4
31	Sri Madhopur	31,366	45,000	25	2,500-5,000 per 20 days	..	Green belt and vehicle washing	150-160
32	Bayana	38,502	56,000	35	40,000 per week	..	Used within the premises	2-3% of the received FS
33	Rajgarh, Churu	59,193	85,000	35	4,000 per day	3,000	Stored	2-3% of the received FS
34	Nohar	49,835	72,000	35	4000-12000 per day	3000-9000	Used within the premises	2-3% of the received FS
35	Pilani	29,741	43,000	35	4,000-8,000 per day	3,000-6,000	Used within the premises	2-3% of the received FS
36	Kekri	41,890	60,000	35	4,000-8,000 per week	6,000	Used within the premises	2-3% of the received FS
37	Kotputli	49,202	71,000	35	8,000-12,000 per day	3,000-4,000	Gardening, greenbelt within the premises	1,000
38	Shri Dungargarh	53,294	77,000	35	60,000 per day	5,000-7,000	Greenbelt	30
39	Khairthal	38,298	54,000	35			Gardening within the premises	2-3% of the received FS

*The 2026 estimated population is calculated using a uniform growth factor multiplier (geometric growth rate approach) applied to the 2011 Census population

Source: EML, CSE

Two FSTPs at Kahirthal and Kishangarh Bas with POP technology were evaluated by EML, CSE for FSTP performance and the quality of biosolids and biochar in 2025. The same FSTPs were reevaluated in the current study to assess the improvement/decline in the treatment in terms of the quality of treated effluent, biosolids and biochar.¹⁰ A decline in the quality of effluent (in parameters such as COD, BOD, TKN, TP and FC) as well as biosolids (moisture and pathogen content) was observed in both the locations indicating operational instability or poor maintenance, leading to the decline in treatment efficiency at both sites.

Map 1: Locations of 10 KLD and 15 KLD FSTPs evaluated in this study



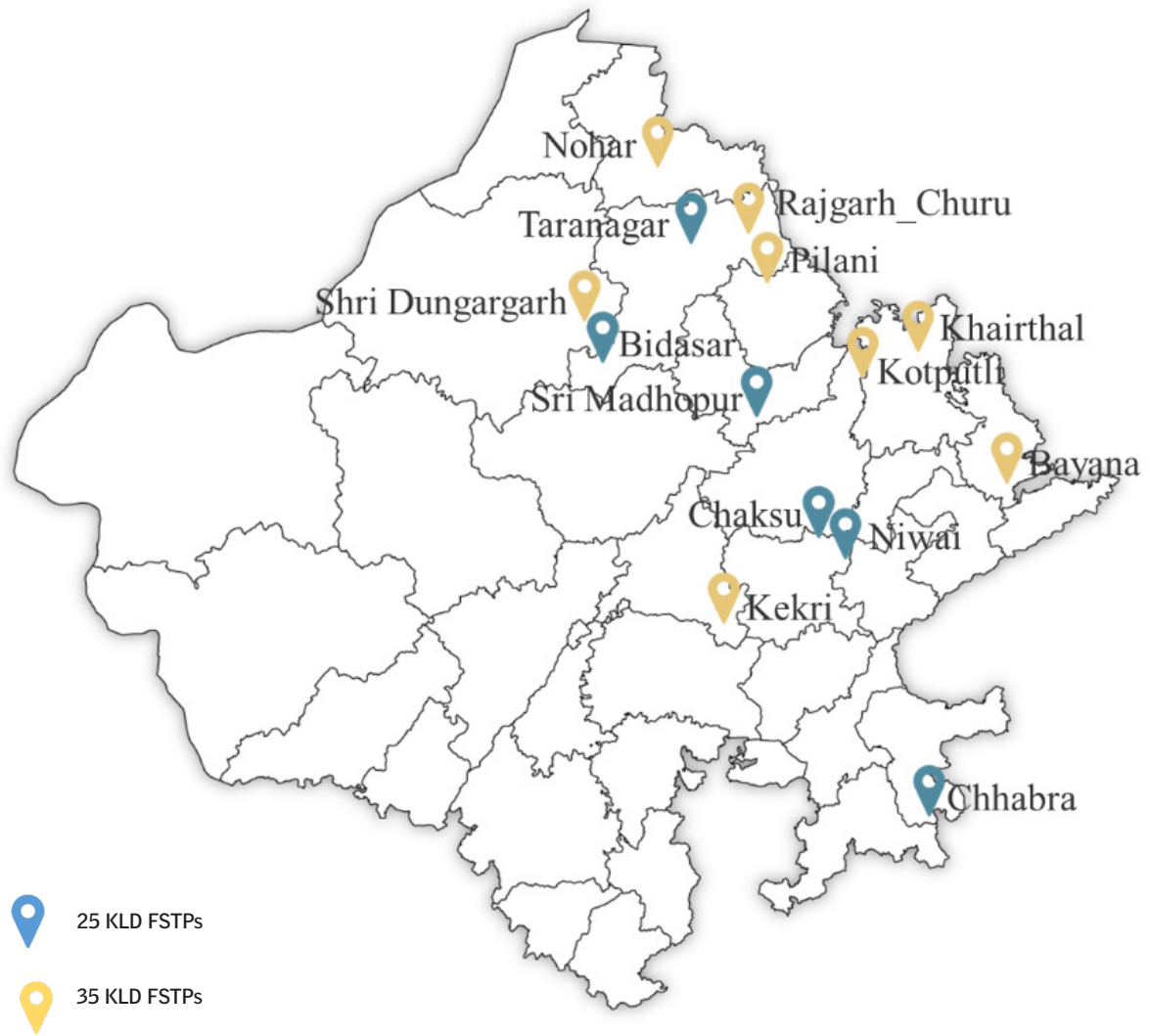
Source: EML, CSE

Map 2: Locations of 20 KLD FSTPs evaluated in this study



Source: EML, CSE

Map 3: Locations of 25 KLD and 35 KLD FSTPs evaluated in this study



Source: EML, CSE

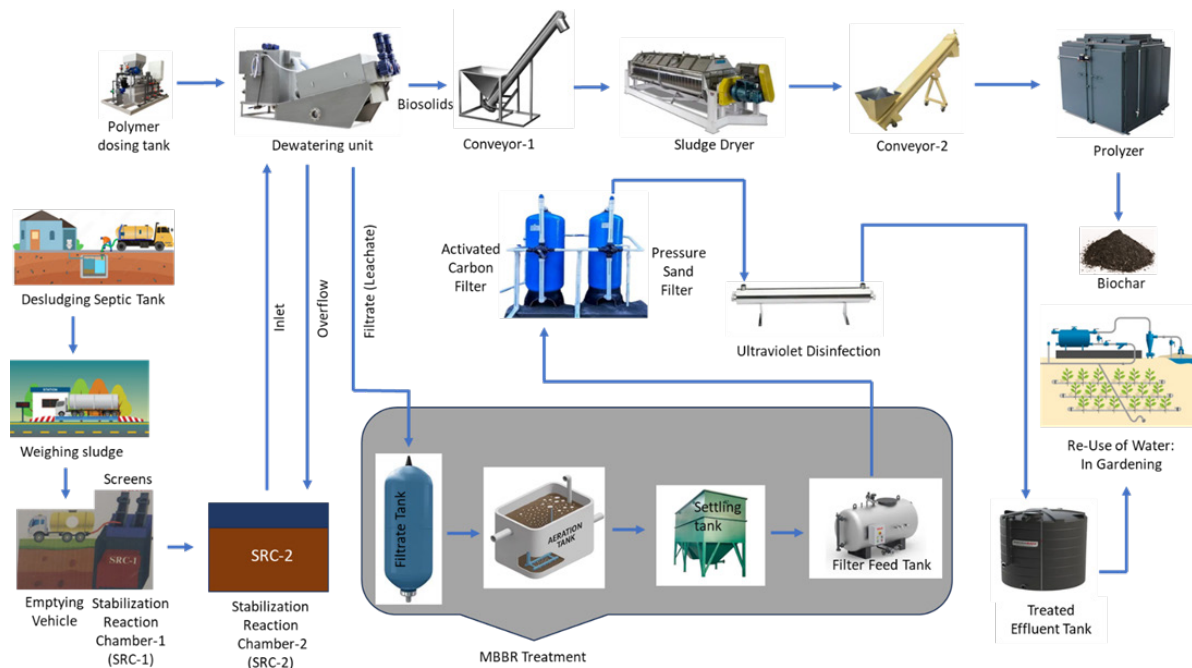
6.1 FSTP technology

The treatment process employs a dual-stream approach, utilizing Moving Bed Biofilm Reactor (MBBR) technology for leachate and pyrolysis for biosolids. Initially, faecal sludge (FS) is discharged into a receiving unit where parallel screens remove large debris and grit. The sludge then undergoes stabilization in two sequential reaction chambers (SRC-1 and SRC-2) before being pumped into a dewatering unit. Here, a mechanical screw press, aided by polymer flocculation, separates the solids from the liquid leachate.

The liquid leachate enters a single-chambered MBBR system, where plastic biofilm carriers facilitate the aerobic and anaerobic degradation of organic matter and nutrients. Following biological treatment, the effluent is clarified in a settling tank and further refined through activated carbon and pressure sand filters. A final pass through a UV chamber ensures disinfection before the treated water is stored for on-site gardening.

Simultaneously, the separated solids are transported via conveyor to a heat-pump belt dryer operating between 60°C and 75°C. Once dried, the biosolids enter a wood-chip-fuelled pyrolyzer, where they are heated to temperatures between 170°C and 750°C in an oxygen-limited environment. This thermal conversion produces biochar, which is currently bagged and stored for future use (see *Figure 1: Process flow in the evaluated FSTPs*).

Figure 1: Process flow in the evaluated FSTPs



Source: EML, CSE



Pyrolysis-based Omni Processor (POP) at Khairthal FSTP showing conveyers, belt dryer and pyrolizer



Wood chips at Khairthal FSTP



Dewatered biosolids mixed with wood chips at Kishangarh Bas FSTP

7. The results of the study

The inlet and outlet samples collected from the FSTPs 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 and biochar samples collected from the FSTPs were analysed for nine parameters (as mentioned in Section 5.5).

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 the two FSTPs (see *Annexure 1, Tables 1-2*). The physicochemical parameters in biosolids and biochar are compared with Fertilizer Control Order (FCO) 2023 to evaluate the nutrient value of biosolids/biochar for agricultural applications (see *Annexure 1, Table 3*). To assess the pathogen level in biosolids and biochar, this study follows the regulatory limit set by WHO in 2006, and the US Environment Protection Agency (EPA) for Class A biosolids (see *Annexure 1, Table 4*). The consolidated data of all the results is tabulated and depicted in *Annexure 2, Tables 1-3*.

7.1 Performance evaluation of FSTPs for effluent treatment and quality

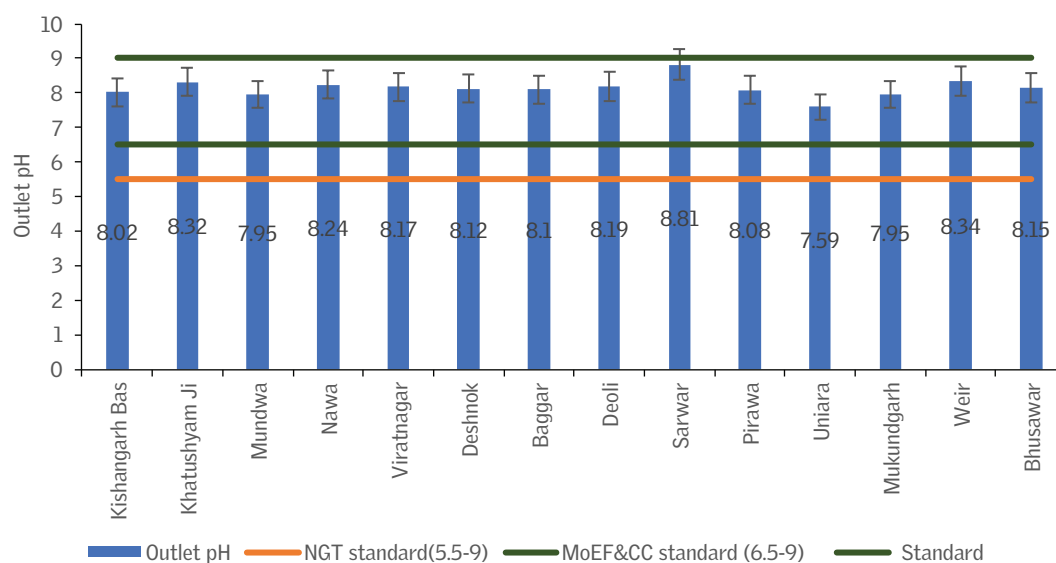
Ten different parameters were selected for the evaluation of physicochemical and microbiological characteristics of FSTP inlet and outlet samples, namely pH, solids content such as total solids (TS), total dissolved solids (TDS) and total suspended solids (TSS), organic content based on chemical oxygen demand (COD) and biochemical oxygen demand (BOD), nutrient content such as total Kjeldahl nitrogen (TKN), ammoniacal nitrogen (AN) and total phosphate (TP) and pathogen content such as faecal coliform (FC). All the parameters are represented here to evaluate the performance of FSTPs.

7.1.1 Performance evaluation of 10 KLD and 15 KLD FSTPs for effluent treatment and quality

7.1.1.1 pH

In this study, the pH of the treated effluent across all 14 FSTPs remained well within regulatory limits, ranging from a minimum of 7.59 in Uniara to a maximum of 8.81 in Sarwar.

Graph 1: pH in the outlet of 10 KLD and 15 KLD FSTPs



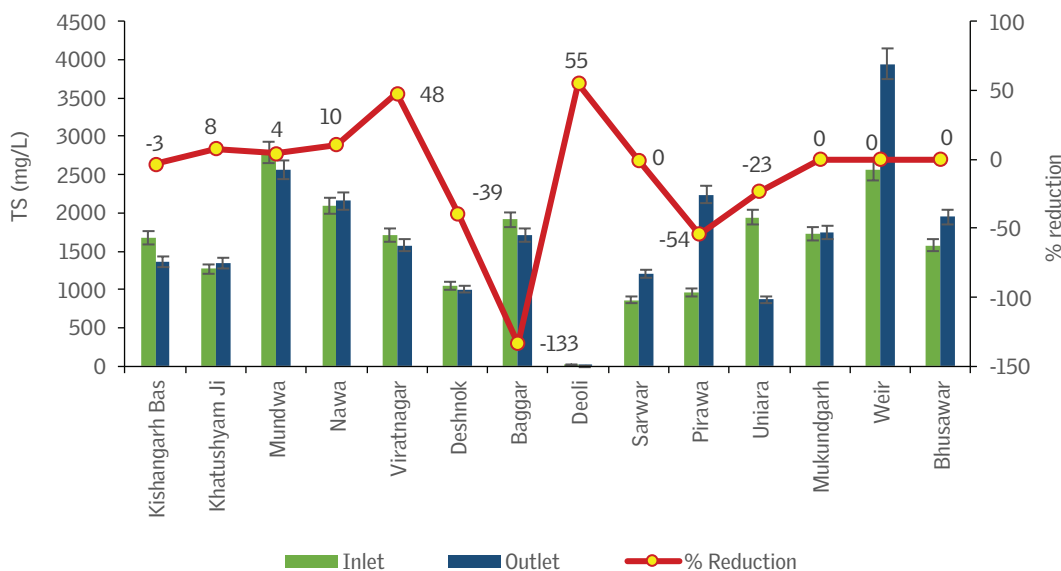
Source: EML, CSE

As illustrated in Graph 1, these values align with the discharge standards established by both the Ministry of Environment, Forest and Climate Change (MoEF&CC), which mandates a range of 6.5–9.0, and the National Green Tribunal (NGT), which allows for a slightly broader range of 5.5–9.0. The consistently high pH of the treated water indicates that the flocculant dosing prior to the screw press is suboptimal. Both the dosage and feed rate must be optimized for each specific plant and operational batch.

7.1.1.2 Total solids (TS)

The inlet, outlet and the percentage reduction for TS has been provided below. The highest solid content present in inlet was seen in Mundawa (2,784 mg/L) and lowest in Deoli (25 mg/L). For treated effluent highest TS was observed in Weir which went up to 3,943 mg/L and least in Deoli showing 13 mg/L. In terms of treatment efficiency (the percentage removal from inlet to outlet) Uniara demonstrated maximum reduction of 55 per cent and least in Pirawa (see *Graph 2: Per cent reduction of TS from inlet to outlet in 10 KLD and 15 KLD FSTPs*). In India, there are no regulatory limits set for TS (total solids) and TDS (total dissolved solids). However, the TDS of treated water is seen to be consistently high. This indicates that the flocculant dosing prior to the screw press is not optimized and hence the residual dissolved flocculant in the water contributes to the constant high TDS. Both the dosage and feed rate must be optimized for each specific plant and operational batch.

Graph 2: Per cent reduction of TS from inlet to outlet 10 KLD and 15 KLD FSTPs

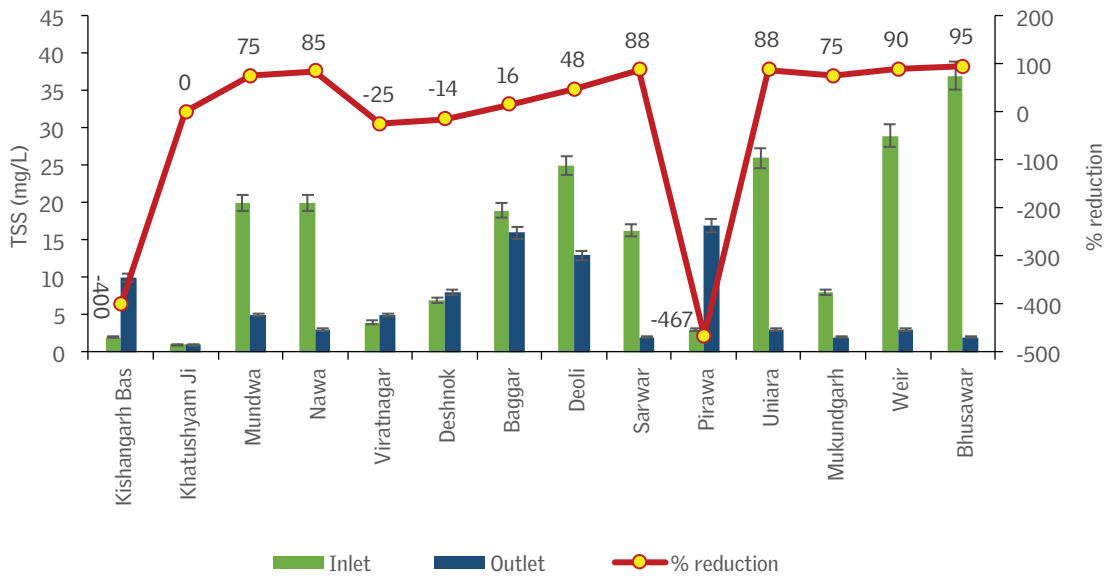


Source: EML, CSE

7.1.1.3 Total suspended solids (TSS)

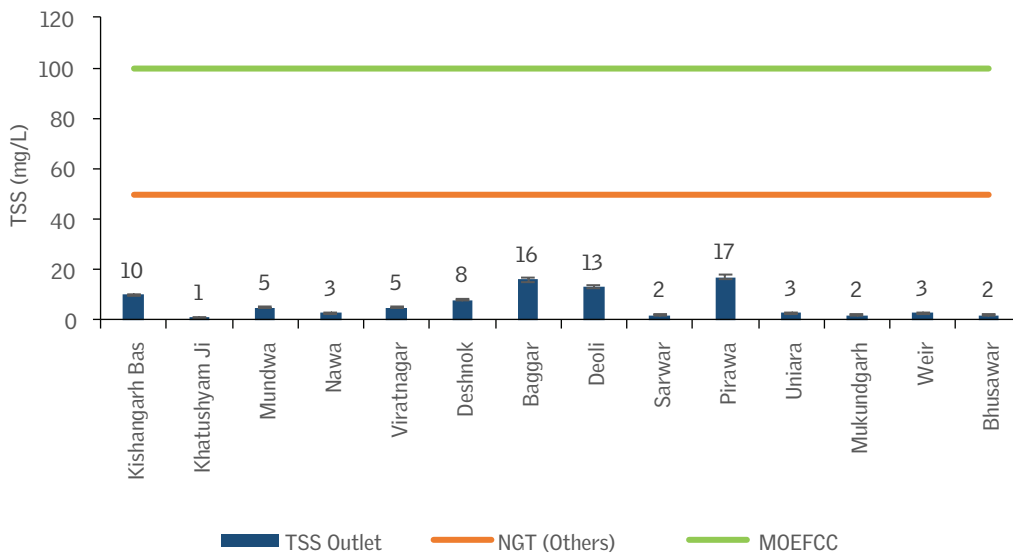
Two sets of standards for TSS are suggested by MoEF&CC and NGT. MoEF&CC limits are set at 50 mg/L for metro cities (referred as Category 1 cities/town) and 100 mg/l for other cities (referred as Category 2 cities/town). As per the NGT norms, the standards are set for TSS final discharge as 20 mg/L (mega and metro cities) and 50 mg/L for others. In terms of per cent removal of TSS from inlet to outlet, the maximum removal was seen in Bhusawar, accounting for 95 per cent removal, and the least was observed in Pirawa (see *Graph 3: Per cent reduction of TSS from inlet to outlet in 10 KLD and 15 KLD FSTPs*). Treated water from all the sites are compliant to both MoEF&CC and NGT standards (see *Graph 4: TSS in the outlet of 10 KLD and 15 KLD FSTPs*).

Graph 3: Per cent reduction of TSS from inlet to outlet in 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 4: TSS in the outlet of 10 KLD and 15 KLD FSTPs

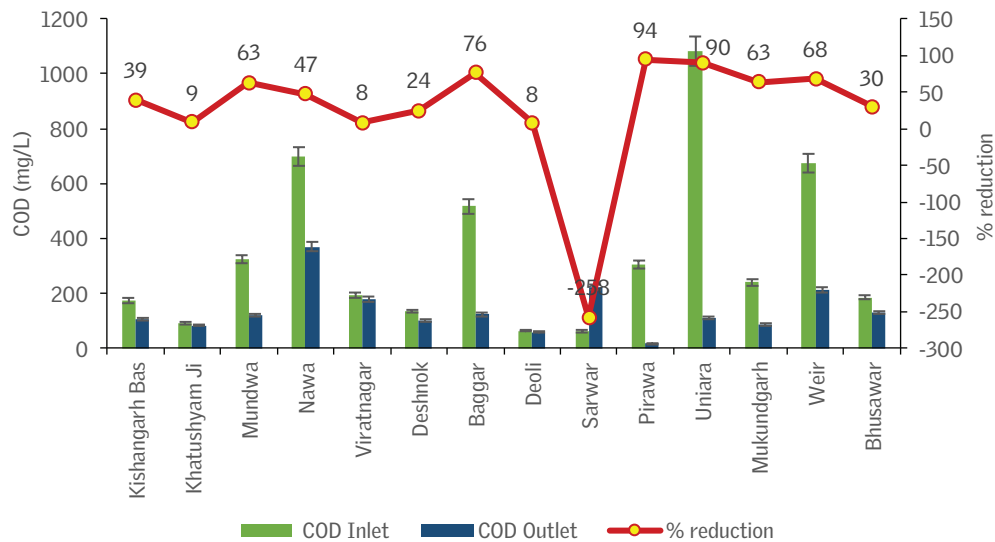


Source: EML, CSE

7.1.1.4 Chemical oxygen demand

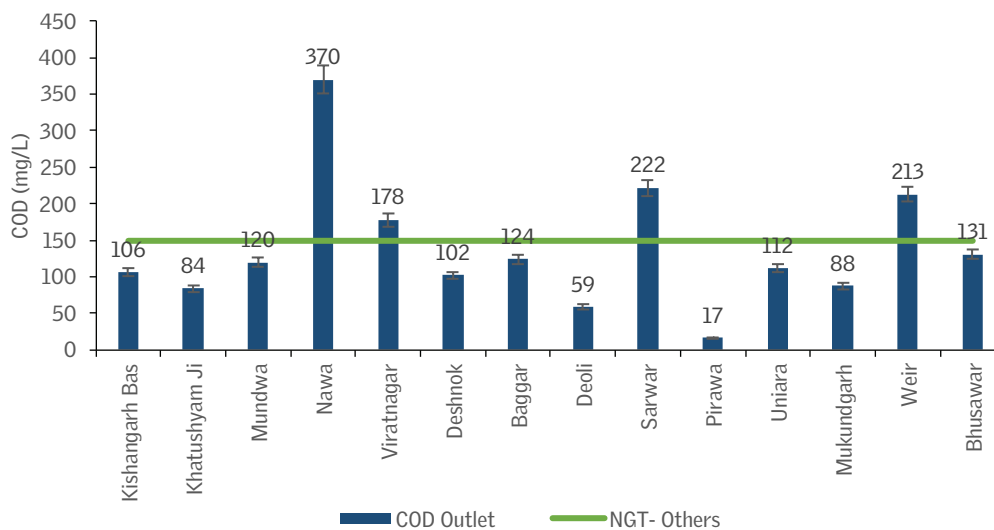
The inlet (COD), outlet (COD) and the per cent removal has been provided in the graph below (see *Graph 5: Per cent reduction of COD from inlet to outlet*). COD in inlet across the FSTPs varied from 62 mg/l in Sarwar to as high as 1,084 mg/l in Uniara. For outlet, COD was observed in the range of 17 mg/l in Pirawa to 370 mg/l in Nawa. In the current study, maximum per cent removal of COD was observed in Pirawa (94 per cent) and minimum in Viratnagar and Deoli (8 per cent). According to NGT, 2019 standards, the final discharge for COD from the STPs should be 50 mg/L (mega and metropolitan cities) and 150mg/l (for others). Out of 14 plants, 10 plants meet the standards and for the remaining four plants (Nawa, Viratnagar, Sarwar and Weir) improvement in performance is required to meet the discharge standards (see *Graph 6: COD in the outlet of 10 KLD and 15 KLD FSTPs*).

Graph 5: Per cent reduction of COD from inlet to outlet of 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 6: COD in the outlet of 10 KLD and 15 KLD FSTPs



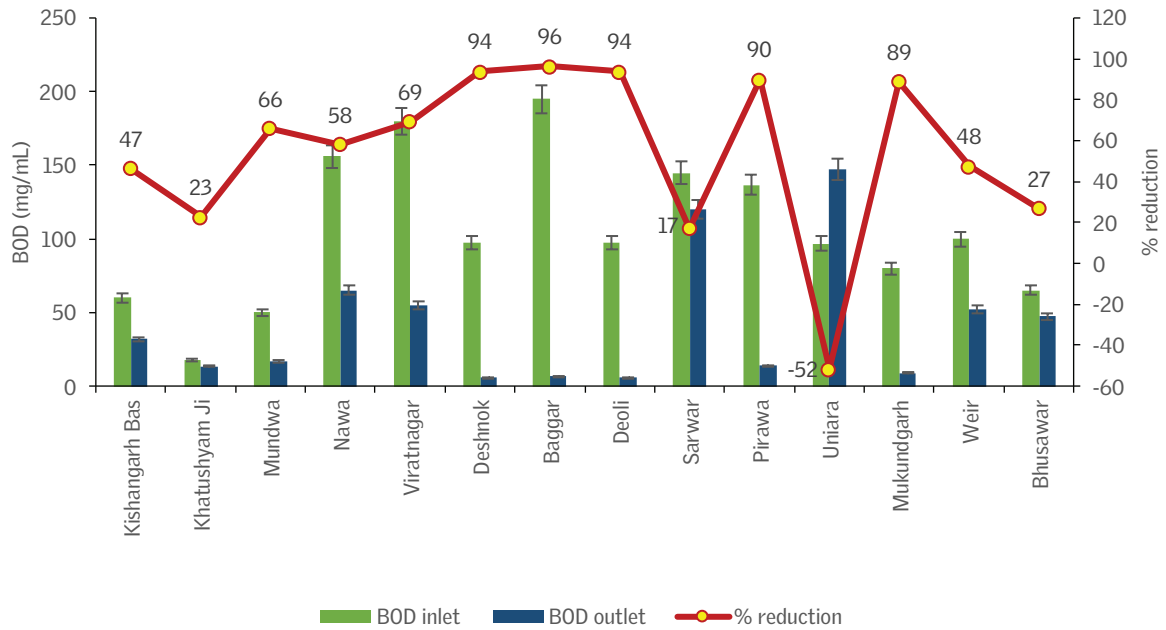
Source: EML, CSE

7.1.1.5 Biological oxygen demand (BOD)

Graph 7 highlights the per cent reduction of BOD in treated effluent. At the inlet, BOD ranged from 60 mg/l to 180 mg/l (Kishangarh Bas and Viratnagar). Similarly, at the outlet, BOD was observed to be 6 mg/L to 147 mg/L (Deoli, Deshnok and Uniara). The maximum per cent reduction of 96 per cent was seen in Baggar and minimum in Uniara (see *Graph 7: Per cent reduction of BOD from inlet to outlet of 10 KLD and 15 KLD FSTPs*).

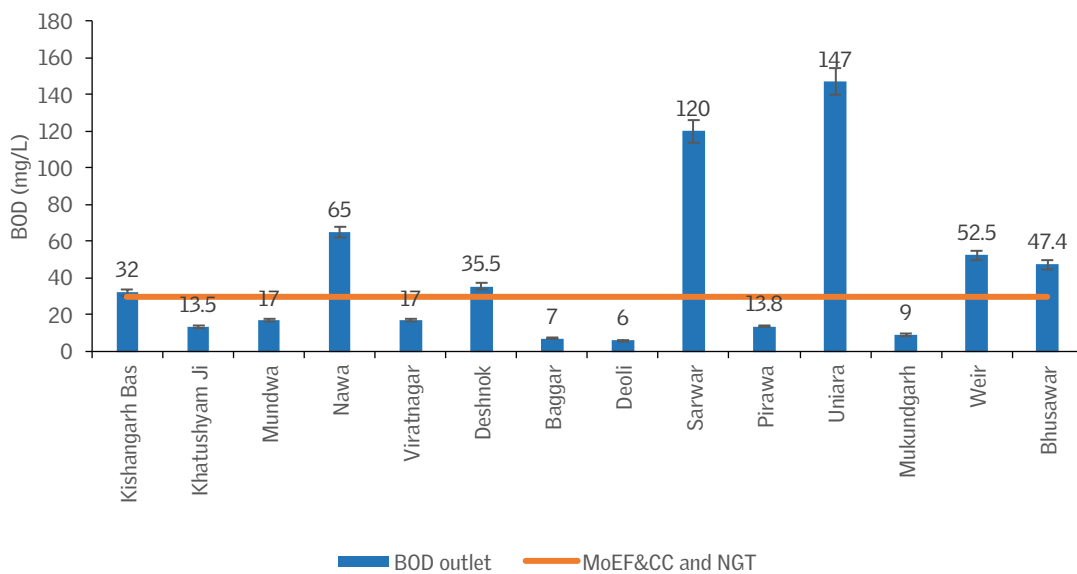
According to NGT, 2019, the standards set for BOD is 30 mg/L (for others), while MoEF&CC states that the BOD of discharge effluent should be within 20 mg/L for metro and state capitals and 30 mg/L for others. In accordance with the standards, seven FSTPs (Khatushyam ji, Mundawa, Viratnagar, Baggar, Deoli, Pirawa and Mukundgarh) lie within the prescribed standards, while two plants (Kishangarh Bas and Deshnok) are slightly above the standards. The remaining five FSTPs need improvement in performance to meet the discharge standards (see *Graph 8: BOD in the outlet of 10 KLD and 15 KLD FSTPs*).

Graph 7: Per cent reduction of BOD from inlet to outlet of 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 8: BOD in the outlet of 10 KLD and 15 KLD FSTPs

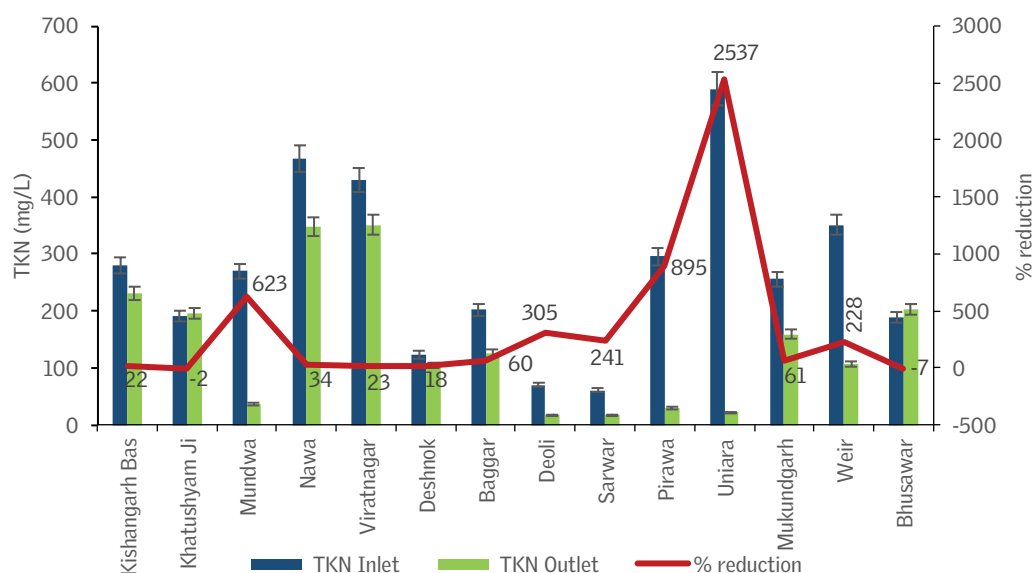


Source: EML, CSE

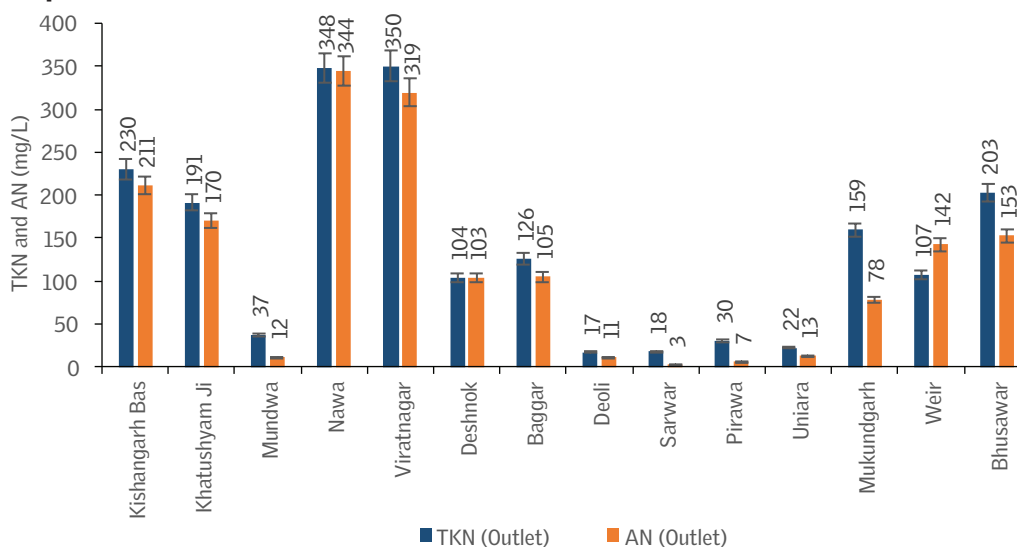
7.1.1.6 Total nitrogen (TN)

TN consists of all forms of nitrogen present in waste or treated water. If TN is not controlled in the FSTPs or in wastewater treatment unit, it can lead to severe nutrient pollution. *Graph 9* shows the presence of TKN in inlet, outlet and the per cent reduction from inlet to outlet. TKN level varied significantly across all the FSTPs. At the inlet, TKN ranged from 61 mg/L in Sarwar to 589 mg/L in Uniara. After treatment, outlet TKN levels were between 17 mg/L in Deoli to 350 mg/L in Viratnagar. In terms of per cent reduction from inlet to outlet, Uniara achieved the highest TKN reduction (96 per cent) and least was observed in Bhusawar (see *Graph 9: Per cent reduction of TKN from inlet to outlet of 10 KLD and 15 KLD FSTPs* and *Graph 10: TKN and AN in the outlet of 10 KLD and 15 KLD FSTPs*). For TKN and AN there are no regulatory standards provided by MoEF&CC. However, NGT, 2019 has provided standard for TN limits 10mg/L (mega and metropolitan cities), 15 mg/L for (Class I cities) and for others the standards are not prescribed.

Graph 9: Per cent reduction of TKN from inlet to outlet of 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 10: TKN and AN in the outlet of 10 KLD and 15 KLD FSTPs

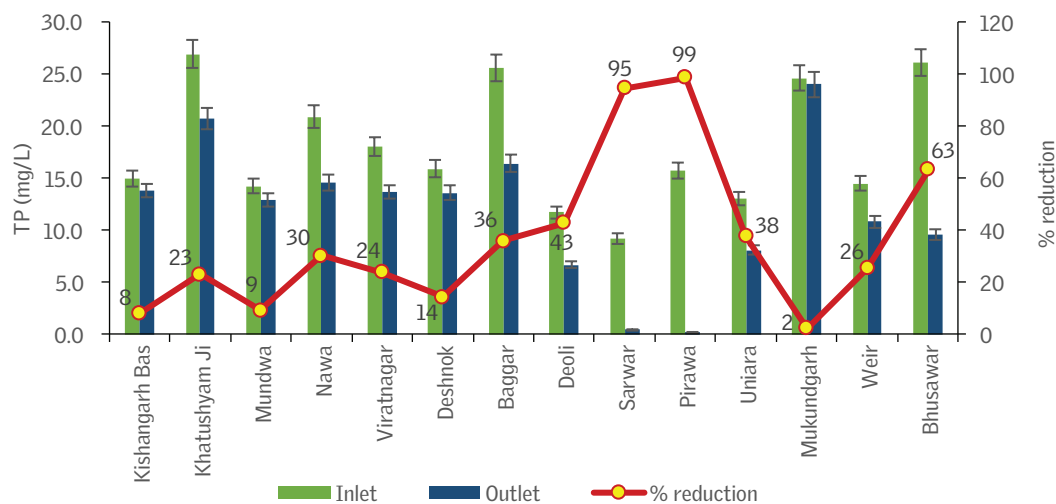
Source: EML, CSE

7.1.1.7 Total phosphorus

Total phosphorus signifies the presence of nutrient in the wastewater or treated water which once present in excess can lead to eutrophication. Therefore, removal of TP becomes essential in any wastewater treatment unit.

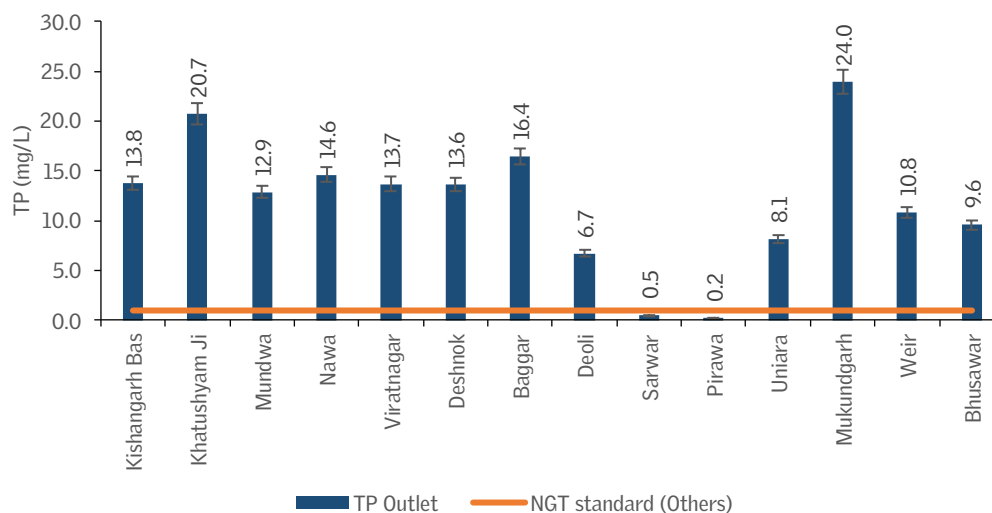
In our current study, the range of TP in the inlet varied from 9 mg/L in Sarwar to 27 mg/L in Khatushyam ji, while in terms of outlet the range varied from the lowest in Pirawa and Sarwar (0.2 mg/L and 0.5 mg/L) and the highest in Mukundgarh (25 mg/L). In term of per cent removal, the maximum removal was observed in Pirawa (99 per cent) and minimum in Kishangarh Bas (8 per cent) (see *Graph 11: Per cent reduction of TP from inlet to outlet of 10 KLD and 15 KLD FSTPs*). For the compliance with respect to TP, NGT, 2019 standard has provided three regulatory limits all set at 1 mg/L for the discharge of treated effluent from STPs into ponds and lakes. Out of all the fourteen plants, only two plants Pirawa and Sarwar (0.2 mg/L and 0.5 mg/L) are meeting the standards. The remaining twelve plants needs performance improvement in order to meet the discharge standards (see *Graph 12: TP in the outlet of 10 KLD and 15 KLD FSTPs*).

Graph 11: Per cent reduction of TP from inlet to outlet of 10 KLD and 15 KLD FSTPs



Source: EML, CSE

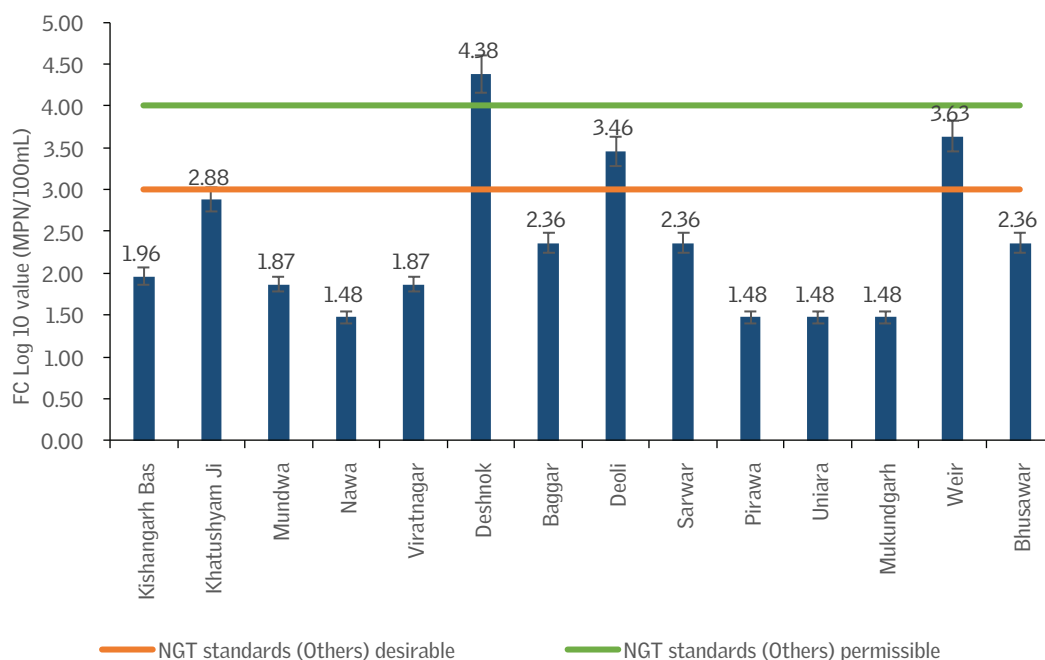
Graph 12: TP in the outlet of 10 KLD and 15 KLD FSTPs



Source: EML, CSE

7.1.1.8 Faecal coliform

The presence of faecal coliform (FC) in treated water indicates the presence of potential pathogens and also reflects the inefficiency of the disinfectant unit established in the plant. *Graph 13* shows the presence of FC in treated effluent (\log_{10} value) for 14 FSTPs. For the compliance with respect to pathogenic content,

Graph 13: FC in the outlet of 10 KLD and 15 KLD FSTPs

Source: EML, CSE

especially FC content in the treated effluent discharge from STPs, NGT, 2019 has prescribed the following standards:

- Desirable limit: 1,000 MPN/100 mL ($\log_{10} 1000 = 3$)
- Permissible limit: 10,000 MPN/100 mL ($\log_{10} 10000 = 4$)

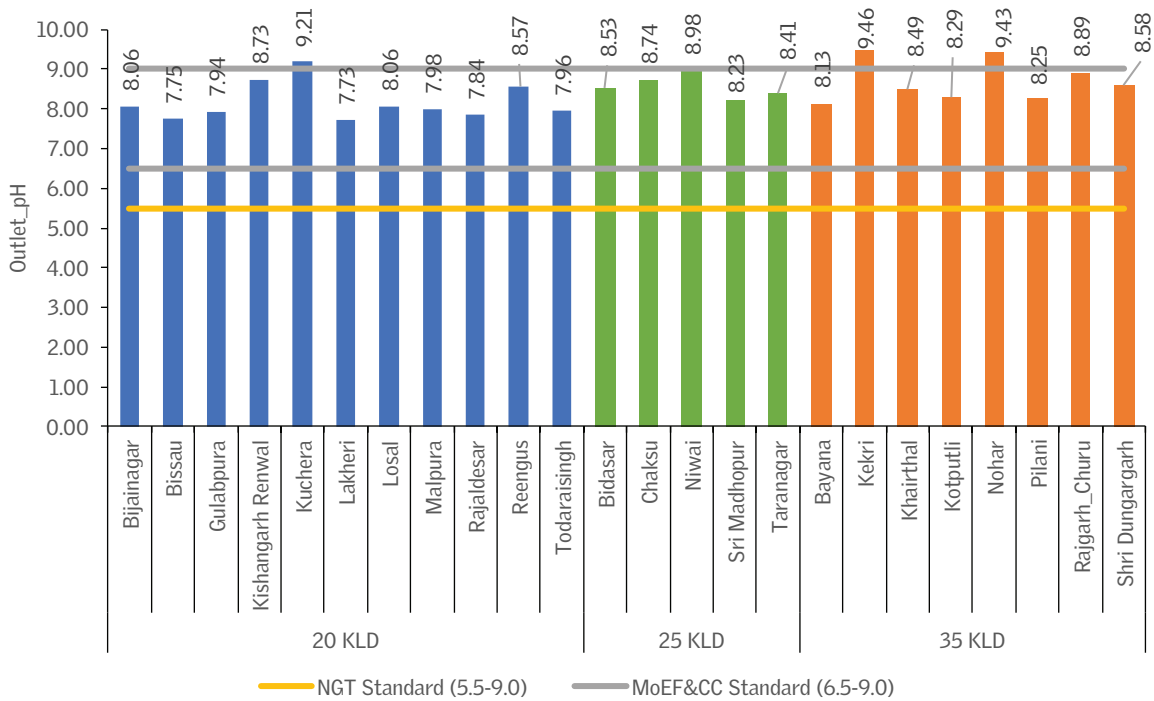
Out of 14 FSTPs, 11 meet the desirable limit set by NGT, two plants (Deoli and Weir) meet the permissible limits, and Deshnok exceeds both the desirable and the permissible limits (see *Graph 13: FC in the outlet of 10 KLD and 15 KLD FSTPs*).

7.1.2 Performance evaluation of 20 KLD, 25 KLD and 35 KLD FSTPs for effluent treatment and quality

7.1.2.1 pH

MoEF&CC's standard limit for the pH of treated effluent discharged from STPs is in the range of 6.5–9.0 while NGT's is 5.5–9.0. The pH of the outlet/treated effluent in the 20 KLD, 25 KLD and 35 KLD FSTPs was found to be slightly alkaline, ranging from 7.73 (Lakheri) to 9.46 (Kekri). While the majority of the plants remained compliant, a few sites such as Kuchera (9.21), Kekri (9.46) and

Graph 14: pH in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

Nohar (9.43) slightly exceeded the upper limit of 9.0, though the overall results indicate effective stabilization of the effluent across the monitored locations (see *Graph 14: pH in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). However, the tendency of the constant high pH of the treated water indicated that the flocculant that was added before the screw press was not optimized. The dosage and dosing rate need to be optimized for each plant and batch of operations.

7.1.2.2 Solids content (TS, TSS and TDS)

The inlet total solids (TS), outlet TS and the per cent removal of TS in 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 15 (see *Graph 15: Total solids (TS) in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet*); the inlet total suspended solids (TSS), outlet TSS and the per cent removal of TSS in 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 16 (see *Graph 16: Total suspended solids (TSS) in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet*).

The inlet TS was found to be in the range of 436 mg/l (Kuchera) to 19,602 mg/L (Bayana) while in the outlet, TS ranged from 114 mg/L (Rajaldesar) to 59,208

mg/l (Losal). While a few plants such as Rajaldesar (95.13 per cent), Niwai (85.84 per cent), Pilani (82.56 per cent), Bayana (81.59 per cent) and Bijainagar (81.04 per cent) showed substantial removal of TS, several plants in all the three capacities showed either low (0.79 per cent to 17.74 per cent) or negative per cent removal (-1.28 per cent to -3680.84 per cent), especially in plants such as Lakheri and Losal (with a per cent removal of -3089.29 per cent to -3680.84 per cent), indicating potential failure in the removal of solids in these plants which requires immediate intervention.

The inlet TSS was found to be in the range of 2 mg/L (Kekri) to 115 mg/l (Bayana) while in the outlet, TSS ranged from 1 mg/L (Kekri) to 42 mg/l (Nohar). The 'per cent removal' of TSS ranged from 35.71 per cent (Kishangarh Renwal) to 98 per cent (Lakheri). While several plants showed significant TSS removal, a few plants showed negative removal (-31.25 to -680.00), indicating poor maintenance.

The solids content such as TS and total dissolved solids (TDS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 17 (see *Graph 17: Total solids (TS) and total dissolved solids (TDS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*); the TSS in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 18 (see *Graph 18: Total suspended solids (TSS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). It was observed from Graph 17 that the vast majority of solids remaining in the treated effluent of the plants are dissolved minerals and salts rather than suspended particles. Performance varied considerably across the sites; while plants such as Rajaldesar, Niwai and Bijainagar maintain low outlet concentrations, a few significant outliers emerge. Specifically, Lakheri and Losal in the 20 KLD category show extreme peaks exceeding 50,000 mg/L, followed by Taranagar in the 25 KLD category at approximately 24,000 mg/L. These high concentrations suggest that the effluent at these specific sites remains highly mineralized or saline, potentially due to the source of the faecal sludge or localized operational issues within the treatment modules.

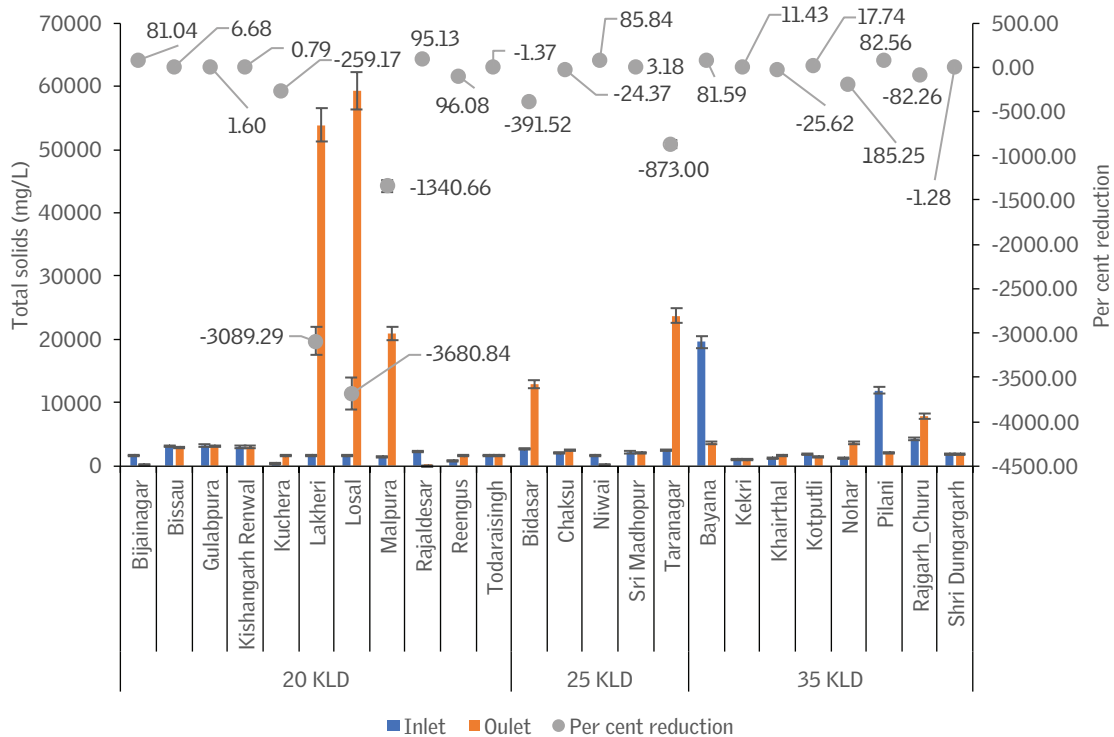
While no regulatory limits exist in India for TS and TDS, MoEF&CC has set two regulatory limits for TSS of treated effluent discharged from STPs in various cities/towns (see *Annexure 1, Table 2*). The MoEF&CC limits are set at 50 mg/L for metro cities and other cities with over 10 lakh population (referred 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). In line with the MoEF&CC norms, the NGT has prescribed three separate regulatory limits: one for 'mega and metropolitan cities' with populations above 1 crore and 10 lakh respectively; another for 'Class I cities' with populations between ten lakh and one lakh; and a third for 'Other' areas with

populations below one lakh (see *Annexure 1, Table 1*). All the 24 FSTPs in the 25–35 KLD capacity described here with a population of less than 1 lakh fall under the MoEF&CC’s ‘Category 2 cities/towns’ and NGT’s ‘others’ category of cities/towns; hence the FSTPs were compared with the MoEF&CC and NGT limits accordingly.

The National Green Tribunal (NGT) prescribes a TSS limit of 50 mg/L for treated effluent from STPs in the ‘Others’ category (see *Annexure 1, Table 1*). All the FSTPs showed an outlet TSS within the respective NGT and MoEF&CC limits of 50 mg/L and 100 mg/L (see *Graph 18: Total suspended solids (TSS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*).

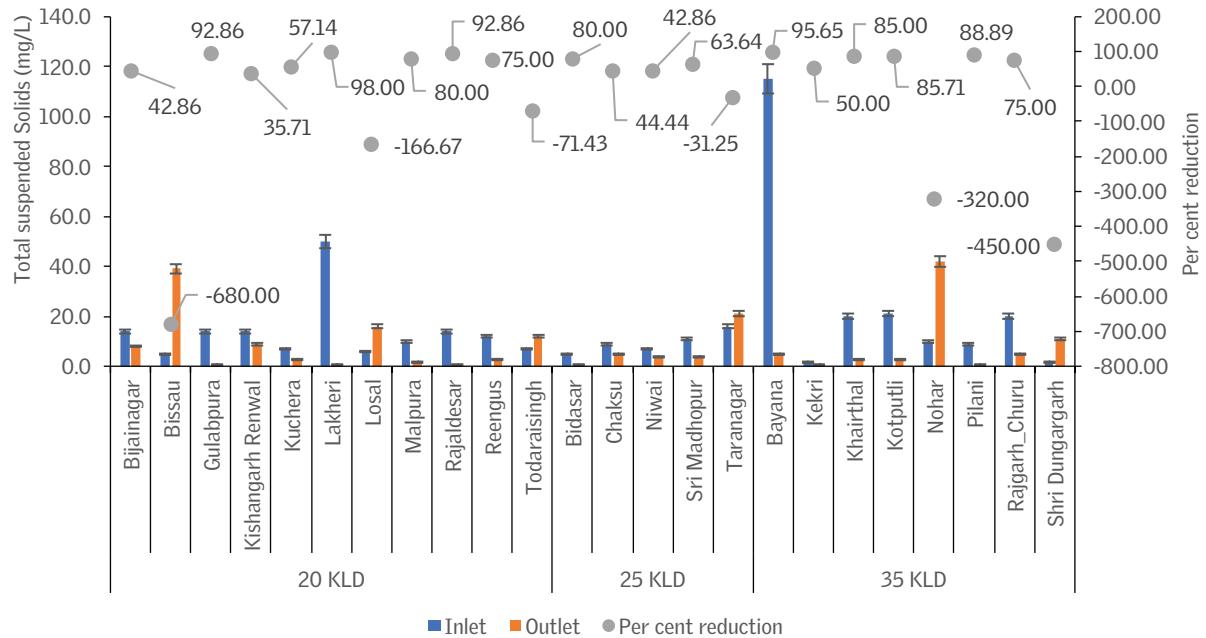
The consistently high TDS in the treated water suggests that pre-screw-press flocculant dosing is unoptimized, leaving residual chemicals that drive up TDS levels. Consequently, both the dosage and feed rate require precise calibration for each plant and individual batch.

Graph 15: Total solids (TS) in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet



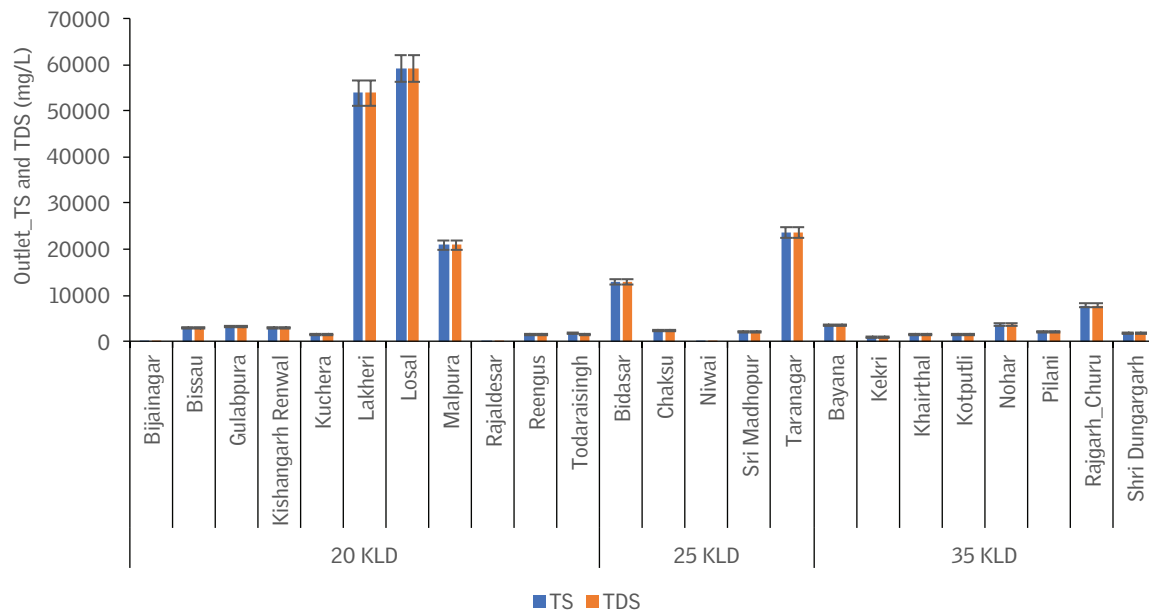
Source: EML, CSE

Graph 16: Total suspended solids (TSS) in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet



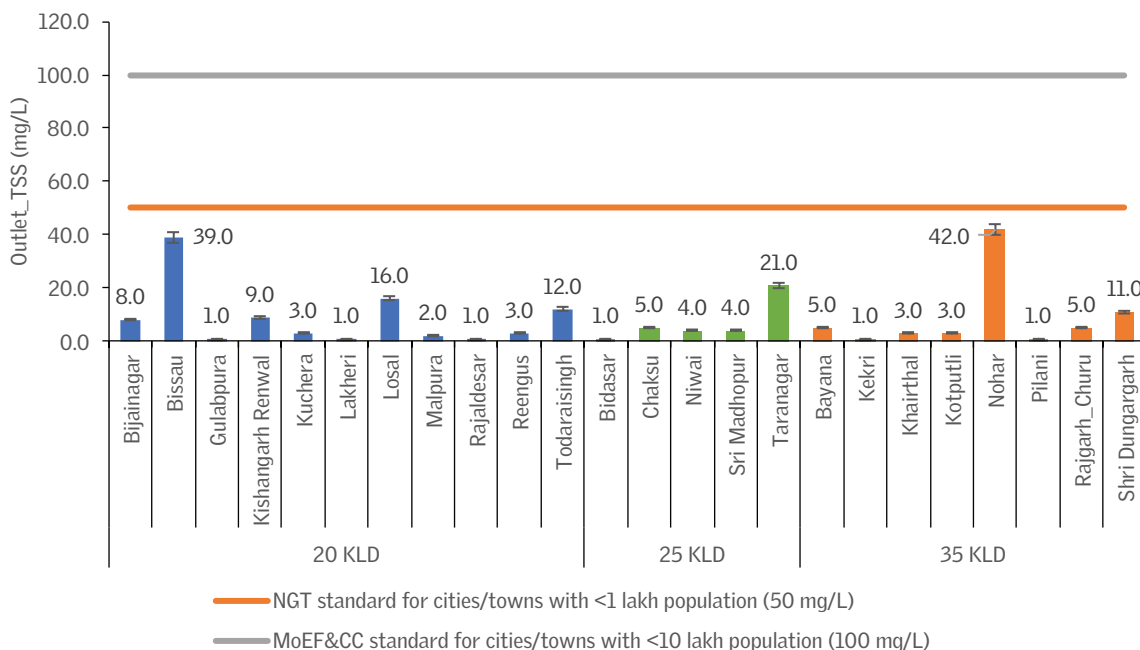
Source: EML, CSE

Graph 17: Total solids (TS) and total dissolved solids (TDS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

Graph 18: Total suspended solids (TSS) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs

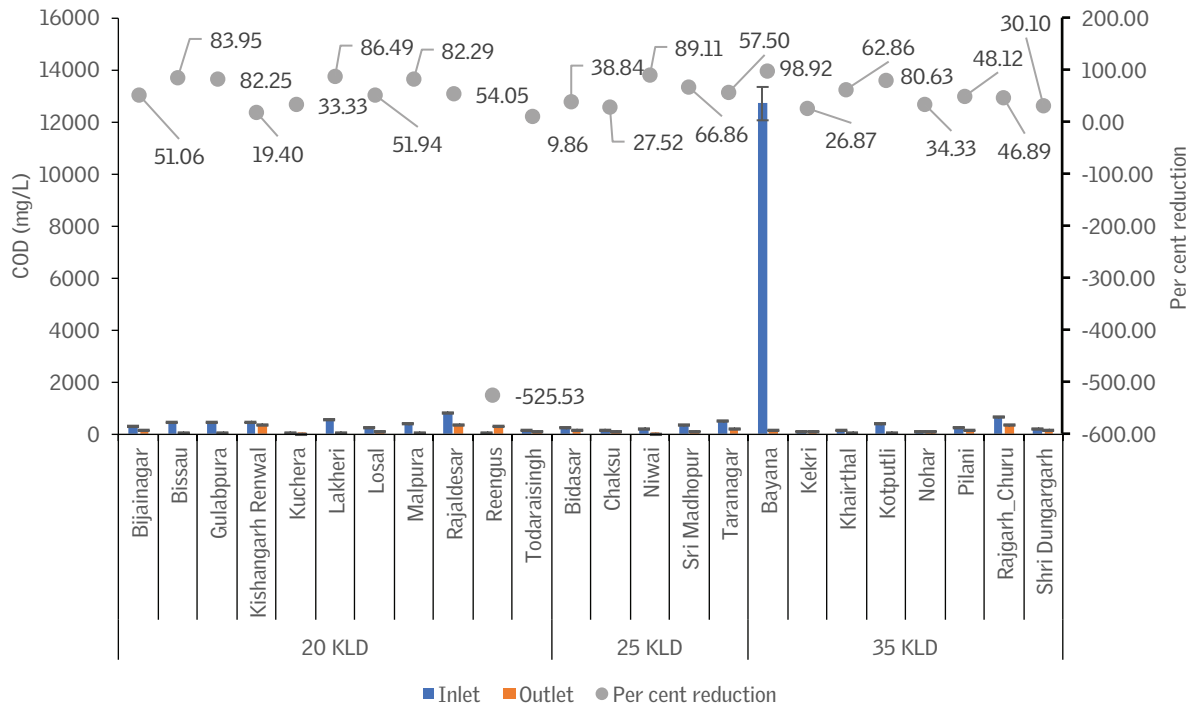


Source: EML, CSE

7.1.2.3 Chemical oxygen demand (COD)

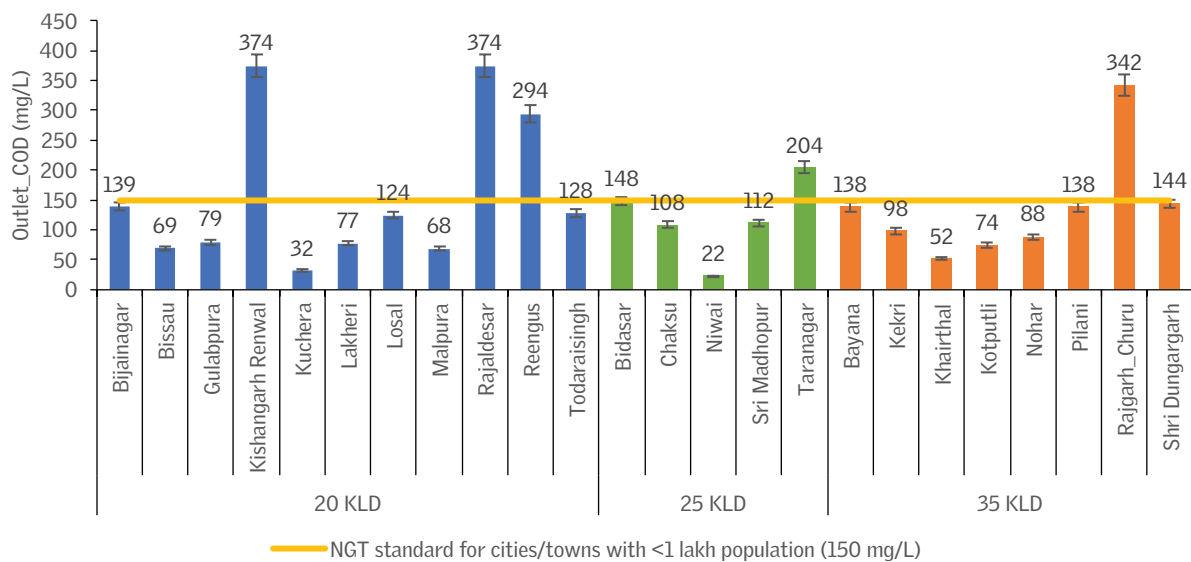
The inlet COD, outlet COD and the ‘per cent removal’ of COD in 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 19 (see Graph 19: COD in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet). COD in the inlet of FSTPs ranged from 47 mg/l (Reengus) to 12,720 mg/l (Bayana), while in the outlet COD ranged from 22 mg/L (Niwai) to 374 mg/L (Kishangarh Renwal). The ‘per cent removal’ of COD varied from -525.53–98.92 per cent. Negative removal was observed in one FSTP (Reengus). Six plants showed good removal (> 80 per cent) and several plants showed moderate removal (30–50 per cent) across the three capacities of plants. No regulatory limit was given by the MoEF&CC for COD of the treated effluent discharged from STPs. Three regulatory limits are given by NGT for various cities/towns depending on their population as described above in Section 7.2.2 (see Annexure 1, Table 1). Five of the 24 plants exceeded the 150 mg/L limit of the NGT standard for cities/towns with <1 lakh population (‘Others’ category) under which all the 24 FSTPs in the 20–35 KLD range fall (see Graph 20: COD in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs).

Graph 19: COD in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet



Source: EML, CSE

Graph 20: COD in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



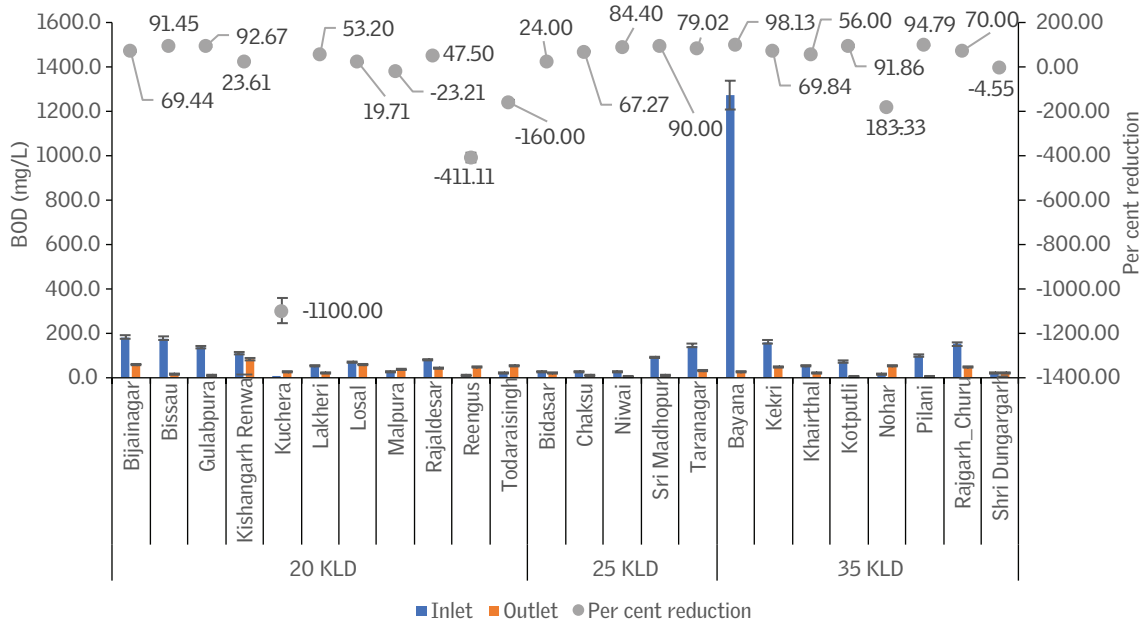
Source: EML, CSE

7.1.2.4. Biochemical oxygen demand (BOD)

The inlet BOD, outlet BOD and the 'per cent removal' of BOD in 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 21 (*see Graph 21: BOD in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet*). BOD in the inlet of FSTPs ranged from 2 mg/L (Kuchera) to 1,270 mg/L (Bayana), while in the outlet BOD ranged from 3.9 mg/l (Niwai) to 82.5 mg/L (Kishangarh Renwal). The 'per cent removal' of BOD varied from -1100.00 to 98.13 per cent. Negative removal was observed in six FSTPs, four of which fall in the 20 KLD capacity, indicating process instability in the lower-capacity FSTPs compared to the higher ones. The majority of plants showed good BOD removal (7 plants > 80 per cent removal; 7 plants > 50–80 per cent removal) across the three capacities.

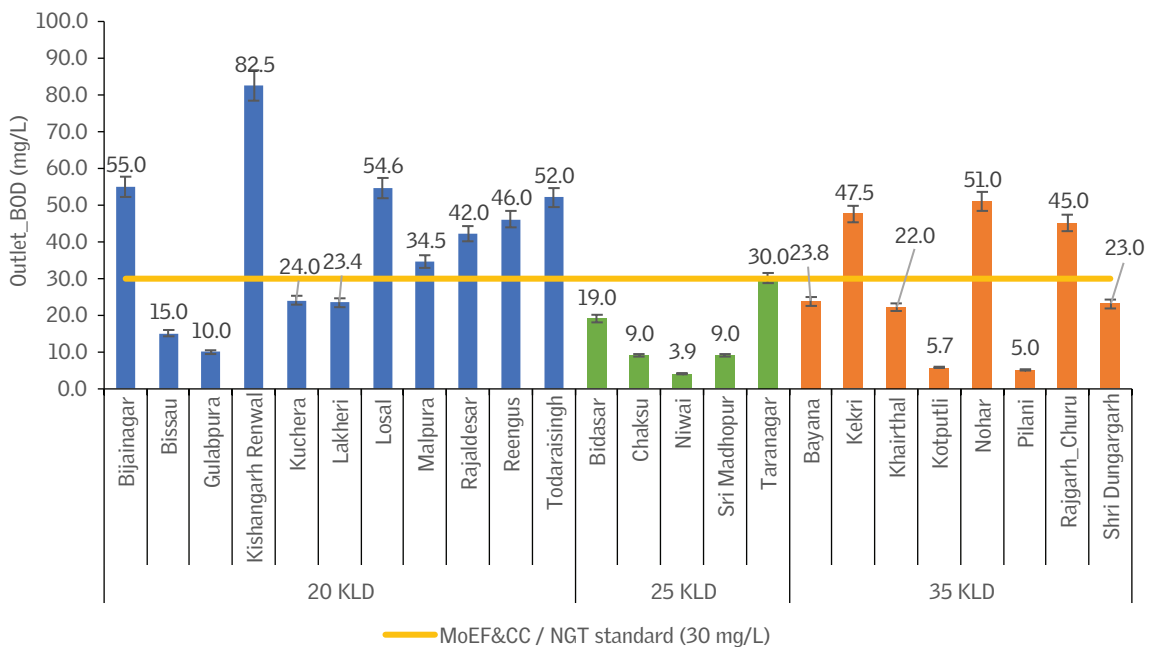
Two regulatory limits are given by the MoEF&CC for BOD of the treated effluent discharged from STPs of various cities/towns, depending on their population (*see Annexure 1, Table 2*). The MoEF&CC limits are set at 30 mg/L for 'Category 2' cities/towns under which all 24 FSTPs falls as described earlier in Section 7.2.2. Similarly, NGT has set three regulatory limits for BOD across various cities/towns (*see Annexure 1, Table1*). The NGT limits are set at 30 mg/L for 'others' category of cities/towns under which all 24 FSTPs falls; hence all the FSTPs were compared with the MoEF&CC and NGT limits accordingly. Ten plants are exceeding the MoEF&CC and NGT limits of 30 mg/L BOD of which majority of plants (seven plants) are falling under 20 KLD capacity indicating issues in the treatment process (*see Graph 22: BOD in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*).

Graph 21: BOD in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet



Source: EML, CSE

Graph 22: BOD in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

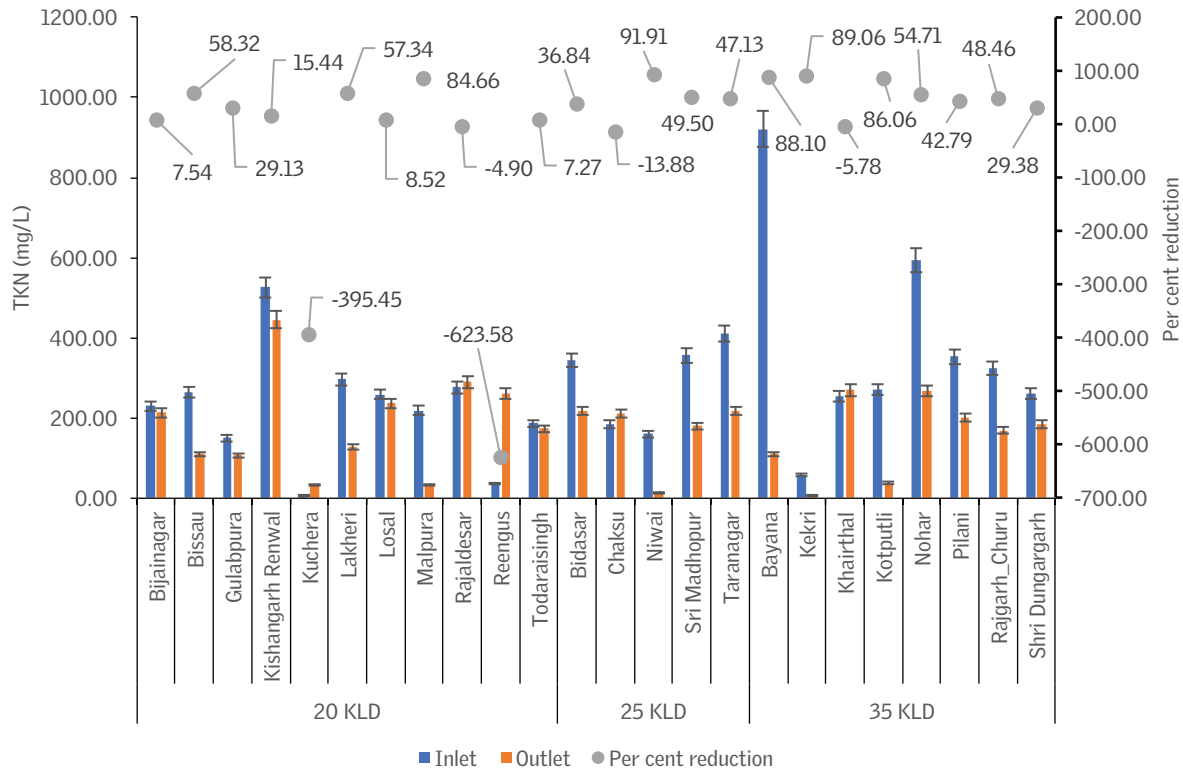
7.1.2.5 Nutrients (TKN, AN, TP)

The inlet TKN, outlet TKN and the per cent removal of TKN in 20 KLD, 25 KLD and 35 KLD FSTPs are shown in Graph 23 (see *Graph 23: TKN in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet*). TKN present in the inlet of FSTPs ranged from 6.47 mg/L (Kuchera) to 921.40 mg/L (Bayana) whereas in the outlet, TKN ranged from 6.17 mg/L (Kekri) to 444.53 mg/L (Kishangarh Renwal). The per cent removal of TKN varied from -623.58 to 91.91 per cent. Negative removal was observed in five plants. Five plants showed high efficiency for TKN removal (> 80 per cent) and several plants showed moderate to low removal (< 50 per cent) across the three capacities of plants.

No regulatory limits for TKN or AN in treated effluent from STPs are specified under MoEF&CC guidelines. The NGT, however, prescribes total nitrogen (TN) limits; however, no limits are provided by NGT for the 'Others' category under which all 24 FSTPs falls (see *Graph 24: TKN and AN in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). Except five plants—Kekri, Niwai, Kuchera, Malpura and Kotputli, which had the effluent TKN of < 50 mg/L—all the plants showed high TKN (100–300 mg/L) in the effluent. Similar to TKN, < 50 mg/L AN was observed only in effluent from six plants (Kekri, Niwai, Kuchera, Nohar, Malpura and Kotputli). The remaining plants showed higher AN levels in the effluent (50–300 mg/L). Kishangarh Renwal showed highest TKN and AN level (>400 mg/L). This shows poor removal of nutrients in the plants warrants reduction before reuse/discharge.

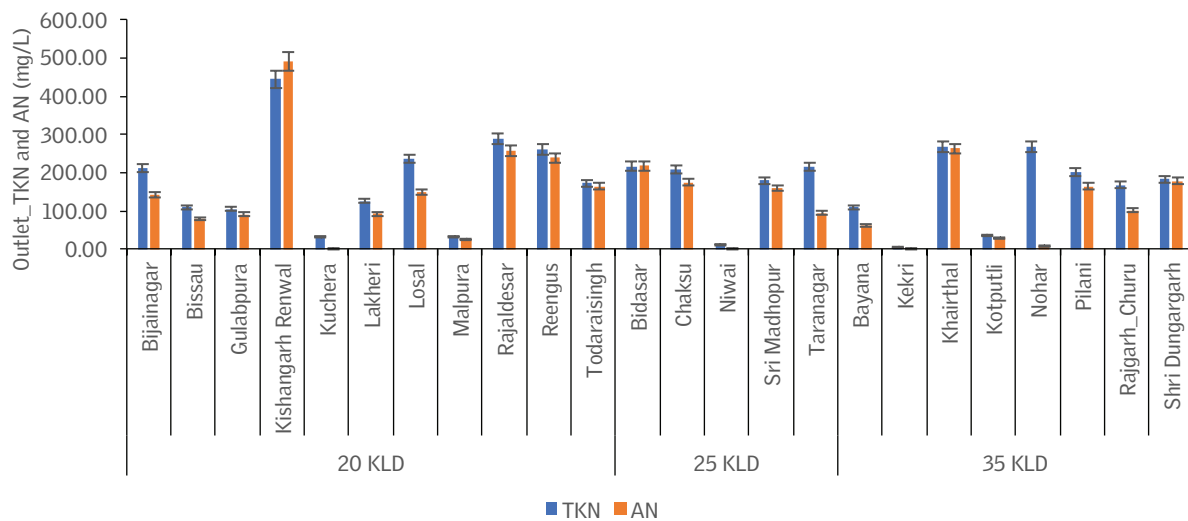
TP in the outlet ranged from 0.1 mg/L (Kuchera) to 28.5 mg/L (Bijainagar). No regulatory limit was given by the MoEF&CC for TP of the treated effluent discharged from STPs. Three regulatory limits, all set at 1.0 mg/L, are given by NGT for total phosphorus (TP) of the treated effluent from STPs for discharge into ponds, lakes for 'mega and metropolitan cities', 'Class I cities' and 'others' category of cities/towns (see *Annexure 1, Table 1*). Three plants—Kuchera, Niwai and Nohar—had effluent TP < 1 mg/L; all the remaining plants had TP of 5–20 mg/L except Bijainagar (28.5 mg/L TP), which should be reduced before reuse (see *Graph 25: TP in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*).

Graph 23: TKN in the inlet and outlet of 20 KLD, 25 KLD and 35 KLD FSTPs and per cent removal from inlet to outlet



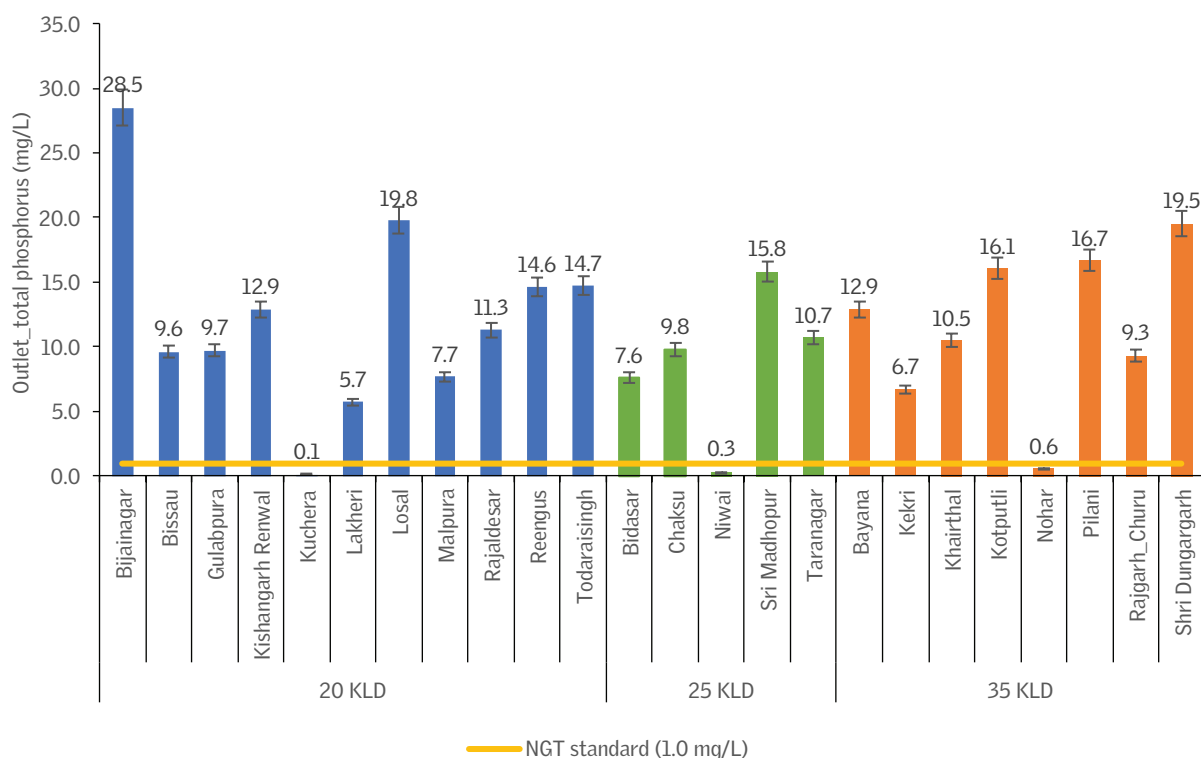
Source: EML, CSE

Graph 24: TKN and AN in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

Graph 25: TP in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

7.1.2.6 Faecal coliform (FC)

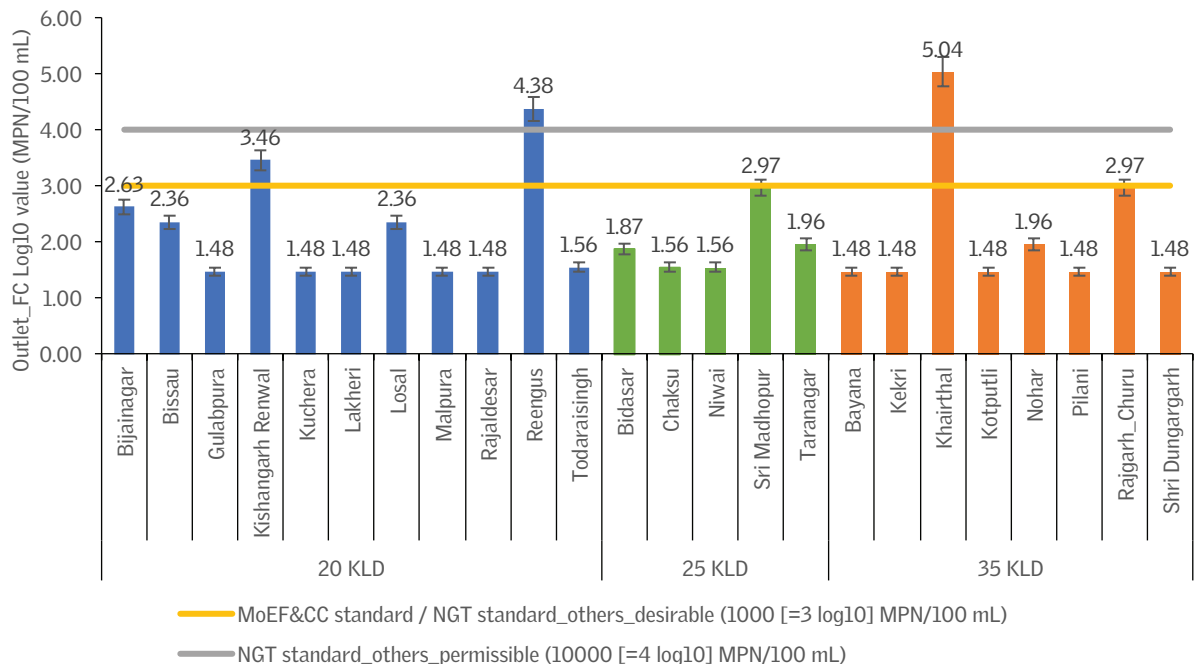
The faecal coliform (FC) content in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs is shown in Graph 26 (see *Graph 26: Faecal coliform (FC) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). As the microbial populations (FC, *E. coli*, *Salmonella* etc.) show several-fold variations in their numbers across the samples, their estimates which are expressed in most probable numbers (MPN) or colony forming units (CFU) are represented in logarithmic (log) values (see *Graph 26: Faecal coliform (FC) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). This representation of MPN/CFU in logarithmic (\log_{10}) values is followed throughout the report for the indicator/pathogenic microorganisms (FC, *E. coli* and *Salmonella*) for better visualization of the results.

The regulatory limit given by 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 (see *Annexure 1, Table 2*). Six regulatory limits are provided by the NGT for various classes of cities/towns for FC in the treated effluent discharged

from STPs (see *Annexure 1, Table 1*). It limits about 1,000 MPN/100 mL as the desirable limit and 10,000 MPN/100 mL ($\log_{10} 10,000 = 4$) as the permissible limit for the ‘Others’ category of cities/towns under which all the 24 FSTPs fall. Hence the FSTPs were compared with the MoEF&CC and NGT limits accordingly.

Faecal coliform (FC) in the outlet of the FSTPs ranged from 30 MPN/100 mL ($\log_{10} 30 = 1.48$) to 110,000 MPN/100 mL ($\log_{10} 110000 = 5.04$). When compared to the respective MoEF&CC and NGT standards described, 21 FSTPs showed FC within the 1,000 mg/L limit and 22 FSTPs showed FC within the 10,000 mg/L NGT permissible limit in the outlet (see *Graph 26: Faecal coliform (FC) in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs*). In most of the FSTPs, tertiary treatment through UV radiation, which is one of the disinfection methods to effectively kill the pathogens in the outlet water, is available. Presence of FC in the outlet within the regulatory limits of both MoEF&CC and NGT indicates the effective functioning of UV disinfection in the plants.

Graph 26: FC in the outlet of 20 KLD, 25 KLD and 35 KLD FSTPs



Source: EML, CSE

7.2 Quality evaluation of biosolids and biochar from the FSTPs

In this study, the selected sites are a combination of FSTP and pyrolysis-based Omni Processor (POP). This approach focuses on maximizing the recovery of carbon and nutrients in the form of biochar. Pyrolysis is performed at high temperatures (800°C) in either a low-oxygen or zero-oxygen environment. Treated water is also recovered from the sludge drying process.

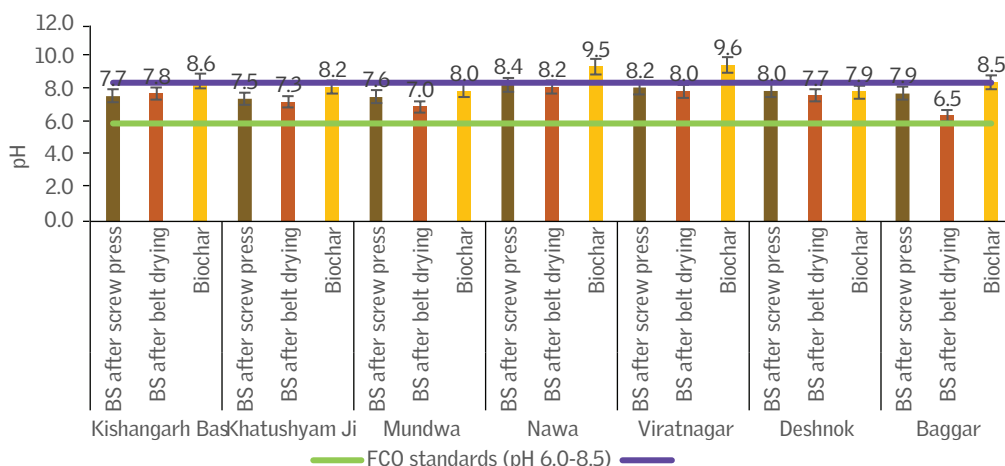
To understand the performance efficiency of POP, we collected the following three solid samples from each site: one, sludge after screw press; two, sludge obtained after belt dryer, and three, biochar. To understand the quality of obtained biochar, the following parameters were assessed pH, moisture, electrical conductivity, CN ratio, *E. coli* and *Salmonella*. Since there are no Indian standards for biosolids, it is compared with the Fertilizer Control Order (FCO), 2023.

7.2.1 Evaluation of biosolids and biochar quality from 10 KLD and 15 KLD FSTPs

7.2.1.1 pH

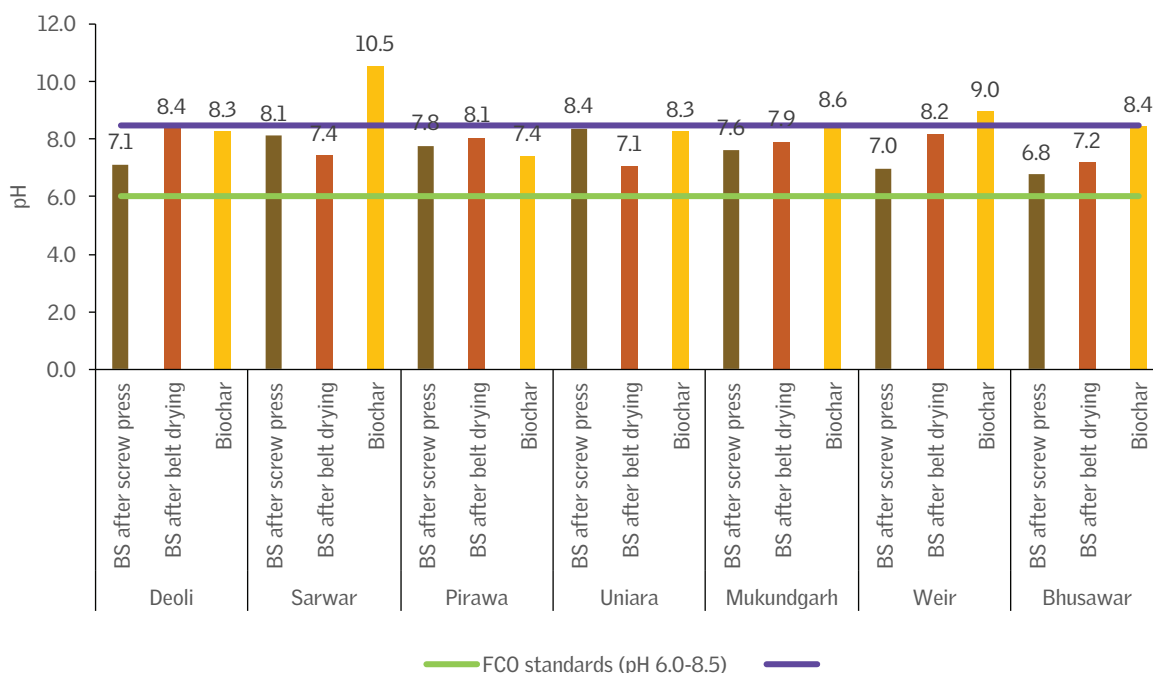
The norms set by Fertiliser Control Order (FCO), 2023 for organic manure in terms of pH lie in the range of 6–8.5. Out of all 14 plants, biochar in two plants, Nawa (pH 9.5) and Viratnagar (pH 9.6), showed pH slightly above the standards. Remaining 12 plants were complaint with the standard (see *Graph 27: pH of biosolids and biochar from 10 KLD and 15 KLD FSTPs* and *Graph 28: pH of biosolids and biochar from 10 KLD and 15 KLD FSTPs*).

Graph 27: pH of biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 28: pH of biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs

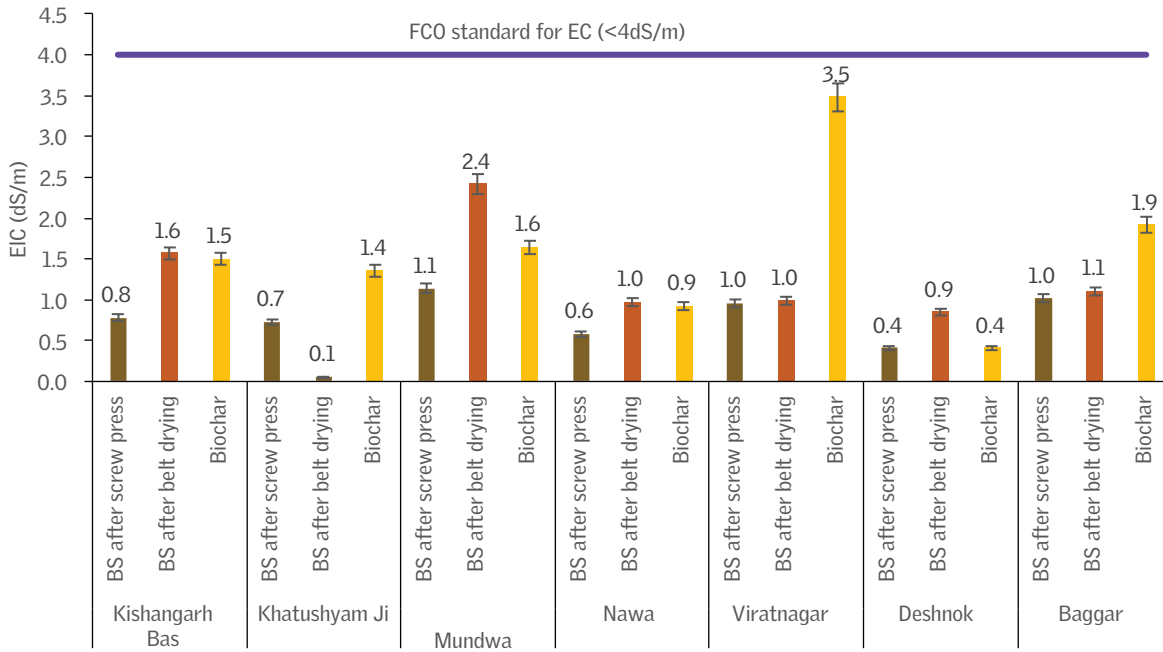


Source: EML, CSE

7.2.1.2 Electrical conductivity (EC)

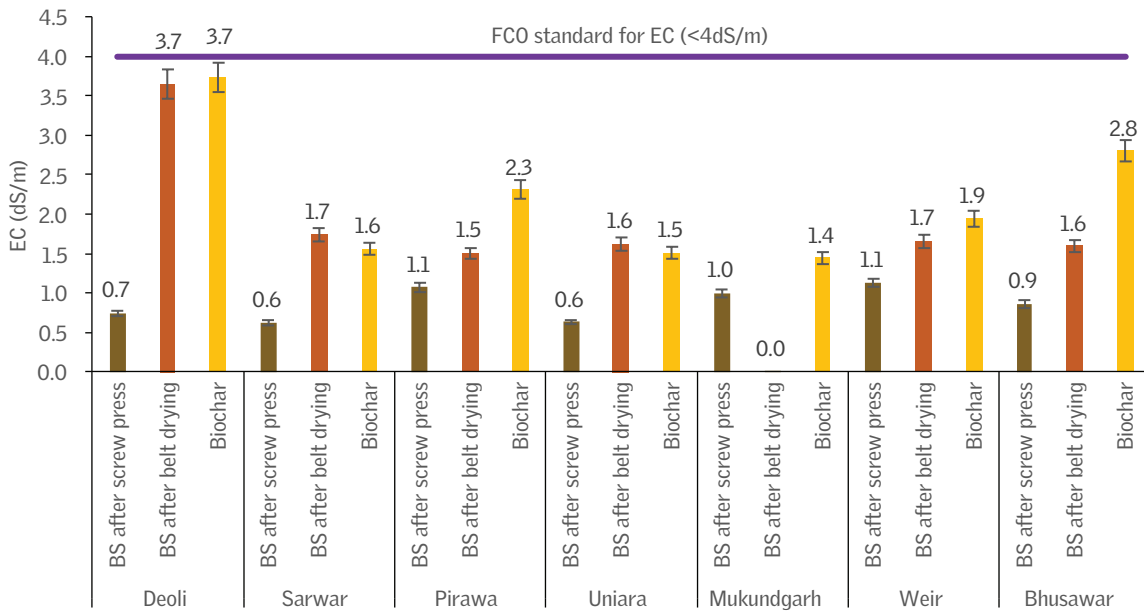
The electrical conductivity of the biosolid after screw press, biosolid obtained after belt dryers and biochar is shown in the *Graph 29*. EC observed for biosolid after screw press lies in the range of 0.4 dS/m to 1.1 dS/m, for biosolid obtained after belt dryers varies from 0.4 dS/m to 3.7 dS/m and for biochar it ranges from 0.4 dS/m to 3.7 dS/m. FCO, 2023, does not mention the term EC. However, it is mentioned in FCO, 2013 for organic manure as <4 dS/m, indicating that all the solid samples collected from each site lies within the prescribed range (see *Graphs 29: EC of biosolids and biochar from 10 KLD and 15 KLD FSTPs* and *Graph 30: EC of biosolids and biochar from 10 KLD and 15 KLD FSTPs*).

Graph 29: EC of biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 30: EC of biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs

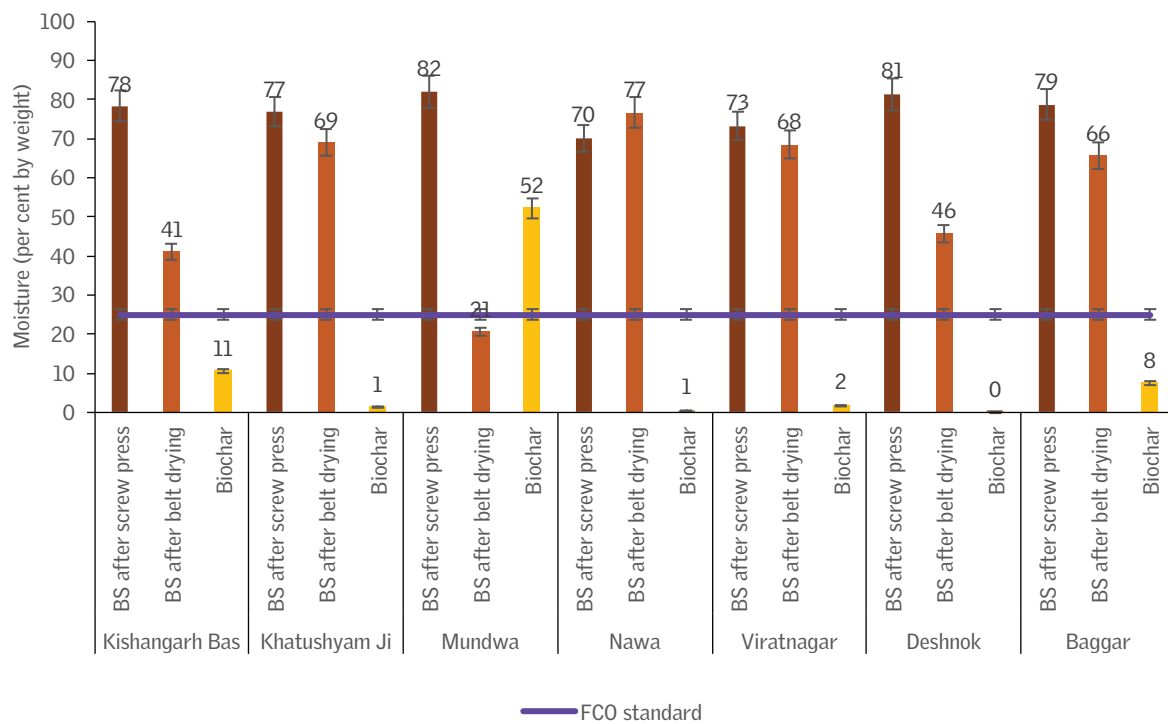


Source: EML, CSE

7.2.1.3 Moisture

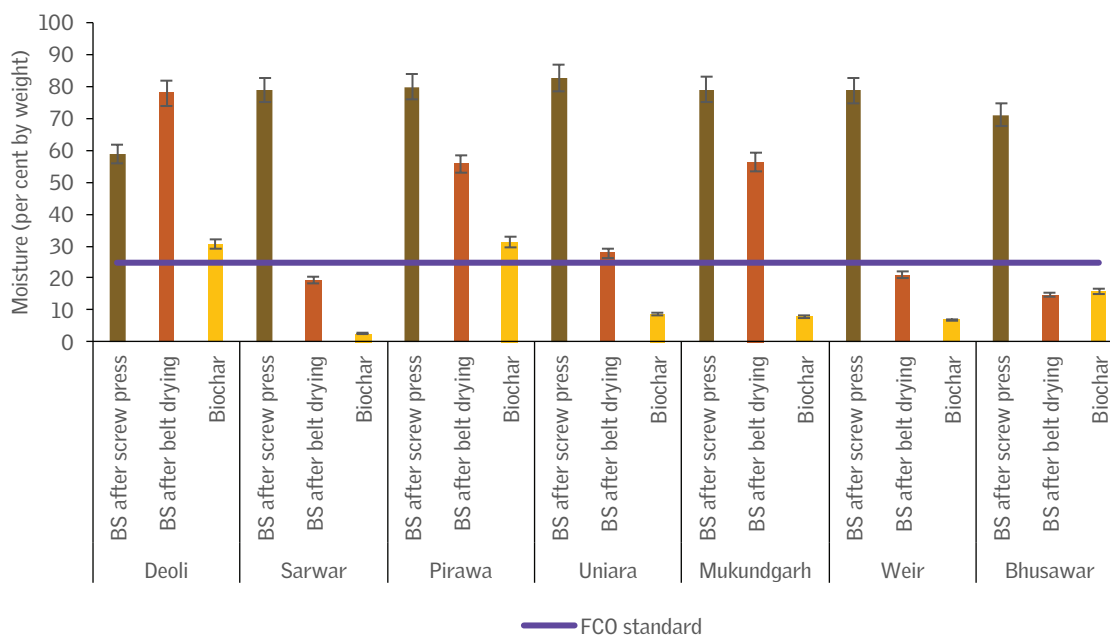
The moisture content associated with the biosolids and biochar has been provided in the Graphs 31 and 32. The FCO, 2023 norm in terms of moisture for organic manure is prescribed as <25 per cent. The moisture content seen in biosolids after screw press lies in the range of (59–83 per cent). The reduction of moisture content under the influence of belt dryer varied from (15–78 per cent) and in biochar least per cent of moisture was seen in Deshnok (0.13 per cent) and highest in Mundawa (52 per cent) (see *Graph 31: Moisture content of biosolids and biochar from 10 KLD and 15 KLD FSTPs* and *Graph 32: Moisture content of biosolids and biochar from 10 KLD and 15 KLD FSTPs*).

Graph 31: Moisture content of biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 32: Moisture content of biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs



Source: EML, CSE

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

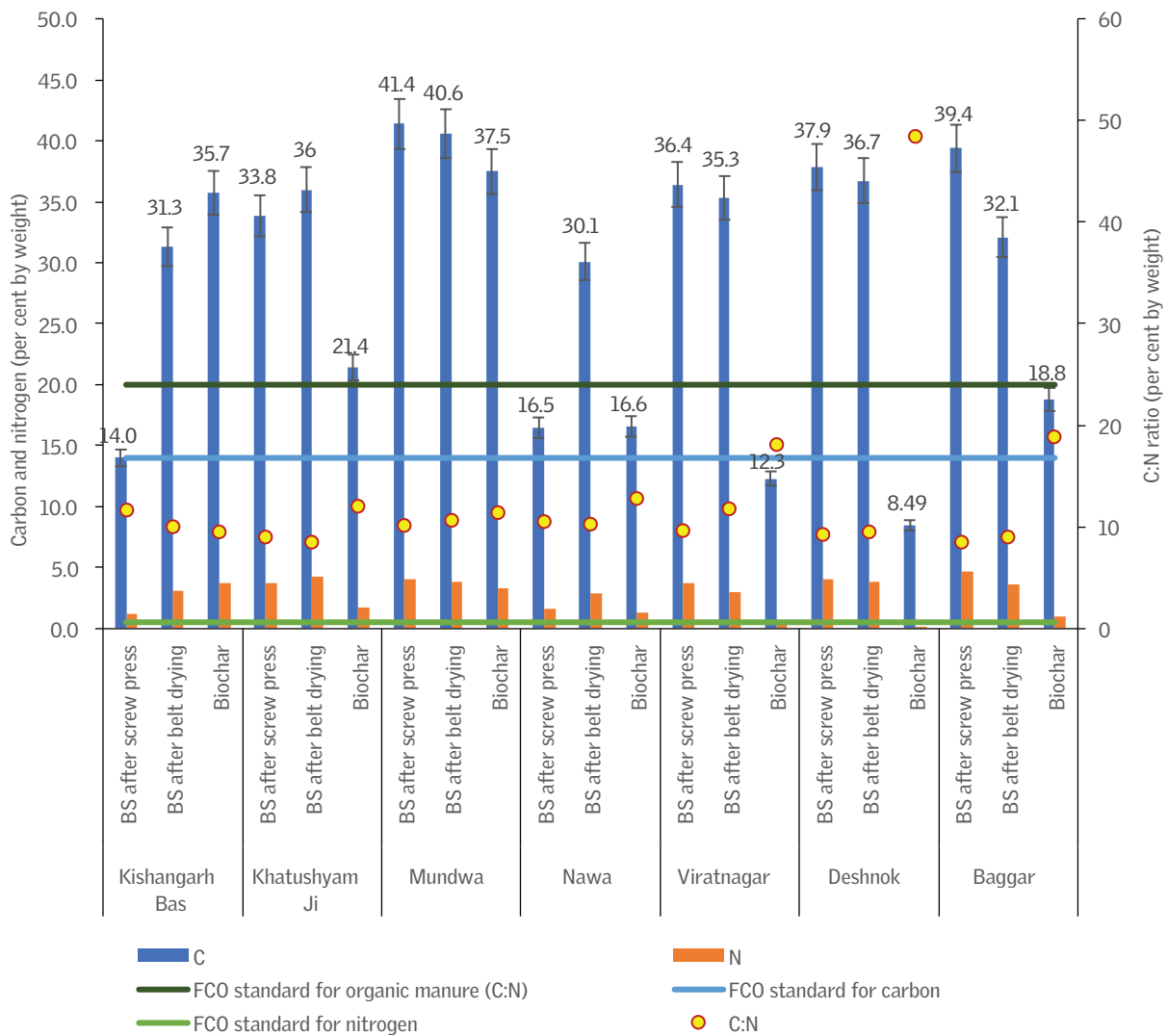
The organic matter or content in biosolids and biochar is one of the key parameters that needs to be considered when applied to soil for agricultural application. The C-to-N ratio acts as a fuel for the soil ecosystem. The organic matter influences several factor of soil like carbon content, moisture, physical structure by creating air pockets, all such factors further impacts the soil biota. In the graph provided below reflects the carbon, nitrogen and C:N ratio in the solid samples.

For the compliance of C:N, FCO, 2023 has set the standard for C:N ratio of organic manure as <20. The standard given for total organic carbon content of the organic manure in FCO, 2023 is ≥ 14 per cent by weight, whereas, in case of total nitrogen, the standard is ≥ 0.5 per cent by weight.

The total carbon content in biosolids collected after screw press lies in the range of (14-41.4 per cent), in biosolids collected after belt drying was found in the range from (26.6-40.6 per cent) and in biochar from (8.36-37.5 per cent). The total nitrogen content in biosolids after screw press was seen in the range of (1.20-4.78 per cent), in biosolids (after belt drying) from (1.5-4.23 per cent) and biochar

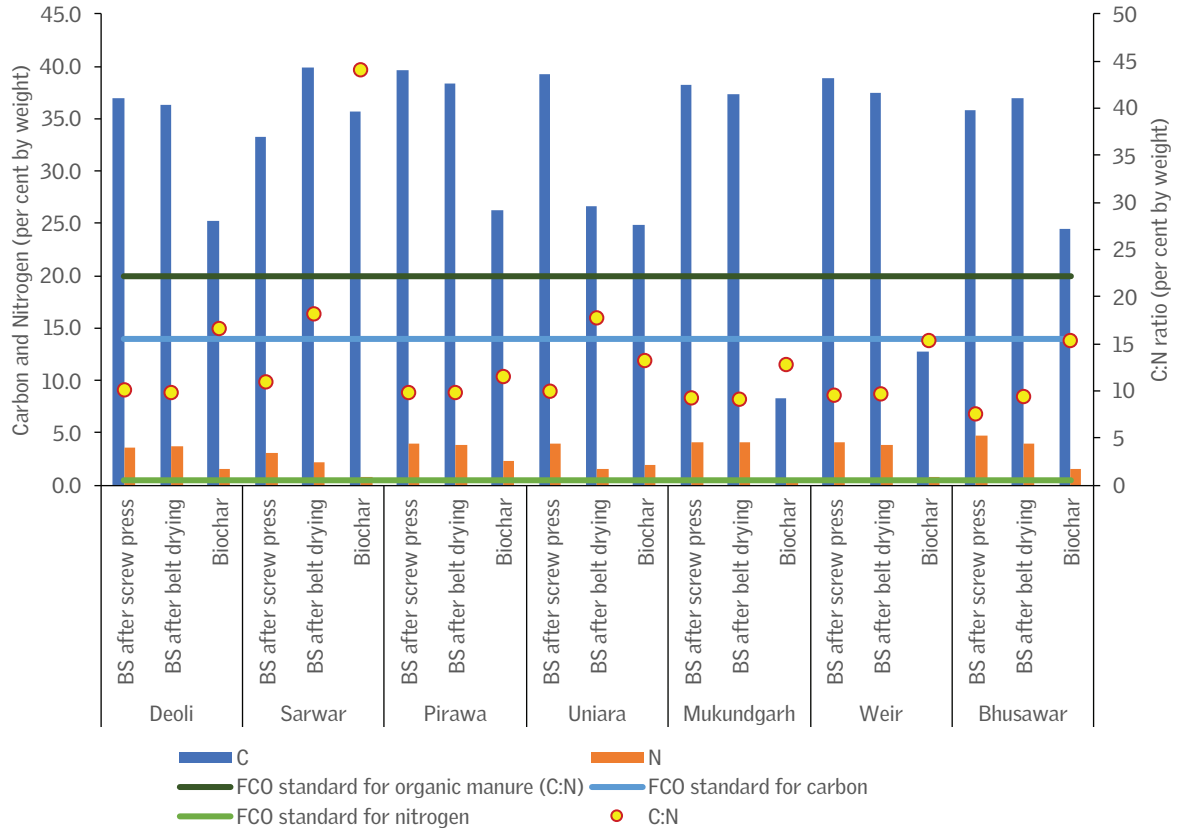
(0.17–3.76). In this study the C:N were most compliant with the standard except two sites Deshnok and Sarwar were the C:N ratio exceeded beyond 20 (see *Graph 33: C:N ratio of biosolids and biochar from 10 KLD and 15 KLD FSTPs* and *Graph 34: C:N ratio of biosolids and biochar from 10 KLD and 15 KLD FSTPs*).

Graph 33: Carbon, nitrogen and C:N ratio of biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 34: Carbon, nitrogen and C:N ratio of biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs



Source: EML, CSE

7.2.1.5 Heavy metals

The presence of heavy metals in biosolids can be attributed to various factors like industrial discharge, agricultural runoffs and urban waste. Sometimes the presence of specific heavy metals can be geogenic (geogenic contamination). Moreover, they are widely distributed through mining, manufacturing and energy production.

The range of heavy metals found in the biosolids and biochar are given in *Table 4*.

Arsenic cadmium and lead were within the prescribed range, set by FCO, 2023 standards. The presence of mercury (Hg) was felt more in biochar samples collected from Kishangarh Bas, Deoli, Pirawa, Uniara and Weir. Similarly, chromium (Cr) in biochar collected from six sites (Baggar, Deoli, Pirawa, Uniara, Weir and Bhusawar) were above the standards. Out of the 14 sites, biochar collected from Nawa, Pirawa and Weir showed the presence of zinc (Zn) exceeding the limits.

Nickel (Ni) in biochar collected from Mundwa, Uniara, Mukundgarh and Weir were above the standard limits (see *Table 4: Heavy metals in the biosolids and biochar of 10 KLD and 15 KLD FSTPs*).

Table 4: Heavy metals in the biosolids and biochar of 10 KLD and 15 KLD FSTPs

Locations	Type of sample	Heavy metals							
		As	Hg	Cd	Cr	Pb	Zn	Cu	Ni
		(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.
		10	0.15	5	50	100	1000	300	50
Kishangarh Bas	BS after screw press	0.68	0.87	0.59	4.36	6.53	548.34	83.00	4.87
	BS after belt drying	0.83	1.38	0.77	5.32	7.88	715.06	109.41	6.31
	Biochar	0.52	1.20	0.76	6.77	7.93	628.15	118.26	8.15
Khatushyam Ji	BS after screw press	0.41	0.25	0.61	6.36	6.71	543.25	83.65	6.02
	BS after belt drying	0.42	0.19	0.74	8.41	7.76	651.57	97.68	7.28
	Biochar	0.21	0.27	0.74	9.79	8.50	705.13	118.27	11.55
Mundwa	BS after screw press	0.56	Nil	0.97	28.10	4.05	610.19	95.59	19.00
	BS after belt drying	0.27	Nil	0.40	2.61	2.06	349.22	52.33	4.43
	Biochar	0.43	Nil	0.73	9.56	6.35	550.16	91.52	63.12
Nawa	BS after screw press	0.27	0.19	0.31	4.60	4.38	385.13	56.97	4.70
	BS after belt drying	0.46	0.07	0.76	6.99	6.90	644.99	106.95	7.27
	Biochar	0.31	Nil	1.07	9.53	10.71	1080.33	183.01	17.75
Viratnagar	BS after screw press	0.84	0.96	0.76	5.07	7.90	787.58	135.75	7.88
	BS after belt drying	0.44	0.86	0.45	3.30	5.11	480.83	80.47	5.14
	Biochar	1.72	0.21	1.43	22.79	12.82	967.49	188.01	22.52
Deshnok	BS after screw press	0.58	0.47	3.07	7.45	34.93	555.47	99.52	9.06
	BS after belt drying	0.73	1.27	4.30	9.57	47.64	725.51	135.69	10.63
	Biochar	0.55	Nil	0.89	6.60	17.73	375.61	99.32	11.28
Baggar	BS after screw press	0.85	0.18	0.69	28.82	5.91	705.62	97.71	16.59
	BS after belt drying	1.12	0.25	1.04	30.16	6.95	833.38	127.03	16.50
	Biochar	0.49	Nil	0.43	79.46	4.66	485.32	118.12	57.15
Deoli	BS after screw press	0.75	2.44	1.47	25.68	15.71	1224.84	194.49	17.19
	BS after belt drying	1.48	3.97	1.53	30.02	17.45	1208.68	203.73	18.74
	Biochar	0.84	1.13	0.79	81.85	9.68	646.31	124.46	50.48
Sarwar	BS after screw press	0.43	Nil	0.88	29.77	11.13	618.91	92.72	17.83
	BS after belt drying	0.23	0.11	1.06	3.77	7.13	576.39	78.77	6.31
	Biochar	0.02	Nil	0.46	7.36	5.13	368.89	51.70	10.93

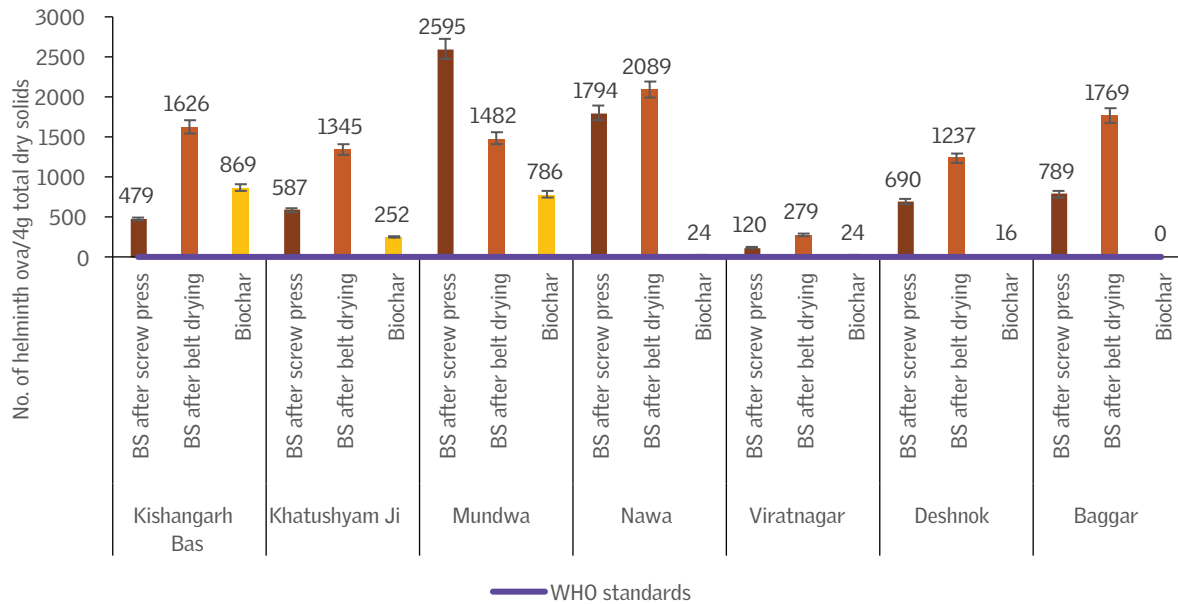
Locations	Type of sample	Heavy metals							
		As	Hg	Cd	Cr	Pb	Zn	Cu	Ni
		(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.	(mg/kg) max.
		10	0.15	5	50	100	1000	300	50
Pirawa	BS after screw press	2.22	2.66	1.46	81.46	24.29	1969.98	342.18	65.97
	BS after belt drying	1.66	5.38	1.13	39.58	22.34	1480.97	281.07	26.99
	Biochar	1.60	4.26	1.20	67.82	30.18	1684.49	341.13	49.47
Uniara	BS after screw press	1.45	2.89	1.36	23.92	14.27	1135.71	180.67	16.01
	BS after belt drying	1.67	4.51	1.57	31.26	18.16	1259.00	214.38	19.60
	Biochar	1.19	1.34	0.90	88.04	10.70	530.30	136.78	54.83
Mukundgarh	BS after screw press	0.84	2.80	0.84	24.95	6.77	816.97	117.16	12.46
	BS after belt drying	0.80	2.96	0.85	24.42	7.51	788.63	116.58	12.33
	Biochar	1.22	0.19	0.73	131.84	7.95	937.49	179.82	69.85
Weir	BS after screw press	1.51	4.09	3.16	33.87	22.64	1378.52	261.37	20.45
	BS after belt drying	1.42	4.72	2.53	27.99	19.02	1251.20	216.20	16.91
	Biochar	1.67	1.45	3.72	117.43	33.10	2032.62	531.23	81.72
Bhusawar	BS after screw press	1.40	1.57	1.74	34.16	12.58	1549.04	217.93	21.29
	BS after belt drying	1.20	1.47	1.82	34.94	13.29	1461.54	204.50	19.26
	Biochar	0.65	0.40	0.59	65.62	6.12	705.96	108.15	30.02

Source: EML, CSE

7.2.1.6 Helminths

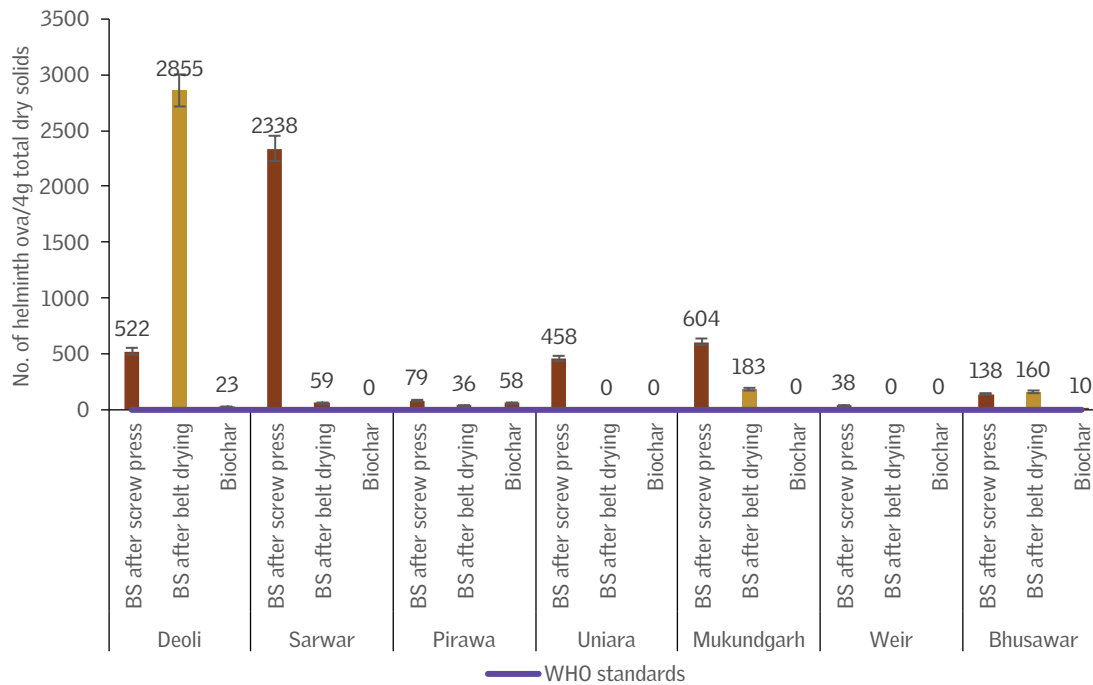
Helminths are a large group of multicellular parasites worms. Some infects human, while the other infects animals or plants. There are three major groups of helminths—hookworms, tapeworms and roundworms. The prevalence of helminths infection in people living with basic water and sanitation in third-world countries are generally high. Due to the extreme hardiness of the egg of the roundworms, *Ascaris lumbricoides*, they are used in the waste and sanitation filed as a marker for the safe reuse of human waste. In the graph provided below shows the presence of helminths in the solid samples collected from all the 14 sites. There are no Indian standards for helminths, therefore, USEPA, class-A standard <1 viable helminth ova/4 g total dried weight of biosolid has been used in our current study. Out of 14 sites, biochar from five sites(Baggar, Sarwar, Uniara and Mukundgarh) showed no presence of helminth ova, therefore, meeting the prescribed standard (see *Graph 35: Helminths ova in biosolids and biochar from 10 KLD and 15 KLD FSTPs* and *Graph 36: Helminths ova in biosolids and biochar from 10 KLD and 15 KLD FSTPs*).

Graph 35: Helminths ova in biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 36: Helminths ova in biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs



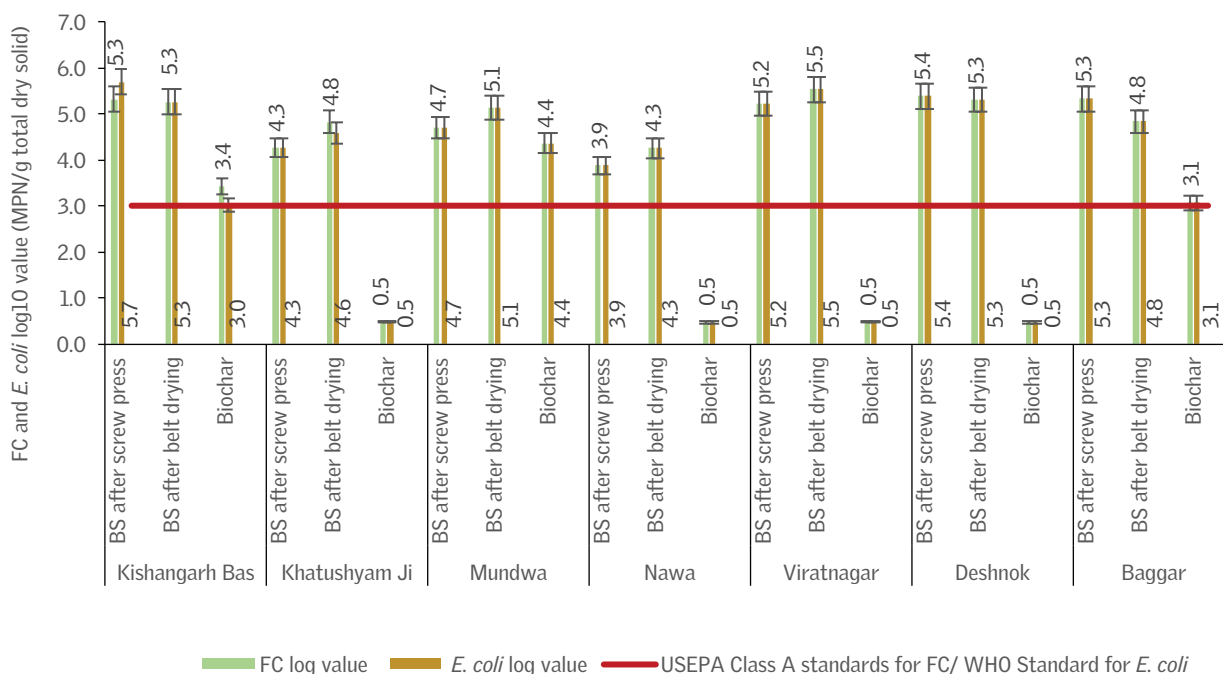
Source: EML, CSE

7.2.1.7 Faecal coliform and *E. coli*

Graph 37 represents the faecal coliform (FC) and *E.coli* (proxy indicator) in the solid samples (BS after screw press, BS after belt dryer and biochar) collected from 14 FSTPs. The range of FC and *E. coli* in biochar was observed in FSTPs from 0.5–4.4 log₁₀ MPN/g total dry solid in (lowest in Khatushyam ji, Viratnagar, Deshnok, Nawa and Sarwar and highest in Mundwa).

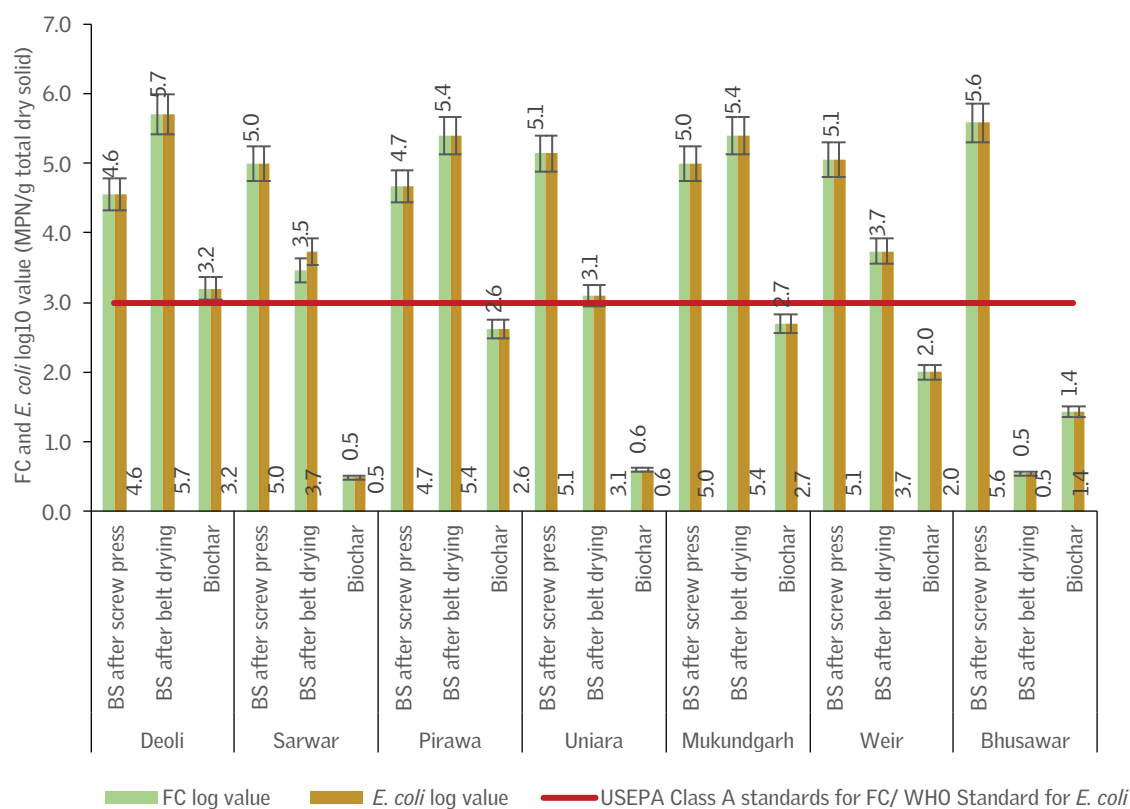
In FCO, 2023, the regulatory limit for pathogen content of the organic manure is set as nil. The presence and extent of FC and *E.coli* in the biosolids/biochar samples and their suitability for agricultural purposes are compared with the respective limits set by the USEPA and the WHO (2006). According to the above mentioned standards USEPA (class A biosolid)/WHO standards for land application for biosolids, the number of FC and *E.coli* must be below 1,000 MPN/g (log 1000 = 3). Out of 14 plants, seven plants for biochar are compliant with the standards. Remaining all the plants for BS after screw press and BS after belt dryer needs improvement to meet the given standards (see Graph 37: FC and *E.coli* in biosolids and biochar from 10 KLD and 15 KLD FSTPs and Graph 38: FC and *E.coli* in biosolids and biochar from 10 KLD and 15 KLD FSTPs).

Graph 37: FC and *E. coli* in biosolids and biochar of 1–7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 38: FC and *E.coli* in biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs

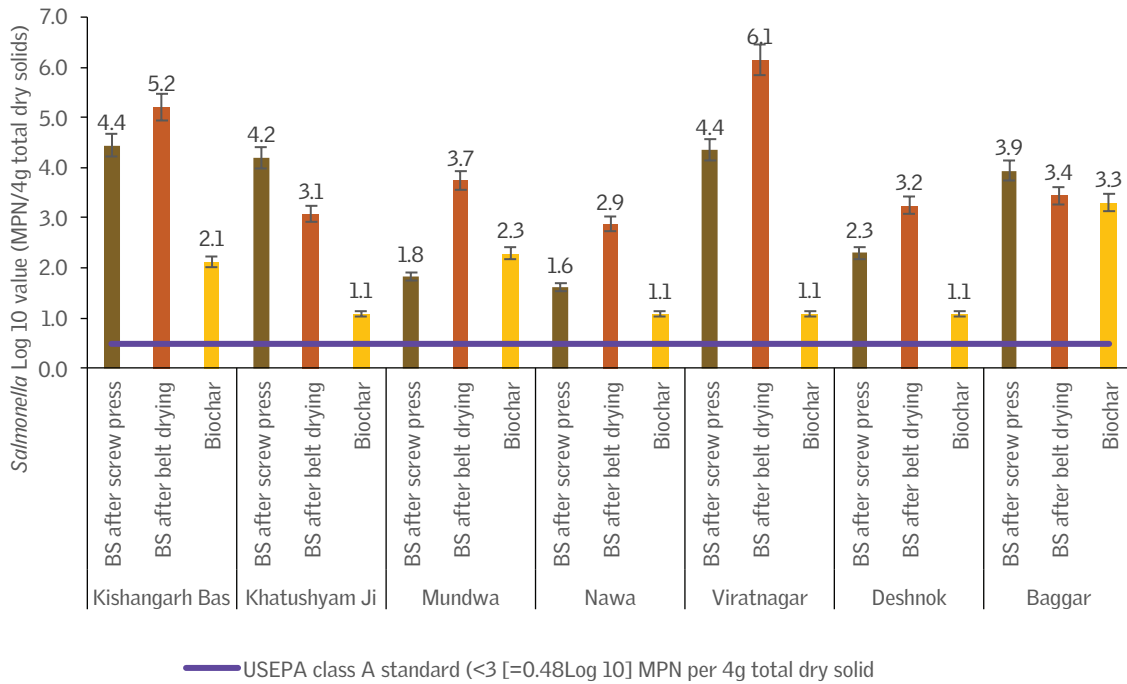


Source: EML, CSE

7.2.1.8 Salmonella

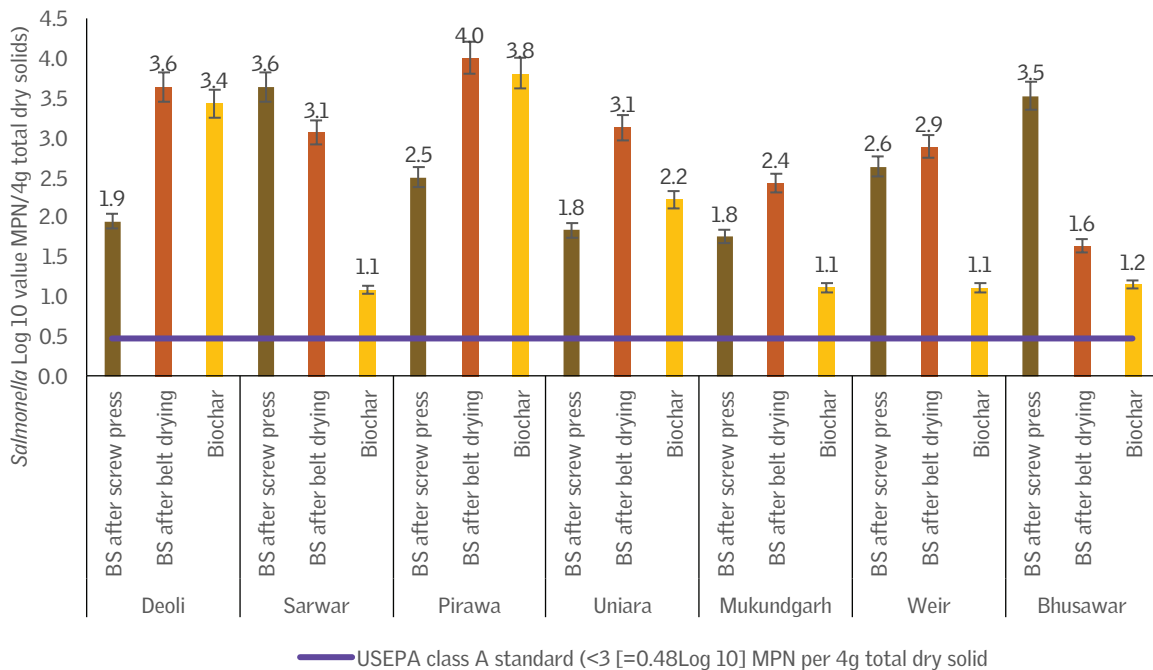
FCO, 2023, states that the presence of pathogens in organic manure should be nil (free from all pathogens), which is applicable to *Salmonella* as well. Since its presence is felt across all the solids samples collected from the sites, the *Salmonella* concentration in samples are compared with the standards set by USEPA (Class A biosolids) and shall not exceed 3MPN/4g total dry solid ($\log_{10} 3 = 0.48$), which is applicable to all the biosolids use for land application. *Salmonella* in biochar was found in the range of 1.1–3.4 \log_{10} MPN/4g total dry solids. The presence of *Salmonella* in biochar indicates that the pop including stream drying and pyrolysis needs to be optimized (see Graph 39: *Salmonella* in biosolids and biochar from 10 KLD and 15 KLD FSTPs and Graph 40: *Salmonella* in biosolids and biochar from 10 KLD and 15 KLD FSTPs).

Graph 39: Salmonella in biosolids and biochar of 1-7 10 KLD and 15 KLD FSTPs



Source: EML, CSE

Graph 40: Salmonella in biosolids and biochar of 8-14 10 KLD and 15 KLD FSTPs



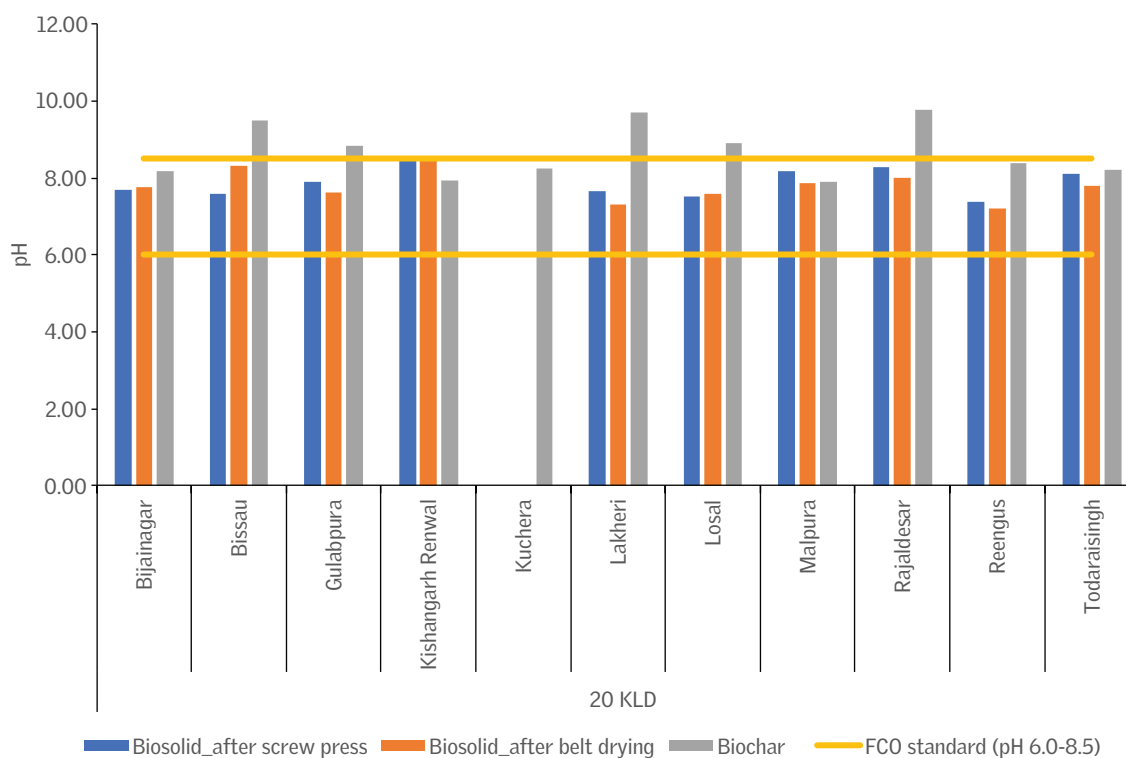
Source: EML, CSE

7.2.2 Evaluation of biosolids and biochar quality from 20 KLD, 25 KLD and 35 KLD FSTPs

7.2.2.1 pH

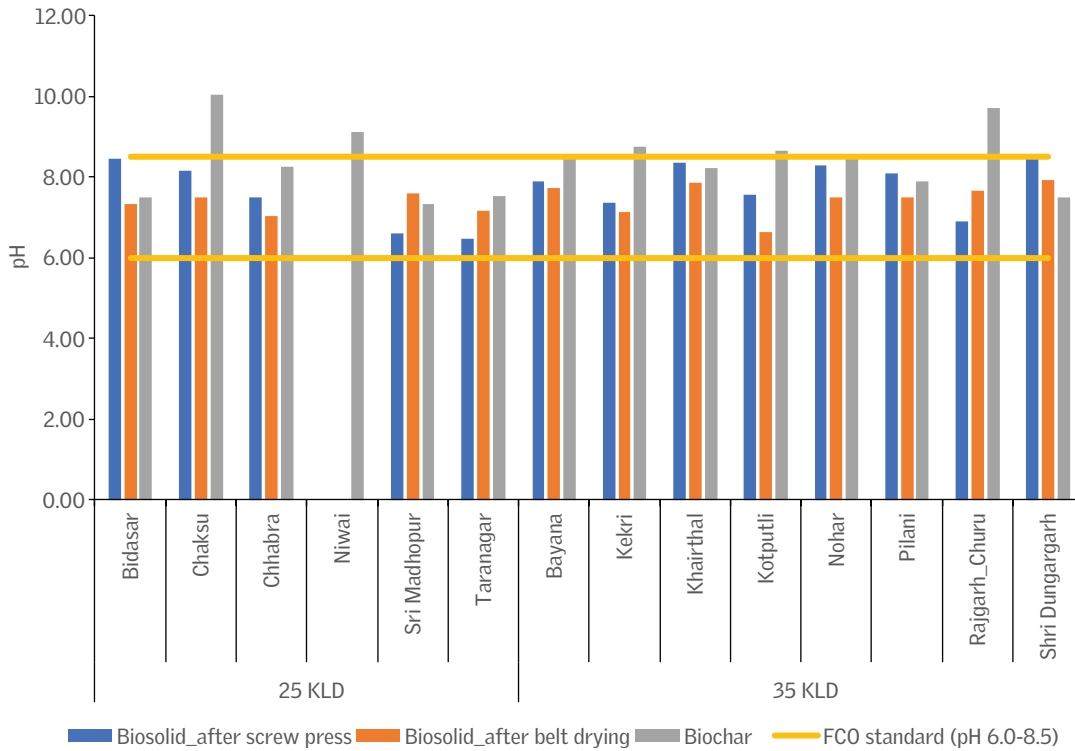
The pH of the biosolids and biochar from 20 KLD FSTPs is shown in *Graph 41*, while the pH of the biosolids and biochar from 25 KLD and 35 KLD FSTPs is shown in *Graph 42* (see *Graph 41: pH of the biosolids and biochar from 20 KLD FSTPs* and *Graph 42: pH of the biosolids and biochar from 25 KLD and 35 KLD FSTPs*). The standard for pH of the organic manure in FCO 2023 is at 6.0–8.5. The pH in the biosolids (6.48–8.46) from the 25 FSTPs is slightly acidic to slightly alkaline, with slightly alkaline in majority of samples. Biochar had slightly higher alkalinity than biosolids (7.33–10.05); biochar from ten FSTPs exceeded the FCO limit across capacities.

Graph 41: pH of biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 42: pH of biosolids and biochar from 25 KLD and 35 KLD FSTPs

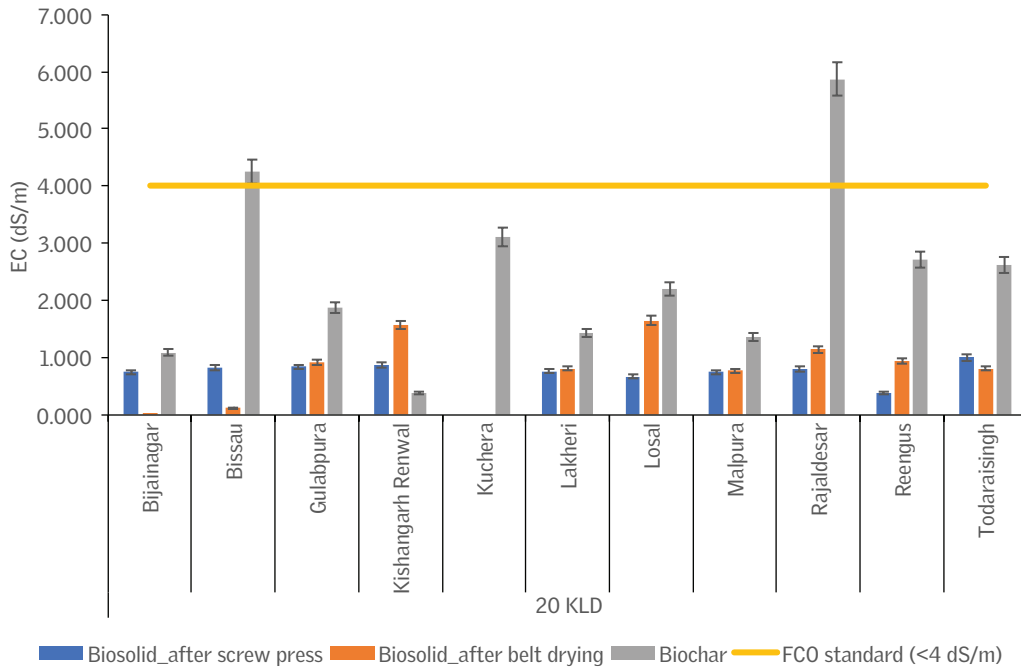


Source: EML, CSE

7.2.2.2 EC

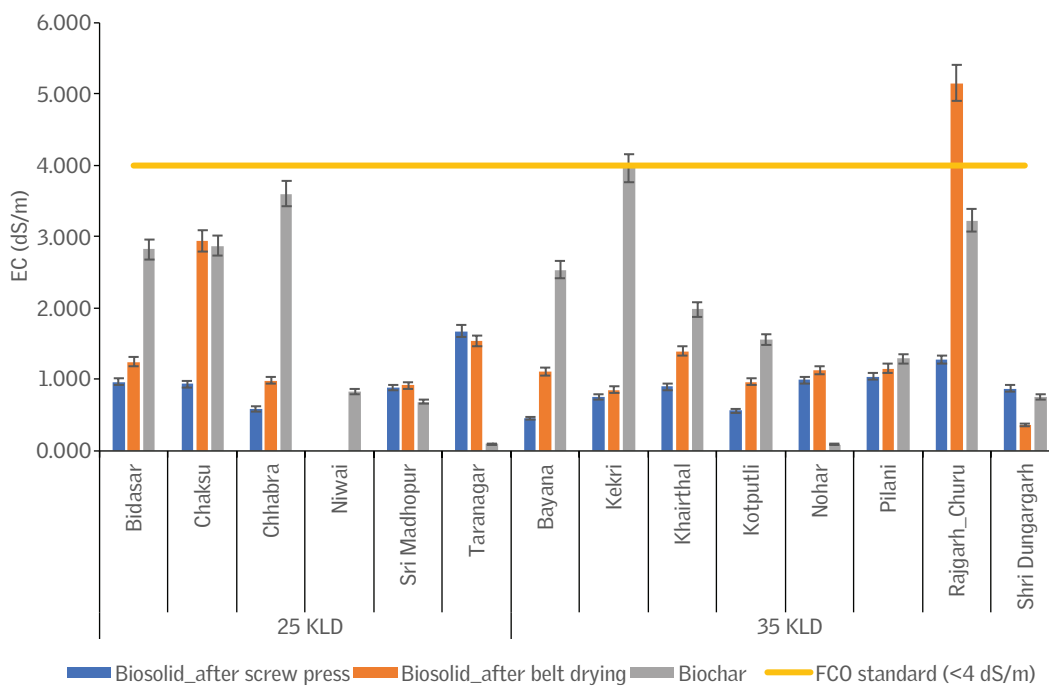
The EC of the biosolids and biochar from 20 KLD FSTPs is shown in *Graph 43*, while the EC of the biosolids and biochar from 25 KLD and 35 KLD FSTPs is shown in *Graph 44* (see *Graph 43: EC of the biosolids and biochar from 20 KLD FSTPs* and *Graph 44: EC of the biosolids and biochar from 25 KLD and 35 KLD FSTPs*). The standard for EC of the organic manure in FCO is <4 dS/m. Except in biochar from two locations (Rajaldesar and Bissau) and biosolid from one location (Rajgarh, Churu), the EC in both the biosolids (0.01–5.15 dS/m) and biochar (0.08–5.87 dS/m) is within the FCO limit across capacities.

Graph 43: EC of biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 44: EC of biosolids and biochar from 25 and 35 KLD FSTPs

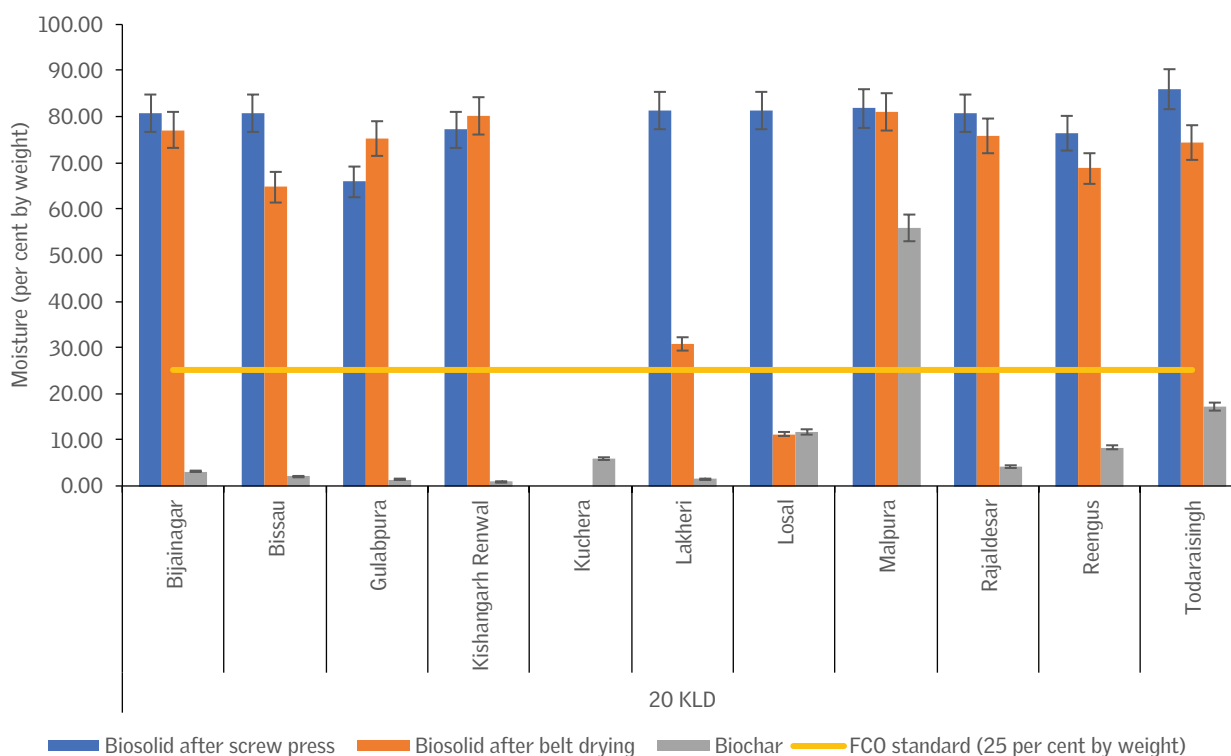


Source: EML, CSE

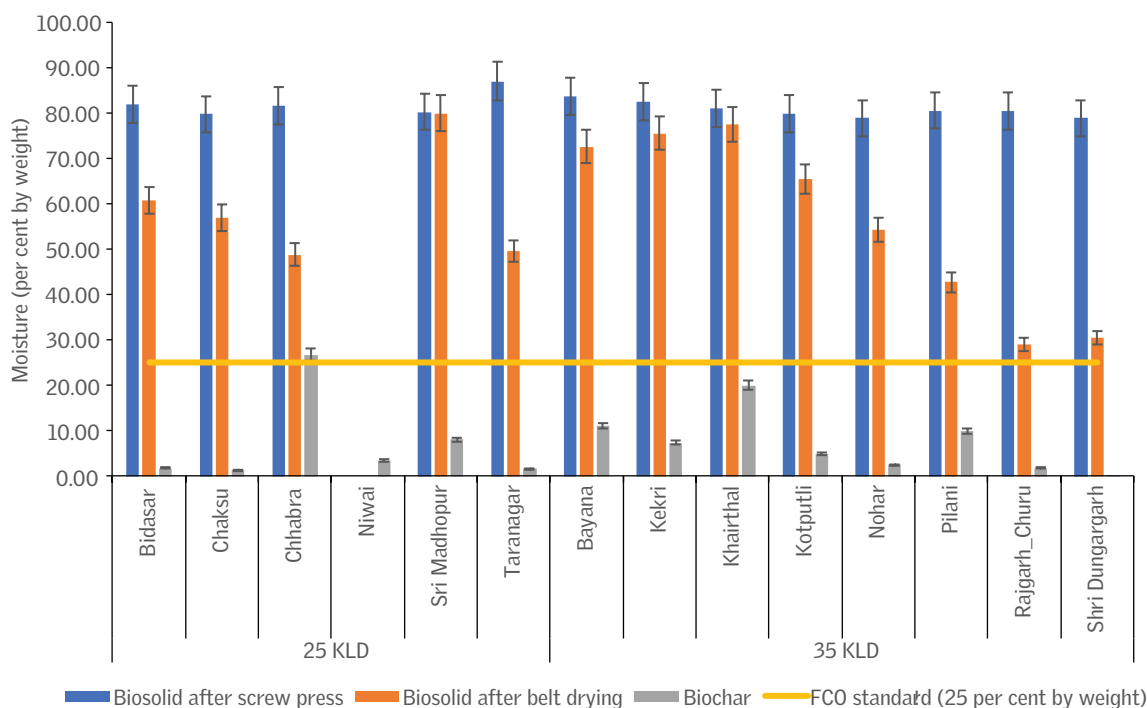
7.2.2.3 Moisture content

The moisture content of the biosolids and biochar from 20 KLD FSTPs is shown in *Graph 45*, whereas the moisture content of the biosolids and biochar from 25 KLD and 35 KLD FSTPs is shown in *Graph 46* (see *Graph 45: Moisture content of the biosolids and biochar from 20 KLD FSTPs* and *Graph 46: Moisture content of the biosolids and biochar from 25 KLD and 35 KLD FSTPs*). The standard for moisture content of the organic manure in FCO is <25 per cent (by weight). The moisture content in the biosolids was in the range of 65.95–86.92 per cent after screw press and 11.28–80.96 per cent after belt drying, with only slight reduction observed after belt drying. The moisture content in the biochar was in the range of 0.03–55.94 per cent and within the FCO limit in all except two FSTPs (Malpura and Chhabra).

Graph 45: Moisture content of biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 46: Moisture content of biosolids and biochar from 25 and 35 KLD FSTPs

Source: EML, CSE

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

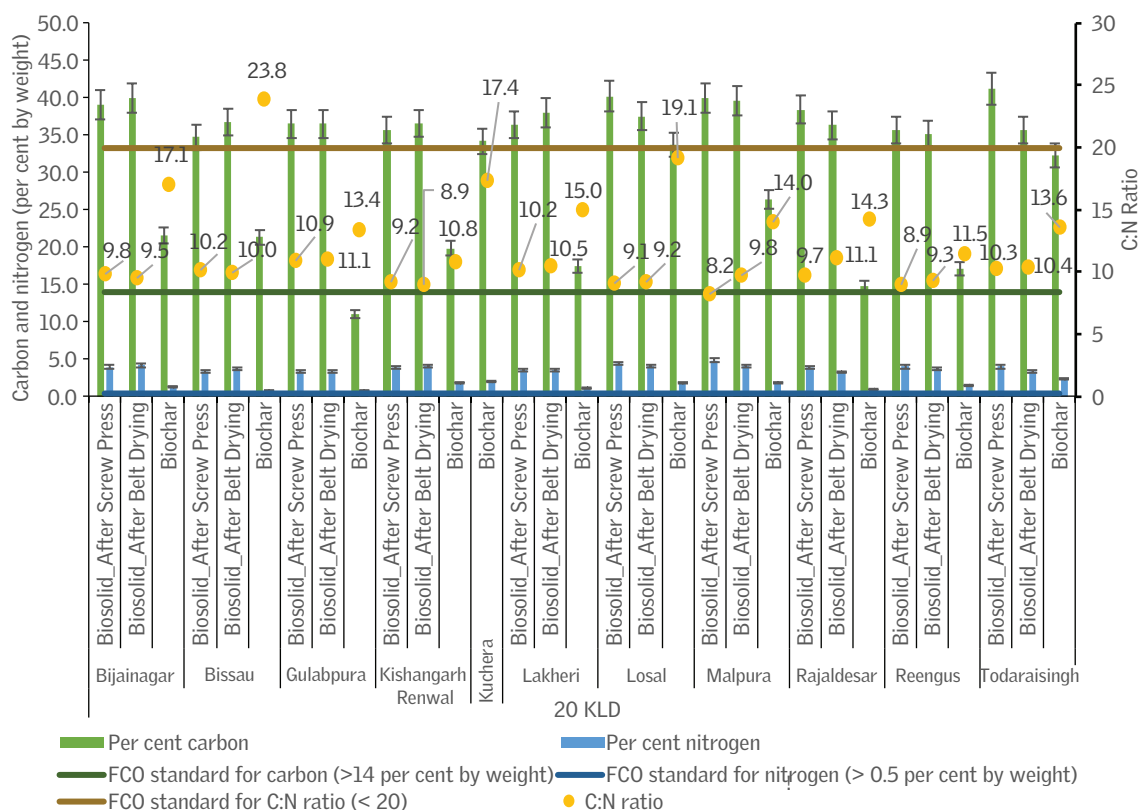
The carbon (C), nitrogen (N) and carbon-to-nitrogen ratio (C:N ratio) of the biosolids and biochar from 20 KLD FSTPs is shown in *Graph 47*; the carbon (C), nitrogen (N) and carbon-to-nitrogen ratio (C:N ratio) of the biosolids and biochar from 25 KLD and 35 KLD FSTPs is shown in *Graph 48* (see *Graph 47: Carbon (C), nitrogen (N) and C:N ratio of biosolids and biochar from 20 KLD FSTPs* and *Graph 48: Carbon (C), nitrogen (N) and C:N ratio of biosolids and biochar from 25 KLD and 35 KLD FSTPs*).

The standard given for total organic carbon content of the organic manure in FCO 2023 is 14 per cent by weight, while for total nitrogen (as N) the standard is 0.5 per cent by weight. The standard set for C:N ratio of the organic manure in FCO 2023 is <20. The total carbon content of the biosolids was in the range of 28.1–42.9 per cent, while that of biochar was in the range of 5.5–35.5 per cent in the 25 FSTPs. Organic carbon in biosolids is compliant with the FCO standard in all the FSTPs, while in biochar it is compliant in 20 FSTPs. The total nitrogen content of the biosolids was in the range of 2.4–4.9 per cent, while that of biochar

was in the range of 0.2–3.0 per cent in the 25 FSTPs. Total nitrogen in biosolids is compliant with the FCO standard in all the FSTPs, while in biochar it is compliant in 23 FSTPs.

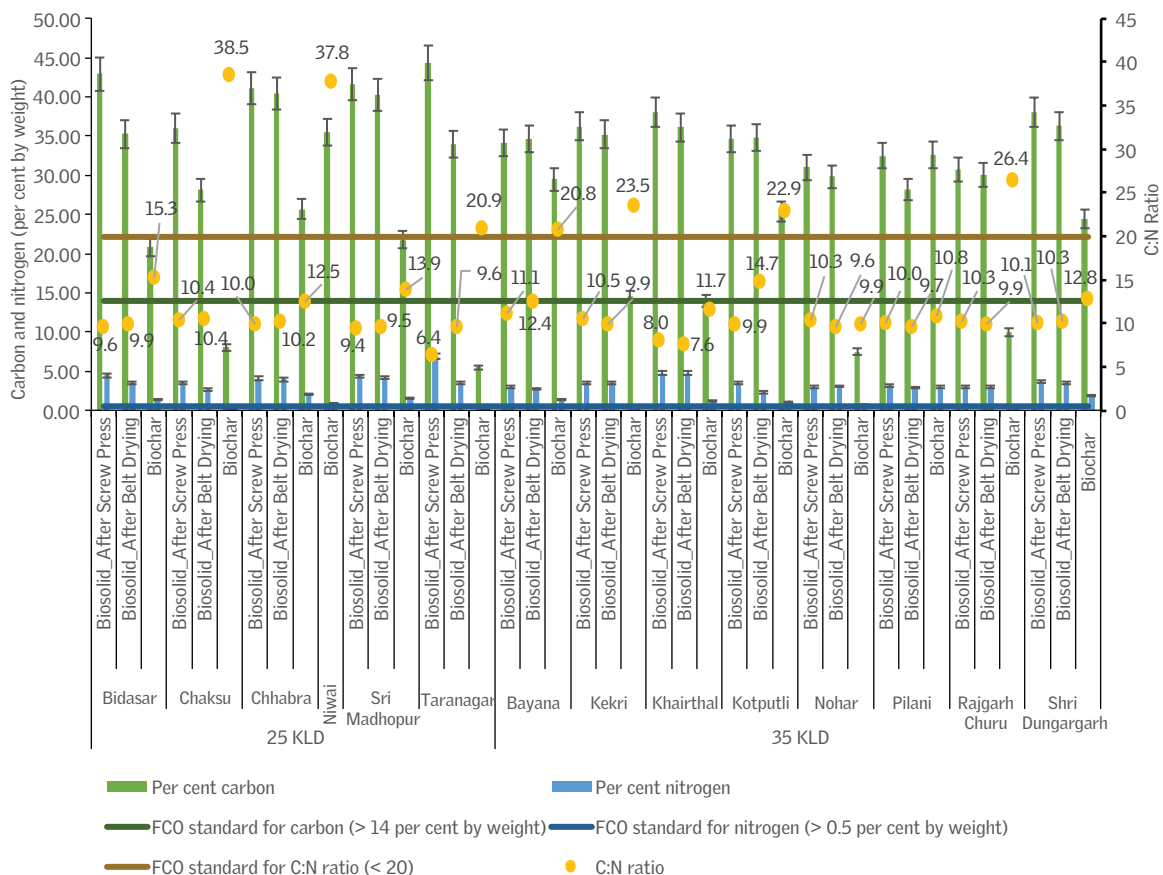
The carbon-to-nitrogen (C:N) ratio is a more critical determinant of soil health than the standalone concentrations of either element, as it dictates the balance of nutrient availability for both vegetation and microbial life. An ideal ratio, typically in the range of 15:1 to 20:1, ensures an equilibrium between nitrogen mineralization (the conversion of organic nitrogen to plant-available forms) and immobilization (the microbial consumption of nitrogen).¹¹ In this study, the C:N ratio in the biosolids was in the range of 7.6–14.7, while that in biochar was 9.9–38.5 in the 24 FSTPs. While C:N ratio in all the biosolids is within the FCO limit, C:N ratio in biochar exceeded the FCO limit from eight locations (of which seven are higher capacity FSTPs) which is possible due to the presence of high carbon content in the biochar. However, it is recommended that a C:N ratio of 15:1 to 20:1 be maintained in biosolids and biochar to provide optimal growth of the plants.

Graph 47: Carbon and nitrogen content and C:N ratio of biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 48: Carbon and nitrogen content and C:N ratio of biosolids and biochar from 25 KLD and 35 KLD FSTPs



Source: EML, CSE

7.2.2.5 Heavy metals

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 and biochar from the 25 FSTPs. The standards set by the FCO for each heavy metal are also provided in Table 5 (see Table 5: Heavy metal content in biosolids and biochar from 20 KLD, 25 KLD and 35 KLD FSTPs).

In this study, the heavy metals arsenic, cadmium and lead were found to be within the FCO limit in both biosolids and biochar in all 25 FSTPs. Nickel exceeded the FCO limit in biochar from six locations. Copper exceeded the limit in biosolid

Table 5: Heavy metal content in biosolids and biochar from 20 KLD, 25 KLD and 35 KLD FSTPs

Location	Sample type	As (mg/kg) max. 10.0 as As ₂ O 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. 1,000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0
20 KLD FSTPs									
Bijainagar	BS after screw press	1.24	3.73	2.67	29.58	19.71	1,323.52	220.56	17.73
	BS after belt drying	0.87	4.32	2.60	29.67	20.23	1,347.82	223.57	17.82
	Biochar	1.46	1.55	3.04	97.68	27.52	1,737.23	435.36	68.08
Bissau	BS after screw press	0.76	2.18	0.77	28.68	10.35	691.37	101.57	11.48
	BS after belt drying	0.78	3.34	0.83	30.15	9.08	761.47	110.31	12.26
	Biochar	0.67	0.47	0.43	66.78	4.61	472.74	89.47	29.04
Gulabpura	BS after screw press	1.02	4.06	2.25	35.14	37.76	1,547.21	246.44	21.97
	BS after belt drying	1.14	3.95	1.88	31.40	31.95	1,246.17	204.67	18.80
	Biochar	1.58	0.13	1.91	119.42	40.64	2,337.10	499.02	73.07
Kishangarh Renwal	BS after screw press	0.85	1.25	0.74	7.18	9.82	635.71	107.28	8.46
	BS after belt drying	0.73	2.19	0.82	13.37	11.40	982.44	108.97	10.43
	Biochar	0.38	0.05	0.84	10.77	15.12	944.38	150.17	15.10
Kuchera	Biochar	0.08	Nil	0.10	10.56	2.33	189.17	33.95	11.31
Lakheri	BS after screw press	6.48	0.52	1.48	29.38	9.58	925.71	120.97	17.75
	BS after belt drying	8.68	0.96	1.68	46.33	8.32	893.34	117.79	23.25
	Biochar	10.28	1.73	2.56	45.22	15.70	1,335.12	183.10	24.16
Losal	BS after screw press	0.70	1.44	1.60	31.48	11.94	1,463.41	195.78	19.76
	BS after belt drying	0.67	1.95	1.83	35.22	14.10	1,577.67	202.04	20.07
	Biochar	0.82	0.38	0.69	72.08	6.86	775.23	117.44	33.16
Malpura	BS after screw press	1.98	3.12	1.79	22.19	35.04	1,210.20	198.80	18.01
	BS after belt drying	1.18	3.45	1.37	14.82	30.00	1,123.82	189.08	13.18
	Biochar	0.47	0.92	0.83	44.73	13.14	641.21	127.01	34.38
Rajaldesar	BS after screw press	0.69	0.66	1.33	8.06	7.38	691.57	111.86	8.99
	BS after belt drying	0.45	0.77	0.99	8.19	6.75	492.20	80.31	7.32
	Biochar	0.48	0.18	0.75	10.49	4.79	309.55	60.24	14.36
Reengus	BS after screw press	0.45	0.17	0.88	13.63	6.60	532.75	81.10	5.49
	BS after belt drying	0.25	0.03	0.51	8.09	4.06	344.06	48.30	2.95
	Biochar	0.11	Nil	0.27	5.39	2.54	231.22	36.23	4.40
Todaraisingh	BS after screw press	0.60	0.35	1.07	6.18	13.52	832.91	146.69	10.96
	BS after belt drying	0.47	0.23	1.08	6.75	11.27	900.20	160.71	11.09
	Biochar	0.33	0.17	0.61	6.65	8.63	539.52	98.27	8.28

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Sample type	As (mg/kg) max. 10.0 as As ₂ O 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. 1,000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0
25 KLD FSTPs									
Bidasar	BS after screw press	0.42	0.12	1.10	4.22	6.81	694.26	111.85	742
	BS after belt drying	0.26	Nil	0.76	3.86	4.39	480.20	75.71	5.55
	Biochar	0.28	Nil	0.97	6.72	11.50	714.60	128.13	9.75
Chaksu	BS after screw press	0.70	0.37	0.90	5.70	9.81	640.74	116.72	6.88
	BS after belt drying	1.09	0.86	1.83	43.56	18.17	965.24	209.76	46.05
	Biochar	0.47	Nil	0.31	12.04	3.90	273.60	97.63	27.35
Chhabra	BS after screw press	2.77	5.95	2.30	38.10	29.06	2367.60	390.94	32.06
	BS after belt drying	2.43	6.24	2.40	39.93	29.76	2444.97	401.21	33.35
	Biochar	0.78	3.34	1.37	57.68	15.08	1193.86	190.68	36.99
Niwai	Biochar	0.63	Nil	0.49	23.91	29.24	399.10	102.65	67.05
Sri Madhopur	BS after screw press	0.75	1.14	0.84	6.84	8.67	733.90	123.76	7.11
	BS after belt drying	0.48	0.16	0.36	2.83	4.53	394.41	60.54	3.21
	Biochar	0.51	0.35	0.53	5.96	5.08	452.62	96.86	8.07
Taranagar	BS after screw press	0.54	1.18	1.29	27.19	8.09	965.34	138.51	24.14
	BS after belt drying	1.37	5.01	1.69	40.57	10.90	1164.11	169.46	26.08
	Biochar	1.11	0.39	1.29	156.90	10.02	1236.35	279.01	100.87
35 KLD FSTPs									
Bayana	BS after screw press	0.92	2.47	0.85	31.60	11.50	654.41	114.67	12.62
	BS after belt drying	0.60	2.85	0.71	25.77	7.15	583.52	95.81	10.34
	Biochar	0.68	0.98	0.30	57.34	3.58	330.57	78.76	24.94
Kekri	BS after screw press	0.90	4.86	2.23	9.08	26.62	1143.74	219.63	14.03
	BS after belt drying	0.81	6.30	2.15	10.23	30.95	1154.48	222.74	15.33
	Biochar	0.60	1.01	0.93	9.80	14.92	409.02	228.37	14.38
Khairthal	BS after screw press	2.07	1.82	1.73	50.47	23.21	1327.92	204.35	27.00
	BS after belt drying	1.37	0.81	0.97	30.10	15.78	918.26	119.74	15.83
	Biochar	0.60	0.29	0.54	12.08	8.96	299.91	59.84	13.23
Kotputli	BS after screw press	0.63	0.56	0.40	4.61	5.64	424.82	72.11	6.36
	BS after belt drying	0.55	0.43	0.46	5.08	6.44	446.05	80.11	5.85
	Biochar	1.09	0.15	0.76	11.84	11.08	623.53	117.88	16.24
Nohar	BS after screw press	2.13	3.87	1.09	32.11	12.82	849.41	138.21	19.92
	BS after belt drying	2.47	3.21	1.24	37.22	14.72	948.22	154.10	21.99
	Biochar	2.42	0.53	1.35	98.03	19.30	1363.19	251.24	61.89
Pilani	BS after screw press	4.77	0.52	1.56	28.15	9.11	871.33	119.57	17.21
	BS after belt drying	6.95	0.93	1.74	47.02	8.76	896.01	117.22	24.46
	Biochar	6.73	1.36	2.16	36.02	12.62	1066.37	147.33	19.53

Location	Sample type	As (mg/kg) max. 10.0 as As ₂ O 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. 1,000.0	Cu (mg/kg) max. 300.0	Ni (mg/kg) max. 50.0
Rajgarh Churu	BS after screw press	1.84	1.57	2.08	401.86	22.47	1289.57	198.74	174.12
	BS after belt drying	1.90	1.44	1.98	95.62	20.75	1232.14	187.66	43.87
	Biochar	1.16	0.05	1.50	326.53	21.92	1059.09	227.81	235.08
Sri Dungargarh	BS after screw press	0.75	0.29	1.38	18.45	13.78	681.15	116.48	8.48
	BS after belt drying	0.44	0.25	1.21	15.28	10.48	544.04	88.99	7.45
	Biochar	0.54	Nil	1.50	18.84	15.85	859.48	146.88	11.80

Source: EML, CSE

in one location (Chhabra) and in biochar from two locations, Gulabpura and Bijainagar. Chromium exceeded the FCO limit in the biochar from nine locations and in biosolids from only one location (Rajgarh, Churu). Zinc exceeded the FCO limit in the biosolids and biochar from nine and eight locations respectively, mostly exceeding in both biosolids and biochar from the same location. Mercury exceeded the FCO limit in almost all the biosolids and in biochar from 15 locations.

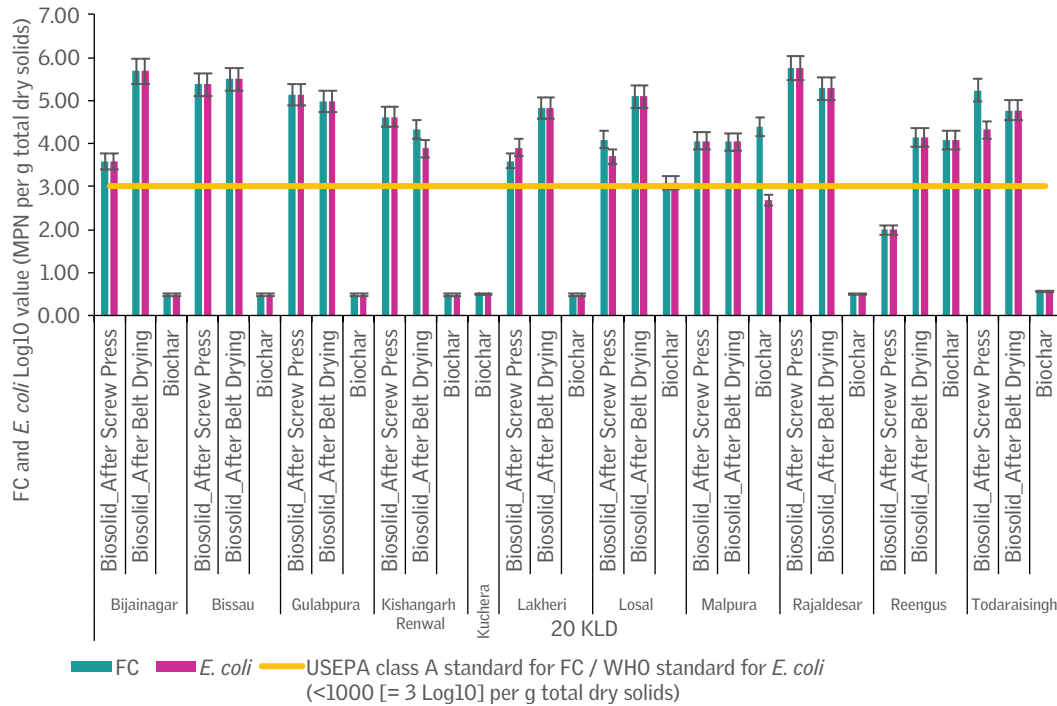
7.2.2.6 Faecal coliform and *E. coli*

The faecal coliform (FC) and *E. coli*, which are used as a proxy indicator to assess the pathogen content in the biosolids/biochar samples collected from the FSTPs, are shown in Graphs 49 and 50 (see *Graph 49: Faecal coliform (FC) and E. coli in the biosolids and biochar from 20 KLD FSTPs* and *Graph 50: Faecal coliform (FC) and E. coli in the biosolids and biochar from 25 KLD and 35 KLD FSTPs*).

The regulatory limit given for pathogen content of the organic manure in the FCO 2023 is nil. As FC/*E. coli* were detected in most of the samples, the presence and extent of FC and *E. coli* in the biosolids/biochar 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 ($\log_{10} 1000 = 3$) (see *Annexure 1, Table 4*).

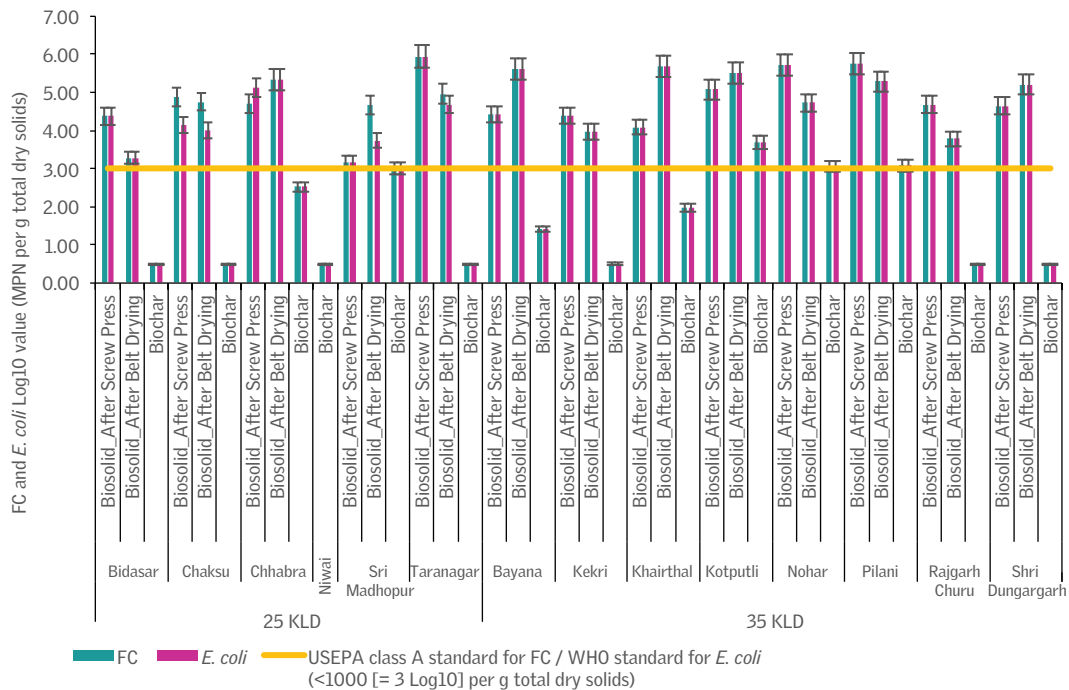
In this study, both FC and *E. coli* in the biosolids from the 24 FSTPs were in the range of 1.99–5.92 \log_{10} MPN/g total dry solids (=98–840858 MPN/g total dry solids). In most of the biosolids, after belt drying, an increase was observed in these two indicator organisms which might be due to the following: limited disinfection achieved in this process, which operates at 60–75°C, might have retained the bacterial load in the biosolids. If drying temperatures might have reached only

Graph 49: FC and *E. coli* in the biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 50: FC and *E. coli* in the biosolids and biochar from 25 and 35 KLD FSTPs



Source: EML, CSE

up to 45°C, this will promote the growth of thermotolerant coliforms including *E. coli*, thereby increasing their population. None of the biosolids after belt drying showed FC and *E. coli* within USEPA/WHO limits.

FC in the biochar from the 25 FSTPs was in the range of 0.48–4.40 log₁₀ MPN/g total dry solids (=3-24964 MPN/g total dry solids). *E. coli* in the biochar from the 24 FSTPs was in the range of 0.48–4.08 log₁₀ MPN/g total dry solids (=3-11996 MPN/g total dry solids). FC and *E. coli* in the biochar were found to be above the USEPA/WHO limits in six locations of which only in two locations (Kotputli and Reengus) they exceeded 3.5 log₁₀ MPN/g total dry solids. FC/*E.coli* was absent in 14 biochar samples (the values indicate only the minimum detection limit of MPN procedure). This indicates that biochar produced through POP in the FSTPs is efficient enough to kill pathogens or keep pathogens within safe limits.

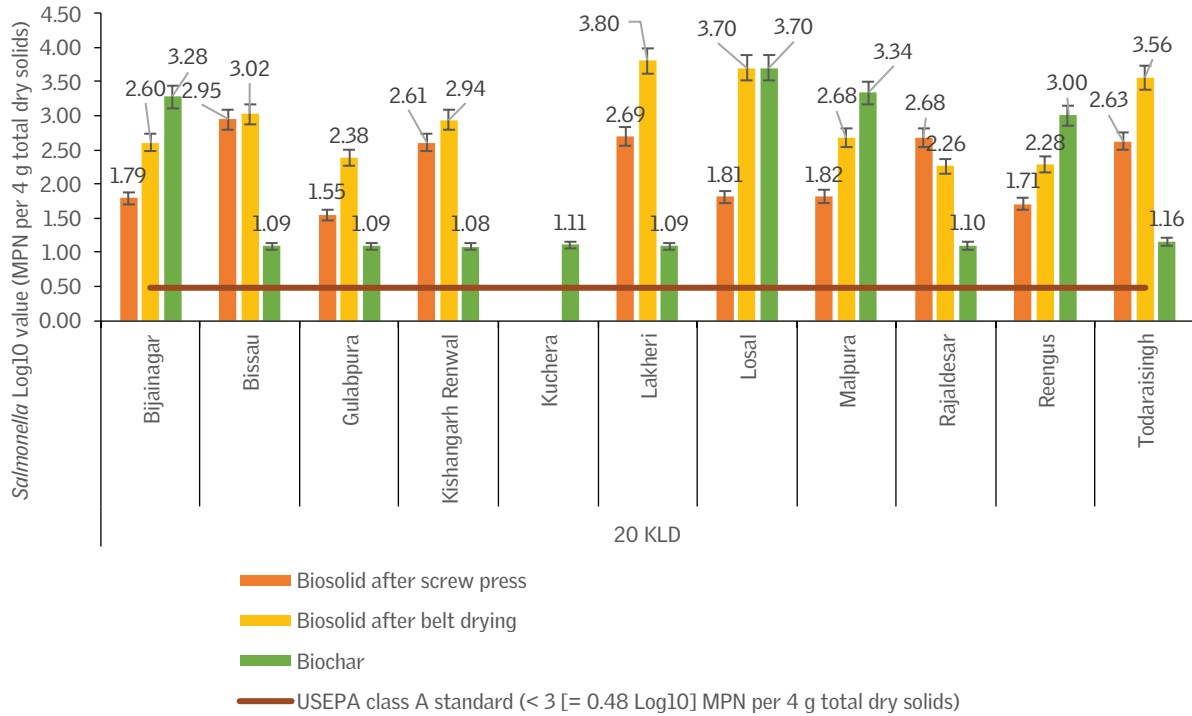
7.2.2.7 *Salmonella*

Salmonella is an enteric and food/water-borne pathogenic bacterium that causes typhoid fever and salmonellosis, through infection from (faecal) contaminated food/water. It is found in the faeces of infected humans and animals, and hence, also present in FS biosolids. *Salmonella* found in the biosolids, and biochar from 20 KLD FSTPs is shown in *Graph 51*; *Salmonella* found in the biosolids, and biochar from 25 KLD and 35 KLD FSTPs is depicted in *Graph 52* (see *Graph 51: Salmonella in the biosolids and biochar from 20 KLD FSTPs* and *Graph 52: Salmonella in the biosolids and biochar from 25 KLD and 35 KLD FSTPs*).

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*. As *Salmonella* was detected in several biosolid/biochar samples, their quantity is compared with available global standards such as USEPA to assess the sample quality and safety for reuse specifically in agriculture. The USEPA standard for *Salmonella* for class A biosolids is < 3 MPN/4 g total dry solids [log₁₀ 3 = 0.48] which includes all types of biosolids that can be applied to all land types (see *Annexure 1, Table 4*).

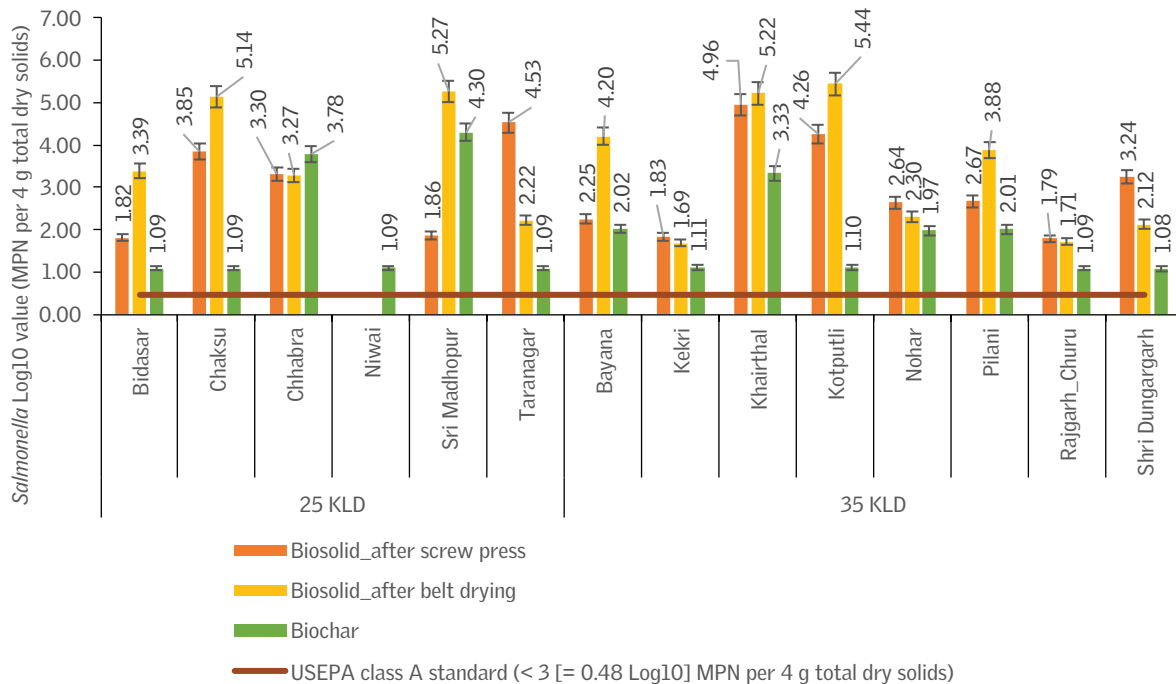
In this study, *Salmonella* in the biosolids from the 25 FSTPs was in the range of 1.55–5.44 log₁₀ MPN/4 g total dry solids (=35-278059 MPN/4 g total dry solids). After steam drying, an increase in *Salmonella* was observed in the biosolids from most of the FSTPs, as was observed with FC and *E. coli*. Same conditions that might have caused increase in FC/*E. coli* as described above might also have caused increase in *Salmonella*. None of the biosolids after belt drying showed *Salmonella* within USEPA limit.

Graph 51: Salmonella in the biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 52: Salmonella in the biosolids and biochar from 25 KLD and 35 KLD FSTPs



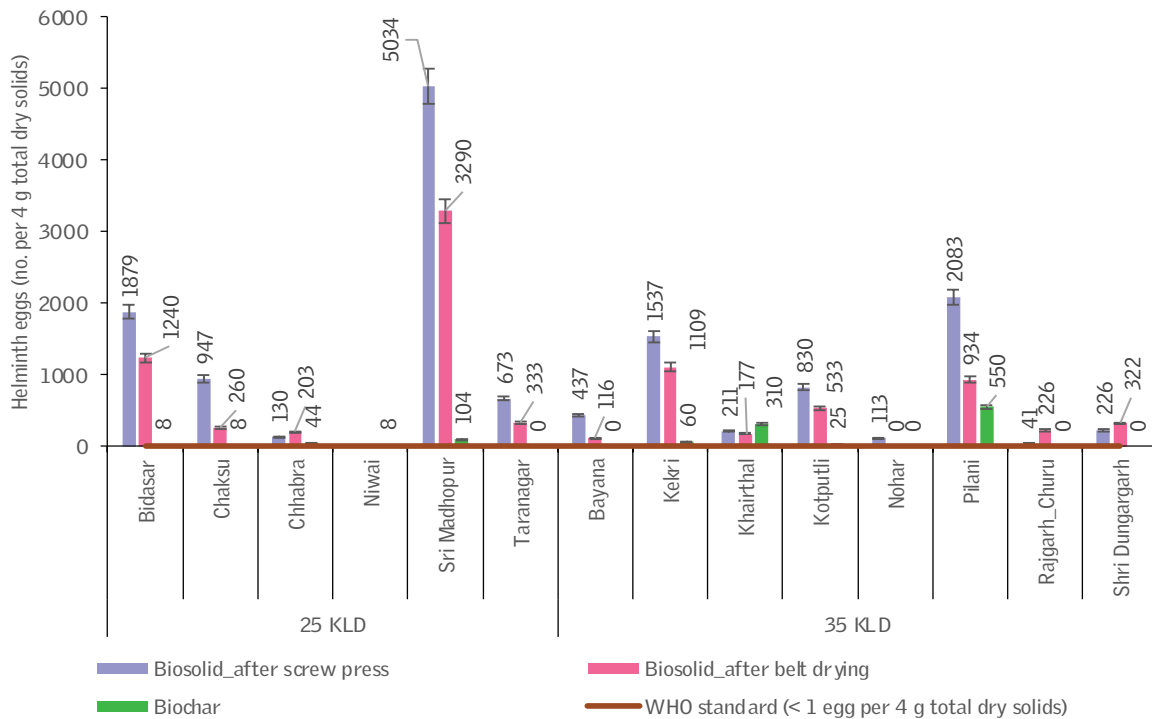
Source: EML, CSE

Salmonella in the biochar was found to be in the range of 1.08–4.30 log₁₀ MPN/4g total dry solids (=12–20005 MPN/4 g total dry solids) in the 25 FSTPs. Ten biochar samples has shown high levels of *Salmonella* (1.97–4.3 log₁₀ MPN/4 g total dry solids). *Salmonella* was negligible or absent in the remaining 15 biochar samples (the values indicate only the minimum detection limit of MPN procedure). This indicates that biochar produced through POP in the FSTPs is efficient enough to eliminate pathogens such as *Salmonella* if properly managed.

7.2.2.8 Helminth eggs

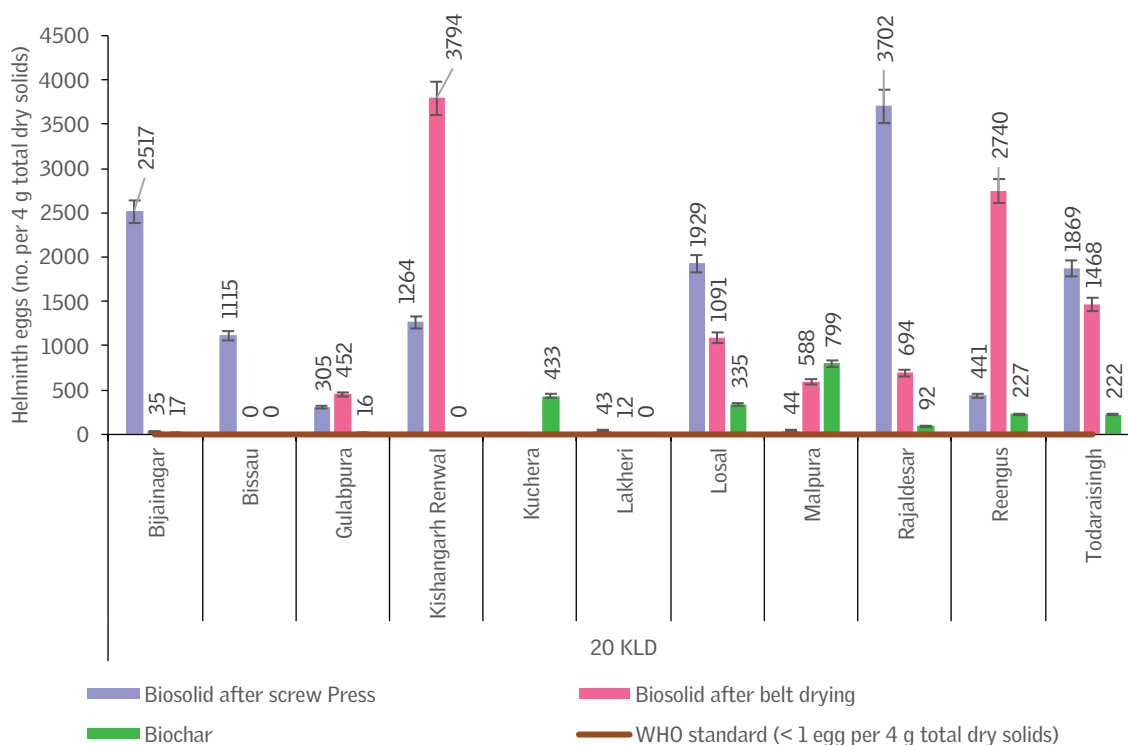
Helminth eggs found in the biosolids and biochar is shown in *Graphs 53 and 54* (see *Graph 53: Helminth eggs in the biosolids and biochar of 20 KLD FSTPs* and *Graph 54: Helminth eggs in the biosolids and biochar of 25 KLD and 35 KLD FSTPs*).

Graph 53: Helminth eggs in the biosolids and biochar from 20 KLD FSTPs



Source: EML, CSE

Graph 54: Helminth eggs in the biosolids and biochar from 25 KLD and 35 KLD FSTPs



Source: EML, CSE

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 most of the biosolids and biochar samples evaluated in this study. The USEPA class A standard of <1 helminth egg/4 g total dry solids of biosolids for unrestricted use in agriculture is used to assess the suitability of biosolids and biochar for agricultural purposes (see Annexure 1, Table 4).

In this study, helminth eggs in the biosolids from 25 FSTPs were in the range of 0–5034 eggs/4 g total dry solids. Helminth eggs were absent in only two of the biosolids after belt drying, indicating the difficulty in this step for helminth egg removal. Helminth eggs in the biochar from 25 FSTPs were in the range of 0–799 eggs/4 g total dry solids. Helminth eggs were not detected in eight biochar samples, which fall under USEPA Class A biosolids limit for unrestricted agricultural use. This also indicates that they can be eliminated completely through POP technology by proper management.

7.3 The findings: A summary

7.3.1 Treatment technologies

- All 39 FSTPs are equipped with a screw press, which is a mechanical solid-liquid separation technology; they have MBBR technology for liquid treatment, and pyrolysis-based Omni Processor (POP) for biosolids treatment. The end products generated are treated effluent and biochar, the latter being a good organic and nutrient source for agricultural purposes.

7.3.2 Treatment efficiency and effluent quality

- **pH and solids removal:** The outlet pH across all sites remained within the regulatory range of 5.5–9.0. Total suspended solids (TSS) removal was consistently high, with many sites achieving over 90 per cent removal, resulting in outlet concentrations well within the NGT limits of 30–50 mg/L. However, total dissolved solids (TDS) content in the effluent was very high in a few plants which needs intervention.
- **Organic load (BOD and COD):** The plants demonstrated exceptional organic removal efficiencies, often exceeding 95 per cent for both COD and BOD. The majority of the sites discharged effluent with BOD levels below 10 mg/L, complying with the most stringent national standards.
- **Nutrient removal (nitrogen and phosphorus):** Treatment performance for nutrients was highly variable. While some plants like Kekri and Niwai showed excellent nitrogen reduction, others—particularly Kishangarh Renwal and Khairthal—showed significantly higher nitrogen levels in the outlet, exceeding the NGT limit of 15 mg/L. Similarly, total phosphorus (TP) exceeded the 1.0 mg/L limit in several locations, including Kishangarh Bas.
- **Pathogen reduction (liquid):** Faecal coliform (FC) levels in the treated effluent were generally well within the 1,000 MPN/100 mL limit, indicating the effective functioning of UV for disinfection.

7.3.3 Quality of biosolids and biochar

- **pH and conductivity:** Both biosolids and biochar maintained pH and Electrical Conductivity (EC) levels compliant with the Fertilizer Control Order (FCO) standards for organic manure, making them chemically suitable for soil application.

- **Moisture and carbon content:** Biochar consistently met the FCO moisture standard (<25 per cent), while biosolids after belt drying often remained too wet for direct storage. Both products showed high organic carbon (>14 per cent), fulfilling FCO requirements for soil conditioners.
- **Nutrient profile (NPK):** The pyrolysis process concentrated phosphorus and potassium, while nitrogen was partially lost due to volatilization. However, the total NPK content in both biosolids and biochar consistently exceeded the FCO minimum of 3 per cent, making them potent nutrient sources for agriculture.
- **Heavy metal concerns:** While arsenic, cadmium, and lead were within limits, mercury (Hg) and zinc (Zn) frequently exceeded FCO standards in both products. In specific sites such as Khairthal, chromium and nickel also exceeded permissible limits, posing a potential risk for unrestricted soil application.

7.3.4 Pathogen inactivation in solids

- **Thermal destruction efficiency:** The study highlighted a significant disparity between biosolids and biochar. Biosolids after belt drying or screw pressing retained high levels of *E. coli*, *Salmonella* and helminth eggs, making them unsafe for unrestricted use.
- **Biochar performance:** While pyrolysis significantly reduced pathogen loads compared to biosolids, several biochar samples still exceeded the USEPA Class A limit (<1 helminth egg/4g). This suggests that in many operational POPs, the pyrolysis temperature or residence time was not optimally maintained to achieve total sterilization.
- **Requirement for optimization:** The report concludes that while the POP technology is inherently capable of producing sterile biochar, precise operational control over the ‘time–temperature’ relationship during pyrolysis and the efficiency of the pre-treatment drying stage is mandatory to ensure public health safety.

In conclusion, the evaluation of 39 Pyrolysis-based Omni Processor (POP) faecal sludge treatment plants (FSTPs) across Rajasthan highlights a pioneering shift in sanitation management from simple waste disposal to a sustainable circular economy. These self-sustaining, modular facilities utilize a dual-stream treatment process: a single-chambered Moving Bed Biofilm Reactor (MBBR) manages liquid leachate, while a wood-chip-fueled pyrolyzer converts separated solids into carbon-rich biochar. Across the sites evaluated, the treated effluent consistently

met regulatory pH standards and demonstrated an average removal efficiency of approximately 50 per cent for total suspended solids (TSS). By effectively ‘locking’ carbon into a stable form that can remain sequestered in the soil for centuries, these systems transform a potential environmental hazard into a powerful tool for climate change mitigation.

The study indicates that when pyrolysis is performed at high temperatures—typically between 170°C and 750°C—the resulting biochar can meet USEPA Class A standards for pathogen reduction, effectively neutralizing resilient microorganisms, including bacteria, viruses and helminth eggs. This biochar and the preceding biosolids serve as nutrient-dense organic soil amendments that provide a synchronized, slow-release of nutrients to plants, thereby reducing the environmental leaching and industrial emissions associated with chemical fertilizers. While primary macronutrients and organic carbon levels remained largely compliant with Fertilizer Control Order (FCO) 2023 standards, the study identified specific challenges with heavy metal concentrations. Notably, mercury levels exceeded regulatory limits at 15 biochar production sites and nearly all biosolid locations, while other metals like zinc, chromium and nickel showed localized excesses.

The report concludes that POP technology offers a viable and scalable business case for resolving the sanitation crisis in arid regions like Rajasthan while protecting local ecosystems. The transition to this decentralized infrastructure allows for significant resource recovery and the creation of valuable agricultural byproducts. However, achieving consistent compliance with health and organic manure standards requires rigorous operational oversight, specifically regarding the optimization of pyrolysis temperatures and residence times to ensure total pathogen inactivation and the stabilization of heavy metals. These findings provide a strategic roadmap for the continued modernization of India’s decentralized sanitation systems through sustainable resource recovery.

7.4 Recommendations

Challenges for effluent and biosolids treatment / biochar quality faced by the FSTPs were identified and accordingly recommendations were provided for mitigation (see *Table 6: Effluent treatment challenges identified in the study*, *Table 7: Challenges with biosolids treatment (post-screw press and belt dryer) identified in the study* and *Table 8: Challenges with biochar quality identified in the study*).

Table 6: Effluent treatment challenges identified in the study

FSTP	Challenge category	Specific challenge/parameter failure
Lakheri, Losal	Solids removal	Negative TS removal; extreme concentrations (>50,000 mg/L)
Taranagar	Solids removal	Highly mineralized effluent (TDS ~24,000 mg/L)
Reengus	Organic load	Negative COD removal (process instability)
Malpura, Rajaldesar, Todaraisingh, Bidasar, Kishangarh Renwal	Organic load	Negative BOD removal (process instability)
Nawa, Viratnagar, Sarwar, Weir, Kishangarh Renwal	Organic load	Failed NGT COD discharge standards
Kishangarh Bas, Deshnok, Malpura, Rajaldesar, Todaraisingh, Bidasar, Chaksu, Sri Madhopur, Pilani	Organic load	Exceeded the 30 mg/L BOD limit
Kishangarh Bas	Nutrients	Decreased N and P efficiency; exceeded NGT limits
Kishangarh Renwal	Nutrients	Highest TKN and AN levels (>400 mg/L) in effluent.
Bhusawar	Nutrients	Least TKN reduction among smaller plants
Deshnok	Pathogens	Exceeded desirable/permisible faecal coliform (FC) limits.
Kuchera, Kekri, Nohar	pH Stability	Exceeded upper pH limit of 9.0.
General (most plants)	Nutrients	12/14 small plants & majority of large plants failed TP standard (1.0 mg/L)

Table 7: Challenges with biosolids treatment (post-screw press and belt dryer) identified in the study

Processing stage	Impacted FSTPs	Primary challenges
Screw press	All sites	High moisture (58.65%–86.92%) and high pathogen load (FC, <i>E. coli</i> , etc.)
Screw press	Almost all sites	Mercury (Hg) exceeded Fertilizer Control Order (FCO) limits
Screw press	Chhabra	Copper (Cu) exceeded FCO limits
Screw press	Rajgarh, Churu	Chromium (Cr) exceeded FCO limits
Belt dryer	25 larger FSTPs	None met USEPA/WHO pathogen limits for unrestricted agricultural use
Belt dryer	General/majority	Inefficient drying (>25% moisture); Pathogen regrowth (FC, <i>E. coli</i> , <i>Salmonella</i>) after drying due to low temperatures (60–75 °C)

Table 8. Challenges with biochar quality identified in the study

FSTP(s)	Challenge parameter	Specific observation
Nawa, Viratnagar (+10 others)	Alkalinity/pH	Exceeded the FCO pH limit of 8.5
Deshnok, Sarwar (+8 others)	C:N ratio	Exceeded the limit of 20 (risk of nitrogen immobilization)
Kishangarh Bas, Deoli, Pirawa, Uniara, Weir (+15 others)	Heavy metals	Mercury (Hg) exceeded safe standards
Baggar, Deoli, Pirawa, Uniara, Weir, Bhusawar, Taranagar, Rajgarh_Churu, Nohar	Heavy metals	Chromium (Cr) exceeded safe standards
Mundwa, Uniara, Mukundgarh, Weir, Niwai, Taranagar, Nohar	Heavy metals	Nickel (Ni) exceeded safe standards
Nawa, Pirawa, Weir (+8 others)	Heavy metals	Zinc (Zn) exceeded safe standards
Khairthal, Gulabpura, Bijainagar	Heavy metals	Copper (Cu) exceeded safe standards
Mundwa, Reengus, Kotputli (+others)	Pathogens	High levels of FC and <i>E. coli</i> remained in biochar
Baggar, Kishangarh Bas (+10 larger plants)	Pathogens	High <i>Salmonella</i> and helminths (pyrolysis optimization required)
Mundwa	Pathogens	Highest FC/ <i>E.coli</i> levels among the 10–15 KLD plants

Source: EML, CSE

7.4.1 Measures to improve the treatment efficiency and effluent quality

As solids (TS, TDS) and nutrients such as TKN, AN and TP are found to be in high amounts (i.e., above the respective MoEF&CC/NGT standard limits) in several FSTPs in this study, we have provided several approaches to reduce these parameters in the pyrolysis-MBBR based technology present in the FSTP.

7.4.1.1 Reduce nitrogen content¹²

Nitrogen removal in wastewater primarily relies on biological nitrification and denitrification. Nitrification occurs under aerobic conditions where autotrophic bacteria oxidizes ammonia into nitrate, while denitrification takes place in anoxic environments where bacteria convert that nitrate into atmospheric nitrogen gas. In Moving Bed Biofilm Reactor (MBBR) systems, these processes can be separated into two chambers or integrated into one. Single-chambered systems utilize Simultaneous Nitrification and Denitrification (SND) by leveraging oxygen gradients within the biofilm itself; the aerobic outer layer facilitates nitrification, while the oxygen-depleted deeper layers provide the anoxic zone necessary for denitrification.

To optimize nitrogen removal in single-chambered MBBR systems, such as those in the studied FSTPs, several operational adjustments are essential.

Maintaining dissolved oxygen (DO) levels—ideally below 2 mg/L—is critical to ensure that oxygen does not penetrate too deeply and collapse the anoxic zone. Additionally, a balanced carbon-to-nitrogen (C:N) ratio must be maintained, as denitrifiers require organic carbon; if the influent ratio is insufficient, external sources like methanol can be added. Other efficiency-boosting measures include extending the Hydraulic Retention Time (HRT), maintaining favourable pH and temperature ranges, using high-surface-area carriers like polyurethane sponges, and introducing specific zooplankton to regulate biofilm thickness and microbial activity.

7.4.1.2 Reduce phosphorus content¹³

Phosphorus removal in wastewater is primarily achieved through a combination of biological and chemical processes. In a single-chambered Moving Bed Biofilm Reactor (MBBR), biological removal is facilitated by phosphorus-accumulating organisms (PAOs) that thrive within the stratified layers of the biofilm. In the anaerobic inner layers, PAOs release stored phosphorus while absorbing volatile fatty acids (VFAs) as an energy source. As the carriers circulate into the aerobic outer zones, these organisms utilize their stored energy to absorb significantly higher amounts of phosphorus from the water, storing it as polyphosphates. These phosphorus-rich bacteria eventually detach from the biofilm and are removed from the system as waste sludge.

Effective biological performance requires precise operational control, specifically maintaining alternating dissolved oxygen (DO) levels to sustain both anaerobic and aerobic zones, ensuring a sufficient supply of organic carbon (VFAs), and managing temperatures to prevent microbial suppression. When biological methods alone are insufficient to meet strict discharge standards, chemical precipitation serves as a vital polishing step. By adding metal salts such as aluminium sulphate or ferric chloride, soluble phosphorus is converted into insoluble precipitates. These solids are then easily separated and removed with the plant's sludge, providing a reliable and robust final treatment stage.

7.4.1.3 Reduce dissolved solids (TDS) content

Reducing total dissolved solids (TDS) in a faecal sludge treatment plant equipped with MBBR and screw press technology is particularly challenging because these primary and secondary stages are designed to remove suspended matter rather than dissolved ions. Since the screw press physically separates larger solids and the MBBR biological process converts dissolved organic matter into biomass, the inorganic salts and minerals that constitute TDS remain in the water. To effectively lower TDS, advanced tertiary treatments such as reverse osmosis (RO) or ion

exchange are required. In an RO system, high pressure is used to force the effluent through a semi-permeable membrane that rejects dissolved salts and minerals, thereby significantly reducing salinity.

7.4.2 Measures to improve biosolids quality

The following are some measures to reduce moisture and pathogens that are present in high levels in the evaluated biosolids.

7.4.2.1 Measures to reduce moisture content

Faecal sludge biosolids generated at FSTPs must be rigorously treated to neutralize high pathogen loads before they can be safely reused. Effective moisture reduction is the primary defence, as high water content dissolves nutrients and creates an ideal environment for microbial proliferation. While solar drying is the conventional approach, its efficacy depends on spreading biosolids in thin layers to ensure uniform evaporation. In mechanized facilities, optimizing the temperature and duration within belt dryers can achieve specific moisture targets.

To further enhance safety, pulverization—the mechanical breakdown of large flakes into fine particles—can be employed. By increasing the surface area, pulverization ensures that heat or drying treatments reach the core of the material, which is particularly effective at destroying resilient helminth eggs. Due to the increased operational costs associated with this mechanical process, its use is typically prioritized for high-moisture environments, such as coastal areas or regions with frequent rainfall, where natural drying is less reliable.

7.4.2.2 Measures to prevent pathogen regrowth

Due to their high nutrient density, dried biosolids are highly susceptible to pathogen regrowth if exposed to moisture or external contaminants. Research indicates that while faecal coliforms and *E. coli* typically re-emerge from indigenous microbial populations, *Salmonella* regrowth is almost exclusively triggered by external factors, such as contamination from animal feces or stormwater runoff.¹⁴ To prevent this re-inoculation and subsequent microbial multiplication, it is essential to store treated biosolids in a secure, enclosed facility. Additionally, implementing long-term storage—exceeding one year—serves as a natural secondary treatment phase, significantly reducing the numbers of resilient pathogens such as *Salmonella* and helminth eggs through prolonged environmental exposure.

7.4.2.3 Measures to reduce pathogen content

While solar drying is a highly effective primary method for pathogen reduction, practical operational constraints often necessitate supplemental chemical or

thermal treatments to ensure complete sterilization. Alkaline stabilization using lime (at 20–40 per cent dry weight) can significantly raise pH levels above 12, effectively inactivating up to 8 log units of faecal coliforms and Salmonella. Similarly, high-intensity chemical treatments like peracetic acid (550 ppm) can achieve dramatic bacterial inactivation within minutes.

However, parasitic helminth eggs pose a unique challenge due to their resilient protective envelopes, rendering standard chemical dosages far less effective. To guarantee the inactivation of these resistant ova, more intensive thermal processes are required, such as pasteurization at 70°C, irradiation or high-heat treatment reaching 108°C. While solar drying contributes to helminth reduction, these advanced thermal technologies remain the most reliable benchmarks for achieving a total pathogen-free biosolid product.¹⁵

7.4.3 Measures to improve biochar quality

Some measures to reduce pathogens and heavy metals (in POP) that are present in high levels in the evaluated biochar are provided below. Measures to reduce heavy metals in biochar provided in this section are also applicable to biosolids.

7.4.3.1. Measures to reduce pathogen content¹⁶

The pyrolysis-based Omni Processor (POP) transforms faecal sludge biosolids into sterile, nutrient-rich biochar through two fundamental stages: intensive pre-drying and high-heat pyrolysis. The process begins by reducing moisture content through steam or belt drying, which is critical because excessive water consumes the energy needed for thermal destruction and can lead to uneven reactor temperatures. Achieving a homogenous feedstock—free of large, dense clumps—further ensures that heat penetrates the entire mass uniformly, eliminating ‘cold spots’ where pathogens might otherwise survive.

Optimization of the pyrolysis chamber involves a delicate trade-off between total sterilization and nutrient retention. While temperatures of 300–400°C initiate the inactivation process, operating at 600–700°C ensures the rapid and complete destruction of all bacteria, viruses and resilient helminth eggs. However, these higher temperatures cause a significant decrease in carbon (C), nitrogen (N) and phosphorus (P) content, though they benefit the biochar by increasing its surface area, porosity and carbon stability for long-term sequestration. To complement these temperatures, a residence time of 30–60 minutes is maintained along with internal agitation to ensure that every particle reaches the required thermal threshold.

The final stage focuses on maintaining sterility achieved during thermal treatment. Once produced, the hot biochar must be immediately cooled and sealed in airtight containers to prevent recontamination from environmental dust, moisture, or insects. Rigorous quality control, including regular testing for indicator organisms like *E. coli* and *Salmonella*, serves as the final validation that the POP is functioning correctly and producing a safe, standardized soil amendment.

7.4.3.2 Keep heavy metals in safe limits¹⁷

While biosolids and biochar serve as excellent nutrient sources, they often contain heavy metals that must be managed to meet Fertilizer Control Order (FCO) standards. In this study, levels of mercury, zinc, chromium, nickel and copper exceeded safe limits, necessitating specific removal or stabilization strategies. The effectiveness of these strategies depends heavily on the metal's properties and the treatment temperature. For instance, during high-temperature pyrolysis (>650°C), volatile metals like mercury and zinc are vapourized and removed from the solid mass, while copper, nickel and chromium tend to concentrate within the remaining char. However, the complex carbon structures formed during pyrolysis can sequester these non-volatile metals, trapping them to prevent environmental leaching.

Beyond thermal stabilization, several specialized techniques can physically extract these contaminants. Acid leaching is highly effective for removing divalent metals such as zinc and nickel, though chromium often requires additional oxidative steps due to its chemical resilience. Alternatively, bioleaching utilizes acid-producing microorganisms like *Acidithiobacillus* to solubilize metals; while this is a cost-effective and environmentally friendly 'green' solution, it operates at a significantly slower pace than chemical methods. For high-precision removal, electrokinetic treatment applies a low-level electric current to migrate metal ions toward electrodes for collection, offering a sophisticated approach to remediation when traditional leaching or thermal trapping is insufficient.

To qualify it as a good quality biochar, it must exhibit high carbon and nutrient content, stable pH (neutral to slightly alkaline), low electrical conductivity (to avoid salt stress in soil), heavy metals strictly below permissible toxic thresholds and absence of viable pathogens. It can be mixed with soil at recommended ratios (e.g., 5–10 per cent by weight) to improve fertility and carbon sequestration.

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Annexures

Annexure I

Table 1: National Green Tribunal (NGT) standards 2019 for effluent discharge from STPs

S. no.	Parameters	Standards			
		(Applicable to all mode of disposal)			
		Mega and metropolitan cities	Class I Cities	Others	Deep Marine Outfall
1	pH	5.5-9.0	5.5-9.0	5.5-9.0	5.5-9.0
2	Biochemical Oxygen Demand (BOD) (mg/L)	10	20	30	30
3	Total suspended solids (TSS) (mg/L)	20	30	50	50
4	Chemical oxygen demand (COD) (mg/L)	50	100	150	150
5	Total nitrogen (mg/L)	10	15	-	-
6	Phosphorus total (for discharge into ponds, lakes) (mg/L)	1.0	1.0	1.0	
7	Faecal coliform (FC) (Most Probable Number per 100 millilitre, MPN/100 mL)	Desirable: 100 Permissible: 230	Desirable: 230 Permissible: 1000	Desirable: 1000 Permissible: 10,000	Desirable: 1000 Permissible: 10,000

Notes:

- (i) Mega-Metropolitan Cities have population more than 1 crore, Metropolitan Cities- Population more than 10 Lakh and Class-1 Population more than 1 Lakh.
- (ii) All value in mg/l except for pH and faecal coliform.
- (iii) These standards will be applicable for discharge into water bodies as well as for land disposal/applications.
- (iv) These standards shall apply to all new STPs for which construction is yet to be initiated.
- (v) The existing/under construction STPs shall achieve these standards within 7 years from the date of notification.
- (vi) In case where the marine outfall provides a minimum initial dilution of 150 times at the point of discharge and a minimum dilution of 1500 times at a point 100 m away from discharge point, then norms for deep sea marine discharge shall be applied.
- (vii) Reuse/recycling of treated effluent shall be encouraged.
- (viii) State Pollution Control Boards/Pollution Control Committees may make these norms more stringent taking into account the local conditions.

Table 2: Ministry of Environment, Forest and Climate Change (MoEF&CC) standards 2017 for effluent discharge from STPs

S. no.	Parameters	Standards	
		Effluent discharge standards (applicable to all mode of disposal)	
		Location	Concentration not to exceed
		(a)	(b)
1	pH	Anywhere in the country	6.5-9.0
2	Biochemical oxygen demand (BOD) (mg/L)	Cities (with more than 10 lakh population): Metro Cities*, all State Capitals except in the State of 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	20
		Areas/regions other than mentioned above	30
3	Total suspended solids (TSS) (mg/L)	Cities (with more than 10 lakh population): Metro Cities*, all State Capitals except in the State of 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	<50
		Areas/regions other than mentioned above	<100
4	Faecal coliform (FC) (MPN/100 mL)	Anywhere in the country	<1000

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

Notes:

- (i) All values in mg/l except for pH and Fecal Coliform.
- (ii) These standards shall be applicable for discharge into water bodies as well as for land disposal/applications.
- (iii) The standards for Fecal Coliform shall not apply in respect of use of treated effluent for industrial purposes.
- (iv) These Standards shall apply to all STPs to be commissioned on or after the 1st June, 2019 and the old/existing STPs shall achieve these standards within a period of five years from date of publication of this notification in the Official Gazette.
- (v) In case of discharge of treated effluent into sea, it shall be through proper marine outfall and the existing shore discharge shall be converted to marine outfalls, and in cases where the marine outfall provides a minimum initial dilution of 150 times at the point of discharge and a minimum dilution of 1500 times at a point 100 meters away from discharge point, then, the existing norms shall apply as specified in the general discharge standards.
- (vi) Reuse/Recycling of treated effluent shall be encouraged and in cases where part of the treated effluent is reused and recycled involving possibility of human contact, standards as specified above shall apply.
- (vii) Central Pollution Control Board/State Pollution Control Boards/Pollution Control Committees may issue more stringent norms taking account to local condition under section 5 of the Environment (Protection) Act, 1986.

Table 3. Fertilizer Control Order standards for organic manure 2023*

S. 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/cm ³)	<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 P ₂ O ₅) per cent by weight, minimum	0.5
7	Total potash (as K ₂ O) per cent by weight, minimum	0.5
8	NPK nutrients—Total N, P ₂ O ₅ and K ₂ O 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 As ₂ O ₃)	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

*Electrical conductivity (EC) and its limit is not mentioned in FCO 2023 for organic manure; however, it is mentioned in FCO 2013 for organic manure with limit as <4 dS/m, which is used for evaluating EC in this report.

Table 4. Global standards for pathogens in biosolids

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

Annexure 2

Table 1: Consolidated data of physicochemical parameters and pathogen content in inlet and outlet from FSTPs

Location	Month	Type of sample	Physicochemical parameters									Pathogen content	
			pH	TS (mg /L)	TSS (mg /L)	TDS (mg /L)	COD (mg /L)	BOD (mg /L)	TKN (mg /L)	AN (mg /L)	TP (mg /L)	FC (MPN/100 mL)	FC Log10 value (MPN/100 mL)
10 KLD FSTPs													
Baggar	February 2026	Inlet	8.27	1913	19.0	1894	518	195.0	125.83	264.65	25.6	110000	5.04
		Outlet	8.10	1713	16.0	1697	124	70	205.51	104.59	16.4	230	2.36
Khatu Shyam Ji	January 2026	Inlet	8.25	1271	1.0	1270	92	175	191.39	170.24	26.9	30	1.48
		Outlet	8.32	1350	1.0	1349	84	13.5	196.10	193.88	20.7	750	2.88
Kishangarh Bas	January 2026	Inlet	8.32	1676	2.0	1674	174	60.0	281.06	252.20	15.0	3600	3.56
		Outlet	8.02	1360	10.0	1350	106	32.0	230.20	211.05	13.8	92	1.96
Mundwa	January 2026	Inlet	8.40	2784	20.0	2764	324	50.0	269.89	259.65	14.2	3600	3.56
		Outlet	7.95	2562	5.0	2557	120	17.0	37.34	11.71	12.9	74	1.87
Pirawa	February 2026	Inlet	7.64	959	3.0	956	304	136.5	295.47	97.54	15.7	4300	3.63
		Outlet	8.08	2239	17.0	2222	17	13.8	29.69	6.82	0.2	30	1.48
Uniara	February 2026	Inlet	7.85	1946	26.0	1920	1084	97.0	589.18	81.62	13.0	460000	5.66
		Outlet	7.59	875	3.0	872	112	147.0	22.34	13.30	8.1	30	1.48
15 KLD FSTPs													
Bhusawar	February 2026	Inlet	7.98	1579	37.0	1542	186	65.0	189.04	102.60	26.1	230	2.36
		Outlet	8.15	1949	2.0	1947	131	47.4	203.15	153.07	9.6	230	2.36
Deoli	February 2026	Inlet	8.21	1876	25.0	1851	64	97.5	70.27	61.50	11.7	36	1.56
		Outlet	8.19	1886	13.0	1873	59	6.0	17.35	10.74	6.7	30	1.48
Deshnok	January 2026	Inlet	8.06	1049	7.0	1042	135	25.0	123.19	111.80	15.9	9200	3.96
		Outlet	8.12	1005	8.0	997	102	35.5	104.37	103.28	13.6	24000	4.38
Mukundgarh	February 2026	Inlet	8.25	1733	8.0	1725	240	80.0	256.07	495.76	24.6	4300	3.63
		Outlet	7.95	1739	2.0	1737	88	9.0	159.35	77.87	24.0	30	1.48
Nawa	January 2026	Inlet	8.42	2089	20.0	2069	698	156.0	466.28	228.61	20.9	460000	5.66
		Outlet	8.24	2157	3.0	2154	370	65.0	347.80	344.22	14.6	30	1.48
Sarwar	January 2026	Inlet	8.06	865	16.3	848.7	62	145.0	61.15	31.89	9.2	3600	3.56
		Outlet	8.81	1206	2.0	1204	222	120.0	1793	2.56	0.5	230	2.36

Location	Month	Type of sample	Physicochemical parameters									Pathogen content	
			pH	TS (mg /L)	TSS (mg /L)	TDS (mg /L)	COD (mg /L)	BOD (mg /L)	TKN (mg /L)	AN (mg /L)	TP (mg /L)	FC (MPN/100 mL)	FC Log10 value (MPN/100 mL)
Viratnagar	January 2026	Inlet	8.26	1710	4.0	1706	194	275	429.53	382.82	18.0	3600	3.56
		Outlet	8.17	1575	5.0	1570	178	170	350.45	319.21	13.7	74	1.87
Weir	January 2026	Inlet	8.15	2561	29.0	2532	674	100.0	351.04	113.79	14.5	150000	5.18
		Outlet	8.34	3943	3.0	3940	213	52.5	107.02	142.16	10.8	4300	3.63
20 KLD FSTPs													
Bijainagar	February 2026	Inlet	8.11	1672	14.0	1658	284	180.0	229.91	511.28	23.8	9300	3.97
		Outlet	8.06	317	8.0	309	139	55.0	212.56	143.24	28.5	430	2.63
Bissau	February 2026	Inlet	8.14	3160	5.0	3155	430	175.5	263.13	371.11	19.5	24000	4.38
		Outlet	7.75	2949	39.0	2910	69	15.0	109.66	79.46	9.6	230	2.36
Gulabpura	February 2026	Inlet	7.97	3181	14.0	3167	445	136.5	149.35	135.22	11.0	9300	3.97
		Outlet	7.94	3130	1.0	3129	79	10.0	105.84	91.46	9.7	30	1.48
Kishangarh Renwal	January 2026	Inlet	8.50	3043	14.0	3029	464	108.0	525.67	585.57	18.1	430	2.63
		Outlet	8.73	3019	9.0	3010	374	82.5	444.53	490.98	12.9	2900	3.46
Kuchera	January 2026	Inlet	8.59	436	7.0	429	48	2.0	6.47	4.77	0.4	230	2.36
		Outlet	9.21	1566	3.0	1563	32	24.0	32.05	3.07	0.1	30	1.48
Lakheri	February 2026	Inlet	7.98	1690	50.0	1640	570	50.0	296.35	35.53	22.3	23000	4.36
		Outlet	7.73	53899	1.0	53898	77	23.4	126.42	92.08	5.7	30	1.48
Losal	February 2026	Inlet	8.30	1566	6.0	1560	258	68.0	258.72	257.31	26.5	24000	4.38
		Outlet	8.06	59208	16.0	59192	124	54.6	236.67	150.34	19.8	230	2.36
Malpura	January 2026	Inlet	8.43	1451	10.0	1441	384	28.0	218.44	158.87	23.8	460000	5.66
		Outlet	7.98	20904	2.0	20902	68	34.5	33.52	27.06	7.7	30	1.48
Rajaldesar	January 2026	Inlet	8.04	2342	14.0	2328	814	80.0	275.77	177.68	34.5	93000	4.97
		Outlet	7.84	114	1.0	113	374	42.0	289.30	258.05	11.3	30	1.48
Reengus	January 2026	Inlet	8.44	817	12.0	805	47	9.0	36.16	27.91	5.7	3600	3.56
		Outlet	8.57	1602	3.0	1599	294	46.0	261.66	239.01	14.6	24000	4.38
Todaraisingh	January 2026	Inlet	8.19	1682	7.0	1675	142	20.0	186.10	161.14	17.6	9200	3.96
		Outlet	7.96	1705	12.0	1693	128	52.0	172.58	164.15	14.7	36	1.56
25 KLD FSTPs													
Bidasar	January 2026	Inlet	8.43	2631	5.0	2626	242	25.0	343.98	311.99	8.5	3600	3.56
		Outlet	8.53	12932	1.0	12931	148	19.0	217.27	217.75	7.6	74	1.87

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Month	Type of sample	Physicochemical parameters									Pathogen content	
			pH	TS (mg /L)	TSS (mg /L)	TDS (mg /L)	COD (mg /L)	BOD (mg /L)	TKN (mg /L)	AN (mg /L)	TP (mg /L)	FC (MPN/100 mL)	FC Log10 value (MPN/100 mL)
Chaksu	January 2026	Inlet	8.39	1974	9.0	1965	149	275	184.34	164.27	13.4	92	196
		Outlet	8.74	2455	5.0	2450	108	9.0	209.92	174.73	9.8	36	1.56
Chhabra	February 2026	Inlet	7.68	1313	76.0	1237	490	4575	167.29	82.36	16.2	2300	3.36
Niwai	January 2026	Inlet	8.30	1716	7.0	1709	202	25.0	159.94	142.10	20.1	38000	4.58
		Outlet	8.98	243	4.0	239	22	3.9	12.94	2.22	0.3	36	1.56
Sri Madhopur	January 2026	Inlet	8.15	2169	11.0	2158	338	90.0	356.33	346.33	22.8	15000	4.18
		Outlet	8.23	2100	4.0	2096	112	9.0	179.93	160.12	15.8	930	2.97
Taranagar	February 2026	Inlet	8.34	2437	16.0	2421	480	143.0	410.42	194.22	10.5	4300	3.63
		Outlet	8.41	23712	21.0	23691	204	30.0	216.97	94.70	10.7	92	1.96
35 KLD FSTPs													
Bayana	February 2026	Inlet	7.83	19602	115.0	19487	12720	1270.0	921.40	58.89	189.0	150000	5.18
		Outlet	8.13	3608	5.0	3603	138	23.8	109.66	61.22	12.9	30	1.48
Kekri	January 2026	Inlet	8.05	1137	2.0	1135	134	1575	56.45	59.63	13.5	92	1.96
		Outlet	9.46	1007	1.0	1006	98	47.5	6.17	2.05	6.7	30	1.48
Khairthal	January 2026	Inlet	8.56	1339	20.0	1319	140	50.0	254.31	175.35	10.9	1100000	6.04
		Outlet	8.49	1682	3.0	1679	52	22.0	269.01	262.83	10.5	110000	5.04
Kotputli	January 2026	Inlet	8.22	1832	21.0	1811	382	70.0	269.89	223.67	16.5	43000	4.63
		Outlet	8.29	1507	3.0	1504	74	5.7	37.63	29.90	16.1	30	1.48
Nohar	February 2026	Inlet	8.54	1295	10.0	1285	134	18.0	593.29	137.67	12.8	30	1.48
		Outlet	9.43	3694	42.0	3652	88	51.0	268.72	9.49	0.6	92	1.96
Pilani	February 2026	Inlet	8.15	11938	9.0	11929	266	96.0	352.51	283.40	46.5	24000	4.38
		Outlet	8.25	2082	1.0	2081	138	5.0	201.68	164.61	16.7	30	1.48
Rajgarh_Churu	February 2026	Inlet	8.37	4312	20.0	4292	644	150.0	325.16	286.08	11.9	9300	3.97
		Outlet	8.89	7859	5.0	7854	342	45.0	167.58	101.12	9.3	930	2.97
Shri Dungargarh	January 2026	Inlet	8.27	1870	2.0	1868	206	22.0	260.19	300.57	24.3	92	1.96
		Outlet	8.58	1894	11.0	1883	144	23.0	183.75	178.48	19.5	30	1.48

Table 2: Consolidated data of physicochemical parameters and pathogen content in biosolids and biochar from FSTPs

Location	Month	Sample Type	Physicochemical parameters					Pathogen content						
			pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (Eggs/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)
10 KLD FSTPs														
Baggar	February 2026	BS after screw press	7.85	1.018	78.70	39.40	4.62	789	215994	5.33	215994	5.33	8640	3.94
		BS after belt drying	6.49	1.103	65.64	32.10	3.57	1769	69841	4.84	69841	4.84	2794	3.45
		Biochar	8.54	1.915	7.52	18.80	0.99	0	1189	3.08	1189	3.08	1990	3.30
Khathu Shyam Ji	January 2026	BS after screw press	7.52	0.730	76.84	33.80	3.76	587	18564	4.27	18564	4.27	15887	4.20
		BS after belt drying	7.33	0.057	69.08	36.00	4.23	1345	67912	4.83	38807	4.59	1203	3.08
		Biochar	8.23	1.357	1.49	21.40	1.77	252	3	0.48	3	0.48	12	1.09
Kishangarh Bas	January 2026	BS after screw press	7.70	0.783	78.28	31.30	3.13	479	211762	5.33	506387	5.70	27621	4.44
		BS after belt drying	7.84	1.570	40.95	35.70	3.76	1626	186280	5.27	186280	5.27	162572	5.21
		Biochar	8.61	1.499	10.67	20.50	1.53	869	2687	3.43	1041	3.02	134	2.13
Mundwa	January 2026	BS after screw press	7.64	1.141	82.12	41.40	4.09	2595	52008	4.72	52008	4.72	67	1.83
		BS after belt drying	7.02	2.420	20.65	40.60	3.80	1482	138621	5.14	138621	5.14	5545	3.74
		Biochar	8.01	1.640	52.16	37.50	3.28	786	22994	4.36	22994	4.36	192	2.28
Pirawa	February 2026	BS after screw press	7.78	1.071	79.78	39.60	4.03	79	45989	4.66	45989	4.66	316	2.50
		BS after belt drying	8.06	1.501	55.74	38.30	3.90	36	248557	5.40	248557	5.40	9942	4.00
		Biochar	7.40	2.310	31.22	26.20	2.29	58	422	2.62	422	2.62	6397	3.81
Uniara	February 2026	BS after screw press	8.38	0.629	82.55	39.30	3.96	458	137523	5.14	137523	5.14	69	1.84
		BS after belt drying	7.07	1.622	27.80	26.60	1.50	0	1274	3.11	1274	3.11	1330	3.12
		Biochar	8.26	1.507	8.60	24.90	1.88	0	4	0.60	4	0.60	166	2.22
15 KLD FSTPs														
Bhusawar	February 2026	BS after screw press	6.78	0.857	70.95	35.80	4.78	138	378598	5.58	378598	5.58	3304	3.52
		BS after belt drying	7.20	1.596	14.75	36.90	3.92	160	4	0.55	4	0.55	43	1.64
		Biochar	8.44	2.800	15.96	24.50	1.60	10	27	1.44	27	1.44	14	1.15
Deoli	February 2026	BS after screw press	7.13	0.739	58.65	37.00	3.65	522	36275	4.56	36275	4.56	89	1.95
		BS after belt drying	8.35	3.650	77.87	36.30	3.69	2855	496953	5.70	496953	5.70	4337	3.64
		Biochar	8.25	3.730	30.52	25.20	1.52	23	1583	3.20	1583	3.20	2648	3.42

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Month	Sample Type	Physicochemical parameters					Pathogen content						
			pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (Eggs/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)
Deshnok	January 2026	BS after screw press	8.00	0.409	81.44	3790	4.09	690	247869	5.39	247869	5.39	198	2.30
		BS after belt drying	7.73	0.852	45.68	36.70	3.83	1237	202486	5.31	202486	5.31	1767	3.25
		Biochar	7.93	0.408	0.14	8.49	0.18	16	3	0.48	3	0.48	12	1.08
Mukundgarh	February 2026	BS after screw press	7.60	0.995	78.80	38.20	4.16	604	99068	5.00	99068	5.00	57	1.75
		BS after belt drying	7.91	0.008	56.19	37.30	4.09	183	251075	5.40	251075	5.40	265	2.42
		Biochar	8.57	1.444	7.92	8.36	0.65	0	500	2.70	500	2.70	13	1.12
Nawa	January 2026	BS after screw press	8.38	0.578	70.12	16.50	1.57	1794	7697	3.89	7697	3.89	40	1.60
		BS after belt drying	8.22	0.978	76.64	30.10	2.92	2089	18411	4.27	18411	4.27	736	2.87
		Biochar	9.46	0.924	0.62	16.60	1.30	24	3	0.48	3	0.48	12	1.08
Sarwar	January 2026	BS after screw press	8.12	0.625	78.79	33.30	3.03	2338	98993	5.00	98993	5.00	4337	3.64
		BS after belt drying	7.43	1.736	19.29	39.90	2.20	59	2850	3.45	5328	3.73	1140	3.06
		Biochar	10.52	1.558	2.57	35.70	0.81	0	3	0.49	3	0.49	12	1.09
Viratnagar	January 2026	BS after screw press	8.20	0.954	73.26	36.40	3.75	120	172001	5.24	172001	5.24	22435	4.35
		BS after belt drying	7.99	0.989	68.50	35.30	2.99	279	349189	5.54	349189	5.54	1396757	6.15
		Biochar	9.56	3.480	1.93	12.30	0.68	24	3	0.49	3	0.49	12	1.09
Weir	January 2026	BS after screw press	6.98	1.130	78.72	38.90	4.08	38	112797	5.05	112797	5.05	432	2.64
		BS after belt drying	8.17	1.652	21.03	37.50	3.86	0	5445	3.74	5445	3.74	760	2.88
		Biochar	8.97	1.942	6.87	12.80	0.84	0	100	2.00	100	2.00	13	1.11
20 KLD FSTPs														
Bijainagar	February 2026	BS after screw press	7.70	0.746	80.61	39.10	3.98	2517	3816	3.58	3816	3.58	62	1.79
		BS after belt drying	7.77	0.012	77.01	39.90	4.18	35	478559	5.68	478559	5.68	400	2.60
		Biochar	8.19	1.085	3.17	21.50	1.26	17	3	0.49	3	0.49	1900	3.28
Bissau	February 2026	BS after screw press	7.57	0.820	80.63	34.70	3.40	1115	237487	5.38	237487	5.38	888	2.95
		BS after belt drying	8.33	0.119	64.73	36.70	3.68	0	311878	5.49	311878	5.49	1055	3.02
		Biochar	9.48	4.260	2.10	21.30	0.89	0	3	0.49	3	0.49	12	1.09

Location	Month	Sample Type	Physicochemical parameters					Pathogen content							
			pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (Eggs/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)	
Gulabpura	February 2026	BS after screw press	791	0.838	65.95	36.50	3.35	305	135097	5.13	135097	5.13	35	1.55	
		BS after belt drying	763	0.923	75.23	36.50	3.30	452	96884	4.99	96884	4.99	242	2.38	
		Biochar	8.85	1.865	1.44	11.10	0.83	16	3	0.48	3	0.48	12	1.09	
Kishangarh Renwal	January 2026	BS after screw press	8.46	0.865	77.21	35.60	3.88	1264	40813	4.61	40813	4.61	404	2.61	
		BS after belt drying	8.45	1.568	80.18	36.60	4.09	3794	21697	4.34	7569	3.88	868	2.94	
		Biochar	7.94	0.380	1.01	19.80	1.83	0	3	0.48	3	0.48	12	1.08	
Kuchera	January 2026	Biochar	8.23	3.110	5.86	34.20	1.97	433	3	0.50	3	0.50	13	1.11	
Lakheri	February 2026	BS after screw press	7.65	0.756	81.33	36.40	3.57	43	3964	3.60	8034	3.90	493	2.69	
		BS after belt drying	7.32	0.809	30.76	38.00	3.62	12	66437	4.82	66437	4.82	6355	3.80	
		Biochar	9.70	1.426	1.60	17.40	1.16	0	3	0.48	3	0.48	12	1.09	
Losal	February 2026	BS after screw press	7.51	0.663	81.33	40.20	4.44	1929	12322	4.09	4929	3.69	64	1.81	
		BS after belt drying	7.59	1.645	11.28	37.50	4.06	1091	123979	5.09	123979	5.09	4959	3.70	
		Biochar	8.89	2.200	11.64	33.70	1.76	335	1245	3.10	1245	3.10	4979	3.70	
Malpura	January 2026	BS after screw press	8.19	0.742	81.73	39.90	4.86	44	11492	4.06	11492	4.06	66	1.82	
		BS after belt drying	7.87	0.769	80.96	39.60	4.06	588	11031	4.04	11031	4.04	483	2.68	
		Biochar	7.91	1.350	55.94	26.40	1.88	799	24964	4.40	477	2.68	2179	3.34	
Rajaldesar	January 2026	BS after screw press	8.27	0.800	80.76	38.40	3.94	3702	571871	5.76	571871	5.76	478	2.68	
		BS after belt drying	8.01	1.143	75.79	36.30	3.28	694	189998	5.28	189998	5.28	182	2.26	
		Biochar	9.76	5.870	4.27	14.70	1.03	92	3	0.50	3	0.50	13	1.10	
Reengus	January 2026	BS after screw press	7.38	0.373	76.42	35.70	3.99	441	98	1.99	98	1.99	51	1.71	
		BS after belt drying	7.21	0.929	68.76	35.20	3.79	2740	13763	4.14	13763	4.14	192	2.28	
		Biochar	8.39	2.710	8.30	17.10	1.49	227	11996	4.08	11996	4.08	1003	3.00	
Todaraisingh	January 2026	BS after screw press	8.09	0.998	85.87	41.20	4.00	1869	169883	5.23	20528	4.31	425	2.63	
		BS after belt drying	7.80	0.805	74.38	35.60	3.43	1468	58556	4.77	58556	4.77	3591	3.56	
		Biochar	8.21	2.620	17.15	32.30	2.38	222	4	0.56	4	0.56	14	1.16	
25 KLD FSTPs															

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Month	Sample Type	Physicochemical parameters					Pathogen content						
			pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (Eggs/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)
Bidasar	January 2026	BS after screw press	8.44	0.958	81.70	42.90	4.48	1879	23493	4.37	23493	4.37	66	1.82
		BS after belt drying	7.34	1.241	60.64	35.30	3.56	1240	1880	3.27	1880	3.27	2439	3.39
		Biochar	7.50	2.820	1.85	20.80	1.36	8	3	0.49	3	0.49	12	1.09
Chaksu	January 2026	BS after screw press	8.15	0.931	79.72	36.00	3.46	947	73955	4.87	13805	4.14	7100	3.85
		BS after belt drying	7.50	2.940	56.89	28.10	2.69	260	55666	4.75	9973	4.00	139165	5.14
		Biochar	10.05	2.870	1.37	8.05	0.21	8	3	0.48	3	0.48	12	1.09
Chhabra	February 2026	BS after screw press	7.51	0.579	81.52	41.10	4.12	130	50328	4.70	129880	5.11	2013	3.30
		BS after belt drying	7.02	0.976	48.76	40.40	3.98	203	214675	5.33	214675	5.33	1874	3.27
		Biochar	8.25	3.600	26.72	25.70	2.06	44	328	2.52	328	2.52	6004	3.78
Niwai	January 2026	Biochar	9.11	0.825	3.45	35.50	0.94	8	3	0.49	3	0.49	12	1.09
Sri Madhopur	January 2026	BS after screw press	6.59	0.880	80.14	41.60	4.41	5034	1510	3.18	1510	3.18	72	1.86
		BS after belt drying	7.59	0.914	79.82	40.30	4.22	3290	46084	4.66	5451	3.74	184336	5.27
		Biochar	7.33	0.682	8.02	21.80	1.57	104	1011	3.00	1011	3.00	20005	4.30
Taranagar	February 2026	BS after screw press	6.48	1.668	86.92	44.30	6.88	673	840858	5.92	840858	5.92	33634	4.53
		BS after belt drying	7.15	1.529	49.52	34.00	3.56	333	91126	4.96	47544	4.68	166	2.22
		Biochar	7.53	0.085	1.70	5.52	0.26	0	3	0.48	3	0.48	12	1.09
35 KLD FSTPs														
Bayana	February 2026	BS after screw press	7.89	0.452	83.52	34.20	3.07	437	26092	4.42	26092	4.42	180	2.25
		BS after belt drying	7.72	1.098	72.47	34.60	2.78	116	399499	5.60	399499	5.60	15980	4.20
		Biochar	8.45	2.530	11.19	29.50	1.42	0	26	1.41	26	1.41	104	2.02
Kekri	January 2026	BS after screw press	7.35	0.745	82.31	36.20	3.46	1537	24301	4.39	24301	4.39	68	1.83
		BS after belt drying	7.12	0.848	75.47	35.20	3.55	1109	9378	3.97	9378	3.97	49	1.69
		Biochar	8.74	3.960	7.39	14.50	0.62	60	3	0.51	3	0.51	13	1.11
Khairthal	January 2026	BS after screw press	8.35	0.893	81.00	38.00	4.74	211	12108	4.08	12108	4.08	90549	4.96
		BS after belt drying	7.87	1.391	77.37	36.10	4.77	177	486149	5.69	486149	5.69	164407	5.22
		Biochar	8.22	1.976	19.99	14.00	1.20	310	92	1.97	92	1.97	2150	3.33

Location	Month	Sample Type	Physicochemical parameters					Pathogen content						
			pH	EC (dS/m)	Moisture (%)	Organic Carbon (% by weight)	Total Nitrogen (% by weight)	Helminth Eggs (Eggs/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)
Kotputli	January 2026	BS after screw press	7.57	0.555	79.77	34.60	3.49	830	118626	5.07	118626	5.07	18189	4.26
		BS after belt drying	6.62	0.961	65.48	34.80	2.36	533	318610	5.50	318610	5.50	278059	5.44
		Biochar	8.65	1.556	4.99	25.40	1.11	25	4841	3.68	4841	3.68	13	1.10
Nohar	February 2026	BS after screw press	8.29	0.984	78.76	31.00	3.00	113	517837	5.71	517837	5.71	433	2.64
		BS after belt drying	7.50	1.120	54.15	29.80	3.09	0	52344	4.72	52344	4.72	201	2.30
		Biochar	8.52	0.082	2.52	7.52	0.76	0	1128	3.05	1128	3.05	94	1.97
Pilani	February 2026	BS after screw press	8.08	1.038	80.42	32.50	3.25	2083	561663	5.75	561663	5.75	470	2.67
		BS after belt drying	7.48	1.149	42.64	28.20	2.92	934	191780	5.28	191780	5.28	7671	3.88
		Biochar	7.88	1.289	9.88	32.60	3.03	550	1221	3.09	1221	3.09	102	2.01
Rajgarh_Churu	February 2026	BS after screw press	6.90	1.273	80.36	30.70	2.99	41	47346	4.68	47346	4.68	61	1.79
		BS after belt drying	7.65	5.150	29.07	30.00	3.02	226	6062	3.78	6062	3.78	52	1.71
		Biochar	9.72	3.220	1.84	10.00	0.38	0	3	0.49	3	0.49	12	1.09
Sri Dungargarh	January 2026	BS after screw press	8.45	0.865	78.80	38.00	3.76	226	43867	4.64	43867	4.64	1755	3.24
		BS after belt drying	7.94	0.352	30.46	36.30	3.54	322	158192	5.20	158192	5.20	132	2.12
		Biochar	7.51	0.746	0.03	24.40	1.91	0	3	0.48	3	0.48	12	1.08

Table 3: Consolidated data of heavy metals and nutrients in biosolids and biochar from FSTPs

Location	Month	Sample Type	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
10 KLD FSTPs																
Baggar	February 2026	BS after screw press	0.85	0.18	0.69	28.82	5.91	705.62	97.71	16.59	2.25	0.33	1.65	0.50	0.03	0.21
		BS after belt drying	1.12	0.25	1.04	30.16	6.95	833.38	127.03	16.50	2.67	0.46	2.32	0.67	0.03	0.24
		Biochar	0.49	Nil	0.43	79.46	4.66	485.32	118.12	57.15	3.39	2.71	3.00	0.99	0.04	0.40
Khatu Shyam Ji	January 2026	BS after screw press	0.41	0.25	0.61	6.36	6.71	543.25	83.65	6.02	1.59	0.10	1.57	0.32	0.02	0.11
		BS after belt drying	0.42	0.19	0.74	8.41	7.76	651.57	97.68	7.28	2.13	0.09	1.79	0.47	0.02	0.13
		Biochar	0.21	0.27	0.74	9.79	8.50	705.13	118.27	11.55	3.00	0.20	2.90	0.50	0.03	0.17
Kishangarh Bas	January 2026	BS after screw press	0.68	0.87	0.59	4.36	6.53	548.34	83.00	4.87	2.20	0.06	2.26	0.24	0.02	0.09
		BS after belt drying	0.83	1.38	0.77	5.32	7.88	715.06	109.41	6.31	2.16	0.09	2.23	0.29	0.02	0.12
		Biochar	0.52	1.20	0.76	6.77	7.93	628.15	118.26	8.15	3.69	0.68	3.65	0.46	0.02	0.16
Mundwa	January 2026	BS after screw press	0.56	Nil	0.97	28.10	4.05	610.19	95.59	19.00	1.62	0.17	1.52	0.34	0.02	0.38
		BS after belt drying	0.27	Nil	0.40	2.61	2.06	349.22	52.33	4.43	1.02	0.21	0.99	0.23	0.01	0.18
		Biochar	0.43	Nil	0.73	9.56	6.35	550.16	91.52	63.12	1.77	0.40	2.16	0.47	0.02	0.24
Pirawa	February 2026	BS after screw press	2.22	2.66	1.46	81.46	24.29	1969.98	342.18	65.97	3.13	0.29	4.42	0.72	0.06	0.20
		BS after belt drying	1.66	5.38	1.13	39.58	22.34	1480.97	281.07	26.99	2.06	0.22	3.42	0.56	0.04	0.15
		Biochar	1.60	4.26	1.20	67.82	30.18	1684.49	341.13	49.47	2.87	0.52	4.75	0.77	0.06	0.21
Uniara	February 2026	BS after screw press	1.45	2.89	1.36	23.92	14.27	1135.71	180.67	16.01	1.81	0.41	2.39	0.45	0.02	0.22
		BS after belt drying	1.67	4.51	1.57	31.26	18.16	1259.00	214.38	19.60	1.88	0.52	2.60	0.53	0.03	0.24
		Biochar	1.19	1.34	0.90	88.04	10.70	530.30	136.78	54.83	1.22	2.07	3.39	0.69	0.03	0.41
15 KLD FSTPs																

Location	Month	Sample Type	Heavy metals								Nutrients					
			As (mg/kg) max. 10.0 as As ₂ O 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 (as P ₂ O ₅), per cent by weight, min. 0.5	Total Potash (as K ₂ O), 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
Bhusawar	February 2026	BS after screw press	1.40	1.57	1.74	34.16	12.58	1549.04	21793	21.29	4.18	0.50	3.34	0.97	0.04	0.44
		BS after belt drying	1.20	1.47	1.82	34.94	13.29	1461.54	204.50	19.26	4.10	0.48	3.48	0.83	0.04	0.38
		Biochar	0.65	0.40	0.59	65.62	6.12	705.96	108.15	30.02	2.10	1.51	3.33	0.59	0.06	0.30
Deoli	February 2026	BS after screw press	0.75	2.44	1.47	25.68	15.71	1224.84	194.49	17.19	1.98	0.42	2.57	0.48	0.03	0.23
		BS after belt drying	1.48	3.97	1.53	30.02	17.45	1208.68	203.73	18.74	1.85	0.49	2.57	0.51	0.03	0.22
		Biochar	0.84	1.13	0.79	81.85	9.68	646.31	124.46	50.48	1.12	2.00	3.15	0.65	0.03	0.39
Deshnok	January 2026	BS after screw press	0.58	0.47	3.07	7.45	34.93	555.47	99.52	9.06	1.31	0.11	2.36	0.34	0.02	0.10
		BS after belt drying	0.73	1.27	4.30	9.57	47.64	725.51	135.69	10.63	1.63	0.12	3.05	0.45	0.03	0.13
		Biochar	0.55	Nil	0.89	6.60	17.73	375.61	99.32	11.28	2.16	0.97	3.83	0.57	0.02	0.13
Mukundgarh	February 2026	BS after screw press	0.84	2.80	0.84	24.95	6.77	816.97	117.16	12.46	2.56	0.45	1.99	0.69	0.03	0.26
		BS after belt drying	0.80	2.96	0.85	24.42	7.51	788.63	116.58	12.33	2.48	0.45	1.96	0.66	0.03	0.30
		Biochar	1.22	0.19	0.73	131.84	7.95	937.49	179.82	69.85	3.80	3.04	4.44	1.27	0.06	0.64
Nawa	January 2026	BS after screw press	0.27	0.19	0.31	4.60	4.38	385.13	56.97	4.70	3.33	0.09	2.77	0.39	0.03	0.16
		BS after belt drying	0.46	0.07	0.76	6.99	6.90	644.99	106.95	7.27	3.41	0.18	2.64	0.59	0.03	0.22
		Biochar	0.31	Nil	1.07	9.53	10.71	1080.33	183.01	17.75	7.77	0.42	5.57	1.64	0.07	0.54
Sarwar	January 2026	BS after screw press	0.43	Nil	0.88	29.77	11.13	618.91	92.72	17.83	1.04	0.14	1.97	0.23	0.03	0.17
		BS after belt drying	0.23	0.11	1.06	3.77	7.13	576.39	78.77	6.31	1.15	0.23	1.60	0.19	0.03	0.11
		Biochar	0.02	Nil	0.46	7.36	5.13	368.89	51.70	10.93	1.00	0.95	2.94	0.31	0.04	0.18
Viratnagar	January 2026	BS after screw press	0.84	0.96	0.76	5.07	7.90	787.58	135.75	7.88	3.87	0.11	2.47	0.72	0.03	0.11
		BS after belt drying	0.44	0.86	0.45	3.30	5.11	480.83	80.47	5.14	2.95	0.35	2.14	0.54	0.02	0.09
		Biochar	1.72	0.21	1.43	22.79	12.82	967.49	188.01	22.52	7.03	1.54	6.43	1.25	0.04	0.31

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Month	Sample Type	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
Weir	January 2026	BS after screw press	1.51	4.09	3.16	33.87	22.64	1378.52	261.37	20.45	2.46	0.35	3.17	0.64	0.04	0.25
		BS after belt drying	1.42	4.72	2.53	2799	19.02	1251.20	216.20	16.91	2.18	0.26	2.59	0.54	0.04	0.20
		Biochar	1.67	1.45	3.72	11743	33.10	2032.62	531.23	81.72	4.10	2.50	6.68	1.58	0.11	0.59
20 KLD FSTPs																
Bijainagar	February 2026	BS after screw press	1.24	3.73	2.67	29.58	19.71	1323.52	220.56	17.73	2.17	0.31	2.78	0.58	0.04	0.21
		BS after belt drying	0.87	4.32	2.60	29.67	20.23	1347.82	223.57	17.82	2.30	0.28	2.74	0.57	0.04	0.21
		Biochar	1.46	1.55	3.04	9768	27.52	1737.23	435.36	68.08	3.34	2.17	5.79	1.35	0.09	0.52
Bissau	February 2026	BS after screw press	0.76	2.18	0.77	28.68	10.35	691.37	101.57	11.48	2.20	0.47	1.49	0.60	0.03	0.48
		BS after belt drying	0.78	3.34	0.83	30.15	9.08	761.47	110.31	12.26	2.25	0.37	1.57	0.59	0.03	0.47
		Biochar	0.67	0.47	0.43	66.78	4.61	472.74	89.47	29.04	2.32	2.39	3.67	0.96	0.04	0.84
Gulabpura	February 2026	BS after screw press	1.02	4.06	2.25	35.14	37.76	1547.21	246.44	21.97	2.05	0.40	3.74	0.79	0.03	0.35
		BS after belt drying	1.14	3.95	1.88	31.40	31.95	1246.17	204.67	18.80	1.60	0.36	3.29	0.70	0.03	0.29
		Biochar	1.58	0.13	1.91	11942	40.64	2337.10	499.02	73.07	3.37	1.04	6.55	1.46	0.07	0.89
Kishangarh Renwal	January 2026	BS after screw press	0.85	1.25	0.74	7.18	9.82	635.71	107.28	8.46	3.12	0.16	1.64	0.71	0.02	0.33
		BS after belt drying	0.73	2.19	0.82	13.37	11.40	982.44	108.97	10.43	3.44	0.20	1.81	0.84	0.03	0.50
		Biochar	0.38	0.05	0.84	10.77	15.12	944.38	150.17	15.10	6.46	0.40	3.95	1.58	0.05	0.47
Kuchera	January 2026	Biochar	0.08	Nil	0.10	10.56	2.33	189.17	33.95	11.31	0.67	0.51	1.31	0.18	0.01	0.13
Lakheri	February 2026	BS after screw press	6.48	0.52	1.48	29.38	9.58	925.71	120.97	17.75	2.80	0.40	2.40	0.59	0.03	0.26
		BS after belt drying	8.68	0.96	1.68	46.33	8.32	893.34	117.79	23.25	2.90	0.38	2.65	0.58	0.03	0.24
		Biochar	10.28	1.73	2.56	45.22	15.70	1335.12	183.10	24.16	2.87	0.69	3.48	0.81	0.04	0.29

Location	Month	Sample Type	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
Losal	February 2026	BS after screw press	0.70	1.44	1.60	31.48	11.94	1463.41	195.78	19.76	3.93	0.46	3.13	0.90	0.04	0.40
		BS after belt drying	0.67	1.95	1.83	35.22	14.10	1577.67	202.04	20.07	4.35	0.50	3.64	0.86	0.04	0.39
		Biochar	0.82	0.38	0.69	72.08	6.86	775.23	11744	33.16	2.35	1.72	3.67	0.65	0.06	0.33
Malpura	January 2026	BS after screw press	1.98	3.12	1.79	22.19	35.04	1210.20	198.80	18.01	3.42	0.18	4.01	0.57	0.04	0.25
		BS after belt drying	1.18	3.45	1.37	14.82	30.00	1123.82	189.08	13.18	3.41	0.14	3.67	0.55	0.04	0.23
		Biochar	0.47	0.92	0.83	44.73	13.14	641.21	12701	34.38	2.76	0.59	3.48	0.53	0.04	0.26
Rajaldesar	January 2026	BS after screw press	0.69	0.66	1.33	8.06	7.38	691.57	111.86	8.99	3.10	0.21	2.06	0.73	0.03	0.28
		BS after belt drying	0.45	0.77	0.99	8.19	6.75	492.20	80.31	7.32	2.66	0.48	2.07	0.58	0.03	0.24
		Biochar	0.48	0.18	0.75	10.49	4.79	309.55	60.24	14.36	2.45	3.33	4.51	0.87	0.03	0.28
Reengus	January 2026	BS after screw press	0.45	0.17	0.88	13.63	6.60	532.75	81.10	5.49	1.48	0.08	1.33	0.23	0.02	0.13
		BS after belt drying	0.25	0.03	0.51	8.09	4.06	344.06	48.30	2.95	0.89	0.04	0.84	0.13	0.01	0.08
		Biochar	0.11	Nil	0.27	5.39	2.54	231.22	36.23	4.40	1.06	0.21	1.11	0.14	0.01	0.07
Todaraisingh	January 2026	BS after screw press	0.60	0.35	1.07	6.18	13.52	832.91	146.69	10.96	1.96	0.16	2.64	0.41	0.03	0.19
		BS after belt drying	0.47	0.23	1.08	6.75	11.27	900.20	160.71	11.09	2.61	0.17	3.01	0.40	0.04	0.24
		Biochar	0.33	0.17	0.61	6.65	8.63	539.52	98.27	8.28	2.21	0.69	3.18	0.40	0.03	0.24
25 KLD FSTPs																
Bidasar	January 2026	BS after screw press	0.42	0.12	1.10	4.22	6.81	694.26	111.85	7.42	1.87	0.19	1.87	0.42	0.02	0.25
		BS after belt drying	0.26	Nil	0.76	3.86	4.39	480.20	75.71	5.55	1.68	0.09	1.47	0.35	0.02	0.21
		Biochar	0.28	Nil	0.97	6.72	11.50	714.60	128.13	9.75	4.40	0.25	3.91	0.86	0.05	0.33
Chaksu	January 2026	BS after screw press	0.70	0.37	0.90	5.70	9.81	640.74	116.72	6.88	2.09	0.11	1.94	0.43	0.02	0.23
		BS after belt drying	1.09	0.86	1.83	43.56	18.17	965.24	209.76	46.05	3.94	1.74	4.82	0.95	0.04	0.48
		Biochar	0.47	Nil	0.31	12.04	3.90	273.60	9763	27.35	2.73	1.40	3.78	0.56	0.02	0.22

EVALUATION OF BIOCHAR FROM FSTPS IN RAJASTHAN

Location	Month	Sample Type	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
Chhabra	February 2026	BS after screw press	2.77	5.95	2.30	38.10	29.06	2367.60	390.94	32.06	2.23	0.32	4.27	0.63	0.06	0.15
		BS after belt drying	2.43	6.24	2.40	39.93	29.76	2444.97	401.21	33.35	1.89	0.37	4.53	0.66	0.06	0.15
		Biochar	0.78	3.34	1.37	57.68	15.08	1193.86	190.68	36.99	1.88	3.08	5.38	0.79	0.05	0.22
Niwai	January 2026	Biochar	0.63	Nil	0.49	23.91	29.24	399.10	102.65	67.05	2.04	0.52	3.69	0.51	0.03	0.17
Sri Madhopur	January 2026	BS after screw press	0.75	1.14	0.84	6.84	8.67	733.90	123.76	7.11	1.95	0.10	1.71	0.32	0.02	0.21
		BS after belt drying	0.48	0.16	0.36	2.83	4.53	394.41	60.54	3.21	1.01	0.06	0.96	0.17	0.01	0.11
		Biochar	0.51	0.35	0.53	5.96	5.08	452.62	96.86	8.07	3.03	0.65	2.96	0.39	0.02	0.22
Taranagar	February 2026	BS after screw press	0.54	1.18	1.29	27.19	8.09	965.34	138.51	24.14	3.97	0.49	2.79	0.76	0.04	0.59
		BS after belt drying	1.37	5.01	1.69	40.57	10.90	1164.11	169.46	26.08	3.57	0.61	3.11	0.89	0.04	0.45
		Biochar	1.11	0.39	1.29	156.90	10.02	1236.35	279.01	100.87	5.96	8.40	10.50	2.57	0.10	1.15
35 KLD FSTPs																
Bayana	February 2026	BS after screw press	0.92	2.47	0.85	31.60	11.50	654.41	114.67	12.62	2.39	0.48	1.61	0.64	0.03	0.53
		BS after belt drying	0.60	2.85	0.71	25.77	7.15	583.52	95.81	10.34	1.90	0.31	1.31	0.49	0.03	0.41
		Biochar	0.68	0.98	0.30	57.34	3.58	330.57	78.76	24.94	1.92	2.01	3.06	0.80	0.03	0.74
Kekri	January 2026	BS after screw press	0.90	4.86	2.23	9.08	26.62	1143.74	219.63	14.03	2.15	0.16	3.04	0.37	0.04	0.37
		BS after belt drying	0.81	6.30	2.15	10.23	30.95	1154.48	222.74	15.33	2.13	0.15	3.05	0.38	0.04	0.29
		Biochar	0.60	1.01	0.93	9.80	14.92	409.02	228.37	14.38	2.03	2.99	5.78	0.71	0.03	0.42
Khairthal	January 2026	BS after screw press	2.07	1.82	1.73	50.47	23.21	1327.92	204.35	27.00	3.57	0.15	3.46	0.68	0.03	0.28
		BS after belt drying	1.37	0.81	0.97	30.10	15.78	918.26	119.74	15.83	2.35	0.10	2.39	0.40	0.02	0.20
		Biochar	0.60	0.29	0.54	12.08	8.96	299.91	59.84	13.23	2.31	0.52	3.41	0.62	0.04	0.15

Location	Month	Sample Type	Heavy metals								Nutrients					
			As (mg/kg) max. 10.0 as As ₂ O 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 (as P ₂ O ₅), per cent by weight, min. 0.5	Total Potash (as K ₂ O), 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
Kotputli	January 2026	BS after screw press	0.63	0.56	0.40	4.61	5.64	424.82	72.11	6.36	1.81	0.11	1.33	0.35	0.02	0.13
		BS after belt drying	0.55	0.43	0.46	5.08	6.44	446.05	80.11	5.85	1.79	0.16	1.56	0.30	0.02	0.13
		Biochar	1.09	0.15	0.76	11.84	11.08	623.53	11788	16.24	2.58	0.81	4.22	0.60	0.05	0.24
Nohar	February 2026	BS after screw press	2.13	3.87	1.09	32.11	12.82	849.41	138.21	19.92	3.96	0.79	3.13	1.23	0.05	0.31
		BS after belt drying	2.47	3.21	1.24	37.22	14.72	948.22	154.10	21.99	4.24	0.82	3.16	1.31	0.05	0.28
		Biochar	2.42	0.53	1.35	98.03	19.30	1363.19	251.24	61.89	5.38	2.10	4.71	2.03	0.08	0.51
Pilani	February 2026	BS after screw press	4.77	0.52	1.56	28.15	9.11	871.33	119.57	17.21	2.70	0.37	2.38	0.56	0.03	0.25
		BS after belt drying	6.95	0.93	1.74	47.02	8.76	896.01	117.22	24.46	2.93	0.37	2.75	0.58	0.03	0.25
		Biochar	6.73	1.36	2.16	36.02	12.62	1066.37	147.33	19.53	2.34	0.56	2.87	0.65	0.03	0.24
Rajgarh_Churu	February 2026	BS after screw press	1.84	1.57	2.08	401.86	22.47	1289.57	198.74	174.12	5.58	0.88	4.34	1.58	0.06	1.07
		BS after belt drying	1.90	1.44	1.98	95.62	20.75	1232.14	187.66	43.87	5.65	0.79	4.03	1.56	0.05	0.99
		Biochar	1.16	0.05	1.50	326.53	21.92	1059.09	227.81	235.08	6.36	7.88	15.40	4.23	0.10	2.10
Sri Dungargarh	January 2026	BS after screw press	0.75	0.29	1.38	18.45	13.78	681.15	116.48	8.48	2.51	0.22	2.01	0.56	0.03	0.27
		BS after belt drying	0.44	0.25	1.21	15.28	10.48	544.04	88.99	7.45	2.01	0.19	1.73	0.43	0.02	0.21
		Biochar	0.54	Nil	1.50	18.84	15.85	859.48	146.88	11.80	5.23	0.42	4.29	0.96	0.04	0.36

As urban centres across India's largest arid state Rajasthan embrace decentralized sanitation, sustainable resource recovery has become a pressing environmental priority. This report on the evaluation of biochar from FSTPs in Rajasthan—a first-of-its-kind study by the Environment Monitoring Laboratory (EML) at the Centre for Science and Environment (CSE)—assesses 39 pyrolysis-based faecal sludge treatment plants (FSTPs) operating across central and eastern Rajasthan.

The report critically examines the performance of Omni Processor thermal (pyrolysis) technology for converting human waste into safe, valuable outputs: treated effluent, biosolids, and carbon-negative biochar. Using rigorous multi-parameter testing—including solids, organics, nutrients, heavy-metal monitoring and pathogen analysis—the study benchmarks these facilities against Indian regulatory standards (MoEF&CC, NGT, FCO) and international guidelines (USEPA, WHO).

While underscoring biochar's promise as a durable carbon sink and soil enhancer, the findings also reveal operational instabilities, process fluctuations and compliance gaps in smaller-capacity plants. Serving as both a roadmap and a troubleshooting guide, this report equips policymakers, urban local bodies and environmental engineers to strengthen sanitation systems and advance India's circular economy.



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