QUALITY ASSESSMENT OF COMPOST PRODUCED IN DIFFERENT LOCATIONS OF HARYANA, UTTAR PRADESH AND ODISHA

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Maps in this report are indicative and not to scale.

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Executive summary

Rapid economic growth and overpopulation have made the management of solid waste a serious concern as it directly impacts human health. After segregation of wet waste, composting is an efficient and eco-friendly approach for managing municipal solid waste. For use as a soil nourishing agent, it is equally important that the compost is of good quality.

The Centre for Science and Environment (CSE) conducted this study to assess the quality of 25 compost samples (multiple replicates) collected from 23 sites located in different cities of Haryana (eight sites), Uttar Pradesh (six sites) and Odisha (nine sites). All undertaken composting sites were equipped with aerobic composting method with different process variants such as tub composting (Odisha), organic waste converter (OWC) and tub/pit composting and windrow composting (Agra, Uttar Pradesh) and OWC and aerobic tub composting/AAGA (Gurugram, Haryana).

Results showed that sum of NPK value (the additive value of the macro-nutrients nitrogen (N), phosphorus (P) and potassium (K)) and carbon to nitrogen ratio (C:N ratio) for most of the sites was found to be within the range recommended by FCO (<20:1). Relevant research however shows that a most resourceful compost (fertilizer) should have a minimum C:N ratio of 15:1, which is optimum to maintain soil fertility and the nutrient cycle occurring between plants and soil microbial flora. In consideration of this, the C:N ratio was found to be very low for most of the evaluated samples, which indicates that the samples were rich in nitrogen. This issue can be resolved by addition of carbon-rich organic material (dry leaves) into the source waste material used in composting.

Heavy metal contamination was observed to be significantly high in compost samples of Agra, which may be due to contamination from the source of raw material, improper source segregation or process contamination. The management of heavy metals in the final compost requires segregation so that sources of contamination are removed.

Reduction of microbes seems to be challenging as depicted by the obtained result. All the compost sites in Gurugram (eight) and seven out of nine sites in Odisha showed a significantly high amount of faecal coliform contamination while all the sites of Agra showed faecal coliform within the permissible limit of USEPA (1000 MPN/g). Further, *Salmonella* species was very high in all the compost samples from the sites in Agra, Gurugram and Odisha, which is excessively higher than the U.S. Environmental Protection Agency (USEPA) and World Health Organization (WHO) standard (3 MPN/4 g). However, most of the strains of *Salmonella* species are not as lethal as *Salmonella* Typhi and Paratyphi.

This study recommends that pathogens can be reduced by drying the obtained compost in an open area on a concrete platform for a week—reducing the moisture reduces the microbial load as well. Heavy metals contamination can be eliminated at the initial level of the composting process by proper segregation of heterogeneous source waste material.

This study intends to provide the relevant information that can contribute to maintaining the quality of compost for ongoing composting practices in India.

Abbreviations

APHA	: American Public Health Association
C/N	: Carbon-to-nitrogen ratio
C:N	: Carbon-to-nitrogen ratio
CapEx	: Capital expenditure
CPCB	: Central Pollution Control Board
EC	: Electrical conductivity
FCO	: Fertiliser Control Order
ICP-OES	: Inductively coupled plasma optical emission spectroscopy
MPN	: Most probable number
MSW	: Municipal solid waste
OpEx	: Operational expenditure
SWM	: Solid waste management
TOC	: Total organic carbon
USEPA	: United States Environmental Protection Agency
WHO	: World Health Organization

1. Introduction

Municipal solid waste (MSW) has become a serious concern for developing countries such as India because of expanding population, urbanization, economic development and changing production and consumption habits. Existing studies and literature show that the Indian solid waste management system is expanding but is stochastic. As per the Central Pollution Control Board (CPCB) Annual Report (2018),[1] there was exponential increase in city-wise generation of waste per capita per day (0.24–0.85 kg per person per day) during 2001–18 and this trend is anticipated to continue. A significant fraction of MSW in India is organic waste, which can be defined as organic material that is readily biodegradable. According to the Indian Council for Research's 2018 report *Solid Waste Management in* India,[2] the organic fraction of urban MSW in India is approximately 55–65 per cent. The organic fraction in waste is considered as a source of contamination of soil, water and air if disposed of indiscriminately and requires greater attention for efficient and effective resource recovery.

Most cities, however, either dispose of their waste in low-lying areas outside the city or dump it into landfills, the most common method of waste disposal, done without precautions or operational control. Reasons for this include minimum segregation of waste at source and scarcity of land for waste processing. A limited understanding of technological options to manage segregated organic waste escalates the problem. Further, most cities have adopted centralized systems for managing MSW. Their resources, technology and human capital are best designed and executed at the city level.[3]

A centralized management system has the advantage of processing and treating the bulk of the waste at once at one place with single monitoring points. The system, however, also comes with limitations, including:

- It needs large plots of land;
- Capital expenditure (CapEx) and operational expenditure (OpEx) are too high;
- Any failure in a centralized system leads to the whole system of waste processing coming to a standstill;

- Significant time is required to get clearances (i.e. consent to establish, consent to operate) for the project and the chance of environmental pollution is high if environmental regulations are not in place or monitored; and
- Involves little public participation.

Decentralized waste management systems, on the other hand, reduce the burden of handling large volumes of MSW with lower requirements of CapEx and OpEx. Besides, the adoption of appropriate home-composting methods could help reduce the quantity of organic waste at source to foster a clean and hygienic environment. Therefore, considering the magnitude of current municipal solid waste and the problems accompanying current municipal solid waste management practices, it is critical to consider decentralized management and technology options as a matter of priority. The centralized option should be considered only if the possibility of adopting a decentralized system is ruled out due to a specific constraint. The Solid Waste Management (SWM) Rules 2016[4] also provide a clear policy advisory to cities to adopt community-based waste management and emphasize on decentralized waste management.

Considering the significance of upcoming decentralized treatment technologies for treating organic waste in India, it becomes important to know the quality of compost produced by these technologies. This will help to improve or modify the existing treatment technologies for obtaining better quality compost. In this regard, compost collected from decentralized treatment technologies at different levels like housing societies and ward level were evaluated from three states viz. Haryana (Gurugram), Uttar Pradesh (Agra) and different cities of Odisha for assessing the quality of compost.

1.1 Types of waste

Table 1: Classification of wastes according to biodegradability, utility and risk

Biodegradable or wet waste	Non-biodegradable, dry or recyclable waste	Domestic hazardous waste
• Kitchen waste, including tea leaves, eggs fruits and vegetable peels	• Newspaper	• Aerosol cans
• Meat and bones	• Paper, books and magazines	• Batteries
• Garden and leaf litter, including flowers	• Glass	• Bleaches and household kitchen and drain cleaning agents and their container
• Soiled paper	• Metal objects and wire	• Car batteries, oil filters and car care products and consumables
• House dust after cleaning	• Plastics	• Chemicals and solvents and their container
• Coconut shells	• Cloth rags	• Cosmetic items, chemical-based insecticides and their containers
• Ashes	• Leather	• Paints, oils, lubricants, glues, thinners, and their container
	• Rexene	• Pesticides and herbicides and their container
	• Wood, furniture	• Photographic audio/video tapes and their containers.
	• Polystyrene, packaging material	• Chemicals
		• Styrofoam and soft foam packaging of furniture, packaging and equipment
		• Thermometers and mercury-containing products
		• Discarded medicine and disposable syringes

1.2 Compost

Compost comprises decayed organic matter. It is used as a plant fertilizer and to improve the physical, chemical and biological characteristics of soil. Compost is produced through the activity of both aerobic (oxygen-requiring) microorganisms and anaerobic (in the absence of oxygen) microorganisms. Aerobic microbes require oxygen, moisture and food to grow and multiply. When these resources are maintained at optimal levels, the natural decomposition process is greatly accelerated. The microbes generate heat, water vapour and carbon dioxide as they transform raw materials into stable soil conditioner. Active composting is typically characterized by a high temperature phase, which sanitizes the product and allows a high rate of decomposition, followed by a lower temperature phase, which allows the product to stabilize while still decomposing at a lower rate.

City Compost is an organic matter that has been decomposed and recycled as fertilizer.

The background of City Compost Promotion are as follows:

- The processing and use of city waste as compost is a logical component of the Swachh Bharat Abhiyan campaign of the Government of India launched by the Prime Minister.
- Composting can reduce the volume of waste in landfill/dumpsites by converting waste into useful by-products.
- Composting also prevents the production of harmful greenhouse gases (especially methane) and toxic material that pollutes groundwater apart from polluting the environment.
- Organic carbon content is vital for maintaining and enhancing soil fertility.

1.3 Composting

Composting is a process of controlled decomposition of organic waste, typically in aerobic conditions, resulting in the production of a stable humus-like product, i.e. compost. It is the natural process of recycling organic matter, such as leaves and food scraps, into a valuable fertilizer that can enrich soil and plants. Anything that grows decomposes eventually; composting simply speeds up the process by providing an ideal environment for bacteria, fungi and other decomposing organisms (such as worms, sow bugs, and nematodes) to do their work. The resulting decomposed matter, which often ends up looking like fertile garden soil, is called compost. Fondly referred to by farmers as "black gold", compost is rich in nutrients and can be used for gardening, horticulture and agriculture.

Organic discards can be processed in industrial-scale composting facilities, in smaller-scale community composting systems, and in anaerobic digesters, among other options. They can also be used at the individual household level (home composting) (see *Table 2a: Wastes suitable or not suitable for compost*).

All composting requires the following three basic ingredients:

- Carbon-rich materials ("browns"): Includes materials such as dead leaves, branches and plant twigs, which are rich in carbon.
- Nitrogen-rich material ("greens"): Includes materials such as grass clippings, food and vegetable waste, fruit scraps and coffee grounds, which are rich in nitrogen.

- Water: Having the right amount of water, greens and browns is important for compost development.

Table 2a: Wastes suitable or not suitable for compost[5, 6]

What to compost	What not to compost and why
• Fruits and vegetables • Crushed eggshells • Coffee grounds and filters • Tea bags • Nutshells • Shredded newspaper • Shredded cardboard • Shredded paper • Yard trimmings • Grass clippings • Houseplants • Hay and straw • Leaves • Sawdust • Wood chips • Hair and fur • Fireplace ashes	• Black walnut tree leaves or twigs - Releases substances that might be harmful to plants • Coal or charcoal ash - Might contain substances harmful to plants • Dairy products (e.g., butter, milk, sour cream, yogurt) and eggs* - Creates odour problems and attract pests such as rodents and flies • Diseased or insect-ridden plants - Diseases or insects might survive and be transferred back to other plants • Fats, grease, lard or oils* - Creates odour problems and attract pests such as rodents and flies • Meat or fish bones, seashells, shrimp shells and scraps* - Creates odour problems and attract pests such as rodents and flies • Pet wastes (e.g., dog or cat faeces, soiled cat litter)* - Might contain parasites, bacteria, germs, pathogens, and viruses harmful to humans • Yard trimmings treated with chemical pesticides - Might kill beneficial composting organisms

1.4 Benefits of composting

Use of compost provides a wide range of benefits to soil, plants and environment, including the following:

- It improves soil quality, increases the water retention capacity of soil, increases biological activity and improves pest resistance of crops.
- Composting helps to ensure environmental sustainability as it helps to hold the soil particles together, thereby preventing erosion.
- It also increase biodiversity in the soil by attracting different insects, bacteria, fungi, etc. that are beneficial to the crop.
- As it is rich in both macro- (N, P, K) and micronutrients, it can be used as organic manure and hence reduces dependency on chemical fertilizers and reduces pollution.
- It can be used as a soil amendment, thereby reducing the need for water, fertilizers and pesticides.
- It also acts as a soil conditioner by improving soil fertility in the long-term and therefore can be used to nourish and improve or revive the fertility of poor soils and wastelands.
- As composting is primarily aerobic, it minimizes greenhouse gas (GHG) emissions, which are produced from anaerobic decomposition of organic waste.

- Compost acts as a bio matrix by binding heavy metals and other chemical contaminants, thus helps in remediation of contaminated sites.
- Compost drastically reduces the volume of waste.
- It also helps suppress diseases in plants and enriches the soil.

1.5 Types of composting

Though composting is basically an aerobic process, sometimes anaerobic digestion of organic waste is performed (under controlled conditions) as it generates value products such as biogas (methane, CO_2) which can be used as energy. In this report, only aerobic composting is discussed as all sites analysed use aerobic composting processes.

Aerobic composting:[7] Aerobic composting is the decomposition of biodegradable organic matter in a warm, moist environment by the action of bacteria and other organisms in the presence of oxygen. Segregated organic fraction of solid waste is a suitable substrate for composting.

Phases and critical parameters: During aerobic composting, oxidation of organic compounds takes place by microorganisms, which results in the production of carbon dioxide (CO_2), nitrite and nitrate. Microorganisms use carbon as an energy source and recycle nitrogen. As heat is a by-product of composting process, temperature of the composting materials rises. Several biological, chemical and physical processes contribute to the success of the aerobic composting. Understanding these processes is crucial for making informed decisions when developing and operating a composting plant.

Biological processes: The process of aerobic composting passes through two distinct stages of high significance: thermophilic stage (sanitization) and mesophilic stage (decomposition). Different organisms are known to play a predominant role in breaking down the biodegradable constituents of waste (municipal solid waste). The majority of microorganisms responsible for composting are already present in waste. A succession of microbial growth and activity among the bacteria, fungi, actinomycetes, yeasts, etc. takes place during the process, whereby the environment created by one community of microorganisms encourages the activity of a successor group. Different types of microorganisms are therefore active at different times and locations within the waste depending upon the availability of substrate, oxygen supply and moisture content of the organic matter.

i. Thermophilic stage (sanitization): This is the first phase of composting wherein microorganisms decompose the easily degradable organic substances, producing heat as a result of intense metabolic activity. In most cases with moisture content of 55–60 per cent and air spaces of 20–30 per cent, a temperature rise from 35°C to 55–65°C is achieved within two to three days. Typically, thermo-tolerant fungi, thermophilic bacteria and actinomycetes are the predominantly active microorganisms at this stage. Waste is turned at regular intervals to expose the material in the inner core to air so that temperature in these fresh sections rise again, and gradually the whole waste is sanitized from pathogens.

ii. Mesophilic stage: In the second stage, due to reduction in available nutrients and readily available carbon, microbial activity reduces, causing a decline in the temperature of the heap. There is a shift in the type of active microbial species in the compost heaps. The composted material becomes dark brown during this stage due to humus synthesis and starts to stabilize.

iii. Curing stage: Curing of compost is done after the material from the windrow is screened. The screened material is then allowed to mature in the curing stage. This is a very important phase in the composting process. Microbial species degrading complex polymers, such as cellulose, lignin, and hemicelluloses, increase drastically during this phase. Bacteria represent 80 per cent of this population. Free-living nitrogen-fixing bacteria, denitrifiers, sulphate reducers and sulphur oxidizers are important constituents of the total microbial population.

iv. Microbiology of composting: Composting occurs by the activity of a mixed microbial community. Bacteria and fungi have the highest population. Two different groups of aerobic microorganisms are involved in composting, mesophilic (moderate temperature-loving) and thermophilic (high-temperature-loving) organisms. These organisms could be bacteria, actinomycetes, moulds and yeasts, and they dominate different phases of composting. Actinomycetes have been observed to have strong biodegradative activity; they secrete a wide range of extracellular enzymes and also have the capacity to metabolize recalcitrant molecules. Some lignocelluloses degrading microorganisms are involved in composting. Several fungi are also capable of degrading lignocellulose, three major types of fungi residing in dead woods, viz. soft-rot fungi, brown-rot fungi, and white-rot fungi are among them. The regulation and control of these microorganisms can help to speed up the rate of composting.

1.6 Factors affecting aerobic composting[8, 9]

Moisture: Moisture is a critical factor in establishing stable conditions conducive for composting because the microbes need moisture for survival and growth. Moisture is a key factor that supports the metabolic activities of microbes. The moisture content for composting materials should be maintained at 40–60 per cent. The presence of moisture in compost was reported to come from either the initial water added or the metabolic water produced by the action of microorganism. Moisture tends to occupy the free air space between the decomposing particles. Hence, when the moisture content is very high, anaerobic conditions set in. Excess water leads to a reduction in the diffusion of oxygen, and this, in turn, reduces the metabolic activities of the organisms. Microbial cells fully depend on water for their metabolic activities. Thus the metabolism of organic molecules by microorganisms is only possible when such organic molecules have been dissolved in water. Moisture decreases as the composting process proceeds.

Aeration (oxygen): Oxygen is essential for composting as the organisms involved in composting process generate energy for their growth and metabolism by the oxidation of carbon compounds. The optimum range of oxygen during various stages of composting is 13–18 per cent. Low oxygen levels make the process anaerobic leading to the production of undesirable products and odours.

Carbon-to-nitrogen (C/N) ratio: The carbon to nitrogen (C/N) ratio is important in composting because microorganisms need a good balance of carbon and nitrogen (in the range of 25:1–35:1) in order to remain active. The organisms involved in stabilization of organic matter utilize about 30 parts of carbon for each part of nitrogen. If the composting materials have a low C/N ratio (<25:1), air penetration is limited which results in the generation of unpleasant odours due to the production of methane and ammonia gases by anaerobic microorganisms. Thus, low C/N ratios enhance nitrogen loss. If C:N ratio is very high, composting process will slow down rapidly due to decrease in the metabolic activity of microorganisms, thus leading to prolonged duration of composting.

MSW in India has an initial carbon-to-nitrogen (C/N) ratio of around 30:1, which is ideal for decomposition. Whenever the C/N ratio is less than the optimum, carbon source such as straw, sawdust, paper (also called “browns”) are added. Higher C/N ratios may be reduced by adding biodegradable material having high nitrogen content, such as non-edible oil cakes, green biomass, etc.

(also called greens). It is preferable not to add slaughterhouse waste to MSW waste piles as it requires specific closed systems or in-vessel systems.

The composting process results in a reduction of the C/N ratio. Thus, finished composed usually has a C/N ratio less than the initial ratio of (around) 30:1, which is required and used for the composting process to occur optimally. An ideal finished compost should have a C/N ratio of <20:1 (15:1 to 20:1) for providing better nutrient availability to the plant. A compost C/N ratio of 20 means that there are 20 g of carbon for each 1 g of nitrogen in that organic matter. When an organic substrate has a C/N ratio of 1–15, rapid mineralization and release of N occurs, which is available for plant uptake. The lower the C/N ratio, the more rapidly nitrogen will be released into the soil for immediate crop use. A C/N ratio > 35 results in nitrogen immobilization by microbes. A ratio of 15–30 results in an equilibrium state between mineralization and immobilization (see *Table 2b: The C:N ratio of some organic material and their mineralization and immobilization rates*).In Fertilizer Control Order (FCO) standards,[10] the C/N ratio limit is given as <20:1 but it should have a lower range to maintain a balance between mineralization and immobilization (see *Table 2b: C/N ratio of 15:1 is showing a good balance between mineralization and immobilization*).

Table 2b: C:N ratio of some organic material and their mineralization and immobilization rates

C:N ratio	Mineralization	Equilibrium	Immobilization	Organic examples
5:1	*********			Blood, fish, and soybean meal
10:1	*********			Clovers, vetch, peas
15:1		*********		Grasses in vegetative stage
20:1		*********		Rotted manure, compost
30:1			*********	Grasses at seed set, pea straw
40:1			*********	Feather meal, grass hay
$\geq$50:1			*********	Straw, corn stalks
	Faster ← Slower		Slower → Faster	

[1]The C:N ratios vary over a range for any organic material and these values represent an average of the range.

Source: Gerald E. Brust, Safety and Practice for Organic Food, 2019[11]

pH: pH affects the composting rate. An alkaline pH is best suited for composting while an acidic pH significantly reduces the composting rate due to the death of microorganisms. The optimum pH is 5.5–8 for various stages of composting.

Temperature: Under properly controlled conditions, temperatures are known to rise beyond 70°C in aerobic composting. This increased temperature results in the increased rate of biological activity, resulting in faster stabilization of the material. However, if the temperature rise is very high, due to inactivation of the organisms and enzymes, the rate of activity may decrease. High temperature also helps in destruction of some common pathogens and parasites. Ambient air temperatures have little effect on the composting process, provided the mass of the material being composted can retain the heat generated by the microorganisms under aerobic conditions. If the process is so controlled that the temperature is kept at 55°C or above for at least three days, destruction of pathogens and parasites can be ensured.

Particle size: Optimum particle size should have enough surface area for rapid microbial activity, but also enough void space to allow air to circulate for microbial respiration. The feedstock composition can be manipulated to create the desired mix of particle size and void space.

2. Compost quality standards

Table 3: Compost quality standards; Fertilizer Control Order, 2009[12]

S. no.	Parameter	FCO Standard 2009 City Compost
1	pH	6.5–7.5
2	Colour	Dark brown to black
3	Odour	Absence of foul odour
4	Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
5	Bulk density (g/cm^3)	<1
6	Moisture, % by weight	15.0–25.0
7	Conductivity (as dsm^{-1}), not more than	4.0
8	Total organic carbon, % by weight, minimum	12.0
9	Total nitrogen (as N), % by weight, minimum	0.8
10	Total phosphates (as P_2O_5), % by weight, minimum	0.4
11	Total potassium (as K_2O), % by weight, minimum	0.4
12	NPK nutrients, total N, P_2O_5 and K_2O, not less than	1.5%
13	C:N ratio	<20
14	Pathogens	Nil
15	Sum of % NPK should not be less than	1.5
16	Arsenic (mg/kg)	10.00
17	Cadmium (mg/kg)	5.00
18	Chromium (mg/kg)	50.00
19	Copper (mg/kg)	300.00
20	Mercury (mg/kg)	0.15
21	Nickel (mg/kg)	50.00
22	Lead (mg/kg)	100.00
23	Zinc (mg/kg)	1000.00

Note: As per Solid Waste Management Rules 2016, compost quality shall be met quality standard as given in Fertilizer Control Order, 2009.

Table 4: International regulation for pathogens in biosolids

International regulation for pathogens in biosolids		
Pathogens	USEPA	WHO
Faecal coliforms	< 1,000 MPN/gram of total solids (dry weight basis)	–
Salmonella spp.	< 3 MPN/4 gram of total solids (dry weight basis)	–
E. coli	---	< 1,000/gram total solids

3. Testing methodologies

The samples were collected by visiting the individual composting sites. Using a soil sampler, approximately 1 kg of each sample was collected in a plastic bag, sealed properly, transported to the lab, and stored in the refrigerator until analysis.

The compost samples were evaluated for various parameters, including physical properties: pH, electrical conductivity, moisture; elemental analysis: total organic carbon (TOC), total nitrogen; heavy metals and pathogens/microbiological parameters: *Salmonella* sp., faecal coliform and *E. coli*.

pH and electrical conductivity (EC): The samples were mixed with distilled water in 1:5 ratios (w/v) for 1 hour. After decantation, when the supernatant was separated from the settled material, the pH and the EC were measured using a pH/conductivity meter (as Biofertilizers and Organic Fertilizers in Fertilizer (Control) Order, 1985: Part-D Methods of Analysis of Organic Fertilizers).

CHN analysis

Principle: A CHNS elemental analyser (LECO, USA, 828 series) is used to determine the percentage of carbon, hydrogen, nitrogen and sulphur in organic materials or other substrates such as soil, compost, fertilizer etc. The instrument works on the principle of the classical Pregl-Dumas method where the sample undergoes high temperature combustion in an oxygen-rich environment. During combustion, carbon is converted to carbon dioxide; hydrogen to water; nitrogen to nitrogen gas/oxides of nitrogen and sulphur to sulphur dioxide. The combustion products are swept out of the combustion chamber by inert carrier gas such as helium and passed overheated (about 600°C) high-purity copper. The function of this copper is to remove any oxygen not consumed in the initial combustion and to convert any oxides of nitrogen-to-nitrogen gas. The gases are then passed through the absorbent traps in order to leave only carbon dioxide, water, nitrogen and sulphur dioxide. Detection of the gases can be carried out in a series of separate infrared and thermal conductivity cells for detection of individual compounds. Quantification of the elements requires calibration for each element by using high-purity “micro-analytical standard” compounds such as acetanilide and benzoic acid.

Method for total nitrogen: Samples are weighed in tin capsules. The amount of sample required is less than 0.12 g and after taking the sample in the capsule, it has to be wrapped and introduced into the auto sampler. The sample enclosed in the capsule falls into the reactor chamber (temperature >900°C), where excess oxygen is introduced before which facilitates the sample combustion.

Method for total organic carbon: Samples are weighed in tin capsules and acidified with 2N hydrochloric acid to remove the inorganic carbon and analysed in a CHN analyser as described above.

Heavy metal analysis by ICP-OES: The PerkinElmer Avio® 200 ICP-OES instrument is used to analyse the heavy metals in the compost samples. PerkinElmer NIST® traceable quality-control standards for ICP were used as the stock standards for preparing working standards. For the heavy metal analysis, acid digestion (HNO_3) of compost samples was carried out in microwave digestion as per the USEPA digestion methodology and filtered samples were further analysed in ICP-OES.

Faecal coliform: The faecal coliform in the compost samples were analysed by the MPN method according to the protocol given in "Method 1680" of USEPA (2014)[13] and USDA, MLG Appendix 2.05 (2014).[14]

E. coli: The *E. coli* in the compost samples were analysed by MPN method according to the protocols given in APHA 9221 B and 9221 F, (23rd ed., 2017)[15] and USDA, MLG Appendix 2.05 (2014).

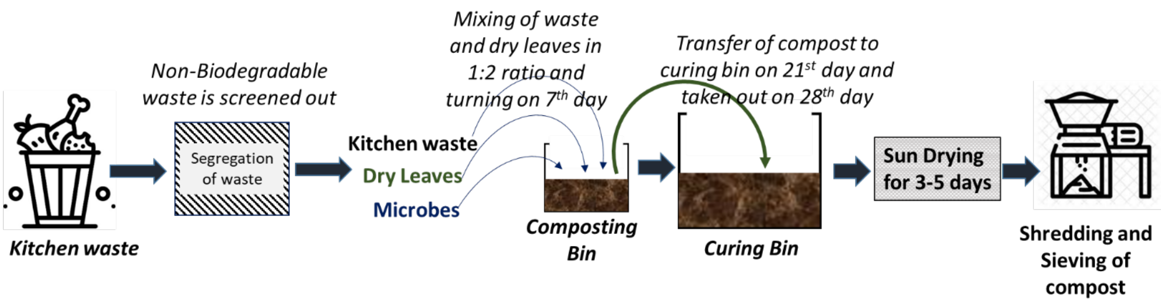
***Salmonella*:** The enumeration of *Salmonella* spp. was carried out using the chromogenic media, HiCrome *Salmonella* Agar (M1296, HIMEDIA), by spread plate method.

4. State-wise evaluation of compost quality

4.1 HARYANA

1. Nirvana Country—The Close North Society, Gurugram, Haryana

Capacity : *400 kg/day*
Operator : *Balancing BITS*
Waste : *Kitchen waste*
Technology : *Aerobic composting tub*
Source : *Household*
Latitude, Longitude : *28.413750, 77.067173*



Picture 1: Location and flow diagram of composting unit in Nirvana Country, North

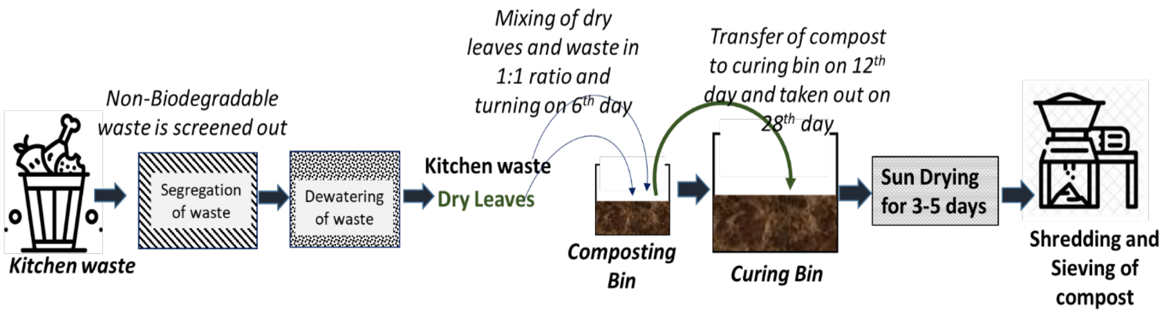
North Nirvana locality of Gurugram, Haryana, installed a composting unit setup in 2019 in an area of 1,200 sq. ft with a production capacity of 400 kg/day. The composting site receives 350 kg wet weight of kitchen waste daily from 660 houses of the society. The technology is called **aerobic mesh composting** and consists of 22 composting tubs in two equal trains.

The composting process occurs in two steps for which there are two types of composting tubs: **composting bins** (small sized) and **curing bins** (large sized). Generally, the composting step leads to decomposition of simple and water-soluble compounds such as sugars whereas the curing step decomposes the complex carbohydrates such as lignin and cellulose. The composting process starts by segregation of kitchen waste material from plastics and other non-biodegradable items followed by mixing of one part of kitchen waste with two parts of dry leaves and microbes. The first step of the process is the **turning of matter**, which is carried out by filling this mixture into the composting tubs for 21 days along with turning of matter once in seven days to ensure required aeration for microbial action. After this, compost is shifted to larger curing tubs for another seven days to ensure better aeration and digestion of complex organic matter. Finally, compost undergoes sun drying for three to five days, followed by shredding and sieving. However, it was observed that North Nirvana site did not have proper sunlight exposure for compost drying.

It takes total 30–35 days to complete the composting process. The composting process generates 120 kg compost daily. The society management self-utilizes the compost for gardening as well as also selling this within the society households at a rate of Rs 20/kg.

2. Nirvana Country—The Close South Society, Gurugram, Haryana

Capacity	*: 500 kg/day*
Operator	*: Balancing BITS*
Waste	*: Kitchen and horticulture waste*
Technology	*: Aerobic composting tub*
Source	*: Household*
Latitude, longitude	*: 28.410719, 77.067721*

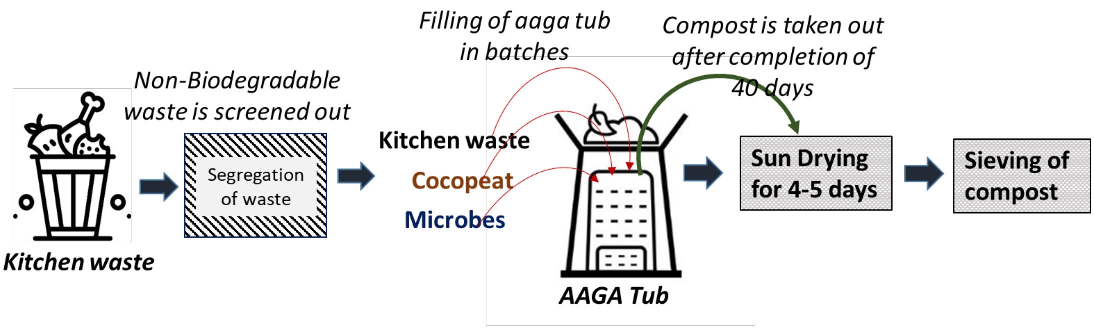


Picture 2: Location and flow diagram of composting unit in Nirvana Country, South

Nirvana South has been carrying out the composting process since 2021 in 1,000 sq. ft of area with a capacity of 500 kg/day. The society has 599 households and receives 450 kg/day wet weight of kitchen waste. **Aerobic tub composting** technology—which consists of 32 composting tubs—is employed in this society. The composting process starts with screening of waste material during which 30 kg/day of non-biodegradable waste such as plastics are screened out. The remaining 420 kg of waste then undergoes the dewatering process through a sieving mechanism followed by addition and mixing of dried leaves in a 1:1 ratio of waste and leaves. This mixture is then filled in composting tubs followed by proper turning of waste on the sixth day. The mixture is kept still for another six days in the same tubs, so it takes a total of 12 days for completion of this step. On completion of the twelfth day, the compost is transferred to another tub for curing and taken out on the twenty-eighth day. Then it undergoes sun drying for three to five followed by shredding and sieving. Thus, it takes a total of 35–40 days for completion of the composting process. However, as in Nirvana North, in this site also the compost did not get proper sunlight exposure. The daily compost output is 150 kg, which is self-utilized for the purpose of gardening.

3. The World Spa West and East Society, Gurugram, Haryana

Capacity	*: 400 kg/day*
Operator	*: GWMS*
Waste	*: Kitchen waste*
Technology	*: AAGA, aerobic composting in pots*
Source	*: Household*
Latitude, longitude	*: 28.460541, 77.057816*



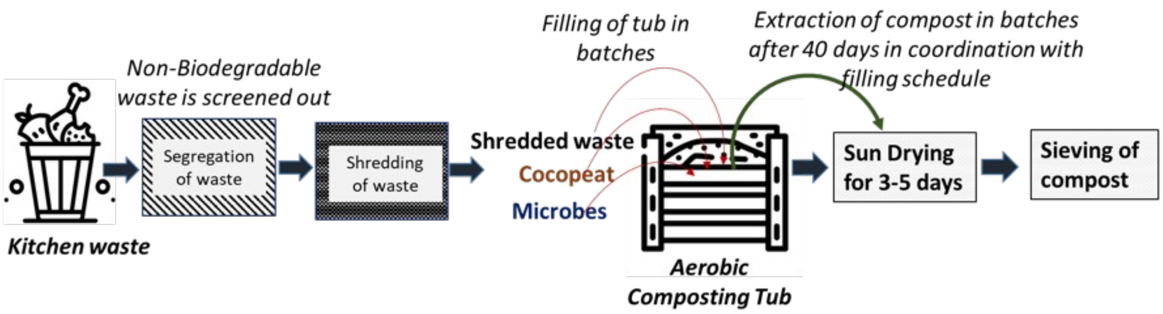
Picture 3: Location and flow diagram of composting unit in World Spa

The World Spa, Sector 30, Gurugram, has installed a composting unit in an area of 1,500 sq. ft with a production capacity of 350–400 kg of compost daily. The composting site receives 200–250 kg kitchen waste material per day collectively from the World Spa East and West buildings, with 367 apartments in total. The technology is called **AAGA aerobic composting**, and consists of 18 AAGA tubs in two equal trains with a capacity of 500 kg/tub to feed the waste material. The input waste is pre-segregated at the household level as every floor of the building has a separate dustbin for kitchen waste. A second segregation is carried out at the composting site during which remaining non-biodegradable waste is screened out. Then the next step is filling of AAGA tubs, done in 20 batches (one batch/day). For one batch, 20 kg of kitchen waste is mixed with half a kg of coco peat and a small part of microbes, and this mixture is filled in the AAGA tub. So, it takes a total of 20 days to fill one AAGA tub, with a capacity of 500 kg.

After filling the AAGA tub to its full capacity, the mixture is kept undisturbed for another 20 days for completion of the composting process. After completion of a total 40 days, starting from filling of first batch, the compost is ready and taken out of the tub. It is then given sunlight exposure for four to five days. Therefore, it takes approximately 40–45 days for completion of the composting process. This process doesn't require shredding so the final product is only sieved and used directly for the purpose of gardening. The society management sells the compost at a price of Rs 12/kg.

4. Westend Heights Society, Gurugram, Haryana

Capacity	*: 400 kg/day*
Operator	*: Green Karma and Associates LLP*
Waste	*: Kitchen waste (with cocopeat and without cocopeat)*
Technology	*: Aerobic composting in tubs*
Source	*: Household*
Latitude, longitude	*: 28.449767, 77.093584*



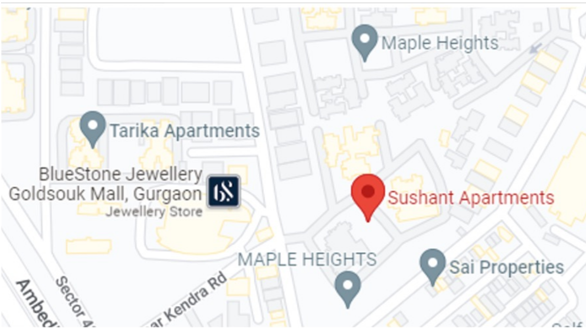
Picture 4: Location and flow diagram of composting unit in Westend Heights

Westend Heights Society has been carrying out the composting process since 2017 in 500 sq. ft of area with production capacity of 400 kg/day. The society has 368 households and receives 100–180 kg of wet kitchen waste. The technology is called **aerobic tub composting**. It consists of 17 tubs in two trains, with each tub having a 400 kg capacity.

The composting process starts with screening, mixing and shredding of the waste material during which non-biodegradable waste is screened out. Then next step is filling of the composting tub, which is done in 40 batches (one batch/day). For one batch, 10 kg of kitchen waste is mixed with cocopeat in a ratio of 30:3 along with a part of microbes. This mixture is filled in the composting tub so it takes a total of 40 days to fill the one composting tub with a capacity of 400 kg. The extraction of compost is carried out in batches from the valve at the bottom of tub in the following sequence. For example, on the forty-first day, 10 kg of compost which was filled on first day is taken out, on the forty-second day a second 10 kg batch filled in second day is taken out and so on. So, every 10 kg compost batch extracted after completion of a cycle of 40 days is given sunlight exposure for three to five days. The total time taken to complete the process is 45 days. A total of 160 kg/day of compost is generated at the site, which is self-utilized for the purpose of gardening as well as sold at a price of Rs 20/kg within the society.

5. Sushant Apartments Society, Gurugram, Haryana

Capacity	*: 100 kg/day*
Operator	*: Green Bandhu*
Waste	*: Kitchen and flower waste*
Technology	*: Aerobic composting in tubs*
Source	*: Household*
Latitude, longitude	*: 28.450068, 77.079659*



Picture 5: Location and flow diagram of composting unit in Sushant Apartments

Sushant Apartments instituted the composting process 2020 in approximately 600 sq. foot of area, with 100 kg/day production capacity. The society receives 150 kg/day of wet kitchen waste from the 200 households of society. The technology installed is **aerobic/smart tub composting.** It consists of 18 composting tubs in two equal trains, with a capacity of 300 kg/tub.

The composting process starts with the screening of waste material, followed by the addition and mixing of dried leaves powder in a 1:1 ratio of waste and leaves powder. This mixture is then gradually filled inside the composting tub followed by proper turning on every third day to ensure proper aeration for microbial action. This mixture is kept for a total of 20 days in the tub for completion of the process. After 20 days, compost is then air dried for three to five days followed by shredding and sieving. Thus, it takes a total of 25 days for completion of the composting process. Ten kg of compost is generated per day, which is self-utilized for the purpose of gardening in the society.

6. DLF Richmond Park Society, Gurugram, Haryana

Capacity : 200 kg/day
Operator : Green Bandhu
Waste : Kitchen waste and garden waste
Technology : Aerobic composting in tubs
Source : Household
Latitude, longitude : 28.458640, 77.089367

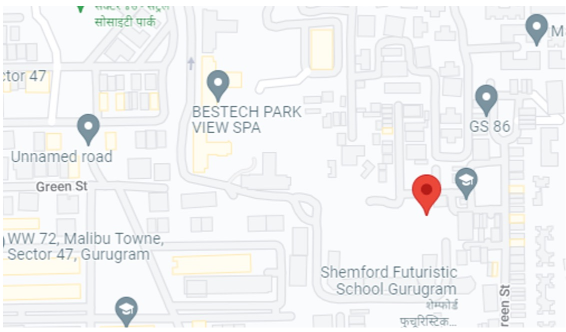
Picture 6: Location and flow diagram of composting unit in DLF Richmond Park

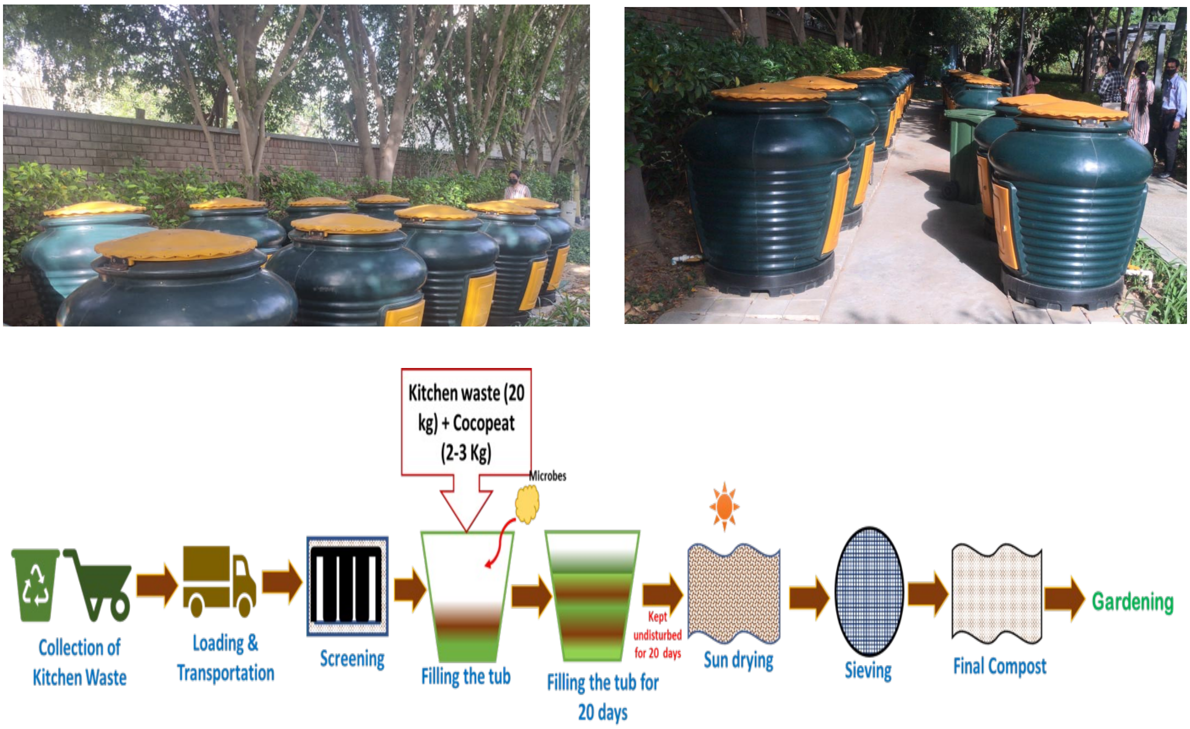
DLF Richmond Park, Sector 43, Gurugram, installed a composting unit in 2017 in an area of approximately 500 sq. ft with 200 kg/day production capacity. The society receives 150 kg/day wet weight of food waste from the 314 households of society. The technology installed is **rapid hybrid aerobic system**. It consists of nine composting tubs.

The composting process starts screening and then dewatering of waste followed by addition and mixing of dried leaves powder in a 1:1 ratio of waste and leaves powder. This mixture is then gradually filled inside the composting tub and followed by proper turning of waste every day to ensure proper aeration for microbial action. This mixture is kept for a total of 21 days in the tub for completion of process. After 20 days, the compost is exposed to sunlight for one to two days and followed by shredding and sieving. Thus, it takes a total of 20–25 days for completion of the composting process. Twenty kg/day of compost is produced, which is self-utilized for the purpose of gardening in the society.

7. Bestech Park View Spa Society, Gurugram, Haryana

Capacity	*: 1 TPD*
Operator	*: M/S Green Karma*
Waste	*: Kitchen waste*
Technology	*: AAGA, aerobic composting*
Source	*: Household*
Latitude, longitude	*: 28.426761, 77.052334*





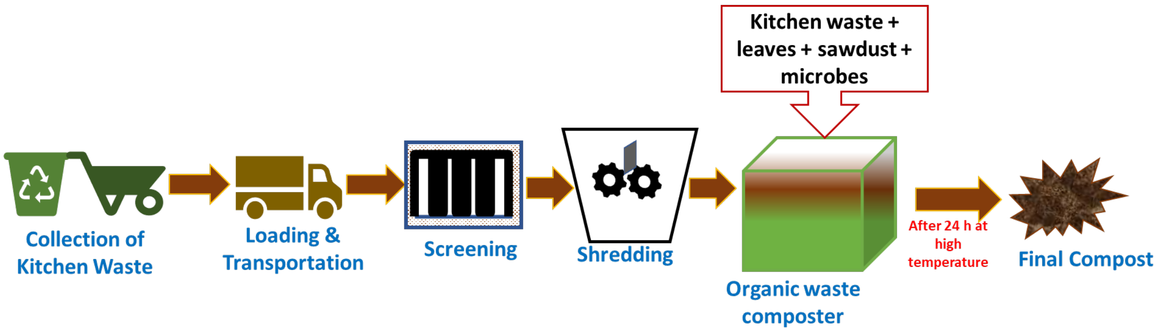
Picture 7: Location and flow diagram of composting unit in Bestech Park

The Park View Spa Society has installed a composting unit in an area of 600 sq. foot, with a production capacity of 1,000 kg of compost daily. The composting site receives 300 kg of kitchen waste material per day collectively from 416 houses of society. The technology is called **AAGA aerobic composting.** It consists of 24 AAGA tubs in two equal trains with a 1000kg capacity of one tub. Compost is first segregated during which non-biodegradable waste is screened out. Then next step is filling of AAGA tub that is done in batches (one batch/day). For one batch, 20 kg of kitchen waste is mixed with 2–3 kg of cocopeat and a small part of microbes. This mixture is then filled in the AAGA tub. The process of filling the AAGA tub is carried out continuously for 20 days.

After filling the AAGA tub for 20 days, the mixture is left undisturbed for another 20 days for completion of the composting process. There is an outlet valve at the bottom of the AAGA tub to take out the leachate. After completion of a total of 40 days starting from filling of the first batch, the compost is ready. It is taken out of the tub and given sunlight exposure for three to five days. Therefore, it takes approximately 40–45 days for completion of the composting process. This process doesn't require shredding so the final product is only sieved and used directly for the purpose of gardening. The society management generates 250 kg compost daily and sells the compost at Rs 5/kg.

8. DLF Cyber Park Society, Gurugram, Haryana

Capacity : 500 kg/day
Operator : Green Motive
Waste : Kitchen waste
Technology : Organic waste converter (mechanical system)
Source : Office canteens
Latitude, longitude : 28.502569, 77.089495



Picture 8: Location and flow diagram of composting unit in DLF Cyber Park

DLF Cyber Park started composting from 2021 in an area of 1,500 sq. foot. The site receives 100 kg of food waste per day from households. The composting is carried out through an **organic waste composter**, which has a capacity of 500 kg. The waste is first segregated and shredded. Then waste, saw dust, microbial inoculum and dried leaves are mixed. After this, the mixture is filled into the composter and the process is allowed to take place for 24 hours at high temperatures. After 24 hours, the final compost generated is collected from the decanter of the composter machine. This process is the fastest amongst all the aforementioned techniques. The compost generated is self-consumed in gardening. Although the society management had two organic waste composters, both had been under maintenance for 15 days during sample collection in March 2022.

Sample collection

A total of 10 compost samples were collected in January 2022, eight in March 2022 and eight in February 2023 from eight different locations of Gurugram, Haryana. These samples were tested and compared for the quality parameters given in regulation FCO 2009. The composting technologies were evaluated on the basis of average values of observed results in different set of samples (see *Table 5: Details of compost sample collected from different locations in Haryana*). See *Annexure 1* for results of individual replicates.

Table 5: Details of compost sample collected from different locations in Haryana

S. no.	Sample details	Technology	Capacity	Latitude, longitude	Operator	Waste
1	World Spa, Sec-30, Gurugram	AAGA: Aerobic composting in pots	400 kg/day	28.460541, 77.057816	GWMS	Compost, kitchen waste
2	Nirvana Country, South, Gurugram	Aerobic composting tub	500 kg/day	28.410719, 77.067721	Balancing BITS	Compost, kitchen and horticulture waste
3	Dlf Cyber Park, Gurugram	Organic waste converter (mechanical system)	500 kg/day	28.502569, 77.089495	Green Motive	Compost, kitchen waste
4	Nirvana Country, North, Gurugram	Aerobic Composting tub	400 kg/day	28.413750, 77.067173	Balancing BITS	Compost, kitchen waste
5	Bestech Park View Spa, Gurugram	AAGA, aerobic composting	1000 kg/day	28.426761, 77.052334	M/S green karma	Compost, kitchen waste
6	Westend Heights, Gurugram	Aerobic composting tub	400 kg/day	28.449767, 77.093584	Green karma and associates LLP	Compost, kitchen waste with cocopeat
7	Westend Heights, Gurugram	Aerobic composting tub	400 kg/day	28.449767, 77.093584	Green karma and associates LLP	Compost, kitchen waste without cocopeat
8	DLF Richmond Park, Gurugram	Aerobic composting tub	200 kg/day	28.458640, 77.089367	Green Bandhu	Compost, kitchen and garden waste
9	Sushant Apartments, Gurugram	Aerobic composting tub	100 kg/day	28.450068, 77.079659	Green Bandhu	Compost, kitchen waste
10	Sushant Apartments, Gurugram	Aerobic composting tub	100 kg/day	28.450068, 77.079659	Green Bandhu	Compost, flower waste

Results and discussion

Multiple parameters were analysed in this study as presented in Table 6. The result obtained for significant parameters is discussed and represented as follows.

Test parameters evaluation based on Organic Compost Standard FCO 2009.

Table 6: Physico-chemical and microbial parameters of compost in Gurugram, Haryana

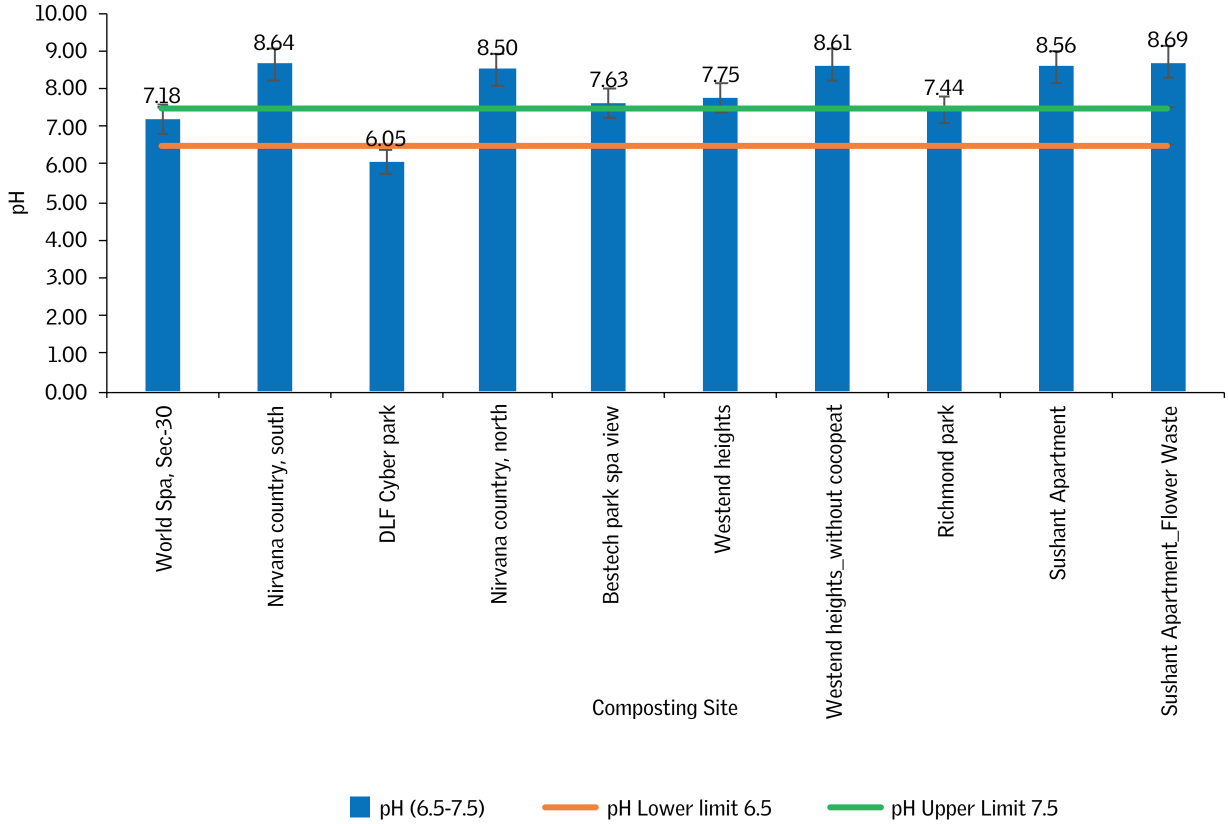
Sample details	pH (6.5–7.5)	Conductivity < 4.0 ds/m	Moisture, % by weight, maximum 25.0	Total organic carbon, per cent by weight, minimum (12)	Total nitrogen (as N), per cent by weight, minimum (0.8)	C:N ratio < 20:1	Total phosphates (as P_2O_5), per cent by weight, minimum 0.4	Total potash (as K_2O), per cent by weight, minimum 0.4	Faecal coliforms MPN per g total solids (dry weight)	*E. coli* MPN per g total solids (dry weight)	*Salmonella* spp. MPN/4 grams of total solids (dry weight) (USEPA)
World Spa, Sec-30	7.18	2.76	71.94	32.78	3.48	9	1.28	1.87	1752	1,242	6,791,959
Nirvana Country, South	8.64	2.87	29.54	28.15	4.00	7	1.40	1.77	167,708	77,821	3,029,172
DLF Cyber Park	6.05	4.79	36.96	42.67	3.12	14	0.62	0.79	1,859	1,857	225,699
Nirvana Country, North	8.50	8.65	35.14	30.37	4.84	6	1.75	1.88	5,143	919	210,935
Bestech Park Spa View	7.63	4.68	63.72	30.80	4.31	7	1.79	1.71	53,254	4,217	1,249,544
Westend Heights	7.75	10.74	13.80	32.93	4.49	7	1.51	2.40	12,528	3,261	24,130
Westend Heights without cocopeat	8.61	5.83	11.59	31.84	2.57	12	1.65	2.20	16,966	16,966	2,081
Richmond Park	7.44	4.23	32.57	17.36	3.05	6	0.95	1.79	27,215	9,840	5,639,704
Sushant Apartments	8.56	5.14	29.09	25.59	3.90	7	1.24	2.09	51,231	5,805	1,293,403
Sushant Apartments flower waste	8.69	3.88	32.59	22.73	1.74	13	0.86	1.80	43,020	13,796	65
Average	7.90	5.36	35.69	29.52	3.55	8	1.31	1.83	38,068	13,572	1,846,669
SD	0.86	2.52	19.04	6.78	0.95	3	0.39	0.43	49,625	23,231	2,502,027
Median	8.12	4.74	32.58	30.59	3.69	7	1.34	1.83	22,090	5,011	737,621
Minimum	6.05	2.76	11.59	17.36	1.74	6	0.62	0.79	1,752	919	65
Maximum	8.69	10.74	71.94	42.67	4.84	14	1.79	2.40	167,708	77,821	6,791,959

First replicate in January 2022, second replicate in March 2022 and third replicate in February 2023

pH

The pH of the compost samples was analysed, and average values were calculated to be in the range of 6.05–8.69. The Fertilizer Control Order (FCO) 2009 suggested the pH should be in the range of 6.5–7.5. Low pH value was observed in DLF Cyber Park (6.05)—the pH of the first set sample was found to be 3.83 while the pH of the second and third sets were found to be 7. In all other sites, pH is above neutral to slightly alkaline (range: 7.18–8.69).

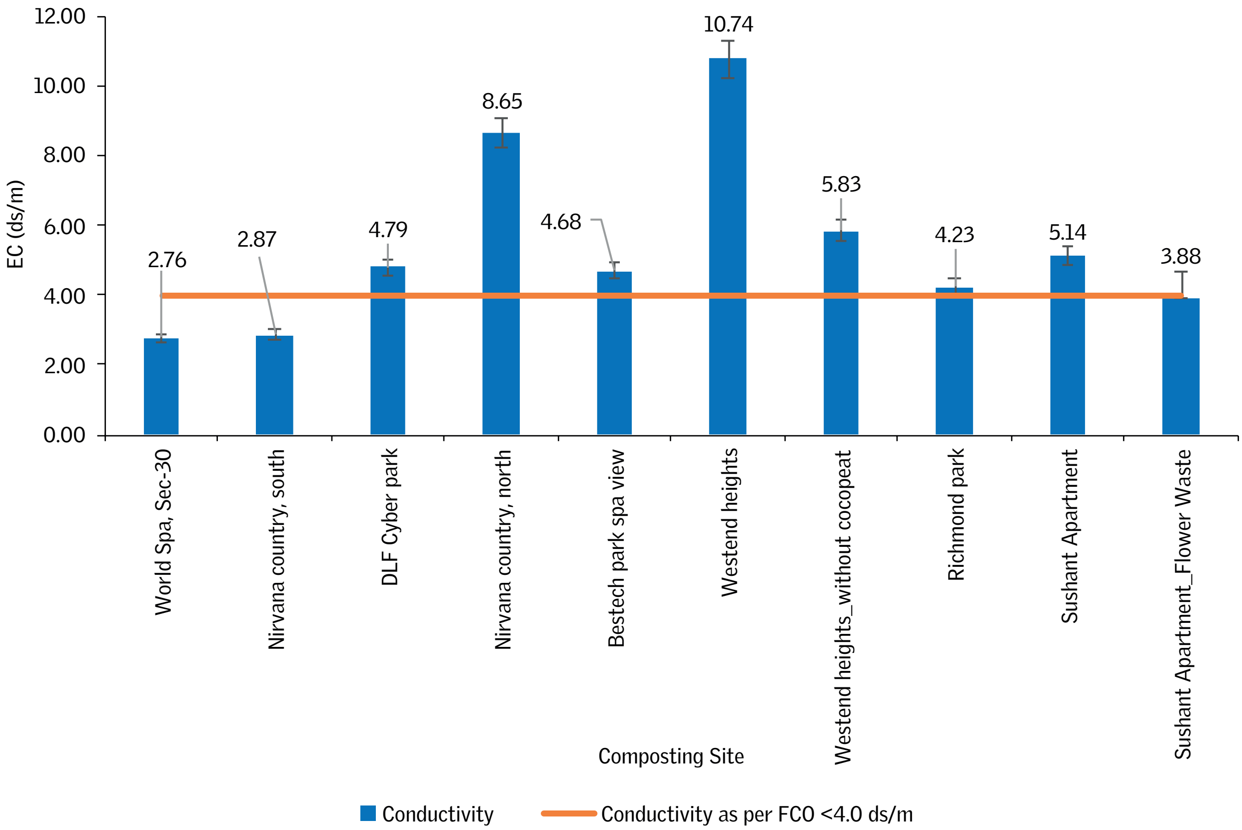
Fig. 1: pH of the compost, Haryana



Electrical conductivity (EC)

The electrical conductivity (EC) of compost in the samples was in the range of 2.76–10.74 dS/m (see *Fig. 2: Electrical conductivity of compost, Haryana*). As per FCO standard recommendation, the EC value should be less than 4 dS/m. However, electrical conductivity in Westend Heights (with cocopeat) and Nirvana Country North was observed to be high (10.74 and 8.65 respectively) compared to other sites. Only World Spa, Nirvana Country South and Sushant Apartments flower compost showed EC within the FCO limit. High EC values could be due to the elevated levels of sodium or other salts found in the kitchen raw material of compost.

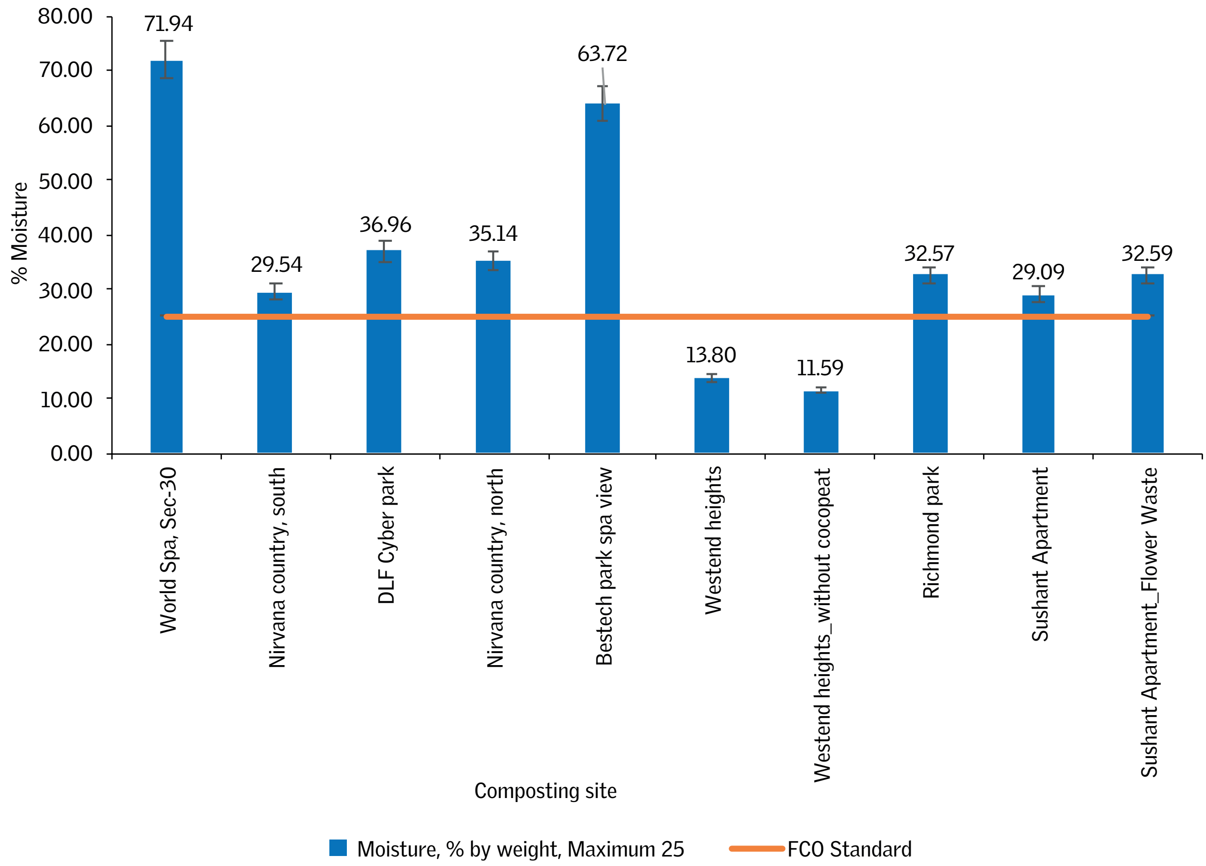
Fig. 2: Electrical conductivity of the compost, Haryana



Moisture content

The moisture content of the compost samples was in range of 11.59–71.94 per cent. Per cent moisture in two sites World Spa (71.9 per cent) and Bestech Park Spa View (63.7 per cent) was observed to be extremely high compared to other sites (11.59–36.96 per cent). This may be due to improper drying conditions. High moisture may lead for high pathogen load in compost samples. Moisture can be controlled by proper sun drying.

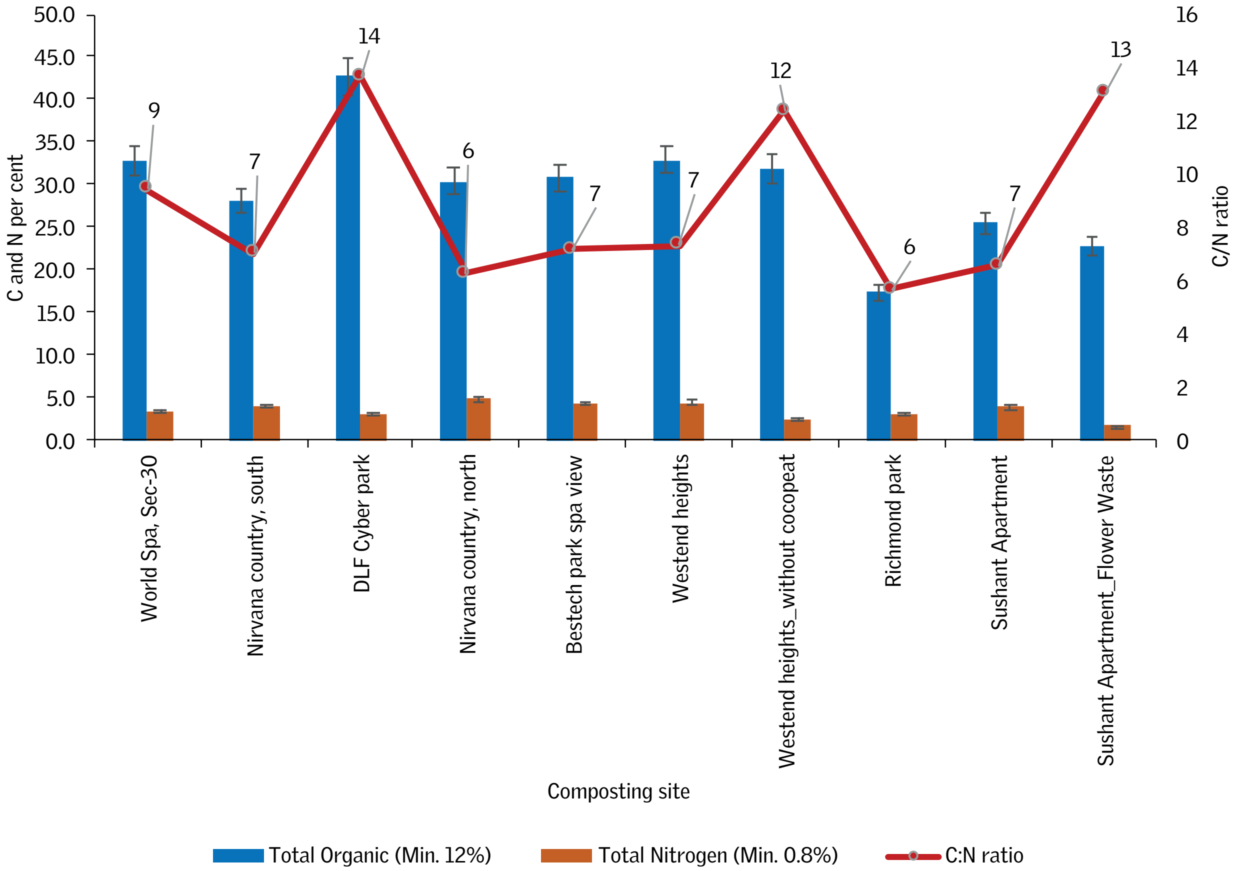
Fig. 3: Moisture content in the samples



C:N ratio

Any type of organic waste with a sufficient carbon-to-nitrogen ratio can be degraded through composting. The organic matter of compost is one of the key components for successful usage as an organic amendment. It has an important role in the soil as it increases the stability of the formed aggregate, reduces the bulk density, and upholds better infiltrations of water. In addition, organic matter positively influences the storage and yield of nutrients, activity and diversity of soil biota. The total organic carbon content of the compost was in the range of 17.4–42.7 per cent and the total nitrogen content was in the range of 1.7–4.8 per cent. The C/N ratio of the collected compost as per FCO was within the range of 6:1–14:1.

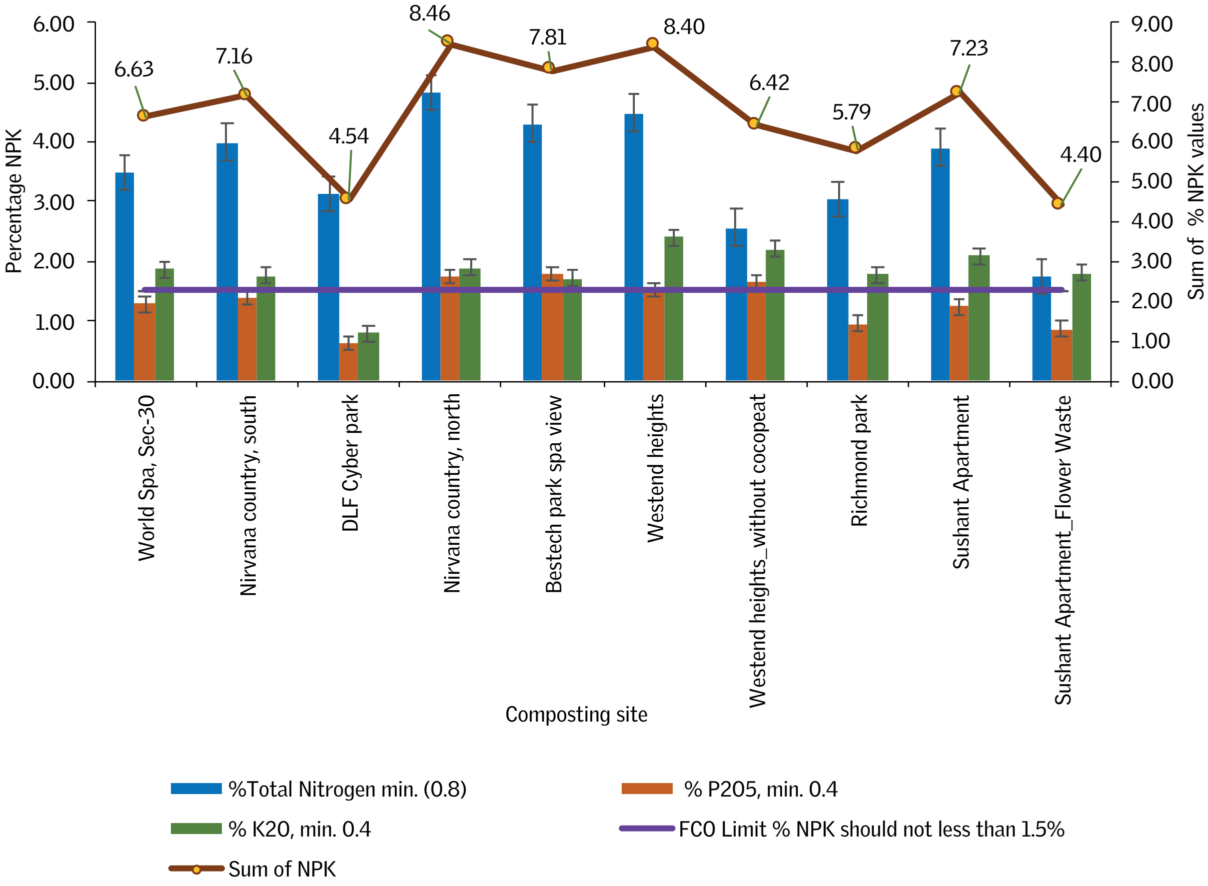
Fig. 4: Carbon and nitrogen content (C/N ratio)



NPK value

The NPK value indicates the amount of nitrogen, phosphorus and potassium in the compost or fertilizer. These three essential macronutrients are needed by all plants. The appropriate NPK ratio for fertilizer under Indian soil conditions is stated to be 4:2:1. The NPK ratio of the compost in Haryana was observed to be close (3:1:1) to the given standard ratio. As per FCO 2009, the per cent NPK should not be less than 1.5 per cent. However, the observed results showed that all sites were rich in NPK and within this regulatory limit. The NPK of the compost was in the range of 4.4–8.5 per cent (see *Fig. 5: Percentage of NPK content*).

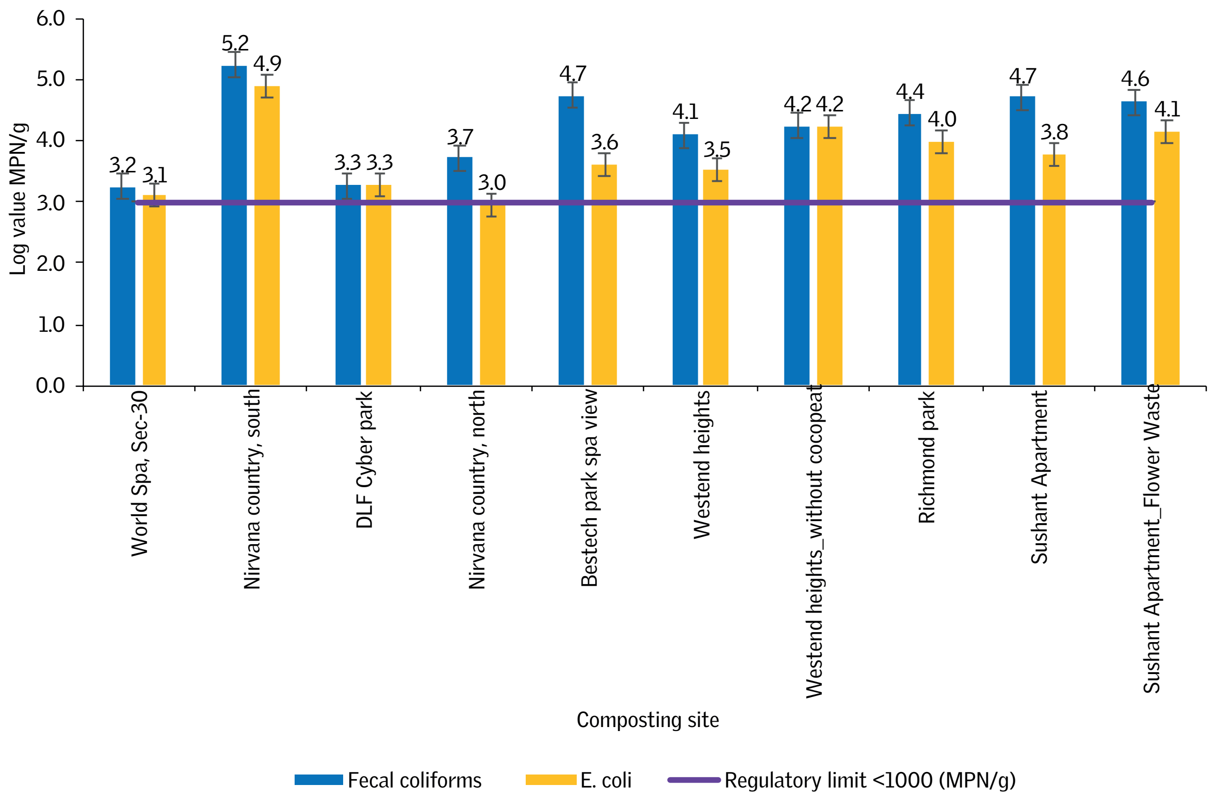
Fig. 5: Percentage of NPK content



Bacterial contamination (*E. coli* and faecal coliform)

To assess the microbial safety of compost, we examined the inactivation of microbial indicators for potential bacterial pathogens. Indicator microorganisms are used as a simple and reliable measure of the potential risk to human health. *E.coli* and faecal coliform (FC) were observed to exist in all the tested locations and hence does not meet the FCO standard (i.e. nil pathogens). However, when the *E. coli* and faecal coliform load is compared with global standards (USEPA, WHO), all the sites showed FC and *E. coli* load higher than the standard value (<1000 MPN/g dry weight) except Nirvana Country North, which showed *E. coli* within the standard. To reduce the risk of biological contamination, composting is the easiest procedure as stable humus can be produced under aerobic thermophilic conditions for more than 30 days at 55–65°C and proper sun drying for a period of four to five days can minimize bacterial load in compost.

Fig. 6: Faecal coliform and *E. coli* load in the compost



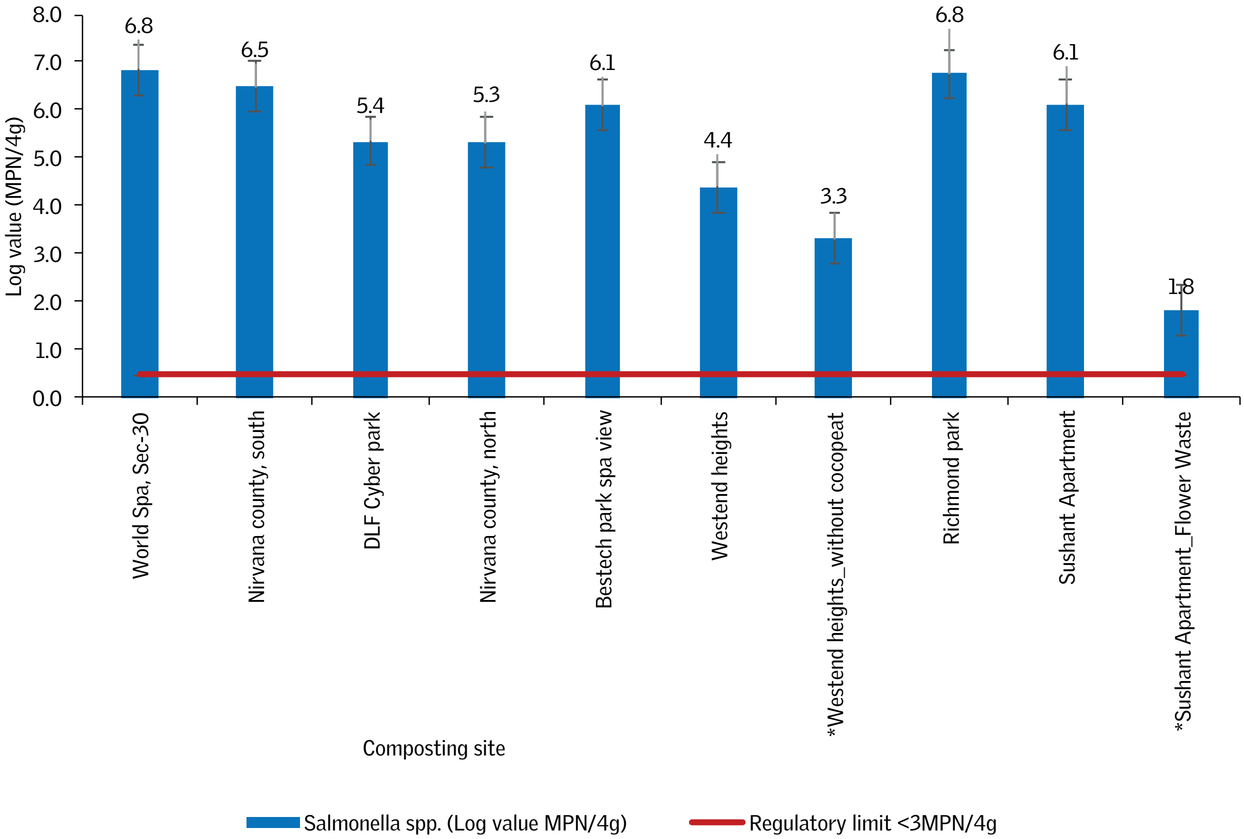
***Salmonella* spp.**

Salmonella is a pathogen that may find its way into the compost through contaminated food waste material. All the compost samples contained *Salmonella* spp. (more detailed study is required to identify whether the *Salmonella* bacteria are typhoidal or non-typhoidal strains) in significant numbers that were higher than the standard value. The standard limit of *Salmonella* in compost and bio-solids is 3 MPN/4 g by WHO/USEPA.

All samples from the sites in Gurugram, Haryana, showed a high amount of *Salmonella spp.*

To reduce the risk of biological contamination, composting is the easiest procedure as stable humus can be produced under aerobic thermophilic conditions for more than 30 days at 55–65°C and proper sun drying for a period of four to five days can minimize the bacterial load in compost.

Fig. 7: *Salmonella* spp. in compost sample



Heavy metals

Heavy metals occur naturally in the environment but are widely distributed through mining, manufacturing, and energy production sectors. Mercury, copper, cadmium, chromium, lead, nickel, arsenic and zinc are all toxic heavy metals that bio-accumulate because they cannot be easily or efficiently eliminated from the body (see *Table 7: Heavy metal concentration in the compost of Haryana*).

Analysis of heavy metals in compost samples is done on the basis of obtained results, described as follows:

Table 7: Heavy metal concentration in the compost of Haryana

Sample details	Arsenic (mg/kg) max. 10.001	Mercury (mg/kg) max 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1,000
World Spa, Sector 30	0.62	0.02	0.67	15.77	21.31	6.62	9.24	84
Nirvana Country, South	0.79	0.07	1.26	20.20	26.69	7.93	11.68	109
DLF Cyber Park	0.18	0.00	0.60	20.62	16.74	9.82	4.78	49
Nirvana Country, North	0.63	0.03	0.60	38.94	132.68	85.08	8.20	247
Bestech Park Spa View	0.70	0.02	0.98	21.79	31.10	9.14	9.90	144
Westend Heights	0.56	0.02	0.53	16.28	24.03	7.23	6.49	102
Westend Heights without cocopeat	0.80	0.00	0.60	24.77	40.45	8.57	19.46	194
Richmond Park	2.26	0.49	1.01	94.25	27.07	14.49	16.03	98
Sushant Apartments	0.87	0.17	1.69	120.30	53.35	8.50	12.98	107
Sushant Apartments flower waste	1.40	0.11	0.89	24.46	35.24	9.76	14.22	148
Average	0.88	0.09	0.88	39.74	40.87	16.71	11.30	128.11
SD	0.57	0.15	0.37	36.69	33.92	24.12	4.49	57.55
Median	0.74	0.03	0.78	23.12	29.09	8.86	10.79	108.14
Minimum	0.18	0.00	0.53	15.77	16.74	6.62	4.78	48.78
Maximum	2.26	0.49	1.69	120.30	132.68	85.08	19.46	247.09

Mercury: Compost samples of Richmond Park showed average concentration of mercury (Hg) of 0.49 mg/kg, which is above the FCO limit. However, in the first replicate the value was 0.00 mg/kg, in the second replicate 1.459 mg/kg, and in the third replicate 0.014 mg/kg. Hence, mercury concentration was higher in the second replicate due to significant contamination.

The compost sample of Sushant Apartments showed an average concentration 0.17 mg/kg, which is above the FCO limit. In the first replicate, mercury concentration was 0.104 mg/kg, in the second replicate it was 0.299 mg/kg and in the third replicate it was 0.103 mg/kg. Mercury concentration was higher in this sample due to significant contamination of mercury in second replicate of the sample.

Chromium: The compost samples of Richmond Park showed the average concentration of chromium was 94.25 mg/kg which out of the FCO limit. In the first replicate it was 33.84 mg/kg, the second replicate it was 224.50 mg/kg, and third replicate it was 24.42 mg/kg. Chromium concentration was higher in this sample due to significant contamination of chromium in second replicate of sample.

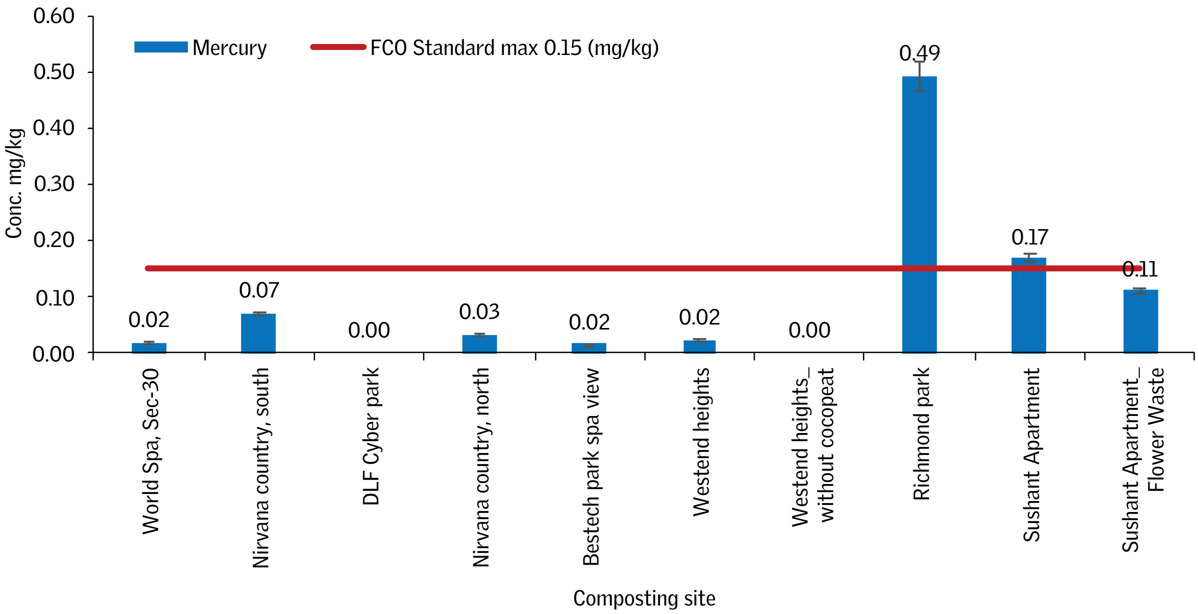
The compost sample of Sushant Apartments showing average concentration of chromium was 120.30 mg/kg which out of the FCO limit. The first replicate had a concentration of 325.30 mg/kg, the second replicate had 25.94 mg/kg, and third replicate 9.66 mg/kg. Chromium concentration was higher in this sample due to significant contamination of mercury in first replicate of sample.

Nickel: Compost samples of Nirvana Country North showed an average concentration of 85.08 mg/kg, which out of the FCO limit. In the first replicate the concentration was 9.82 mg/kg, in the second replicate it was 11.01 mg/kg, and in the third replicate it was 234.40 mg/kg. Nickel concentration was higher in this sample due to significant contamination of nickel in the third replicate of sample.

The aforementioned significant contamination of respective heavy metal may be due to the contamination from source or from in-process. Proper segregation of waste at households and sorting of waste at site may solve the problem of heavy metal contamination.

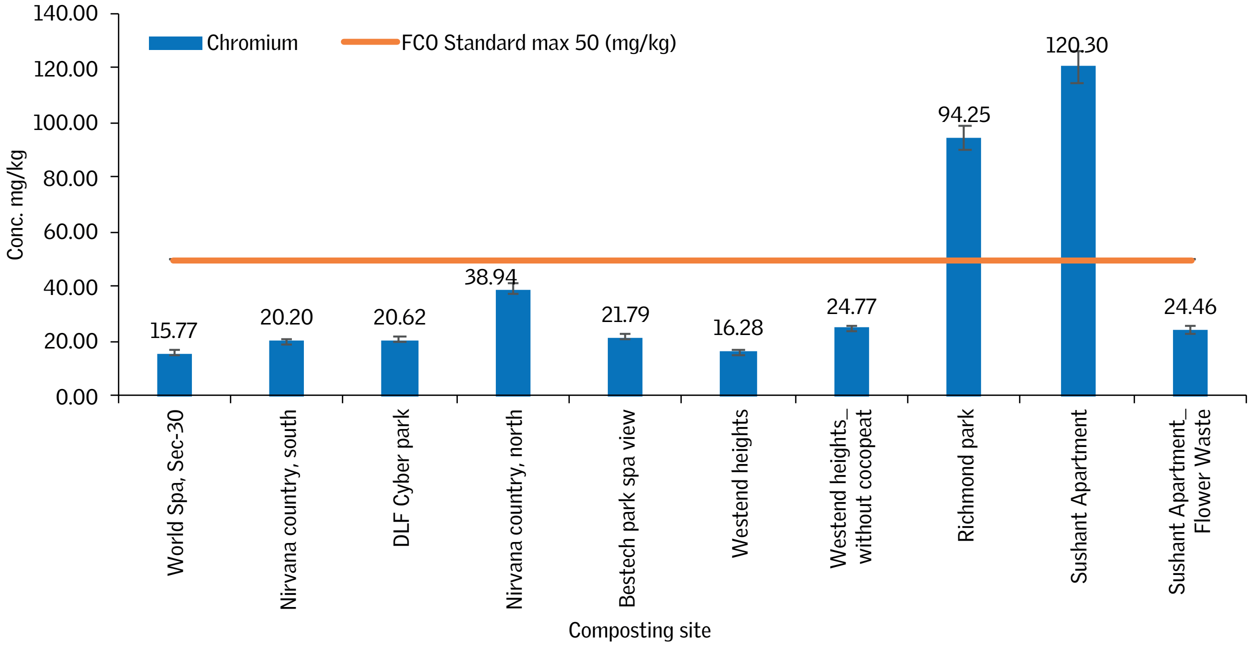
Mercury analysis

Fig. 8: Mercury in the compost



Chromium analysis

Fig. 9: Chromium content in compost



Nickel analysis

Fig. 10: Nickel in compost

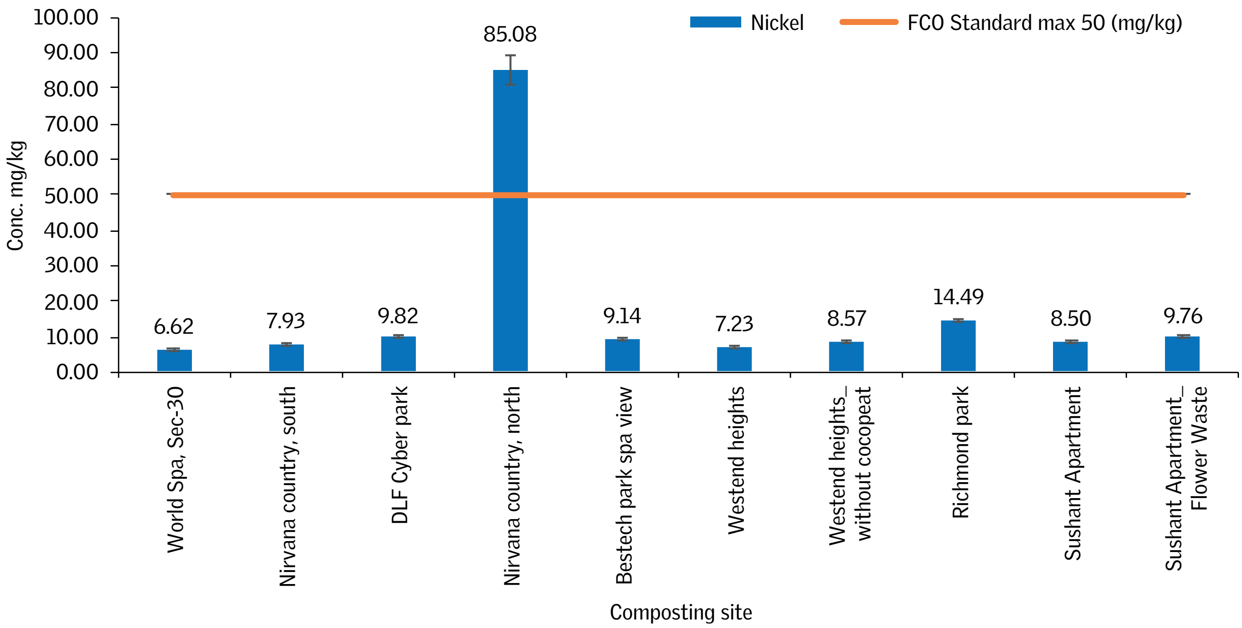


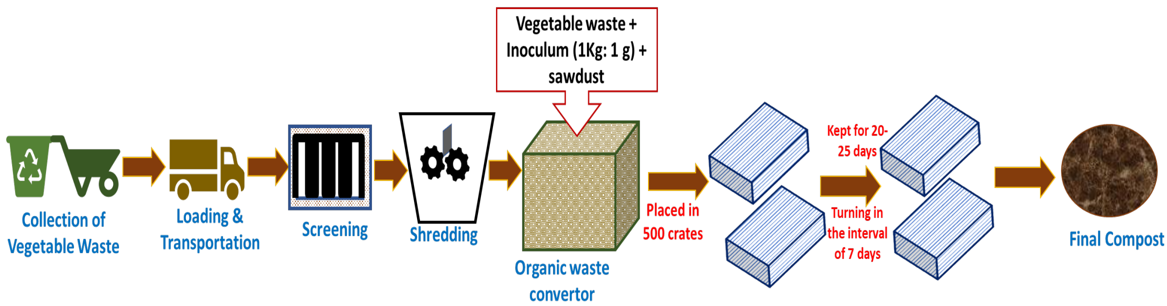
Table 8: Observations and recommendations

S. no.	Sample details	Observations and recommendations
1	World Spa, Sec-30, Gurugram, Haryana	Sample was high in moisture and microbes. Presence of high moisture content in the sample may be one reason for the high content of pathogens in sample. Note: Aeration and sunlight exposure may solve the problem
2	Nirvana Country, South, Gurugram, Haryana	Sample was high in pH (more than desirable), moisture and pathogens. Note: Aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.
3	DLF Cyber Park, Gurugram, Haryana	The sample was low in pH (acidic), moisture was high, pathogen content is higher than the standard. Note: High content of citrus peels in the first set of samples which decreases the pH.
4	Nirvana Country, North, Gurugram, Haryana	The sample conductivity was high, pH not within the limit (more than desirable) and high in moisture content. It was high in *Salmonella* and faecal coliform (FC) but *E. coli* was within the limit. The sample showed a high amount of nickel. Note: Proper segregation or sorting, aeration, turning, sunlight exposure and complete digestion may solve the problem.
5	Bestech Park Spa View, Gurugram, Haryana	The sample was high in moisture content and pathogens (*Salmonella*, *E. coli* and faecal coliform). The presence of high moisture content in the sample may be one reason for high content of pathogens in the sample. Note: Aeration, turning, sunlight exposure and providing sufficient time for digestion of organic matter may solve the problem.
6	Westend Heights, Gurugram, Haryana	Sample conductivity was very high possibly due to the high content of salts in the raw material or due to cocopeat as the sample without cocopeat showed lesser *E. coli* compared to the sample with cocopeat. The sample was high in pathogen content (*Salmonella*, *E. coli* and faecal coliform). The presence of high content of pathogens in the sample may be due to contamination from source or organic contents in sample. Note: Aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.
7	Richmond Park, Gurugram, Haryana	The sample was high in moisture and pathogen content (*Salmonella*, *E. coli* and faecal coliform), heavy metals mercury and chromium also high in the second set of samples. The presence of high content of pathogens in the sample may be due to contamination from source. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem
8	Sushant Apartments, Gurugram, Haryana	The pH of the sample of vegetable compost was not within the limit (more basic than desirable) and it had high pathogen content (*Salmonella*, *E. coli* and faecal coliform). Heavy metals chromium and mercury was also high in sample. Flower compost in same composting site showed high pH (more basic than desirable), *Salmonella* contamination is very low but *E. coli* and faecal coliform contamination was significant. Presence of high content of pathogens in vegetable as well as flower compost sample may be due to contamination from source. Further, presence of high content of chromium and mercury in vegetable compost may be due to contamination from source or in process. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for digestion of organic matter may solve the problem.

4.2 UTTAR PRADESH

1. ISBT T.P. Nagar, Agra, Uttar Pradesh (OWC-decentralized)

Capacity	*: 1 TPD*
Operator	*: Purna Pro.*
Waste	*: Vegetable waste*
Technology	*: Organic waste converter and tub composting*
Source	*: Vegetable Market (Subji Mandi)*
Latitude, longitude	*: 27.20594, 77.984408*

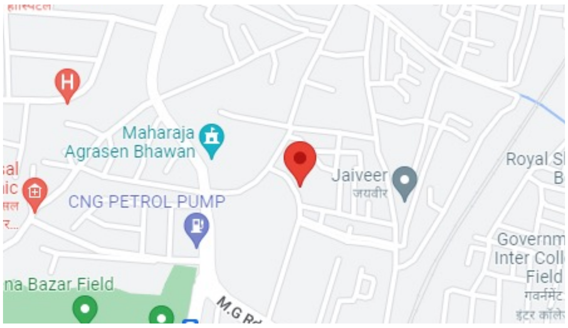


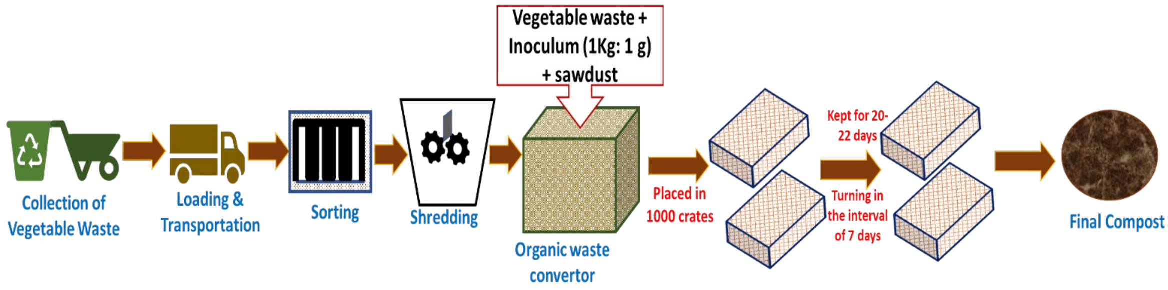
Picture 9: Location and flow diagram of composting unit in ISBT T.P Nagar

A composting unit with tub composting technology was commissioned in January 2019. During the survey, it was found that the treatment system was running on full capacity of 60 kg/day. The total area occupied by the plant is 900 square feet and it is located near the market. The plant receives vegetable waste on a daily basis from the vegetable market. The received vegetable waste is initially shredded and placed into an organic waste convertor along with the microbial inoculum. The inoculum is mixed with waste in the proportion of 1 g per 1 kg of waste. Sawdust is also added to maintain the moisture content. After proper mixing, it is placed in crates (500) and maintained for 20–25 days, with turning after every seven days. The compost is then used for gardening in Nagar Nigam parks. Until now, no attempt was made to check the quality of compost and no income has been generated by selling compost. The cost of project is approximately Rs 30 lakh.

2. Rajnagar, Loha Mandi, Agra, Uttar Pradesh (OWC-decentralized)

Capacity	*: 2 TPD*
Operator	*: Purna Pro.*
Waste	*: Vegetable waste*
Technology	*: Organic waste converter and tub composting*
Source	*: Vegetable market (Subji Mandi)*
Latitude, longitude	*: 27.184335, 77.990745*





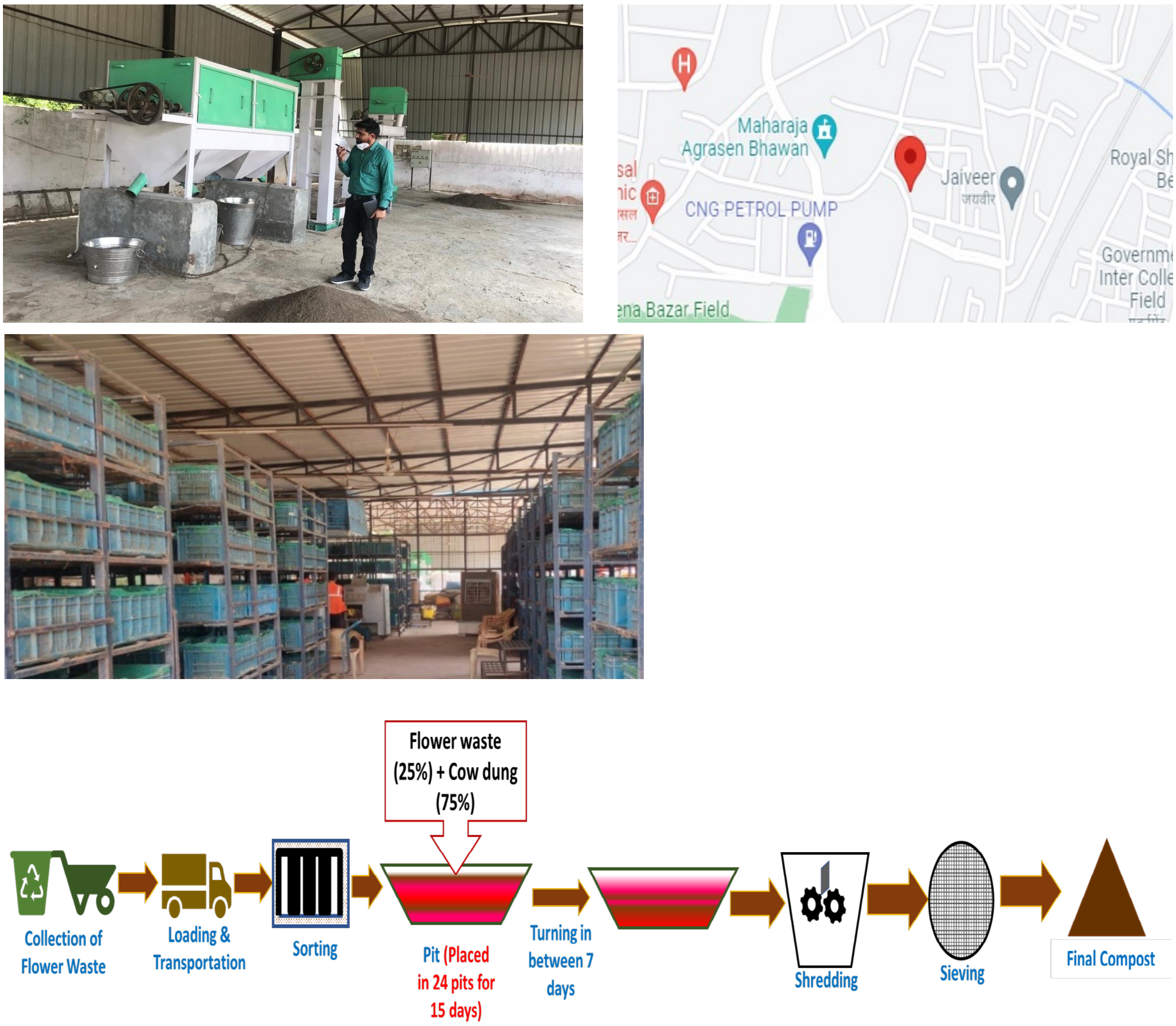
Picture 10: Location and flow diagram of composting unit in Raj Nagar (vegetable waste)

Rajnagar is a locality in Lohamandi in Agra district of Uttar Pradesh. A composting unit in Rajnagar was commissioned in May 2021. As per observation, the system was running on full capacity. The total area occupied by the plant is 1,400 square feet and it is located in a residential area. The plant receives 2 tonne of vegetable waste on a daily basis from the vegetable market.

Prior to composting, vegetable waste is sorted from other waste and shredded to reduce the volume. In the organic waste composter machine, shredded waste is placed along with bio inoculum (1 g/kg of waste) and sawdust. They are placed in crates for 20–22 days for organic decomposition of waste, with periodic turning of the waste every seven days. Around 1,000 crates were used for the composting process. The end use of compost is for gardening in the Nagar Nigams. So far, no revenue has been earned from the compost. The cost of project is approximate Rs 60 lakh and O&M per month is Rs 1.25 lakh.

3. Rajnagar, Lohamandi, Agra, Uttar Pradesh (OWC-decentralized)

Capacity : *2 TPD*
Operator : *Indian Agro Agencies*
Waste : *Flower waste and cow dung*
Technology : *Organic waste converter and tub composting*
Source : *Temple and gaushalas*
Latitude, longitude : *27.184335, 77.990745*



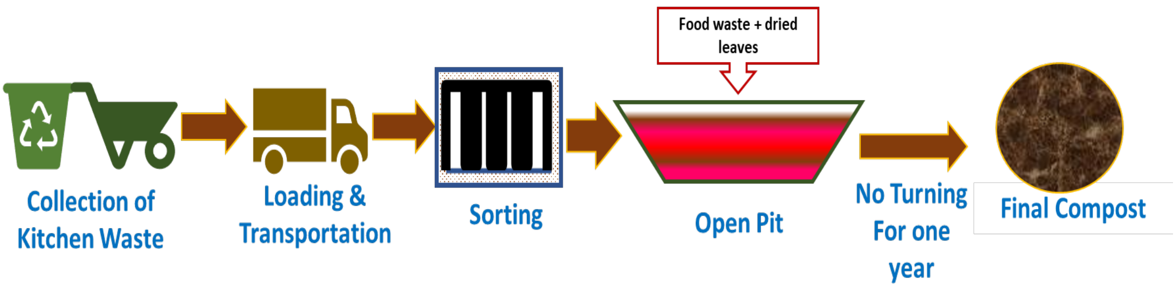
Picture 11: Location and flow diagram of composting unit in Raj Nagar (flower waste)

Another composting unit in Rajnagar specifically for treating flower waste by pit composting technology was commissioned in December 2018. The plant receives flower waste on a weekly basis. It can convert 2 tonne of waste per day into compost. The land occupied for setting up the unit is 1,400 square feet.

The first step in the composting process is sorting of flower waste. Subsequently, flower waste and cow dung is layered in the open pits in a ratio of 1:3 and kept for 15 days, with recurrent turning every seven days. Twenty-four pits are used for composting process. The output from the pits is sent for shredding and sieving process and packed for sale. The compost is sold through Amazon online services and the monthly earning is Rs 6,000. The cost of the project is approximately Rs 15 lakh and O&M per month is Rs 20,000.

4. Dhandupura, Agra, Uttar Pradesh (OWC-decentralized)

Capacity : *4 TPD*
Operator : *NWMS*
Waste : *Kitchen waste*
Technology : *Organic waste converter (or natural pit composting)*
Source : *Hotels*
Latitude, longitude : *27.158087, 78.074678*



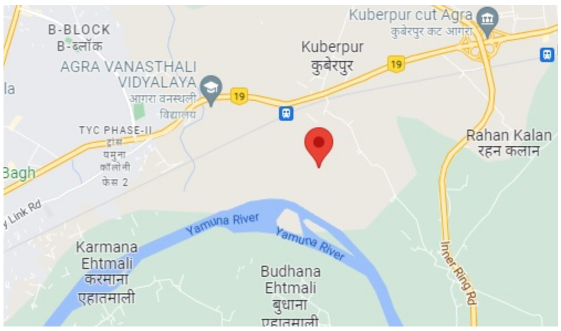
Picture 12: Location and flow diagram of composting unit in Dhandupura

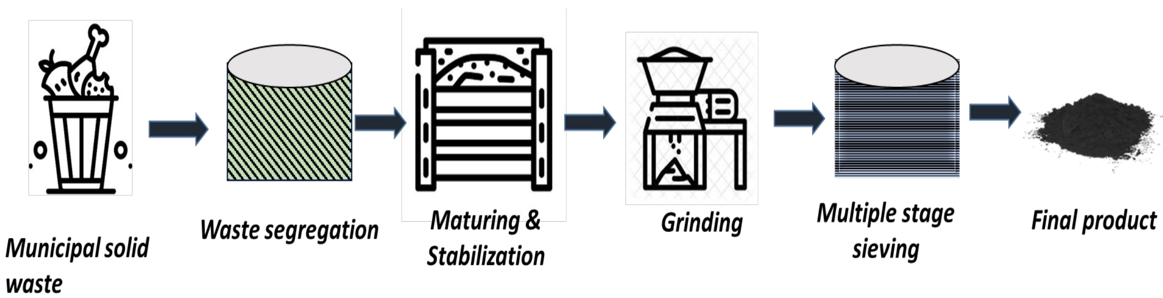
Dhandupura is located in Agra division in Agra district, Uttar Pradesh. The composting unit with capacity of 4 tonne per day was commissioned in 2019. The plant is located in agricultural land and occupies around 5,000 square feet. It processes the food waste received from different hotels. It received around 50 kg every day when the plant was established. However, due to the unavailability of waste material, the plant is not operational.

Currently, the technology used is based on natural pit composting. Initially, the waste is sorted to eliminate non-biodegradable materials. The waste is then arranged in layers in the pits and kept for one year without any turning during the process. The output from the pits is sold in the market.

5. Kuberpur, Agra, Uttar Pradesh (windrow-dentralized)

Capacity : *300 TPD*
Operator : *KAPS, Agra*
Waste : *Mixed municipal waste*
Technology : *Windrow centralized composting*
Source : *Municipal solid waste*
Latitude, longitude : *27.207289, 78.095278*





Picture 13: Location and flow diagram of composting unit in Kuberpur

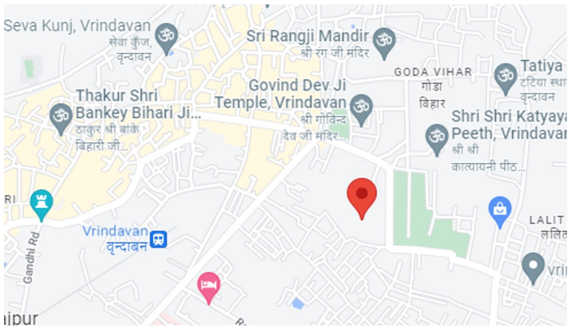
Kuberpur is a village on the border of Agra district. It is located in Khandauli Block and is 11 km from Khandauli.

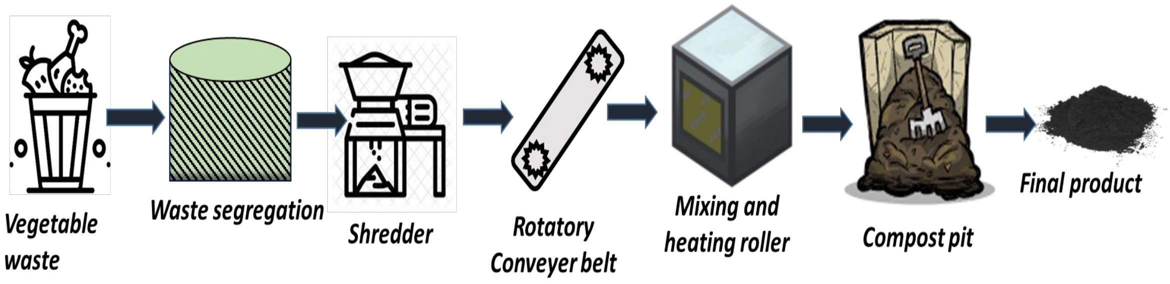
A composting unit with a production capacity of 300 tonnes per day was commissioned in 2020. The plant is near agricultural land and industrial area and occupies a huge area of 2 acre. It processes municipal solid waste via windrow composting technology.

The main source of the input material is municipal solid waste from Agra Municipal Corporation. The process begins with sorting of the input material followed by maturing and stabilization for three weeks. When the compost is ready, multiple stages of sieving is carried out to prepare compost of fine particles before packaging is done. The compost is sold via Kribhco (Krishak Bharati Cooperative Limited) and Rs 50,000 of revenue is generated every month. The CapEx plus OpEx of the project for three years is approximately Rs 11.26 crore and the O&M cost with electricity per month is Rs 15 lakh.

6. Gaura Nagar, Vrindavan, Uttar Pradesh

Capacity : *5 TPD*
Operator : *Purna Pro.*
Waste : *Vegetable waste*
Technology : *Organic waste converter (OWC)*
Source : *Vegetable market (Subji Mandi)*
Latitude, longitude : *27.576974, 77.701768*





Picture 14: Location and flow diagram of composting unit in Gaura Nagar

Vrindavan is a historical city in Mathura district of Uttar Pradesh. It is 11 km from Mathura City and near Agra–Delhi highway.

A fully functional compost unit for processing vegetable waste is located in Vrindavan. The plant was commissioned in October 2021 with a capacity is 5 tonne per day. The land occupied for setting up of the compost unit was 10,000 square feet. The technology used is organic waste converter. As soon as the input materials is received, sorting is done and conveyed to cabins where the vegetable waste is placed. Subsequently, the waste is shredded and conveyed via rotary conveyer for mixing and the heating process. The output generated after heating is placed in compost pits and kept undisturbed for seven to ten days. The prepared compost is used for gardening in Nagar Nigam gardens. The cost of project is approximately Rs 96 lakh and O&M cost with electricity per month is Rs 4.84 lakh.

Sample collection

A total of six compost samples were collected from six different locations of Agra and Vrindavan, Uttar Pradesh, in May 2022, and five compost samples were collected from five different locations of Agra and Vrindavan, Uttar Pradesh, in July 2022. These samples were tested and compared for quality parameters as given in regulation FCO 2009. The composting technologies were evaluated on the basis of average values of observed results in different sets of samples (see *Table 9: Details of compost sample collected from different locations in Uttar Pradesh* and *Table 10: Physico-chemical and microbial parameters of compost of Uttar Prades*h). See *Annexure 2* for results of individual replicates samples.

Table 9: Details of compost sample collected from different locations in Uttar Pradesh

S. no.	Sample details	Technology	Capacity	Latitude, longitude	Operator	Waste
1	OWC-decentralized, ISBT T.P. Nagar, Agra	OWC and tub composting	1 TPD	27.20594, 77.984408	Purna Pro.	Vegetable waste
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	OWC and tub composting	2 TPD	27.184335, 77.990745	Purna Pro.	Vegetable waste
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra	OWC and pit composting	2 TPD	27.184335, 77.990745	Indian Agro Agencies	Flower waste and cow dung
4	Dhandupura, Agra	OWC or natural pit composting	4 TPD	27.158087, 78.074678	NWMS	Kitchen waste
5	Centralized windrow-based composting, Kuberpur, Agra	Windrow composting	300 TPD	27.207289, 78.095278	KAPS, Agra	Mixed municipal waste
6	OWC-Gaura Nagar, Vrindavan	OWC and pit composting	5 TPD	27.576974, 77.701768	Purna Pro.	Vegetable waste

Test parameters evaluation based on organic compost standard FCO 2009

Table 10: Physico-chemical and microbial parameters of compost of Uttar Pradesh

Sample details	pH (6.5–7.5)	Conductivity <4.0 ds/m	Moisture, % by weight, maximum 25.0	Total organic carbon, per cent by weight, min. (12)	Total nitrogen (as N), per cent by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), per cent by weight, min. 0.4	Total potash (as K_2O), per cent by weight, minimum 0.4	Faecal coliforms MPN per g total solids (dry weight)	*E. coli* MPN per g total solids (dry weight)	*Sal-monella* spp. MPN/4 gram of total solids (dry weight) (USEPA)
ISBT T.P. Nagar, Agra	9.90	21.40	15.92	26.95	1.81	15	0.99	2.28	16	6	977
Rajnagar, Agra	9.27	13.68	26.44	18.30	1.47	12	0.95	1.68	103	65	5,405
Rajnagar, Agra flower compost	8.96	3.54	43.88	14.90	1.24	12	0.74	0.94	11	6	179,456
Dhandupura, Agra	9.24	4.62	22.08	14.60	0.62	24	1.63	0.91	4	4	1,760,882
Centralized-Kuberpur, Agra	8.84	4.13	16.55	8.82	0.64	14	0.29	1.05	4	3	1,443
Goura Nagar, Vrindavan	8.90	11.37	3.78	17.95	1.23	15	0.60	1.13	19	6	12,657
Average	9.18	9.79	21.45	16.92	1.17	14	0.87	1.33	26	15	326,803
SD	0.39	7.08	13.38	5.98	0.46	4	0.45	0.54	38	24	706,017
Median	9.10	8.00	19.32	16.43	1.23	14	0.85	1.09	13	6	9,031
Minimum	8.84	3.54	3.78	8.82	0.62	12	0.29	0.91	4	3	977
Maximum	9.90	21.40	43.88	26.95	1.81	24	1.63	2.28	103	65	1,760,882

First replicate in May 2022, second replicate in July 2022

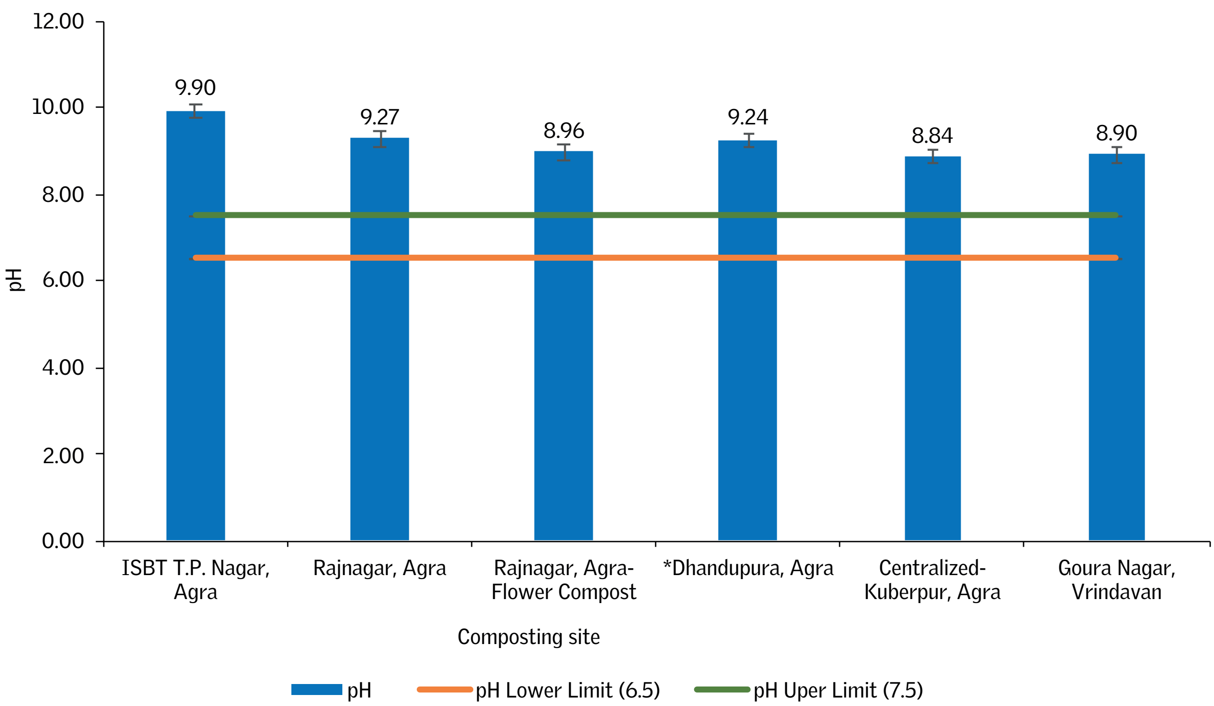
Results and discussion

Multiple parameters were analysed in this study as presented in Table 10. The result obtained for some highly significant parameters is as follows:

pH

The pH of the compost samples was analysed and average values were calculated to be in the range of 8.84–9.90. The Fertilizer Control Order (FCO) 2009 suggested the pH should be in the range of 6.5–7.5. All sites showed higher pH or alkaline pH which is higher than the permissible limit of FCO standard (6.5–7.5).

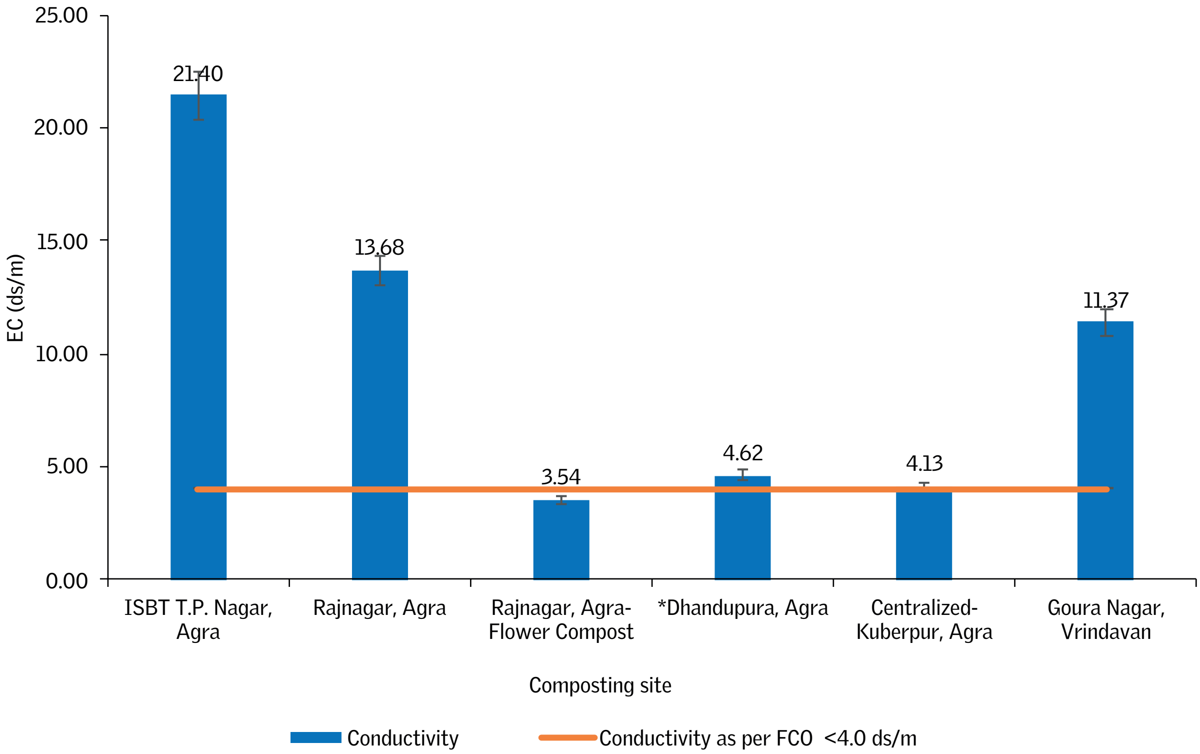
Fig. 11: pH of the compost, Agra, Uttar Pradesh



Electrical conductivity (EC)

The electrical conductivity for the compost is in the range of 3.54–21.40 dS/m. As per the FCO standard recommendation, the EC value should be less than 4 dS/m. However, electrical conductivity in ISBT TP Nagar, Rajnagar and Gaura Nagar Vrindavan showed very high EC values compared to other sites. Rajnagar flower compost, Dhandupura and centralized composting Kuberpur showed EC within the FCO limit. High EC values could be due to the elevated level of sodium or other salts found in food or kitchen raw material used for composting.

Fig. 12: Electrical conductivity of the compost, Agra, Uttar Pradesh



Moisture content

The moisture content of compost samples ranges from 3.78–43.88 per cent. Per cent moisture in samples from Rajnagar vegetable compost (26.44 per cent) and Rajnagar flower compost (43.88 per cent) were observed to be high compared to other sites (3.78–22.08 per cent). This may be due to improper drying conditions. High moisture may lead to high pathogen load in compost samples. Moisture can be controlled by proper sun drying.

C: N ratio

The total organic carbon content of the compost was in the ranges of 8.82–26.95 per cent and the total nitrogen content was in the range of 0.62–1.81 per cent. The nitrogen content is very low in Dhandupura (0.62 per cent) and Centralized Kuberpur (0.64 per cent). Total carbon is also very low in Centralized Kuberpur (8.82 per cent).

The C/N ratio of the collected compost except Dhandupura (24:1) as per FCO standard was in the range of 12:1–15:1.

Fig. 13: Moisture content of the compost, Agra, Uttar Pradesh

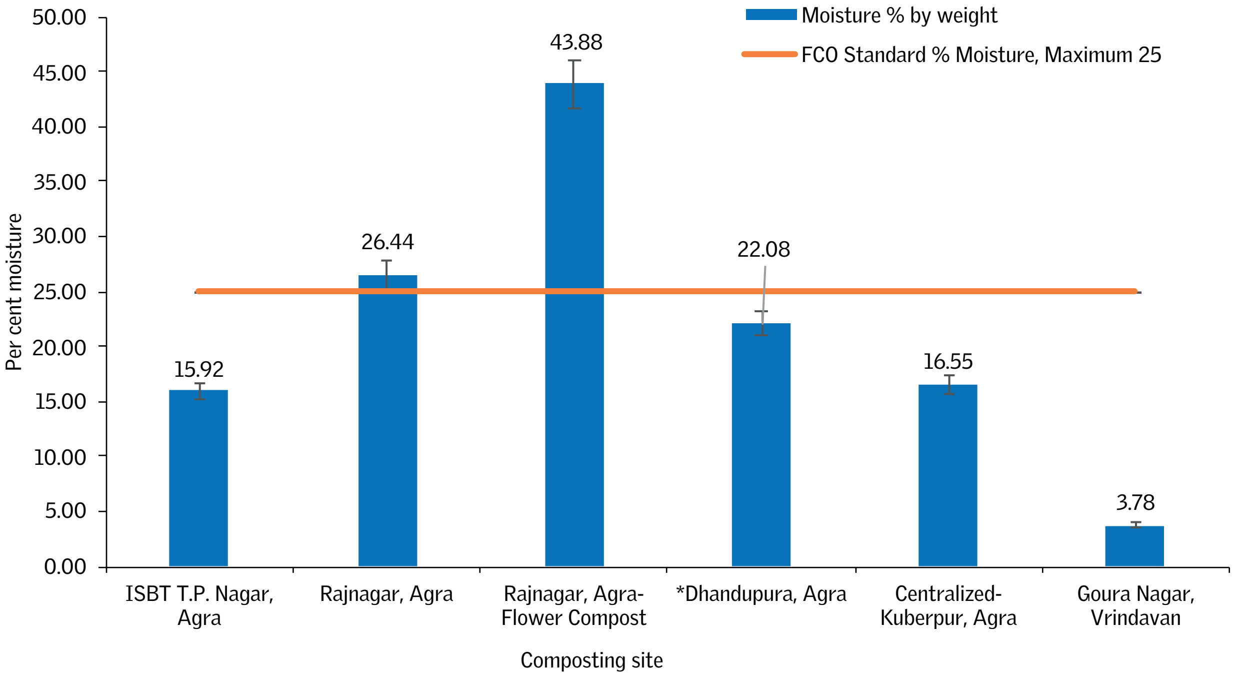
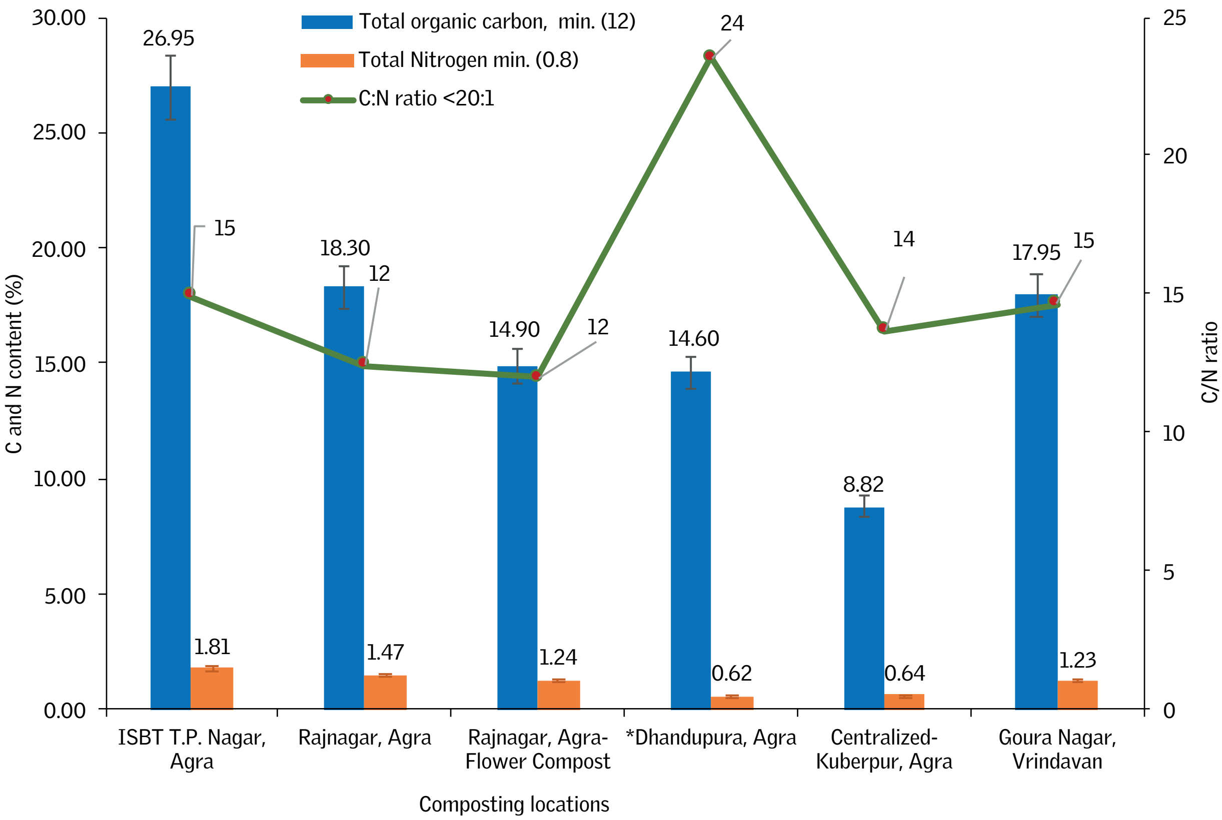


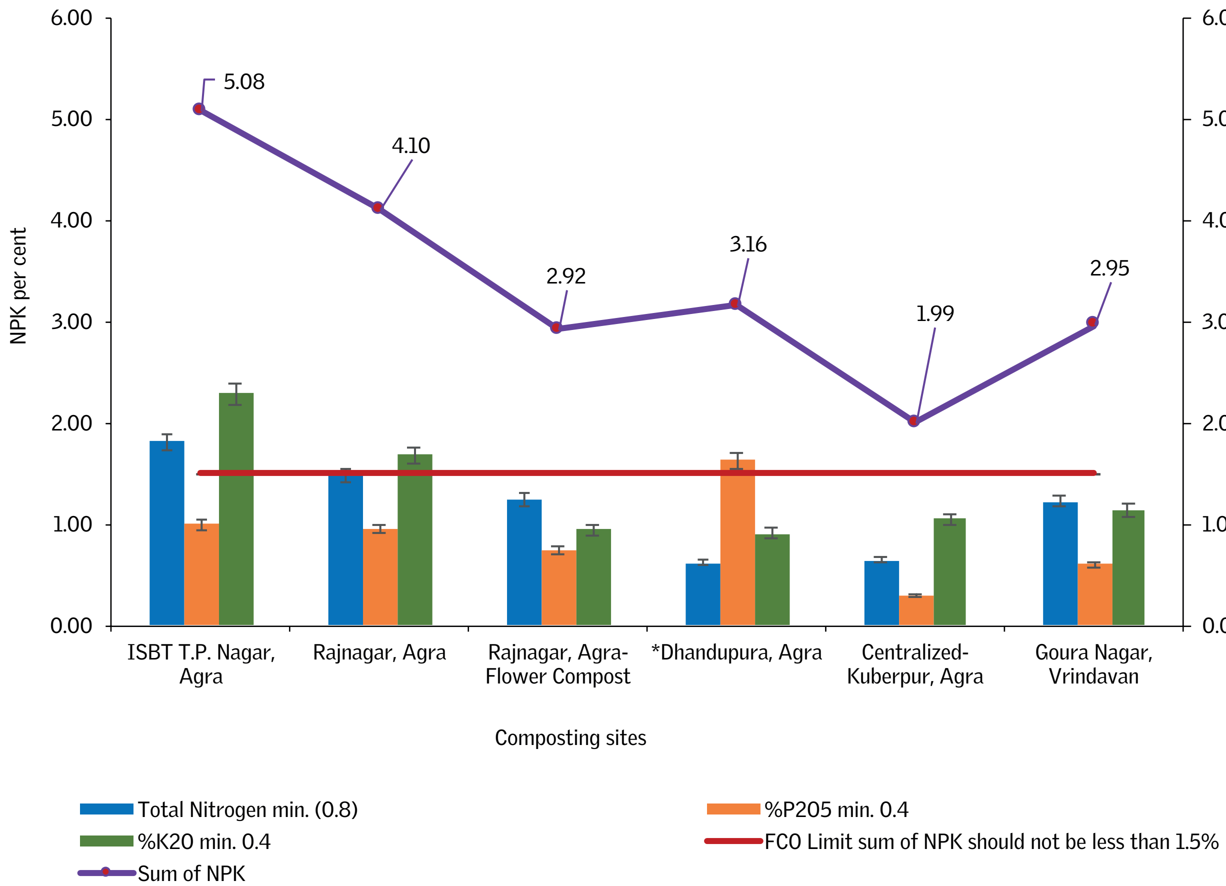
Fig. 14: C:N ratio of the compost, Agra, Uttar Pradesh



NPK value

The NPK value indicates the amount of nitrogen, phosphorus and potassium in the compost or fertilizer. These three essential macronutrients are needed for plant growth. The appropriate NPK ratio for fertilizer under Indian soil conditions is stated to be 4:2:1. The NPK ratio of the compost was observed to be 1:1:2, showing that the compost overall was poor in nitrogen content and rich in potassium content. The NPK of the compost was in the range of 1.99–5.08 per cent. As per FCO standard 2009, the NPK value should not be less than 1.5 per cent. The observed results showed all the sites were rich in NPK and within this regulatory limit.

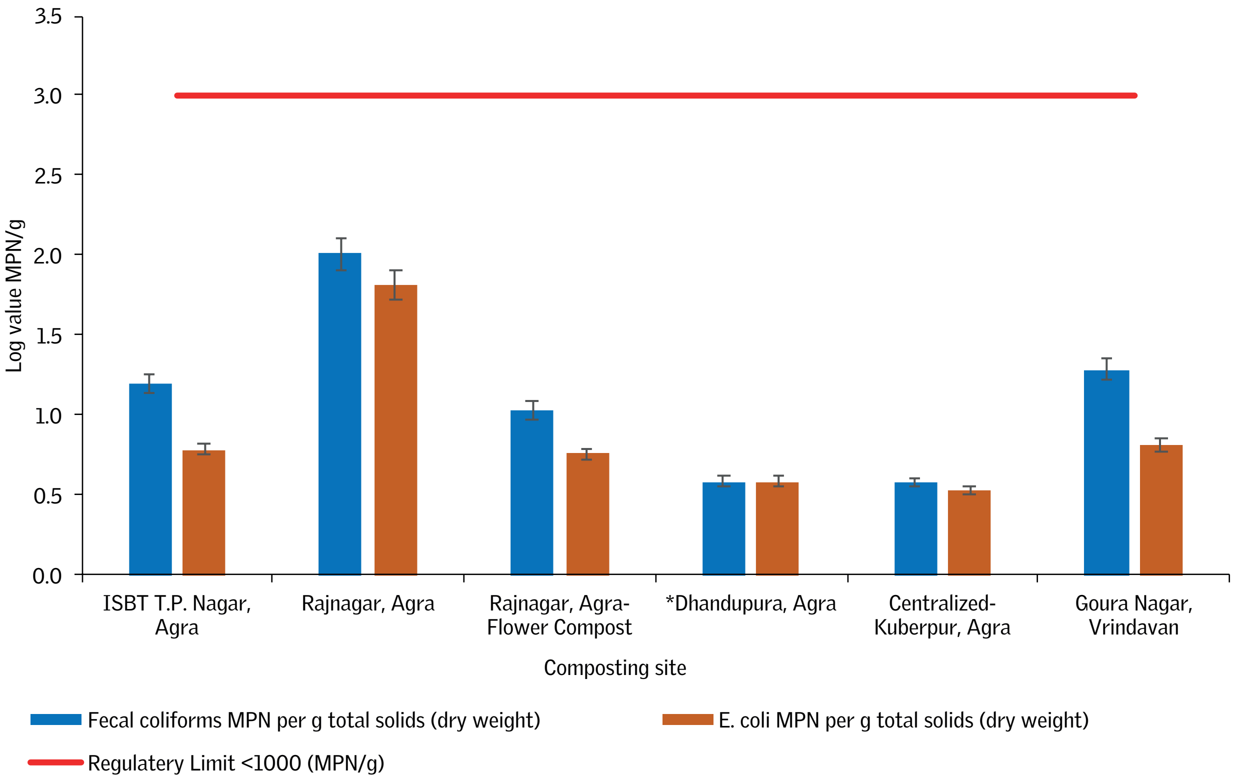
Fig. 15: Per cent NPK content of the compost, Agra, Uttar Pradesh



Bacterial contamination (*E. coli* and faecal coliform)

To assess the microbial safety of compost, we examined the inactivation of microbial indicators for potential bacterial pathogens. Indicator microorganisms are used as a simple and reliable measure of the potential risk to human health. *E.coli* and faecal coliform (FC) were observed to exist in all the tested locations and hence does not meet the FCO standard (pathogens—nil). However, when the *E. coli* and faecal coliform load is compared with global standards (USEPA, WHO), all the sites below the global standards 1,000 or 3 $\log_{10}$ MPN/g and well accepted.

Fig. 16: Faecal coliform and *E. coli* in the compost, Agra, Uttar Pradesh



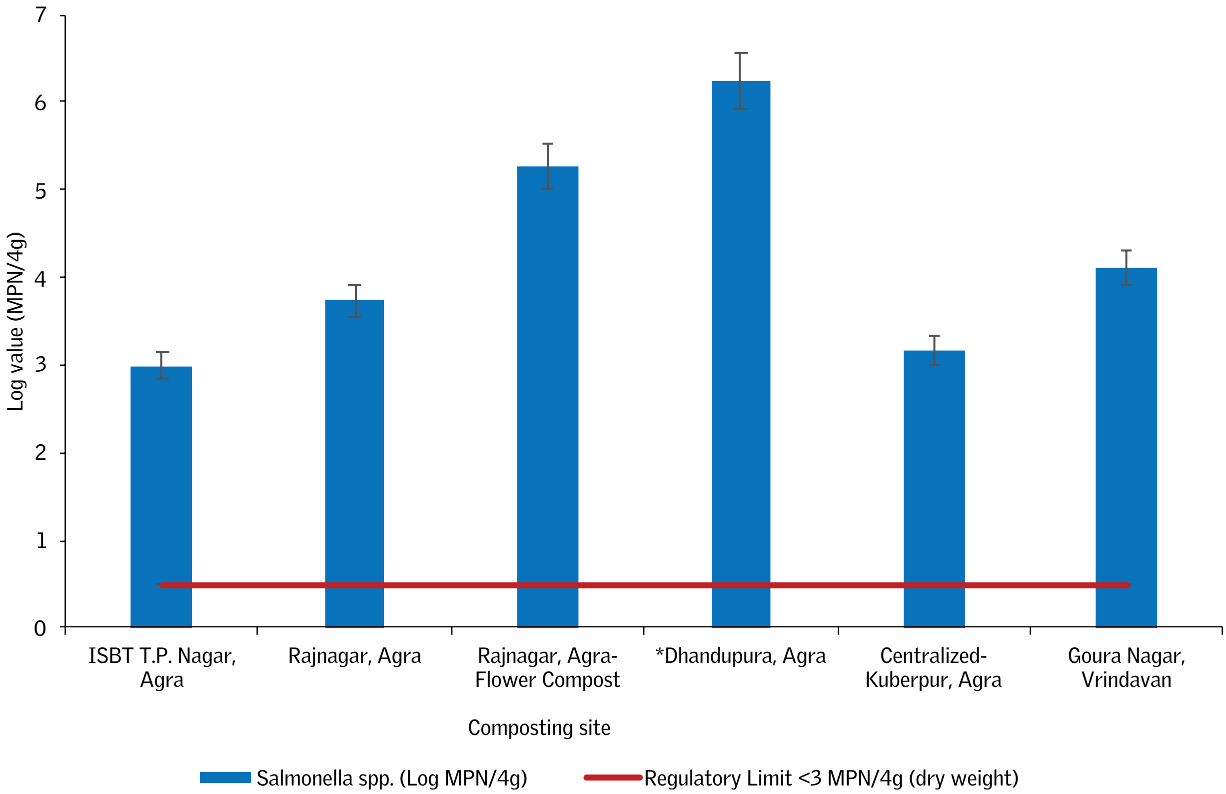
***Salmonella* spp.**

Salmonella is a pathogen that may find its way into the compost through contaminated food waste material. All the compost samples contain *Salmonella* spp. (more detailed study is required to identify whether the *Salmonella* bacteria are typhoidal or non-typhoidal strains) in significant numbers that are higher than the standard value. The WHO/USEPA standard limit of *Salmonella* in compost and biosolids is 3 MPN/4 g.

All the sites showed high amounts of *Salmonella* spp.

Aerobic thermophilic conditions for more than 30 days at 55–65°C and proper sun drying for a period of four to five days can be provided to reduce the risk of biological contamination.

Fig. 17: *Salmonella* spp. in the compost, Agra, Uttar Pradesh



Heavy metals

Table 11: Heavy metal concentration in compost in Uttar Pradesh

Sample details	Arsenic (mg/kg) max. 10.001	Mercury (mg/kg) max 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1,000
ISBT T.P. Nagar, Agra	0.00	0.16	5.60	31.48	64.46	21.71	12.61	151
Rajnagar, Agra	0.07	0.34	32.80	98.56	337.95	96.43	38.31	721
Rajnagar, Agra flower compost	0.10	0.25	93.71	159.93	1,004.25	256.55	112.85	1844
*Dhandupura, Agra	0.08	0.02	1.44	38.34	31.44	15.66	14.97	90
Centralized Kuberpur, Agra	0.03	0.15	2.92	123.67	122.31	19.49	55.53	299
Goura Nagar, Vrindavan	0.00	0.22	1.33	31.40	82.14	10.04	22.08	142
Average	0.05	0.19	22.96	80.56	273.76	69.98	42.72	540.99
SD	0.04	0.11	36.70	54.94	374.14	96.88	37.96	678.59
Median	0.05	0.19	4.26	68.45	102.22	20.60	30.19	225.00
Minimum	0.00	0.02	1.33	31.40	31.44	10.04	12.61	89.85
Maximum	0.10	0.34	93.71	159.93	1,004.25	256.55	112.85	1,843.50

Arsenic: Arsenic in all sites was found within the prescribed limit of FCO standard.

Mercury: All the compost samples except Dhandupura and Centralized-Kuberpur, Agra, showed significant contamination of mercury. This might be due to the contamination from the raw material or through process contamination.

Cadmium: Compost samples of both sites of Rajnagar and ISBT TP Nagar showed high concentration of cadmium contamination. This may due to the contamination from the raw material or through process contamination.

Chromium: Compost samples of both sites of Rajnagar and Kuberpur are showing high concentration of cadmium contamination. This may due to the contamination from the raw material or by in process.

Copper: Rajnagar flower compost showed very high contamination of copper, and Rajnagar vegetable waste compost also showed slightly high copper contamination than the desirable limit. This may due to the

Fig. 18: Mercury content in compost, Agra, Uttar Pradesh

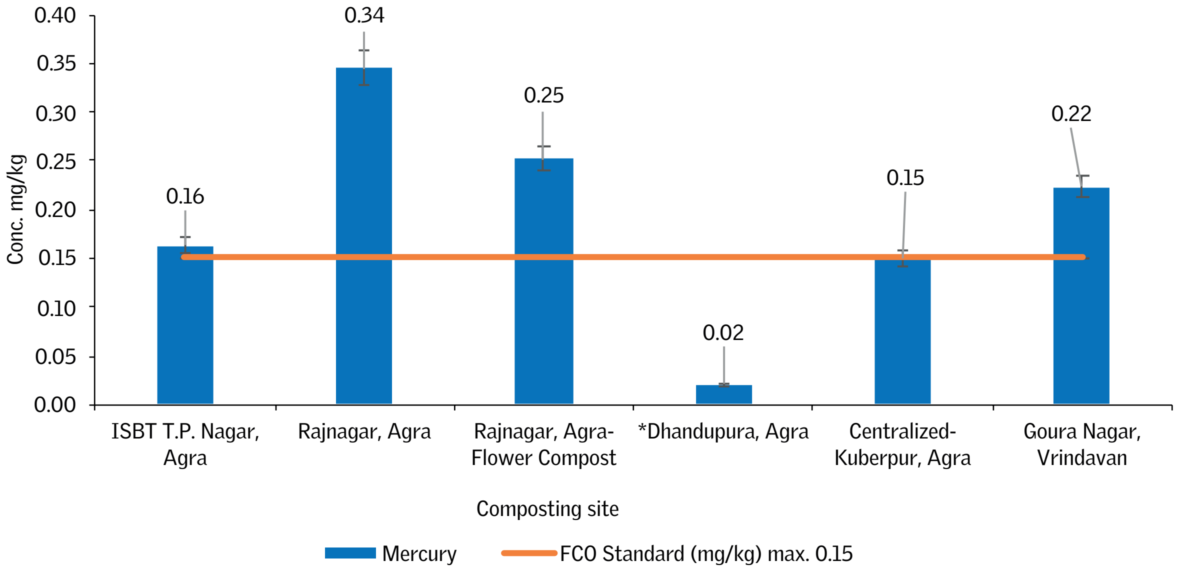


Fig. 19: Cadmium in the compost, Agra, Uttar Pradesh

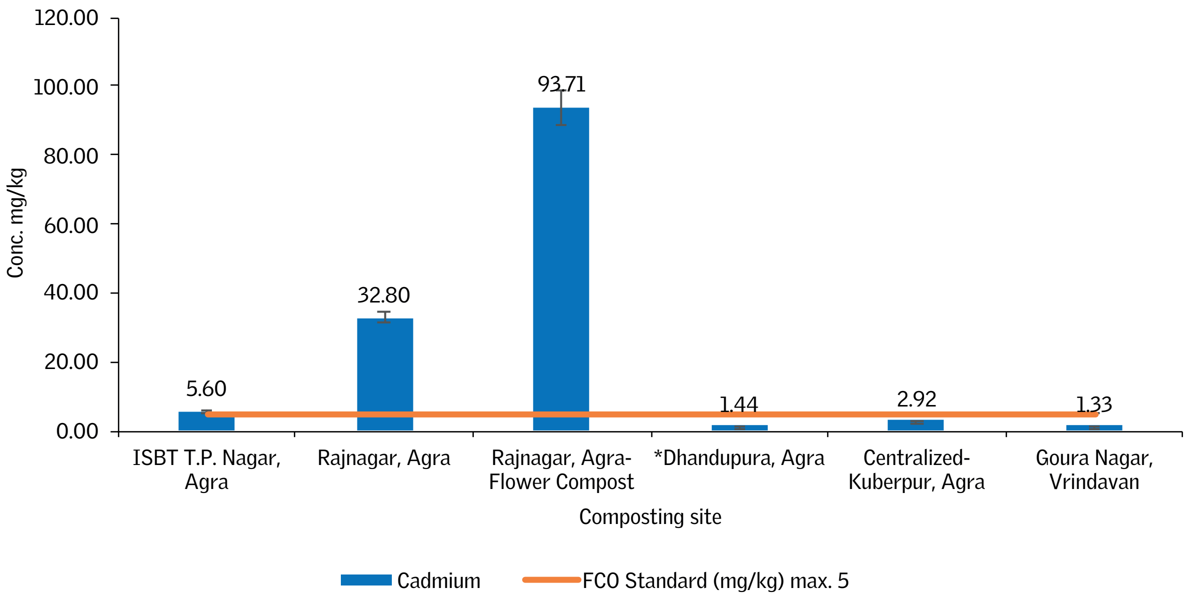


Fig. 20: Chromium content in the compost, Agra, Uttar Pradesh

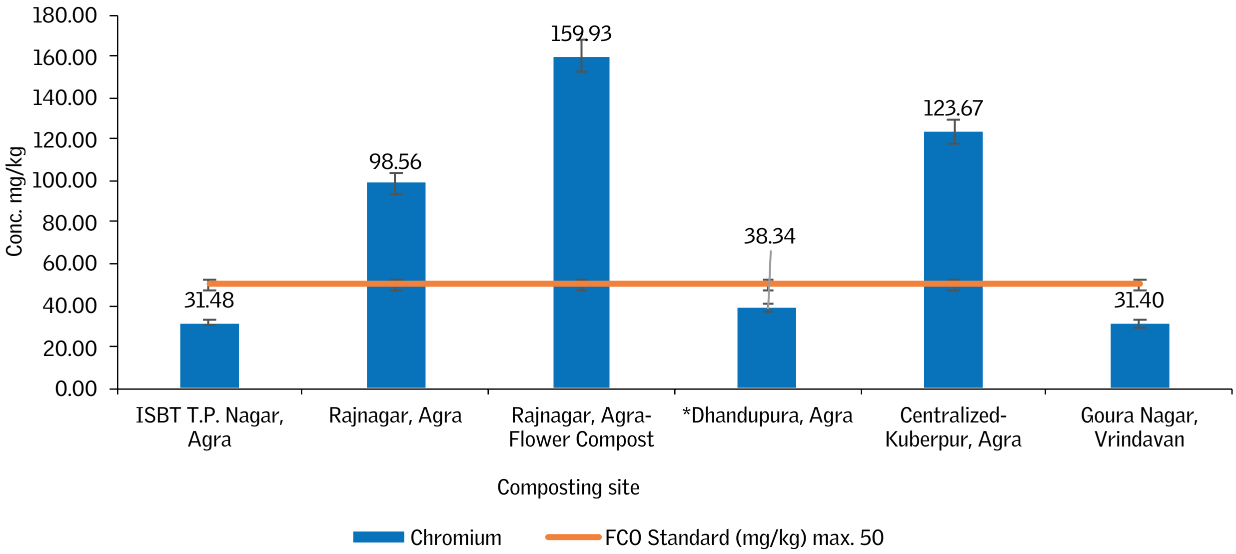
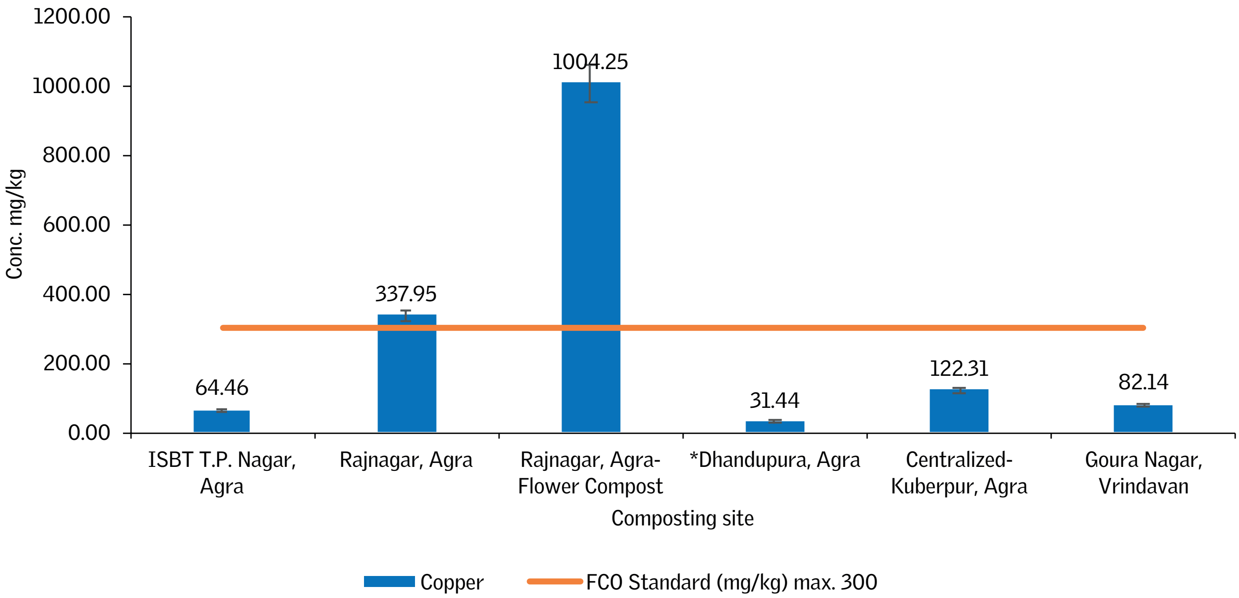


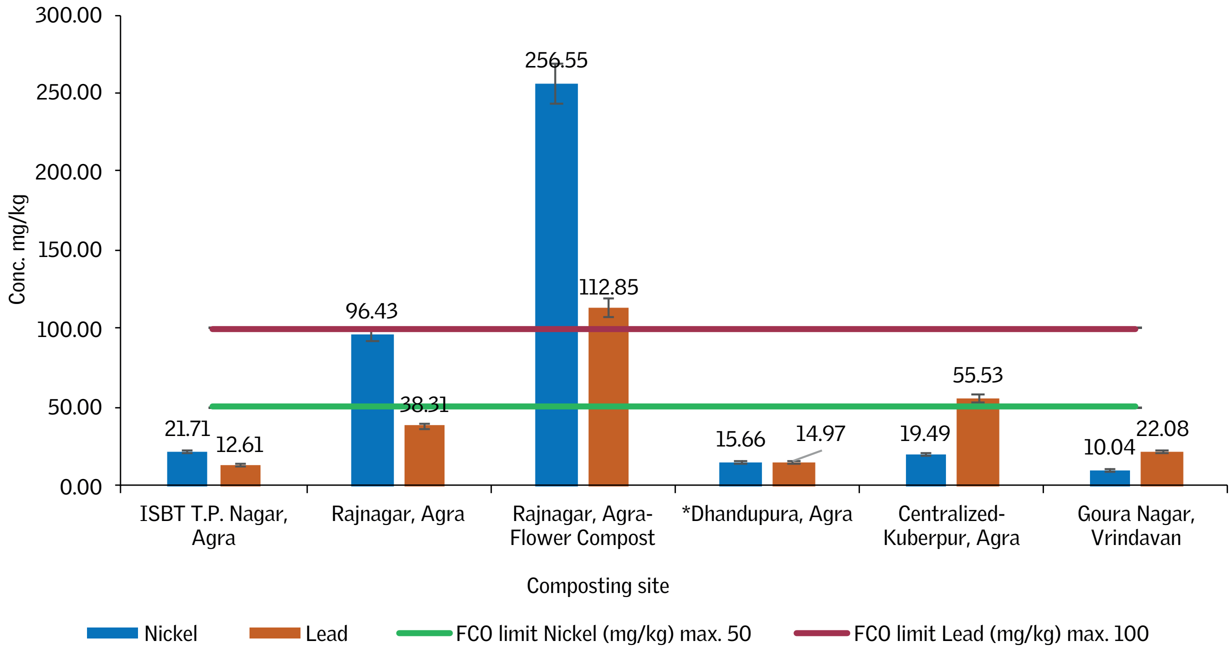
Fig. 21: Copper in the compost, Agra, Uttar Pradesh



contamination from the raw material or through process contamination.

Nickel and lead: Both compost sites of Rajnagar are showing very high contamination of nickel, which was above the desirable limit. All other sites showed values within the FCO limit. Rajnagar flower compost showed

Fig. 22: Nickel and lead in the compost, Agra, Uttar Pradesh



high contamination of lead, which was above the desirable limit as per FCO 2009. All the other sites had values within the FCO limit.

Zinc: Rajnagar flower compost showed high concentration of zinc, with concentration above the FCO limit. In all the other sites, zinc concentration was within the FCO limit. Zinc, however, is less toxic for plants than other heavy metals.

Significant contamination of respective heavy metals may be due to the contamination from source such as cosmetic waste, medicinal waste, contaminated vegetables and fruits. In addition, contamination can occur from the machinery and additives used for composting and from soil or land during compost drying. Segregation of waste in households and sorting of waste at the site may solve the problem of heavy metal contamination.

Fig. 23: Zinc in the compost, Agra, Uttar Pradesh

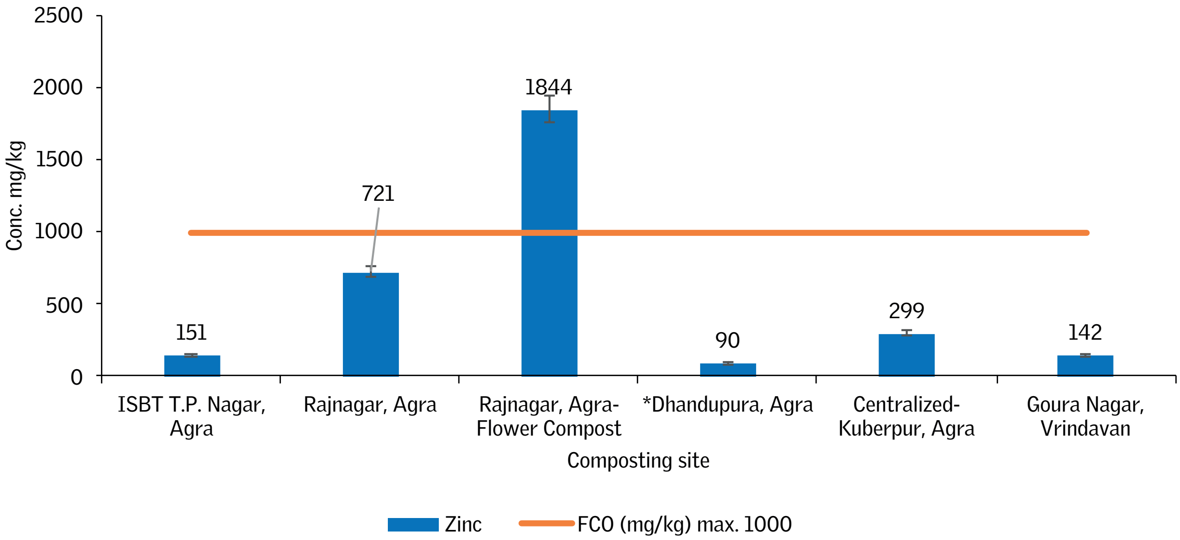


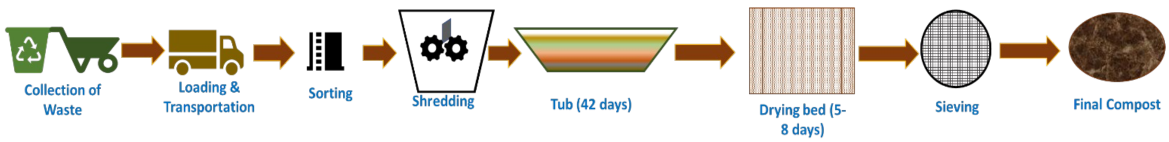
Table 12: Observations and recommendations

S. no.	Sample details	Observation
1	OWC-decentralized, ISBT T.P. Nagar, Agra	Sample conductivity is high and pH is not within the limit (i.e. was more than desirable). Mercury and cadmium levels were high in the sample. Faecal coliform and *E. coli* were within the USEPA limit but *Salmonella* was high. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	Sample conductivity was high and pH not within the limit (i.e. was more than desirable). All heavy metals were high except arsenic, lead and zinc. Faecal coliform and *E. coli* were within the USEPA limit but *Salmonella* is high. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra (flower composting)	Sample pH was not within the limit (i.e. was more than desirable). The sample was high in moisture and *Salmonella*. Except for arsenic all heavy metals were high. Faecal coliform and *E coli* were within the USEPA limit. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.
4	Dhandupura, Agra	Sample pH was not within the limit (i.e. was more than desirable) and sample is high in *Salmonella*. All heavy metals were within the desirable limit of FCO. Faecal coliform and *E coli* within USEPA limit. Note: Aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion n may solve the problem
5	Centralized windrow-based composting, Kuberpur, Agra	The sample pH was not within the limit (i.e. was more than desirable). Chromium was present in significantly high amounts. The sample was high in *Salmonella* but faecal coliform and *E. coli* is within USEPA limit. Total carbon and total nitrogen were also very low when compared to the FCO limits but the C/N ratio was within the limit. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.
6	OWC-Goura Nagar, Vrindavan	Sample conductivity was high and pH not within the limit (more than desirable). Significantly high concentration of mercury was found in the sample. The sample was high in *Salmonella* but faecal coliform and *E. coli* were within the USEPA limit. Note: Proper segregation and sorting, aeration, turning, sunlight exposure and providing sufficient time for organic matter digestion may solve the problem.

4.3 ODISHA

1. Bhadrak Micro Composting Centre (MCC), Odisha

Capacity : 500 kg/day
Operator : ULB
Waste : Food and vegetable
Technology : Aerobic tub composting
Source : Household and municipal waste
Latitude, longitude : 21.055980, 86.523450



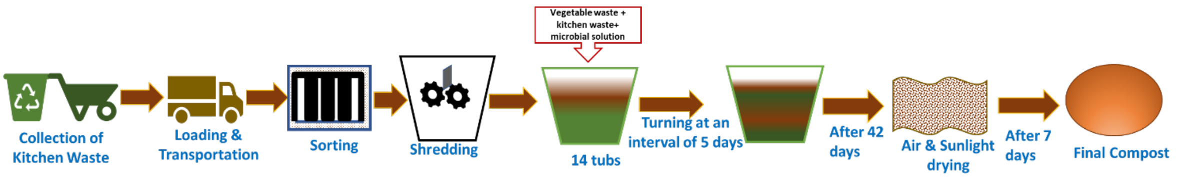
Picture 15: Location and flow diagram of composting unit in Bhadrak

Bhadrak MCC is about 1,000 sq. foot of area with capacity of 500 kg/day. Aerobic tub composting technology is employed at this MCC.

The composting process starts with screening of waste material, where non-biodegradable waste such as plastics are screened out. The remaining waste then undergoes shredding process where size of the waste material is reduced. This mixture is then filled in composting tubs and kept for 42 days with proper turning of waste on every sixth day. The prepared product is harvested after 42 days and kept for sun drying for five to eight days in order to make the compost free from microorganisms. This is followed by sieving to produce the final compost. Thus, it takes a total of 50 days for completion of composting process. The final compost is sold to the farmers for gardening.

2. Paralakhemundi MCC, Odisha

Capacity : 300 kg/day
Operator : ALF
Waste : Food and vegetable
Technology : Aerobic tub composting
Source : Household and municipal waste
Latitude, longitude : 18.789236, 84.093304



Picture 16: Location and flow diagram of composting unit in Paralekhemundi

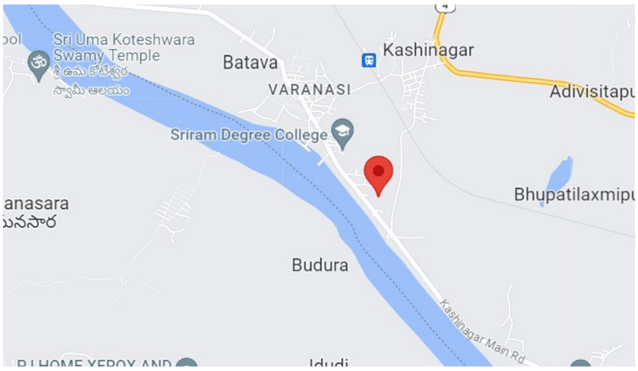
A composting unit in Paralakhemundi was commissioned in 2020. The system was observed to be running at its full capacity of 300 kg/day. The total area occupied by the plant is 3 acre. Aerobic tub composting technology is installed that consists of 14 composting tubs.

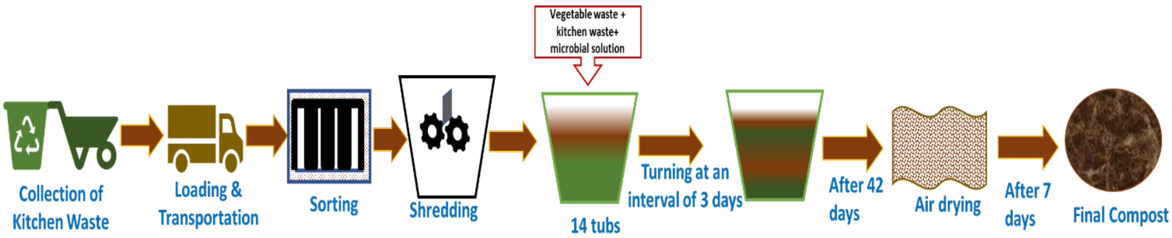
The composting process starts with screening/sorting of waste material followed by shredding and mixing of the waste material. This mixture is then gradually filled inside composting tub along with microbial solution and kept for total 42 days in the tub for completion of process. Turning is done at an interval of every five days to ensure proper aeration for microbial action. After 42 days, the compost is dried in air and sunlight for seven days. Thus, it takes 49–50 days for completion of composting process.

The prepared compost is used for gardening and is sold in market. The cost of the project is approximately Rs 46 lakh. O&M including electricity charges per month is Rs 1 lakh. Total earning of plant by selling compost is about Rs 42,000.

3. Kashinagar MCC, Odisha

Capacity	*: 300 kg/day*
Operator	*: ULB*
Waste	*: Food and vegetable*
Technology	*: Aerobic tub composting*
Source	*: Household and municipal waste*
Latitude, longitude	*: 18.847364, 83.876954*





Picture 17: Location and flow diagram of composting unit in Kashi Nagar

A composting unit in Kashinagar was commissioned in 2019 with a total area of 2 acre and capacity of 300 kg/day. Aerobic tub composting technology consisting of 14 composting tubs is installed.

The composting process starts with screening/sorting of waste material followed by shredding and mixing of waste material. This mixture is then gradually filled inside composting tub with microbial solution followed by proper turning in every three days to ensure proper aeration for microbial action. This mixture is kept for a total of 42 days in the tub for completion of the process. After 42 days, the compost is air dried for seven days. The total time taken for the composting process is 49–50 days. The prepared compost is sold to the customers via an agency. O&M with electricity per month is Rs 95,000 and earning of the plant about Rs 58,000.

4. Hinjilicut MCC (non-black soldier fly [BSF]), Odisha

Capacity : 300 kg/day
Operator : ULB
Waste : Food and vegetable
Technology : Aerobic tub composting
Source : Household and municipal waste
Latitude, longitude : 19.483817, 84.733292

Picture 18: Location and flow diagram of composting unit in Hinjilicut

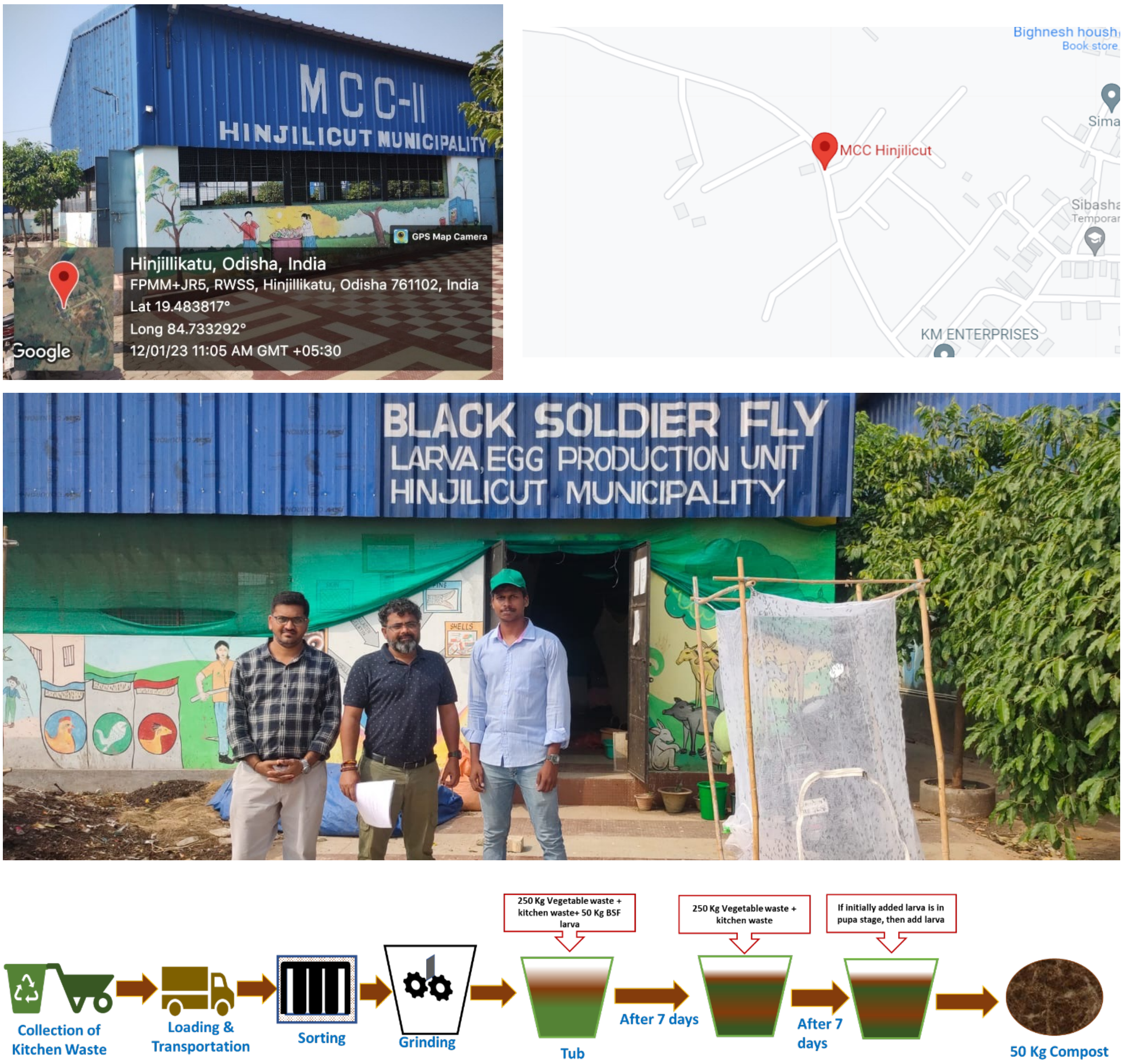
The composting unit in Hinjilicut was commissioned in 2022 with an area of 10,000 sq. feet and capacity of 300 kg/day. Aerobic tub composting technology, consisting of 14 composting tubs, was installed.

The composting process starts with screening/sorting of waste material followed by shredding and mixing of waste material. This mixture is then gradually filled inside the composting tub with jaggery and rice bran, leachate followed by proper turning every five days to ensure proper aeration for microbial action. This mixture is kept for a total of 30 days in the tub for completion of the process. After 30 days, the compost is sun-dried for five days.

The completion of composting process takes 35–37 days. The prepared compost is sold in the market while the leachate is recycled in compost processing. The cost of the project was approximately Rs 20 lakh and O&M cost with electricity charges per month is Rs 1 lakh.

5. Hinjilicut MCC (BSF), Odisha

Capacity	*: 300 kg/day*
Operator	*: ULB*
Waste	*: Food and vegetable*
Technology	*: Aerobic tub composting*
Source	*: Household and municipal waste*
Latitude, longitude	*: 19.483817, 84.733292*



Picture 19: Location and flow diagram of composting unit in Hinjilicut (BSF)

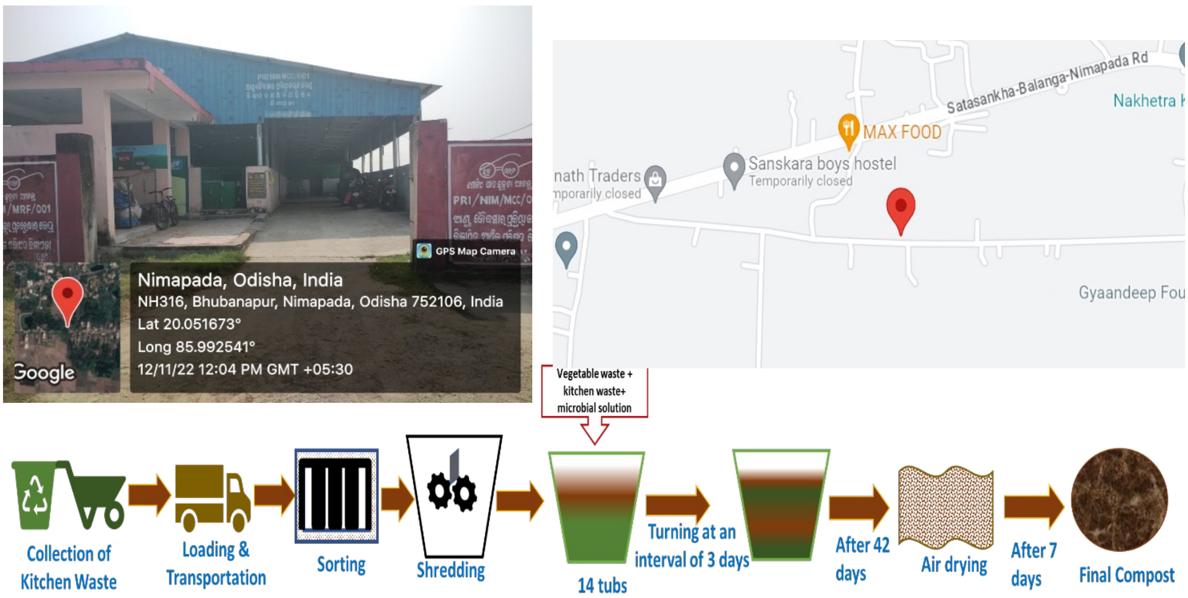
The composting unit in Hinjilicut was commissioned in 2022. The total area occupied by the plant is 10,000 sq. feet and it has a capacity of 300 kg/day. Aerobic tub composting technology, consisting of 14 composting tubs, was installed.

The composting process starts with screening/sorting of waste material, to recover the non-biodegradable materials. The segregated biodegradable waste is grinded and gradually filled inside composting tub along with black soldier fly larvae (250 kg waste and 50 kg BSF larvae). After seven days, 250 kg waste material is again added in the tub. If the initially added larvae has turned into pupa after seven days, 50 kg larvae is added. After seven days, the whole material is kept for sun drying. Thus, it takes a total of 14–18 days for completion of composting process.

While the prepared compost has not been used or sold to farmers so far, there are plans to sell it in the future. The cost of the project is approximately Rs 20 lakh and O&M cost with electricity per month is Rs 1 lakh.

6. Nimapada, Odisha

Capacity : *500 kg/day*
Operator : *ULB*
Waste : *Food and vegetable*
Technology : *Aerobic tub composting*
Source : *Household and municipal waste*
Latitude, longitude : *20.051673, 85.992541*



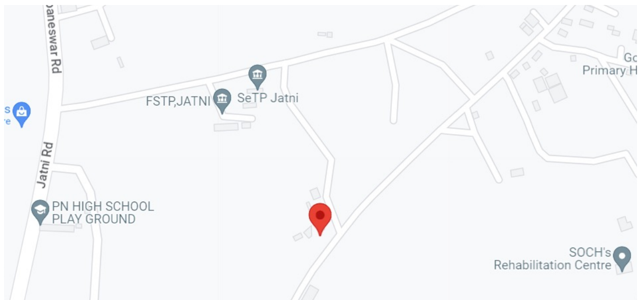
Picture 20: Location and flow diagram of composting unit in Nimapada

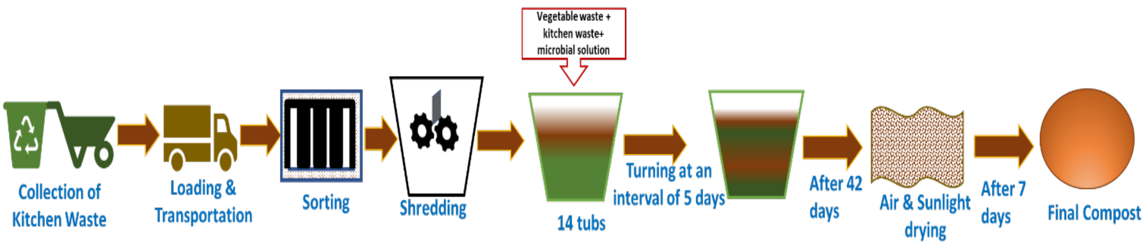
The Nimapada composting unit has a capacity of 500 kg/day. Aerobic tub composting technology, consisting of composting tubs, is installed.

The composting process starts with screening/sorting of waste material followed by shredding and mixing it. This mixture is then gradually filled inside composting tub with microbial solution, followed by proper turning in every three days to ensure proper aeration for microbial action, and kept for total 42 days in the tub for completion of process. After 42 days, the compost is dried in air and sunlight for seven days. Thus, it takes a total of 49–50 days for completion of the composting process. The prepared compost is sold the market at Rs 20/kg.

7. Jatni, Odisha

Capacity	*: 500 kg/day*
Operator	*: ULB*
Waste	*: Food and vegetable*
Technology	*: Aerobic tub composting*
Source	*: House hold and municipal waste*
Latitude, longitude	*: 20.184033, 85.705556*





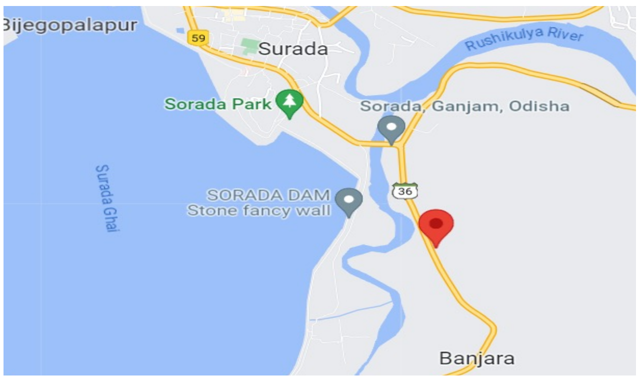
Picture 21: Location and flow diagram of composting unit in Jatni

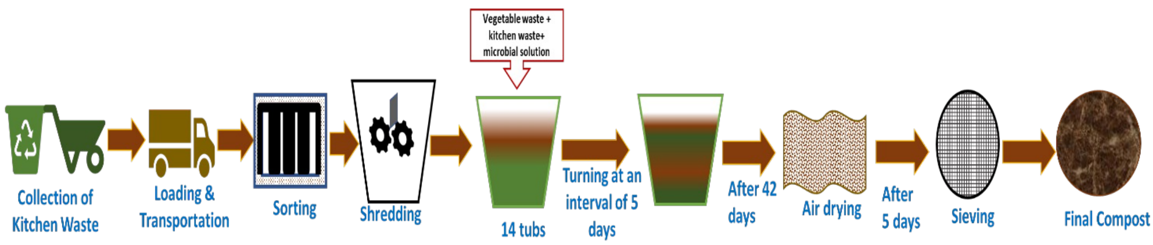
Jatni composting unit has capacity of composting 500 kg of vegetable waste per day. Aerobic tub composting technology, comprising composting tubs, is installed.

The composting process starts with screening/sorting of waste material. Segregation is done to recover the non-biodegradable materials, followed by shredding and mixing of waste material. This mixture is then gradually filled inside a composting tub with microbial solution followed by proper turning in every five days to ensure proper aeration for microbial action. This mixture is kept for total 42 days in the tub for completion of process. Finally, the compost is then dried in air and sunlight for seven days. In total, it takes 49–50 days to produce the compost.

8. Surada, Odisha

Capacity : *500 kg/day*
Operator : *ULB*
Waste : *Food and vegetable*
Technology : *Aerobic tub composting*
Source : *Household and municipal waste*
Latitude, longitude : *19.742884, 84.443018*





Picture 22: Location and flow diagram of composting unit in Surada

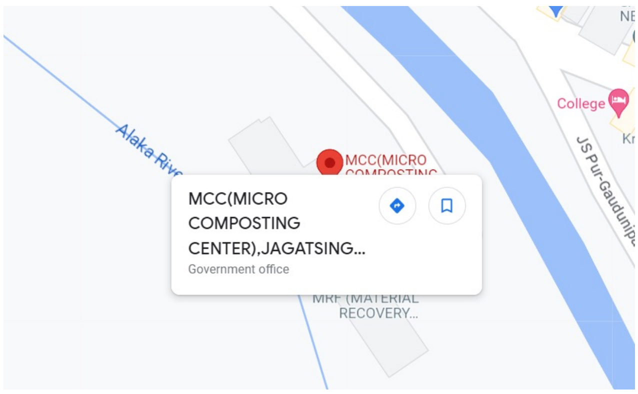
The composting unit of Surada was commissioned in 2020. The total area occupied by the plant is 3 acre and it has a capacity of 500 kg/day. Aerobic tub composting technology, consisting of 14 composting tubs, is installed.

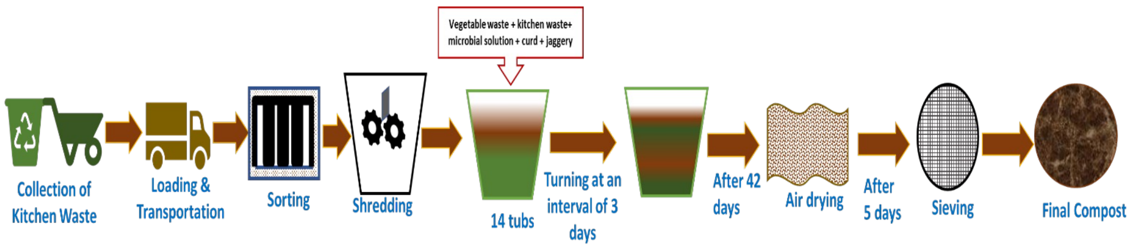
The composting process starts with screening/sorting of non-biodegradable waste material followed by shredding and mixing of waste material. This mixture is then gradually filled inside composting tub with microbial solution followed by proper turning in every 5 days to ensure proper aeration for microbial action. This mixture is kept for a total of 42 days in the tub for completion of process. After 42 days, compost is air dried for five days and sieved. Thus, it takes 47 days for completion of composting process.

The prepared compost is packed and used for selling in market for forest and horticultural use. The cost of project is approximately Rs 1.3 crore.

9. Jagatsinghpur, Odisha

Capacity : *1,000 kg/day*
Operator : *ULB*
Waste : *Food and vegetable*
Technology : *Aerobic tub composting*
Source : *Household and municipal waste*
Latitude, longitude : *20.256703, 86.165327*





Picture 23: Location and flow diagram of composting unit in Jagatsinghpur

The composting unit of Jagatsinghpur was commissioned in 2020. The total area occupied by the plant is 2 acre and it has a capacity of 500 kg/day. Aerobic tub composting technology, consisting of 14 composting tubs, is installed.

The composting process starts with screening/sorting of non-biodegradable waste material followed by shredding and mixing of waste material. This is then gradually filled inside the composting tub with microbial solution, curd and jaggery followed by proper turning in every three days to ensure proper aeration for microbial action. This mixture is kept for total 42 days in the tub for completion of process. After 42 days, compost is then air dried for five days and sieved before it is sold to the farmers. Totally, 47 days are required for the preparation of finished product. The prepared compost is packed and used for selling in market for forest and horticulture at cost Rs 20/kg.

Odisha compost analysis

The composting site receives kitchen waste from households and waste from markets on a daily basis. The production capacity of the plants is in the range of 3–5 TPD. The technology followed for composting is tub composting.

As soon as the waste is received in the site, segregation is done to recover the non-biodegradable materials. Subsequently, the biodegradable materials are shredded to reduce the size, and placed in the tubs. In some of the locations microbial solution is added as inoculum to the tubs while in some places jaggery or rice bran is added. The mixture is kept for composting for 42 days, and turned every three to five days. Finally, the prepared compost is spread for sun drying for five to seven days. Once it is ready it is sold to the farmers. None of the compost units have lab facilities to check the quality of compost.

Sample collection

A total of six compost samples were collected from six different location of Odisha in November 2022 and nine compost samples were collected from nine different location of Odisha in January and March, 2023. These samples were tested and compared for the quality parameters given in regulation FCO 2009. The composting technologies were evaluated on the basis of average values of observed results in different set of samples (see *Table 13: Details of compost samples collected from different locations in Odisha*, *Table 14: Physico-chemical and microbial parameters of compost of Odisha* and *Table 15: Composition of heavy metals*). See *Annexure 3* for results of individual replicates samples.

Table 13: Details of compost samples collected from different locations in Odisha

S. no.	Sample details	Technology	Capacity	Latitude, longitude	Operator	Waste material
1	Bhadrak	Tub composting	5 TPD	21.055980, 86.523450	ULB	Food and vegetable
2	Paralakhemundi	Tub composting	3 TPD	18.789236, 84.093304	ALF	Food and vegetable
3	Kashinagar	Tub composting	3 TPD	18.847364, 83.876954	ULB	Food and vegetable
4	Hinjilicut	Tub composting	3 TPD	19.483817, 84.733292	ULB	Food and vegetable
5	Hinjilicut (BSF)	Tub composting	3 TPD	19.483817, 84.733292	ULB	Food and vegetable
6	Nimapada	Tub composting	5 TPD	20.051673, 85.992541	ULB	Food and vegetable
7	Jatni	Tub composting	5 TPD	20.184033, 85.705556	ULB	Food and vegetable
8	Surada	Tub composting	5 TPD	19.742884, 84.443018	ULB	Food and vegetable
9	Jagatsinghpur	Tub composting	5 TPD	20.256703, 86.165327	ULB	Food and vegetable

ULB: Urban local body; ALF: Area-level federation

Test parameters evaluation based on Organic Compost Standard FCO 2009

Table 14: Physico-chemical and microbial parameters of compost of Odisha

Sample details	pH (6.5–7.5)	Conductivity <4.0 ds/m	Moisture, % by weight, maximum 25.0	Total organic carbon, % by weight, minimum (12)	Total nitrogen (as N), % by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), per cent by weight, minimum 0.4	Total potash (as K_2O), % by weight, minimum 0.4	Faecal coliforms MPN per gram total solids (dry weight) (USEPA)	*E. coli* MPN per gram total solids (dry weight) (WHO)	*Salmonella* spp. MPN/4 gram of total solids (dry weight) (USEPA)
Bhadrak	7.17	8.46	7.2	23.0	4.0	6	2.16	2.30	14,175	8,946	389,524
Paralakhemundi	7.96	8.92	22.8	29.4	4.4	7	1.68	2.47	2,291	2,233	231,380
Kashinagar	8.58	7.91	6.2	21.9	3.9	6	1.62	2.02	302	300	68,299
Hinjilicut	8.04	3.93	6.0	17.2	3.6	5	2.01	1.97	7,941	7,941	187,146
Hinjilicut (BSF)	7.89	6.21	9.5	12.5	5.2	2	2.04	2.39	7,217	7,217	9,798,052
Nimapada	8.45	8.08	6.1	13.9	3.4	4	2.12	3.00	4,140	4,140	49,732
Jatni	7.02	8.29	5.6	27.2	4.9	6	2.04	2.52	6,184	6,184	184,006
Surada	8.28	9.24	5.9	21.0	4.4	5	1.70	2.82	1,081	564	29,661
Jagatsinghpur	8.03	4.62	5.8	16.1	4.2	4	1.59	2.17	3,707	2,652	10,600
Average	7.94	7.29	8.32	20.13	4.20	5	1.88	2.41	5,226	4,464	1,216,489
SD	0.53	1.92	5.55	5.98	0.58	1	0.23	0.34	4,270	3,233	3,220,355
Median	8.03	8.08	6.05	21.00	4.15	5	2.01	2.39	4,140	4,140	184,006
Minimum	7.02	3.93	5.57	11.50	3.35	2	1.59	1.97	302	300	10,600
Maximum	8.58	9.24	22.76	29.40	5.16	7	2.16	3.00	14,175	8,946	9,798,052

Collected in January and March 2023, first replicate in November 2022, second replicate in January 2023 and third replicate in March 2023

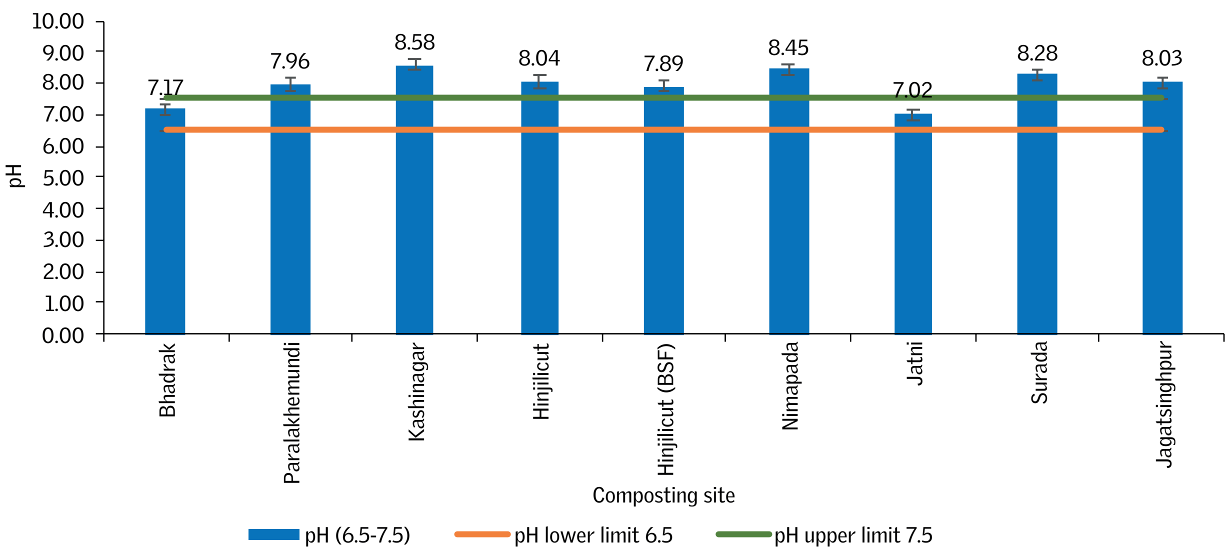
Results and discussion

Multiple parameters were analysed in this study as presented in Table 12. The result obtained for some highly significant parameters are discussed and represented as follows:

pH

The pH of the compost samples was analysed and average value was determined to be in the range of 7.02–8.58. The Fertilizer Control Order (FCO) 2009 suggested the pH should be in the range of 6.5–7.5. All the sites except Bhadrak and Jatni showed pH neutral to slightly alkaline. All the sites showed pH higher than permissible limit of FCO standard.

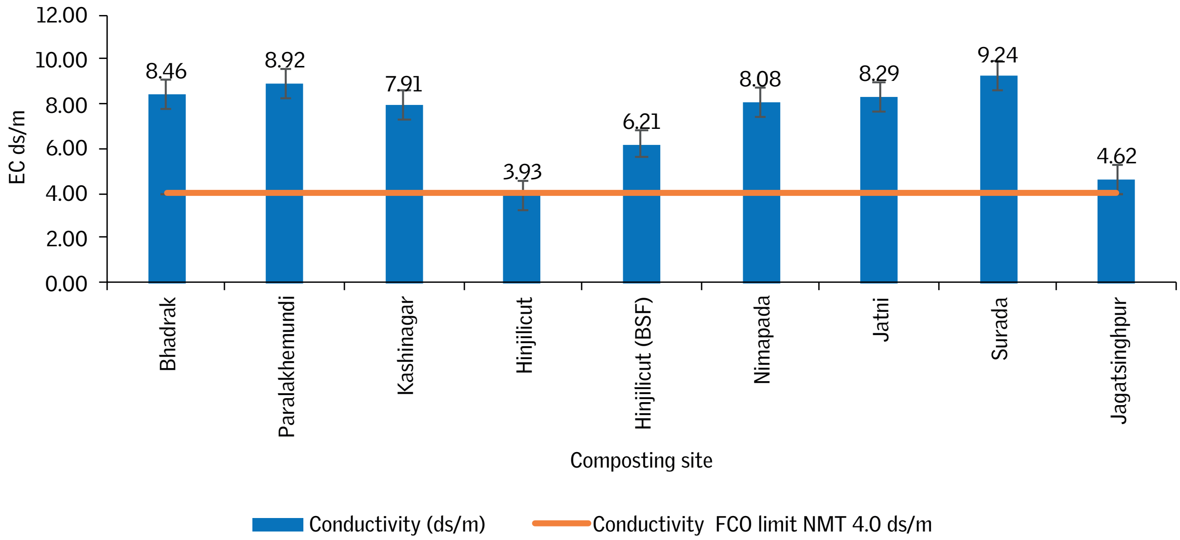
Fig. 24: pH of the compost in samples from Odisha



Electrical conductivity (EC)

Electrical conductivity for the compost was in the range of 3.93–9.24 dS/m. As per the FCO standard recommendation, the EC value should be less than 4 dS/m. Electrical conductivity in Hinjilicut (non- BSF) and Jagatsinghpur was observed to be within the limit or near the FCO standard. Other sites showed high electrical conductivity—above the FCO limit—in the range

Fig. 25: Electrical conductivity in the compost, Odisha

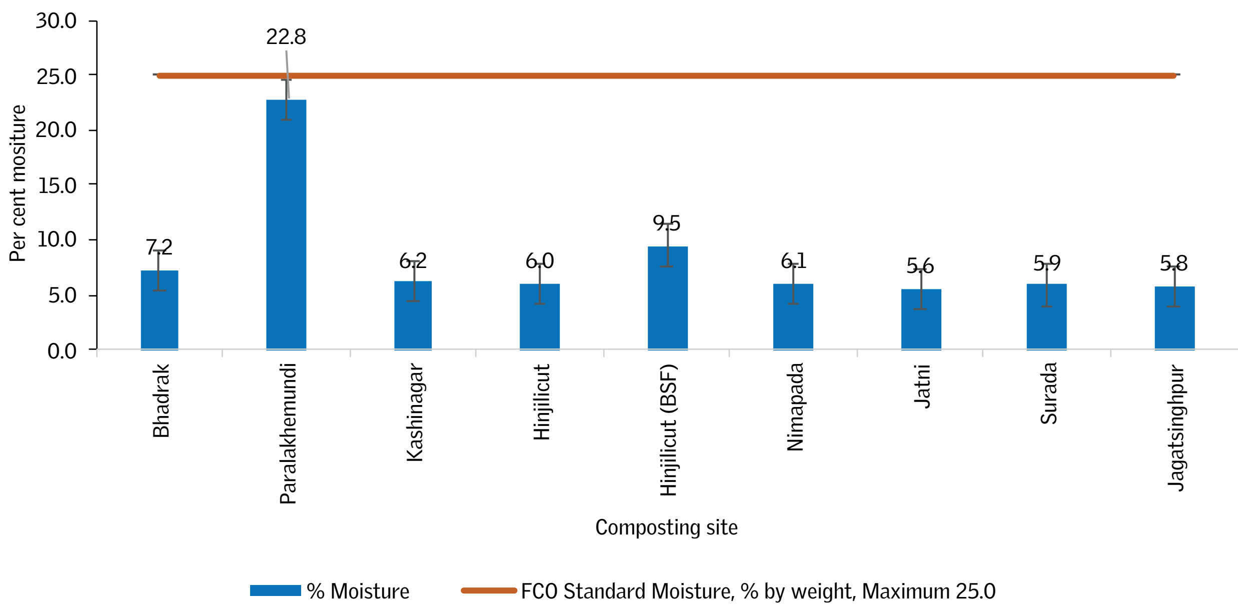


of 6.21–9.24 dS/m. High EC values could be due to the elevated levels of sodium or other salts found in the food or kitchen waste.

Moisture content

The moisture content of the compost samples were in the range of 5.57–22.76 per cent. All the sites showed per cent moisture content below the maximum limit of FCO standard. Hence, all sites were drying the compost properly.

Fig. 26: Moisture content in the compost, Odisha



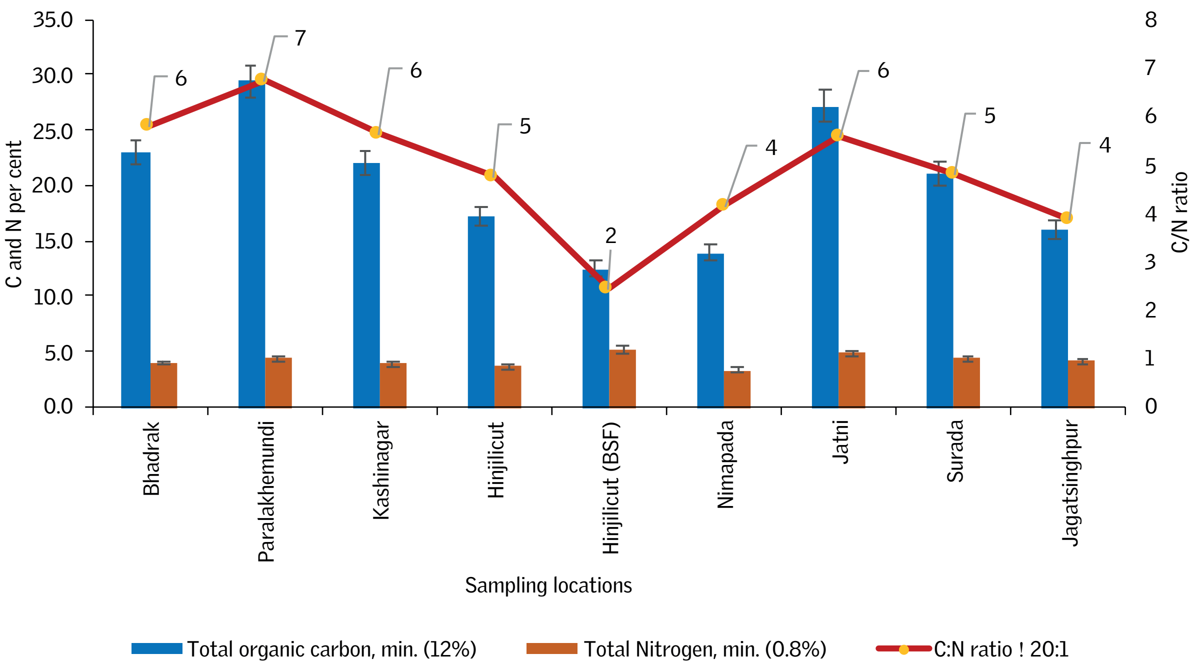
C:N ratio

The total organic carbon content of the compost was in the range of 12.50–29.40 per cent and the total nitrogen content was in the range of 3.35–5.16 per cent. The total organic carbon and the total nitrogen content were within the limit of FCO standard. The C/N ratio of the collected compost as per FCO standard was in the range of 2:1–7:1.

High C:N ratio (>20:1) means lower nitrogen content and vice versa. As the C:N ratio was below 10:1, nitrogen is released more rapidly into the soil for immediate crop use but microbial immobilization of nitrogen is very low.

In the FCO standard, the C:N ratio limit is <20:1, but a lower range is preferable to maintain mineralization and immobilization (see *Table 2b: C:N ratio of some organic material and their mineralization and immobilization rates*). A C:N ratio of 15:1 shows good balance between mineralization and immobilization.

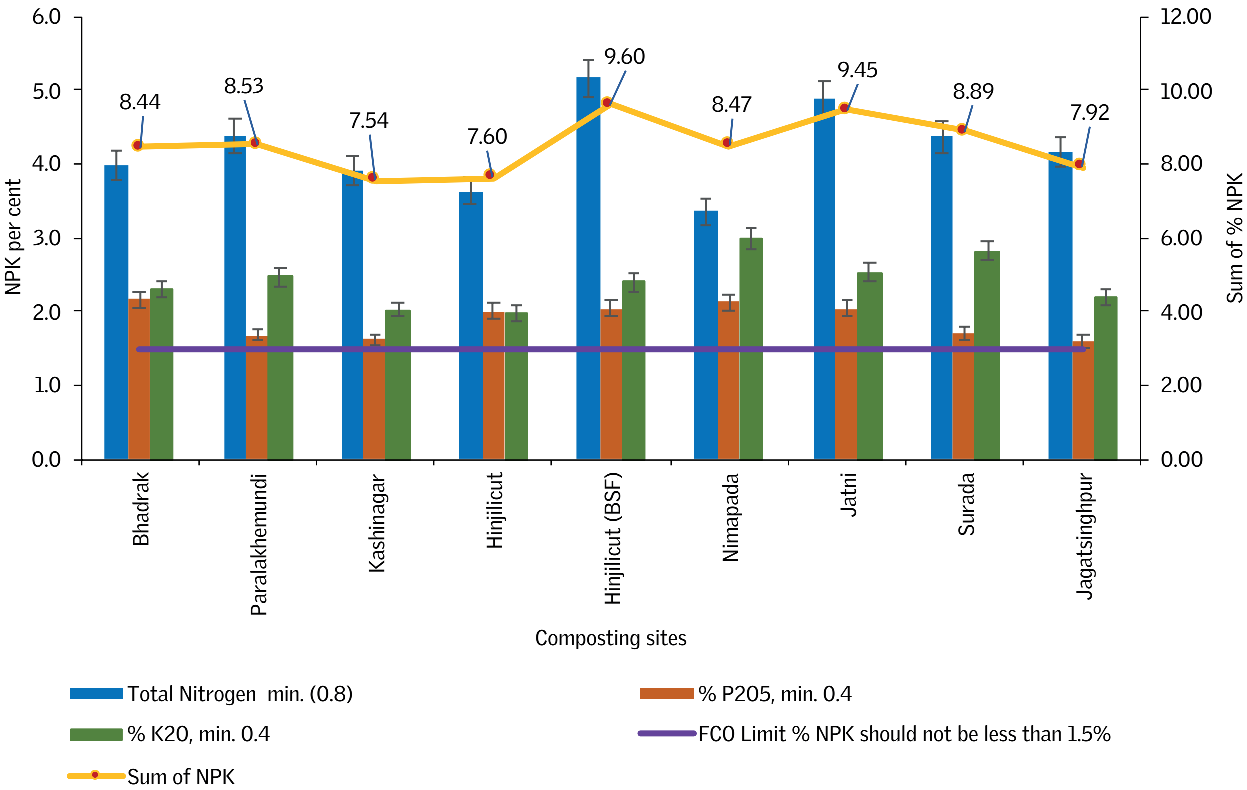
Fig. 27: C:N ratio of the compost, Odisha



NPK content

The NPK value indicates the amount of nitrogen, phosphorus and potassium in the compost or fertilizer. These three essential macronutrients are needed for plant growth. The appropriate NPK ratio for fertilizer under Indian soil conditions is stated to be 4:2:1. The NPK ratio of the compost was observed to 2:1:1, which shows that compost collected from all sites in Odisha is low in nitrogen and phosphorus content. The NPK of the compost was in the range of 7.54–9.60 per cent. As per the FCO standard, the per cent NPK should not be less than 1.5 per cent. However observed results showed all sites were rich in NPK and within this regulatory limit.

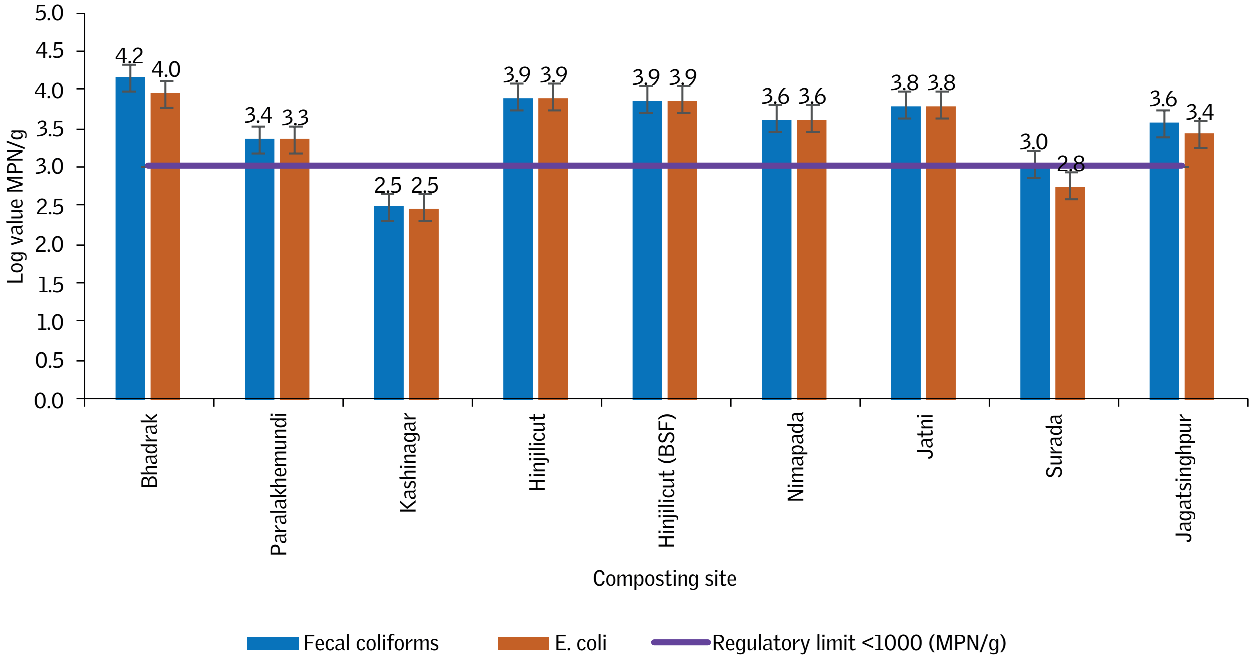
Fig. 28: NPK content of the compost, Odisha



Bacterial contamination (*E. coli* and faecal coliform)

E. coli and faecal coliform were observed in all the tested sites and hence did not meet the FCO standard (pathogens—nil). However, when the *E. coli* and faecal coliform load are compared with global standards (USEPA, WHO), their load was below the limit (<1,000 or 3 log_{10} MPN/g dry weight) in Kashinagar and Surada. In other sites, the microbial load is more than global standards. To reduce the risk of biological contamination, composting can be done under aerobic thermophilic conditions for more than 30 days at 55–65 °C and proper sun drying for a period of four to five days can minimize the bacterial load in compost.

Fig. 29: Faecal coliform and *E. coli* in the compost, Odisha

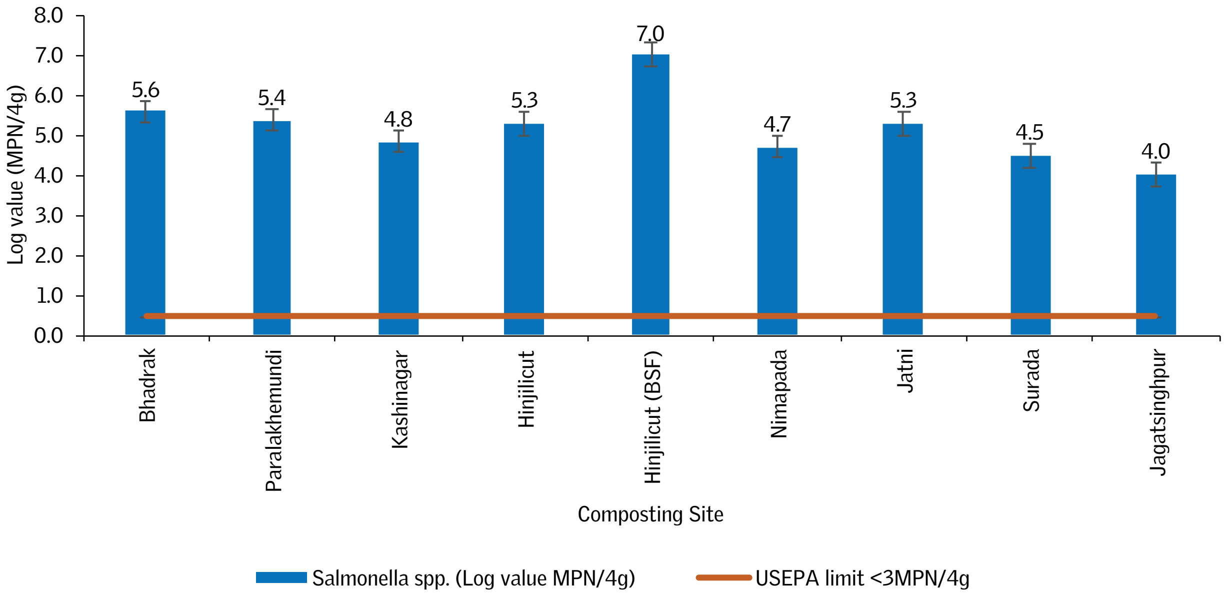


Salmonella spp.

Salmonella is a pathogen that may find its way into the compost through contaminated food waste material. All the compost samples contained *Salmonella* spp. in significant numbers that were higher than the standard value. The standard limit of *Salmonella* in compost and biosolids is 3 MPN /4g by WHO/USEPA.

To reduce the risk of biological contamination and minimize the *Salmonella* load in compost, the compost should be kept under aerobic thermophilic conditions for more than 30 days at 55–65°C and given proper sun drying for a period of four to five days.

Fig. 30: *Salmonella* spp. in the compost, Odisha



Heavy metals: The heavy metal concentration in compost of Uttar Pradesh is represented in the Table 15.

Table 15: Heavy metal concentration in the compost, Odisha

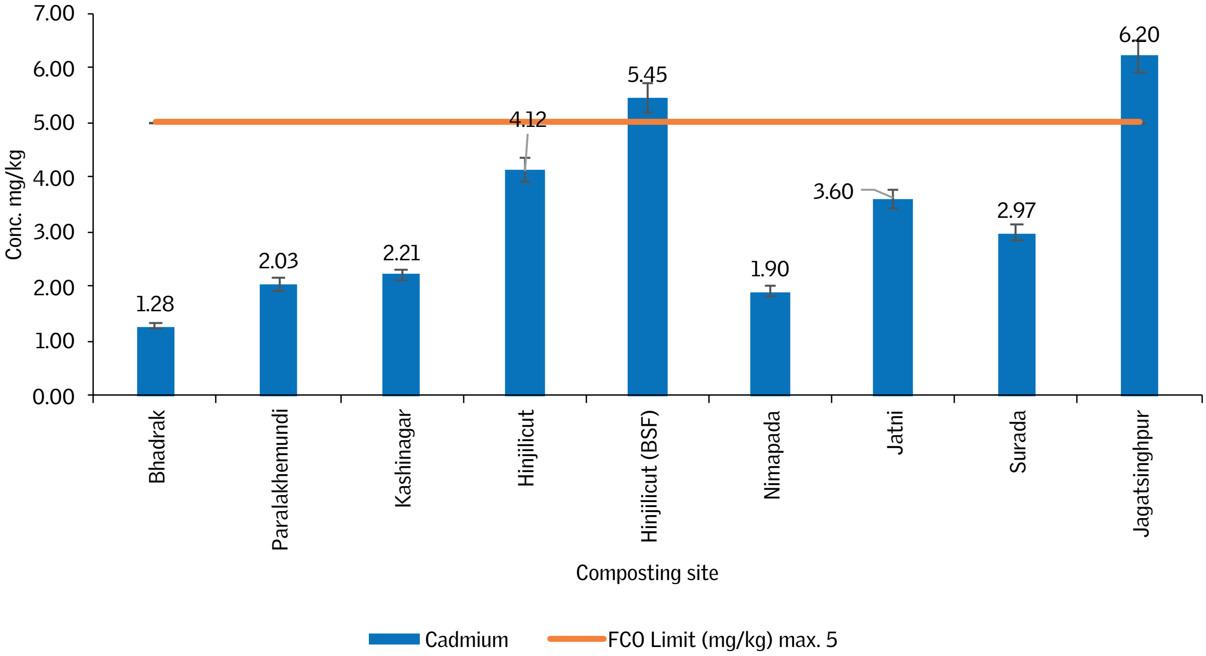
Sample details	Arsenic (mg/kg) max. 10.001	Mercury (mg/kg) max 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1,000
Bhadrak	0.03	0.05	1.28	59.89	49.30	29.99	15.45	121
Paralakhemundi	0.12	0.05	2.03	17.76	57.70	10.65	17.10	242
Kashinagar	0.09	0.04	2.21	24.78	75.15	10.63	17.16	147
Hinjilicut	0.48	0.06	4.12	32.48	163.67	19.54	33.99	248
Hinjilicut (BSF)	0.28	0.05	5.45	20.52	98.34	10.83	46.88	357
Nimapada	0.26	0.10	1.90	42.79	59.72	17.82	26.16	110
Jatni	0.47	0.03	3.60	27.62	52.00	13.73	17.85	193
Surada	0.31	0.05	2.97	22.09	43.38	12.29	17.88	118
Jagatsinghpur	0.64	0.11	6.20	56.79	157.01	18.88	24.03	191
Average	0.30	0.06	3.31	33.86	84.03	16.04	24.05	192
SD	0.20	0.03	1.69	15.74	46.26	6.35	10.43	81
Median	0.28	0.05	2.97	27.62	59.72	13.73	17.88	191
Minimum	0.03	0.03	1.28	17.76	43.38	10.63	15.45	110
Maximum	0.64	0.11	6.20	59.89	163.67	29.99	46.88	357

Analysis of heavy metals is done on the basis of observed results and is explained as follows:

Arsenic and mercury: Arsenic and mercury in all sites were found within the prescribed limit of FCO standard.

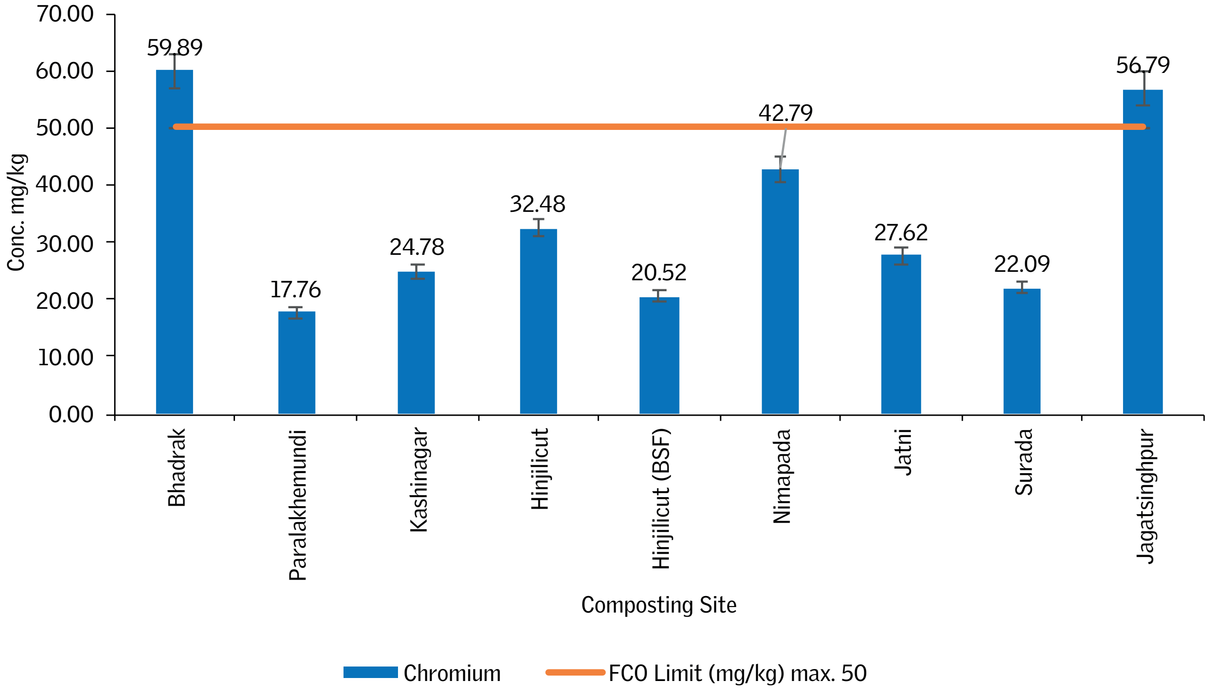
Cadmium: Compost samples of Hinjilicut (BSF) and Jagatsinghpur show high concentrations of cadmium contamination. This may due to the contamination from the raw material or by in process. Segregation of waste at house hold and sorting of waste at site may solve the problem of heavy metal contamination.

Fig. 31: Cadmium in the compost, Odisha



Chromium: Compost samples of Bhadrak and Jagatsinghpur showed high amounts of chromium contamination when compared with the FCO standard 2009. All other samples were found within the desirable limit for chromium as per FCO standard. This may due to the contamination from the raw material or through in-process contamination.

Fig. 32: Chromium in the compost, Odisha



All other heavy metals were within the FCO limit in Odisha compost samples.

Table 16: Observations and recommendations

S. no.	Sample/site details	Observations
1.	Bhadrak	Sample conductivity is not within the limit (more than desirable), high in pathogen contents (salmonella, electrical conductivity and faecal coliform) and high in chromium. Presence of high contents of pathogen in sample may be due to contamination from source. Presence of high contents of chromium in sample may be due to contamination from source or in process. Note: Proper segregation and sorting, turning, aeration and sunlight exposure may solve the problem.
2.	Paralakhemundi	Sample conductivity is not within the limit (more than desirable) and high in pathogen contents (salmonella, electrical conductivity and faecal coliform). Presence of high contents of pathogen in sample may be due to contamination from source. Note: Proper segregation and sorting, aeration and sunlight exposure may solve the problem
3.	Kashinagar	Sample pH and conductivity are not within the limit (more than desirable) and high in salmonella, only electrical conductivity and faecal coliform within the USEPA limit. Note: Proper turning, aeration and sunlight exposure may solve the problem

S. no.	Sample/site details	Observations
4.	Hinjilicut	Sample is high in pH (alkaline) and pathogen contents (salmonella, electrical conductivity and faecal coliform). Note: Proper turning, aeration and sunlight exposure may solve the problem
5.	Hinjilicut (BSF)	Sample conductivity is not within the limit (more than desirable) and high in pathogen contents (salmonella, electrical conductivity and faecal coliform) and high in cadmium. Presence of high contents of pathogen in sample may be due to contamination from source. Presence of high contents of cadmium in sample may be due to contamination from source or in process. Note: Proper segregation and sorting, turning, aeration and sunlight exposure may solve the problem
6.	Nimapada	Sample pH and conductivity is not within the limit (more than desirable) and high in pathogen contents (salmonella, electrical conductivity and faecal coliform). Presence of high contents of pathogen in sample may be due to the contamination from source or in-process. Note: Turning, aeration and sunlight exposure may solve the problem
7.	Jatni	Sample conductivity is not within the limit (more than desirable) and high in pathogen contents (salmonella, electrical conductivity and faecal coliform). Presence of high contents of pathogen in sample may be due to the contamination from source or in-process. Note: Turning, aeration and sunlight exposure may solve the problem
8.	Surada	Sample pH and conductivity is not within the limit (more than desirable) and high in salmonella only electrical conductivity and faecal coliform within the USEPA limit. Note: Turning, aeration and sunlight exposure may solve the problem
9.	Jagatsinghpur	Sample pH is not within the limit (more than desirable) and high in pathogen contents (salmonella, electrical conductivity and faecal coliform) and high in cadmium and chromium. Presence of high contents of pathogen in sample may be due to the contamination from source or in-process. Presence of high contents of cadmium and chromium in sample may be due to the contamination from source or in process. Note: Proper segregation and sorting, turning, aeration and sunlight exposure may solve the problem

5. Inter-state comparison of compost quality

The interstate (Uttar Pradesh, Haryana and Odisha) composting technologies were evaluated on the basis of average values of observed results in different set of samples (see *Table 17: Physico-chemical and microbial parameters of compost: Interstate comparison* and *Table 18: Composition of heavy metals in compost: Interstate comparison*).

Table 17: Physico-chemical and microbial parameters of compost: Interstate comparison

State	pH (6.5–7.5)	Conductivity <4.0 ds/m	Moisture, % by weight, maximum 25.0	Total organic carbon, % by weight, min. (12)	Total nitrogen (as N), per cent by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), per cent by weight, minimum 0.4	Total potash (as K_2O), % by weight, min. 0.4	Sum of NPK (≥1.5)	NPK ratio (4:2:1)	Faecal coliforms MPN per g total solids (dry weight)	*E. coli* MPN per g total solids (dry weight)	*Salmonella* spp. MPN/4 gram of total solids (dry weight) (USEPA)
Uttar Pradesh (Agra)	9.2	9.8	21.4	16.9	1.2	14	0.9	1.3	3.4	1:1:2	26	15	326,803
Haryana (Gurugram)	7.9	5.4	35.7	29.5	3.5	8	1.3	1.8	6.7	3:1:1	38,068	13,572	1,846,669
Odisha	7.9	7.3	8.3	20.2	4.2	5	1.9	2.4	8.5	2:1:1	5,226	4,464	1,216,489

pH: Uttar Pradesh showed more alkaline pH than Haryana and Odisha.

Conductivity: Haryana showed lesser electrical conductivity than Uttar Pradesh and Odisha.

Moisture: Uttar Pradesh and Odisha compost samples showed moisture content below the maximum limit given by FCO.

C:N ratio: Uttar Pradesh showed very good results of C:N ratio compared to other states.

NPK: Sum of NPK was good in the compost from all the states but ratio of NPK was better in Haryana than in other states.

Faecal coliform and *E. coli*: Uttar Pradesh compost is well controlled for faecal coliform and *E. coli* compared to other states.

Table 18: Composition of heavy metals in compost: Interstate comparison

State	Arsenic (mg/kg) max. 10.001	Mercury (mg/kg) max 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1,000
Uttar Pradesh (Agra)	0.05	0.19	22.96	80.56	273.76	69.98	42.72	541.0
Haryana (Gurugram)	0.88	0.09	0.88	39.74	40.87	16.71	11.30	128.1
Odisha	0.30	0.06	3.31	33.86	84.03	16.04	24.05	191.9

On the basis of microbial parameters (FC and EC), Uttar Pradesh showed better results compared to other states. But plant growth factor NPK is good in Haryana followed by Odisha compost. Uttar Pradesh showed very high contamination of heavy metal in compost compared to other states.

6. Summary and conclusion

1. A total of 23 composting sites (Haryana—8, Uttar Pradesh—6 and Odisha—9) were visited twice or thrice to collect samples for analysis.

2. A total of 25 samples in multiple replicates (Haryana—10, Uttar Pradesh—6 and Odisha—9) were analysed to check the physico-chemical, heavy metals and biological quality of the compost.

3. Samples from all sites in Agra, Gurugram and Odisha were showing neutral to alkaline pH, except in one site at Gurugram which is slightly acidic (6.05).

4. The electrical conductivity of the compost in Gurugram (Haryana), Agra (Uttar Pradesh) and Odisha is found to be 5.4 dS/m, 9.8 dS/m and 7.3 dS/m respectively.

5. C:N ratio in all sites were found to be within the desirable limit as per FCO standard.

6. The sum of NPK values for the compost samples collected from all the sites is ranging from 3.4 to 8.5 which is considerably high and well above the recommended value given by FCO where it is stated that the sum of NPK should not be less than 1.5. Hence, all sites are rich in NPK and within this regulatory limit of FCO 2009.

7. The compost of Agra showed a significantly high amount of heavy metals compared to Gurugram and Odisha. Heavy metal contamination in compost may be due to the contamination from the source of raw material such as medical waste, cosmetic waste, electronic waste at household level and improper waste segregation, or through process contamination such as machinery, additives used for composting, and land for compost drying.

8. Almost all the sites in Gurugram compost showed a significantly high amounts of microbial contamination (*E. coli* and faecal coliform) while in all sites of Agra samples showed very low microbial load, which is within the permissible limit. In Odisha, two compost sites were free

from any contamination of *E. coli* and faecal coliform but all other sites showed a significant amount of both.

9. *Salmonella* species was high in almost all sites of Agra, Gurugram and Odisha compost samples.

10. Multiple factors contribute to high microbial load (*E. coli*, faecal coliform and *Salmonella*) in compost, including contamination from source material, improper segregation of waste at source, improper sanitization during composting and regrowth of the microorganisms.

7. Recommendations

pH: One of the simplest and most important factors in all plant-growing systems is maintaining optimal pH levels. The pH level influences nutrient solubility, microbial activity and root growth. pH should be in the range of 6.5–7.5 ideally.

Acidic pH is not suitable for soil application as low pH levels reduce the activity of important microbial decomposers, which can greatly reduce the biological conversion of organic material to usable nutrients for plant growth. Typically, low pH levels (<5.5) reduce the availability of nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and molybdenum. However, the availability of aluminium and manganese can increase to toxic levels at pH levels below 5. Slightly higher pH (>7) will make soil alkaline, but not as harmful as low pH in soil application. High pH (>7.5) favours weathering of minerals, increased bacterial populations, and an increase in the release of cations. However, it also reduces the solubility of salts including carbonates and phosphates.

Compost becomes acidic when there is insufficient oxygen and the microbial activity becomes anaerobic. If anaerobic decomposition occurs, the contents start to turn black, wet and smelly. It becomes more acidic due to the production of organic acids. Aerating or remixing the anaerobic material while including more “browns” should return the mixture to aerobic decomposition and maintain the optimal pH levels.

C:N ratio: C:N ratio plays an essential role during composting process and also in the final compost as discussed below:

***C:N ratio during composting process*:** C:N ratio during composting ideally should be between 20:1–30:1 for efficient composting process. At C:N ratio of >30:1, there will not be enough nitrogen to support sufficient microbial growth. The microbial population will be too low to produce enough heat resulting in prolonged decomposition process. When C:N ratio is <20:1, there is high nitrogen that leads to excessive microbial growth resulting in loss of nitrogen. Lower C:N ratios provides excess nitrogen which results in ammonia production. This has an unpleasant odour, which many composters experience.

C:N ratio of finished compost: C:N ratio is most important as it suggests the quality of compost for land use. High ratio of carbon to nitrogen would mean that the sample has low nitrogen that is not suitable for crops. High C:N ratio (>20:1) means lower nitrogen content and low C:N ratio (<10:1) means higher nitrogen content. As the C:N ratio is below 10:1, there will be high mineralization and nitrogen will be released more rapidly into the soil for immediate crop use. On the other hand microbial immobilization of nitrogen is very low. The FCO standard recommendation for the C:N ratio limit is given as <20:1, but the fertilizer should have a lower limit (approximately 15:1) to maintain an equilibrium between mineralization and immobilization (Table 2b: *C:N ratio of some organic materials and their mineralization and immobilization rates*).

Moisture content: If the moisture content is higher than 25 per cent, aeration is not sufficient as required. Compost with higher moisture will be more difficult to pack and transport. Also, the microbial load will increase with high moisture content. A well-concreted platform for compost drying is necessary to ensure proper drying conditions. A clean storage room is required for storing the compost. This is particularly important during the rainy season. When composting of garden waste and uncooked kitchen waste occurs, the compost becomes too wet. Low moisture content typically results either due to addition of too many "browns" to the compost mix or hot climatic conditions. Turning the composting material to mix the newly added browns aerates the compost and breaks up any compacted areas. Also, a leachate collection outlet must be provided to reduce the risk of excess moisture.

Pathogens: The load of faecal coliform, *E. coli* and *Salmonella* spp. are found to be significantly high in all the compost samples. The main reason could be the use of treated sewage water in the composting units, which substantially increases the concentration of pathogens in the compost sample. Faecal coliform is also found in the contaminated soil, and adding soil as a cover or substrate material to the composting unit could also be a reason for high pathogen concentration.

Generally, there are three phases in composting, i.e. mesosphilic, thermophilic and maturation. One reason could be the decomposition phase not reaching the thermophilic stage, where the maximum temperature is obtained which helps in decontamination process. Wastewater or treated water should never be used to sprinkle over the compost pile to maintain the moisture content. Instead, freshwater should always be used. Drying in sunlight can effectively decrease the microbes or pathogen load in compost. It is suggested that after the composting, the end product should be sun dried in an open area on concrete platform for a week to maintain the moisture, thereby reducing the microbial load as well.

As per the FCO standard recommendation, the limit for pathogens is "nil". However, it is very difficult to maintain this stringent standard. As per the USEPA/WHO standard for biosolids, faecal coliform and *E. coli* (pathogen indicators) is 1,000 MPN/g while for *Salmonella* it is 3 MPN/4 g of sample. The complete removal of pathogens from compost is quite challenging by the natural drying process as recommended by FCO standards.

Heavy metal contamination: Mercury and other heavy metals found in the compost could be due to mixing the household food waste with domestic hazardous waste. Mercury is found in various products, such as fluorescent and other bulbs, batteries, electrical switches and relays, barometers, thermometers, etc. A small portion of mercury in the waste stream can contaminate the whole process. Hence, segregating the waste from the source without mixing it with any potentially hazardous substances could be the solution to avoid mercury contamination.

Heavy metal contamination could be due to the following possible reasons:

1. Use of contaminated materials (fertilizers and industrial wastewater) in agricultural practices due to which the vegetables and fruits crops are contaminated with possible heavy metals. The same food material when used as raw material for composting leads to heavy metal entry into the compost.
2. Contamination can occur during the composting process through machineries, additives used for composting and contaminated soil or land during compost drying.
3. Contamination from source material by mixing of kitchen waste with other household waste like electrical filaments, wires, wall paint, cosmetics, medicines and chemicals.

Use of contaminated materials in agriculture practices and in composting process should be avoided. Proper source segregation of waste at household level and sorting of waste materials at composting site may solve the problem of heavy metal contamination.

References

1. Central Pollution Control Board (CPCB) Annual Report, 2018, available at: https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2018-19.pdf

2. Solid Waste Management in India, Indian Council for Research's Solid Waste Management in India report, 2018, available at: https://icrier.org/pdf/Working_Paper_356.pdf

3. Atin Biswas, Shailshree Tewari and Subhasish Parida 2021, *Decentralized Management of Segregated Organic Waste*, Centre for Science and Environment, New Delhi

4. Ministry of Housing and Urban Development, 'Municipal Solid Waste Management Manual-Part II', 2016, Government of India.

5. https://www.upstateforever.org/blog/connecting-people-to-nature/composting-101-with-sustaining-way

6. https://www.epa.gov/recycle/composting-home

7. Ministry of Housing and Urban Development, *Municipal Solid Waste Management Manual-Part II*, 2016, Government of India.

8. Ibid.

9. Modupe S.A., Oluwaseyi S.O., Olubukola O.B. and Olu O. 2020, Waste Management through Composting: Challenges and Potentials, Sustainability, 12, 4456.

10. FCO Standards 2009 for Organic City Compost

11. Gerald E. Brust 2019, Management Strategies for Organic Vegetable Fertility, Safety and Practice for Organic Food, pp. 193–12. DOI:10.1016/B978-0-12-812060-6.00009-X

12. FCO Standards 2009 for Organic City Compost

13. USEPA, Method 1680: Fecal coliforms in sewage sludge (biosolids) by multiple tube fermentation using Lauryl Tryptose Broth (LTB) and EC Medium, Environ. Regul. Technol. United States Environ. Prot. Agency. (2010).

14. United States Department of Agriculture—Food Safety and Inspection Service. 2014. Microbiology Laboratory Guidebook. Appendix 2.05: Most Probable Number Procedure and Tables. p. 1-8.

15. A.P.H. Association, Standard methods for the examination of water and wastewater. APHA, Am. Water Work. Assoc. Water Environ. Fed. 23rd ed.; Am. Public Heal. Assoc. Washington, DC, USA. (2017).

9. Annexures: Consolidated results

Annexure 1

Table 1: Haryana, Gurugram compost—physical parameters

S. no.	Sample details	Replicates	pH (6.5–7.5)	Conductivity <4.0 ds/m	Odour	Colour dark brown to black	Bulk density (g/cm^3) <1.0	Particle size (%), minimum 90 per cent material should pass through 4 mm sieve	Moisture, % by weight, maximum 25.0
1	World Spa, Sector 30	1	6.49	1.10	Foul odour absent	Black	0.52	80	82.4
2		2	8.24	4.62	Foul odour absent	Dark brown	0.55	98	63.5
3		3	6.82	2.57	Foul odour absent	Dark brown	0.44	90	69.9
4	Nirvana Country, South	1	9.11	1.39	Foul odour absent	Dark brown	0.35	85	16.3
5		2	9.17	2.84	Foul odour absent	Dark brown	0.40	95	45.4
6		3	7.63	4.38	Foul odour absent	Brown	0.40	90	26.9
7	DLF Cyber Park	1	3.83	3.68	Foul odour absent	Dark brown	0.44	80	35.3
8		2	7.13	5.73	Foul odour absent	Dark brown	0.46	90	16.9
9		3	7.18	4.96	Foul odour absent	Brown	0.60	90	58.6
10	Nirvana Country, North	1	8.76	6.86	Foul odour absent	Black	0.33	90	32.6
11		2	8.60	10.24	Foul odour absent	Dark brown	0.38	92	45.3
12		3	8.13	8.85	Foul odour absent	Dark brown	0.47	90	27.6

S. no.	Sample details	Repli-cates	pH (6.5–7.5)	Condu-ctivity <4.0 ds/m	Odour	Colour dark brown to black	Bulk density (g/cm^3) <1.0	Particle size (%), minimum 90 per cent material should pass through 4 mm sieve	Moisture, % by weight, maximum 25.0
13	Bestech Park Spa View	1	7.74	3.72	Foul odour absent	Black	0.46	95	74.7
14		2	8.25	5.69	Foul odour absent	Dark brown	0.45	95	68.1
15		3	6.91	4.64	Foul odour absent	Dark brown	0.47	90	48.3
16	Westend Heights	1	8.40	5.33	Foul odour absent	Dark brown	0.57	95	20.4
17		2	7.51	16.61	Foul odour absent	Dark brown	0.56	95	17.0
18		3	7.33	10.29	Foul odour absent	Brown	0.39	90	4.0
19	Westend Heights without cocopeat	1	8.61	5.83	Foul odour absent	Dark brown	0.23	80	11.6
20	Richmond Park	1	7.83	1.94	Foul odour absent	Dark brown	0.47	90	42.8
21		2	6.80	8.14	Foul odour absent	Dark brown	0.49	95	25.8
22		3	7.69	2.62	Foul odour absent	Brown	0.60	90	29.1
23	Sushant Apartments	1	8.73	3.40	Foul odour absent	Dark brown	0.42	90	47.1
24		2	8.97	5.93	Foul odour absent	Dark brown	0.45	90	11.9
25		3	7.97	6.09	Foul odour absent	Brown	0.49	90	28.3
26	Sushant Apartments flower waste	1	8.69	3.88	Foul odour absent	Dark brown	0.49	90	32.6

Annexure 1

Table 2: Haryana, Gurugram compost—chemical parameters

S. no.	Sample details	Repli-cates	Total organic carbon, % by weight, minimum (12)	Total nitrogen (as N), per cent by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), % by weight, minimum 0.4	Total potash (as K_2O), % by weight, minimum 0.4
1	World Spa, Sector 30	1	40.15	0.95	42	0.64	2.30
2		2	22.60	4.45	5	2.29	2.12
3		3	35.60	5.04	7	0.92	1.20
4	Nirvana Country, South	1	29.16	2.14	14	1.44	1.49
5		2	25.30	4.85	5	1.26	2.38
6		3	30.00	5.01	6	1.50	1.44
7	DLF Cyber Park	1	45.70	0.82	56	0.55	0.62
8		2	44.60	4.37	10	0.65	1.04
9		3	37.70	4.18	9	0.68	0.72
10	Nirvana Country, North	1	32.30	3.16	10	2.13	1.35
11		2	29.30	5.87	5	2.27	3.59
12		3	29.50	5.48	5	0.84	0.70
13	Bestech Park Spa View	1	34.61	2.70	13	1.83	1.99
14		2	33.90	5.44	6	1.89	1.87
15		3	23.90	4.78	5	1.67	1.28
16	Westend Heights	1	34.20	3.01	11	1.51	2.30
17		2	35.60	5.61	6	1.91	2.98
18		3	29.00	4.85	6	1.12	1.93
19	Westend Heights without cocopeat	1	31.84	2.57	12	1.65	2.20
20	Richmond Park	1	18.08	1.38	13	0.99	1.64
21		2	17.30	4.07	4	0.71	2.32
22		3	16.70	3.69	5	1.16	1.39
23	Sushant Apartments	1	25.96	2.11	12	0.99	2.15
24		2	24.10	4.66	5	0.96	2.44
25		3	26.70	4.94	5	1.76	1.69
26	Sushant Apartments flower waste	1	22.73	1.74	13	0.86	1.80

Annexure 1

Table 3: Haryana, Gurugram compost—heavy metals

S. no.	Sample details	Repli-cates	Arsenic (mg/kg) maximum 10.001	Mercury (mg/kg) maximum 0.15	Cadmium (mg/kg) maximum 5	Chromium (mg/kg) maximum 50	Copper (mg/kg) maximum 300	Nickel (mg/kg) maximum 50	Lead (mg/kg) maximum 100	Zinc (mg/kg) maximum 1000
1	World Spa, Sector 30	1	0.265	0.000	0.537	9.19	23.01	3.91	7.71	105.9
2		2	1.434	0.056	1.026	28.84	24.19	11.74	12.23	98.7
3		3	0.155	0.000	0.441	9.27	16.72	4.22	7.78	47.2
4	Nirvana Country, South	1	0.846	0.063	1.003	22.74	23.02	7.78	11.93	150.4
5		2	1.361	0.148	1.080	28.78	25.56	10.48	15.42	96.9
6		3	0.156	0.000	1.711	9.08	31.50	5.52	7.70	80.9
7	DLF Cyber Park	1	0.175	0.000	0.239	24.06	16.84	9.25	3.72	69.2
8		2	0.263	0.000	0.219	28.57	20.43	10.76	4.16	48.9
9		3	0.109	0.000	1.347	9.22	12.94	9.46	6.46	28.2
10	Nirvana Country, North	1	0.722	0.045	0.628	21.33	83.90	9.82	11.59	253.5
11		2	0.812	0.000	0.819	23.65	62.95	11.01	9.24	389.4
12		3	0.368	0.051	0.358	71.83	251.20	234.40	3.77	98.4
13	Bestech Park Spa View	1	0.910	0.000	0.846	21.75	26.68	8.05	7.47	205.5
14		2	0.428	0.000	0.789	19.68	34.46	8.23	8.98	112.0
15		3	0.761	0.049	1.298	23.93	32.16	11.14	13.26	113.1
16	Westend Heights	1	0.836	0.000	0.613	13.44	21.92	7.59	5.99	131.8
17		2	0.385	0.003	0.598	19.94	28.97	8.67	6.25	88.6
18		3	0.472	0.065	0.376	15.45	21.20	5.43	7.23	85.1
19	Westend Heights without cocopeat	1	0.801	0.000	0.602	24.77	40.45	8.57	19.46	194.2
20	Richmond Park	1	3.465	0.000	1.029	33.84	32.58	14.70	15.38	153.8
21		2	2.316	1.459	0.932	224.50	27.89	18.52	15.62	78.6
22		3	0.998	0.014	1.061	24.42	20.75	10.24	17.08	60.8
23	Sushant Apartments	1	1.161	0.104	0.875	325.30	70.52	10.12	14.79	140.9
24		2	1.200	0.299	0.917	25.94	34.24	8.80	15.89	78.6
25		3	0.251	0.103	3.288	9.66	55.29	6.57	8.26	101.1
26	Sushant Apartments flower waste	1	1.399	0.110	0.891	24.46	35.24	9.76	14.22	147.7

Annexure 1

Table 4: Haryana, Gurugram compost—pathogens

S. no.	Sample details	Repli-cates	Faecal coliforms MPN per g total solids (dry weight)	*E. coli* MPN per g total solids (dry weight)	*Salmonella* spp. MPN/4 gram of total solids (dry weight) (USEPA)
1	World Spa, Sector 30	1	245	245	54,631
2		2	2,518	985	2,625,107
3		3	2,495	2,495	17,696,137
4	Nirvana Country, South	1	514	179	1,817
5		2	439,717	170,390	1,757,404
6		3	62,892	62,892	7,328,297
7	DLF Cyber Park	1	5	5	4
8		2	11	4	3
9		3	5,562	5,562	677,089
10	Nirvana Country, North	1	13,797	1,780	272,969
11		2	1,316	658	17,529
12		3	317	317	342,307
13	Bestech Park Spa View	1	8,315	4,356	380,124
14		2	144,092	940	3,004,626
15		3	7,355	7,355	363,883
16	Westend Heights	1	26,375	9,420	1,507
17		2	11,206	361	29,208
18		3	3	3	41,676
19	Westend Heights without cocopeat	1	16,966	16,966	2,081
20	Richmond Park	1	40,231	6,297	1,679
21		2	28,299	10,107	1,292,613
22		3	13,115	13,115	15,624,821
23	Sushant Apartments	1	28,346	6803	1,814
24		2	124,816	10,553	1,088,396
25		3	530	60	2,789,999
26	Sushant Apartments flower waste	1	43,020	13,796	65

Haryana, Gurugram: first replicate in January 2022, second replicate in March 2022 and third replicate in February 2023

Annexure 2

Table 1: Uttar Pradesh, Agra compost—physical parameters

S. no.	Sample details	Repli-cates	pH (6.5–7.5)	Conductivity <4.0 ds/m	Odour	Colour dark brown to black	Bulk density (g/cm^3) <1.0	Particle size (%), minimum 90 per cent material should pass through 4 mm sieve	Moisture, % by weight, maximum 25.0
1	OWC-decentralized, ISBT T.P. Nagar, Agra	1	9.70	21.9	Foul odour present	Dark brown	0.51	90%	19.96
	OWC-decentralized, ISBT T.P. Nagar, Agra	2	10.10	20.9	Foul odour present	Dark brown	0.55	90%	11.89
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	1	9.12	13.5	Foul odour absent	Dark brown	0.66	95%	27.01
	OWC-decentralized, Rajnagar, Loha Mandi, Agra	2	9.41	13.9	Foul odour present	Dark brown	0.70	90%	25.88
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra-Flower	1	9.07	3.8	Foul odour absent	Dark brown	1.05	92%	44.17
	OWC-decentralized, Rajnagar, Loha Mandi, Agra-Flower	2	8.85	3.27	Foul odour absent	Dark brown	0.98	90%	43.60
4	Dhandupura, Agra	1	9.24	4.6	Foul odour absent	Dark brown	0.66	80%	22.08
5	Centralized windrow-based composting, Kuberpur, Agra	1	8.10	5.1	Foul odour present	Dark brown	0.94	95%	21.55
	Centralized windrow-based composting, Kuberpur, Agra	2	9.58	3.17	Foul odour present	Dark brown	1.11	90%	11.56
6	OWC-Goura Nagar, Vrindavan	1	8.83	15.9	Foul odour present	Dark brown	0.36	90%	5.66
	OWC-Goura Nagar, Vrindavan	2	8.97	6.81	Foul odour absent	Dark brown	0.73	90%	1.91

Annexure 2

Table 2: Uttar Pradesh, Agra compost—chemical parameters

S. no.	Sample details	Replicates	Total organic carbon, per cent by weight, min. (12)	Total nitrogen (as N), per cent by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), per cent by weight, min. 0.4	Total potash (as K_2O), per cent by weight, minimum 0.4
1	OWC-decentralized, ISBT T.P. Nagar, Agra	1	27.60	1.06	26	1.361	1.932
	OWC-decentralized, ISBT T.P. Nagar, Agra	2	26.30	2.55	10	0.622	2.627
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	1	14.40	0.41	35	1.295	1.926
	OWC-decentralized, Rajnagar, Loha Mandi, Agra	2	22.20	2.53	9	0.607	1.435
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra-flower	1	15.10	0.46	33	1.037	1.223
	OWC-decentralized, Rajnagar, Loha Mandi, Agra-flower	2	14.70	2.03	7	0.443	0.651
4	Dhandupura, Agra	1	14.60	0.62	24	1.627	0.909
5	Centralized windrow-based composting, Kuberpur, Agra	1	9.95	0.20	50	0.442	1.485
	Centralized windrow-based composting, Kuberpur, Agra	2	7.68	1.09	7	0.147	0.616
6	OWC-Goura Nagar, Vrindavan	1	24.80	1.09	23	0.934	1.313
	OWC-Goura Nagar, Vrindavan	2	11.10	1.36	8	0.258	0.951

Annexure 2

Table 3: Uttar Pradesh, Agra compost—heavy metals

S. no.	Sample details	Replicates	Arsenic (mg/kg) max. 10.001	Mercury (mg/kg) max 0.15	Cadmium (mg/kg) max. 5	Chromium (mg/kg) max. 50	Copper (mg/kg) max. 300	Nickel (mg/kg) max. 50	Lead (mg/kg) max. 100	Zinc (mg/kg) max. 1000
1	OWC-decentralized, ISBT T.P. Nagar, Agra	1	Nil	0.221	7.77	42.81	90.05	30.60	18.07	204.1
	OWC-decentralized, ISBT T.P. Nagar, Agra	2	Nil	0.105	3.428	20.15	38.87	12.81	7.158	98.48
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	1	0.138	0.403	47.69	140.4	485.0	141.9	56.82	1024.0
	OWC-decentralized, Rajnagar, Loha Mandi, Agra	2	Nil	0.286	17.91	56.71	190.9	50.96	19.79	417.8
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra-flower	1	0.198	0.195	123.9	224.9	1338.0	345.0	121.8	2617.0
	OWC-decentralized, Rajnagar, Loha mandi, Agra-flower	2	Nil	0.310	63.51	94.96	670.5	168.1	103.9	1070
4	Dhandupura, Agra	1	0.079	0.021	1.44	38.34	31.44	15.66	14.97	89.85
5	Centralized windrow-based composting, Kuberpur-Agra	1	0.0605	0.055	3.35	172.2	159.6	28.83	84.47	415.5
	Centralized windrow-based composting, Kuberpur-Agra	2	Nil	0.245	2.48	75.14	85.02	10.14	26.59	181.9
6	OWC-Goura Nagar, Vrindavan	1	0.005	0.109	1.59	37.48	67.49	11.26	23.82	127.5
	OWC-Goura Nagar, Vrindavan	2	Nil	0.337	1.07	25.32	96.78	8.825	20.33	155.9

Annexure 2

Table 4: Uttar Pradesh, Agra compost—pathogens

S. no.	Sample details	Replicates	Faecal coliforms MPN per g total solids (dry weight)	*E. coli* MPN per g total solids (dry weight)	*Salmonella* spp. MPN per 4 g total solids (dry weight)
1	OWC-decentralized, ISBT T.P. Nagar, Agra	1	29	9	1,499
	OWC-decentralized, ISBT T.P. Nagar, Agra	2	3	3	454
2	OWC-decentralized, Rajnagar, Loha Mandi, Agra	1	4	4	1,096
	OWC-decentralized, Rajnagar, Loha Mandi, Agra	2	202	125	9,714
3	OWC-decentralized, Rajnagar, Loha Mandi, Agra-flower	1	16	6	358,203
	OWC-decentralized, Rajnagar, Loha Mandi, Agra-flower	2	5	5	709
4	Dhandupura, Agra	1	4	4	1,760,882
5	Centralized windrow-based composting, Kuberpur, Agra	1	5	4	1,530
	Centralized windrow-based composting, Kuberpur, Agra	2	3	3	1,357
6	OWC-Goura Nagar, Vrindavan	1	16	4	848
	OWC-Goura Nagar, Vrindavan	2	23	9	24,467

Uttar Pradesh, Agra: first replicate in May 2022, second replicate in July 2022

Annexure 3

Table 1: Odisha compost—physical parameters

S. no.	Sample details	Replicate	pH (6.5–7.5)	Conductivity <4.0 ds/m	Odour	Colour dark brown to black	Bulk density (g/cm^3) <1.0	Particle size (%), minimum 90 per cent material should pass through 4 mm sieve	Moisture (%), by weight, maximum 25.0
1	Bhadrak	1	7.9	7.6	Foul odour absent	Dark brown	0.37	92	7.8
2		2	6.9	8.0	Foul odour absent	Brown	0.47	90	6.3
3		3	6.7	9.8	Foul odour absent	Brown	0.45	90	7.6
4	Paralakhemundi	1	8.7	8.7	Foul odour absent	Black	0.44	90	19.4
5		2	7.4	8.4	Foul odour absent	Brown	0.36	90	20.1
6		3	7.8	9.6	Foul odour absent	Dark brown	0.30	60	28.8
7	Kashinagar	1	8.9	9.1	Foul odour absent	Dark brown	0.46	90	8.4
8		2	8.5	7.0	Foul odour absent	Brown	0.59	90	7.0
9		3	8.3	7.6	Foul odour absent	Brown	0.60	90	3.0
10	Hinjilicut	1	8.6	2.4	Foul odour absent	Dark brown	0.69	90	6.5
11		2	7.7	4.2	Foul odour absent	Dark brown	0.66	90	7.2
12		3	7.9	5.2	Foul odour absent	Light brown	0.63	90	4.2
13	Hinjilicut (BSF)	1	8.5	6.2	Foul odour present	Black	0.31	80	15.0
14		2	7.7	5.6	Foul odour absent	Dark brown	0.63	90	8.0
15		3	7.5	6.9	Foul odour absent	Dark brown	0.65	90	5.4
16	Nimapada	1	9.5	11.9	Foul odour absent	Dark brown	0.78	90	6.9
17		2	8.9	9.4	Foul odour absent	Dark brown	0.53	90	8.4
18		3	7.0	3.0	Foul odour present	Light brown	0.63	90	2.8
19	*Jatni	1	6.8	9.2	Foul odour present	Brown	0.57	90	8.0
20		2	7.2	7.4	Foul odour present	Brown	0.59	90	3.1
21	*Surada	1	8.2	8.9	Foul odour absent	Dark brown	0.41	90	8.0
22		2	8.3	9.5	Foul odour absent	Dark brown	0.49	90	3.7
23	*Jagatsinghpur	1	8.1	2.9	Foul odour absent	Dark brown	0.55	90	6.6
24		2	8.0	6.3	Foul odour absent	Light brown	0.57	90	5.0

Annexure 3

Table 2: Odisha compost—chemical parameters

S. no.	Sample details	Replicate	Total organic carbon, % by weight, minimum (12)	Total nitrogen (as N), % by weight, minimum (0.8)	C:N ratio <20:1	Total phosphates (as P_2O_5), % by weight, minimum 0.4	Total potash (as K_2O), % by weight, minimum 0.4
1	Bhadrak	1	30.9	2.9	11	2.49	1.96
2		2	23.2	4.6	5	1.82	2.12
3		3	14.9	4.4	3	2.17	2.82
4	Paralakhemundi	1	26.0	2.8	9	1.98	1.98
5		2	28.4	4.8	6	1.67	2.71
6		3	33.8	5.6	6	1.39	2.73
7	Kashinagar	1	26.3	2.8	9	1.83	1.64
8		2	19.6	4.1	5	1.71	2.46
9		3	19.9	4.8	4	1.32	1.97
10	Hinjilicut	1	18.5	2.2	9	1.86	1.71
11		2	17.3	4.2	4	2.04	2.00
12		3	15.8	4.5	4	2.13	2.21
13	Hinjilicut (BSF)	1	12.2	6.3	2	2.40	2.98
14		2	11.1	4.2	3	2.00	2.07
15		3	14.3	5.0	3	1.72	2.13
16	Nimapada	1	10.8	1.6	7	2.27	2.14
17		2	15.9	3.9	4	2.55	4.71
18		3	15.0	4.6	3	1.56	2.14
19	*Jatni	1	29.4	4.8	6	2.01	2.96
20		2	24.9	4.9	5	2.07	2.08
21	*Surada	1	19.4	4.2	5	1.91	3.46
22		2	22.6	4.6	5	1.49	2.18
23	*Jagatsinghpur	1	12.3	3.6	3	1.76	2.34
24		2	19.8	4.7	4	1.42	2.01

Annexure 3

Table 3: Odisha compost—heavy metals

S. no.	Sample details	Replicate	Arsenic (mg/kg) maximum 10.001	Mercury (mg/kg) maximum 0.15	Cadmium (mg/kg) maximum 5	Chromium (mg/kg) maximum 50	Copper (mg/kg) maximum 300	Nickel (mg/kg) maximum 50	Lead (mg/kg) maximum 100	Zinc (mg/kg) maximum 1000
1	Bhadrak	1	0.00	0.03	1.09	53.8	51.1	18.5	11.0	150
2		2	0.00	0.00	0.70	34.7	38.3	15.4	7.1	124
3		3	0.10	0.11	2.05	91.2	58.5	56.1	28.2	90
4	Paralakhemundi	1	0.00	0.01	3.29	17.7	66.0	12.6	23.1	478
5		2	0.00	0.04	1.44	20.1	53.2	9.1	11.4	152
6		3	0.35	0.09	1.37	15.5	53.9	10.2	16.8	97
7	Kashinagar	1	0.00	0.00	2.88	24.2	60.7	8.5	16.5	140
8		2	0.22	0.12	1.29	26.8	82.7	13.2	9.3	169
9		3	0.06	0.01	2.46	23.4	82.0	10.2	25.7	132
10	Hinjilicut	1	0.00	0.00	3.42	44.3	113.9	19.2	41.9	262
11		2	0.45	0.09	1.65	26.9	232.9	23.0	25.5	359
12		3	0.98	0.09	7.29	26.2	144.2	16.4	34.5	122
13	Hinjilicut (BSF)	1	0.00	0.01	6.41	9.9	42.5	4.6	9.4	164
14		2	0.44	0.10	5.91	29.4	180.0	17.7	89.4	788
15		3	0.40	0.05	4.05	22.2	72.5	10.2	41.8	118
16	Nimapada	1	0.00	0.15	2.15	66.5	66.1	24.0	42.4	138
17		2	0.67	0.10	1.77	24.9	68.7	13.0	8.2	135
18		3	0.10	0.05	1.77	37.0	44.4	16.5	27.8	58
19	*Jatni	1	0.00	0.00	2.07	19.8	48.4	12.2	10.8	241
20		2	0.95	0.07	5.14	35.5	55.6	15.3	24.9	145
21	*Surada	1	0.53	0.10	3.42	20.7	53.6	10.5	11.0	164
22		2	0.09	0.00	2.51	23.5	33.2	14.1	24.7	73
23	*Jagatsinghpur	1	0.61	0.12	4.70	26.8	246.4	14.8	24.1	266
24		2	0.66	0.09	7.70	86.7	67.6	23.0	24.0	117

Annexure 3

Table 4: Odisha compost—pathogens

S. no.	Sample details	Replicate	Faecal coliforms MPN per g total solids (dry weight) (USEPA)	*E. coli* MPN per g total solids (dry weight) (WHO)	*Salmonella* spp. MPN/4 grams of total solids (dry weight) (USEPA)
1	Bhadrak	1	11,936	11936	842,001
2		2	25,613	9925	170,752
3		3	4,978	4978	155,820
4	Paralakhemundi	1	53	53	268,078
5		2	363	188	190,234
6		3	6,457	6457	235,828
7	Kashinagar	1	502	502	69,881
8		2	387	387	73,140
9		3	15	9	61,875
10	Hinjilicut	1	492	492	213,972
11		2	11,848	11,848	163,713
12		3	11,485	11,485	183,754
13	Hinjilicut (BSF)	1	1,765	1,765	28,709,244
14		2	11,958	11,958	304,394
15		3	7,927	7,927	380,517
16	Nimapada	1	161	161	8,597
17		2	12,013	12013	82,999
18		3	247	247	57,602
19	*Jatni	1	1,011	1,011	173,913
20		2	11,357	11,357	194,100
21	*Surada	1	1,196	163	26,098
22		2	966	966	33,224
23	*Jagatsinghpur	1	2,569	460	8,562
24		2	4,844	4,844	12,638

Odisha: *Collected in January and March 2023, first replicate in November 2022, second replicate in January 2023 and third replicate in March 2023

The Centre for Science and Environment (CSE) conducted a study to evaluate the quality of compost produced across 23 different sites in the states of Haryana, Uttar Pradesh and Odisha. The composting sites employed various technologies such as tub composting, organic waste converter, pit composting, windrow composting, and AAGA aerobic tub composting.

This study aims to evaluate the composting processes and identify potential areas for improvement. Key highlights of results include the importance of maintaining an optimal carbon-to-nitrogen ratio, addressing heavy metal contamination, and reducing microbial load. The report provides valuable insights for maintaining the quality of compost. It emphasizes the need for improved practices to reduce pathogens and heavy metal contamination. The major recommendations include effective compost drying to reduce moisture and microorganisms and segregating input waste materials to enhance the safety and effectiveness of compost products, contributing to sustainable agriculture and soil health.

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