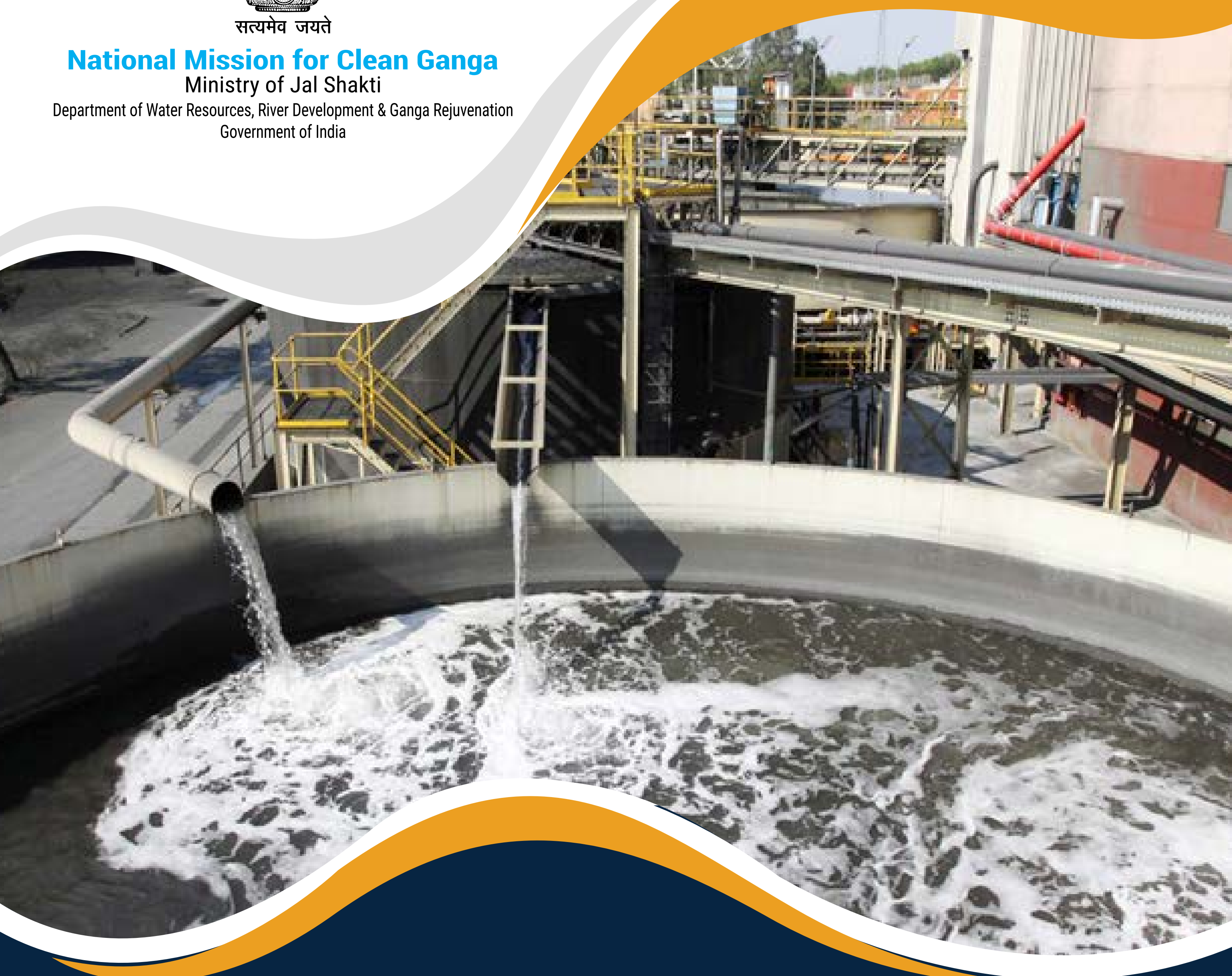
सत्यमेव जयते

National Mission for Clean Ganga

Ministry of Jal Shakti

Department of Water Resources, River Development & Ganga Rejuvenation

Government of India



STP SLUDGES IN INDIA:

STRATEGIES FOR MANAGEMENT AND POTENTIAL PATHWAYS FOR IMPLEMENTATION

REPORT PREPARED BY:

Centre for Ganga River Basin Management and Studies in joint partnership with experts from Norway and India

Supported by NORAD: Norwegian Agency for Development Cooperation

cGanga

Centre for Ganga River Basin Management and Studies

National Mission for Clean Ganga (NMCG)

NMCG is the implementation wing of National Ganga Council which was setup in October 2016 under the River Ganga Authority order 2016. Initially NMCG was registered as a society on 12~~th~~ August 2011 under the Societies Registration Act 1860. It acted as implementation arm of National Ganga River Basin Authority (NGRBA) which was constituted under the provisions of the Environment (Protection) Act (EPA) 1986. NGRBA has since been dissolved with effect from the 7th October 2016, consequent to constitution of National Council for Rejuvenation, Protection and Management of River Ganga (referred to as National Ganga Council).

www.nmcg.in

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this it is also responsible for introducing new technologies, innovations and solutions into India.

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Report Background

The initiation of this report has been numerous technical and scientific discussions that cGanga has led over the years particularly in the India Water Impact Summit programme as well as other dedicated workshops. The sessions on international cooperations in the Summit Editions of 2020 and 2021 led to cGanga entering into a strategic partnership with Norway. It partnered with NIBIO, the Norwegian Institute for Bioeconomy Research and Norwaste to develop this report as well as all the supporting documents. The project has been supported by Norwegian Agency for Development Cooperation.

Additional Reports and Supporting Material

The following reports are to be read in conjunction with this summary report. These are available on request.

- Technological Choices
- Lifecycle costs of each solution
- International best practices

1. Purpose of Sludge Treatment

The purposes of sludge treatment include one or more of the following:

1. Meet Sludge Regulation on national level and local level, if there is one, for the facility.
2. Reduce sludge volume including water content, in order to minimise handling, transportation and disposal costs.
3. Ensure treated sludge is disposed in a safe and environmentally sound way.
4. Protect the health of the citizens, flora and fauna by killing off/ reducing pathogens (disease causing organisms).
5. Ensure stabilisation of sludge, which will prevent vectors (rodents, flies, birds) from spreading pathogens and uncontrolled emission of greenhouse gas.
6. Prevent/ reduce odour by reducing biodegradable organics.
7. Promote circular economy by treating and using the treated sludge, named "biosolids", in an environmentally sustainable manner. Generate useful by-products such as biogas, bio-fertiliser, and soil conditioner/ amendment/enhancer from sludge and extract phosphorus fertiliser from sludge.

There are currently no regulations in India which specifically deal with the handling, transport, treatment, utilisation, storage, or disposal of sewage sludge. However, there are national laws related to waste management (covering municipal wastes, hazardous wastes, sewage, air quality and general environmental protection) which can also impact sludge management. The odours produced by sludge from long time storage/ dumping will provoke complaints and will become a social problem. Awaiting Indian regulations, leading municipalities like Delhi, Mumbai, Bangalore, Ahmedabad and Chandigarh are referring to US EPA 503 sludge regulations in current STP tenders, mostly requiring Class A.

An overall legislation regarding sludge and biosolids management should be in place because it will be fundamental for any future sludge management plans for any region in India. A legal framework should include minimum requirements regarding capacity, sludge treatment,

An overall legislation

regarding sludge and biosolids management should be in place because it will be fundamental for any future sludge management plans for any region in India

quality regarding hygienic standards, storage, odour, contamination, and usage options, and biosolids management. Typically, the following aspects need to be included in any sludge management plan.

- A separate approval for pollution control for the STP and for the sludge processing plants.
- Treatment requirements for sludge (e.g. aerobic or anaerobic digestion with or without pre-treatment, composting, liming, drying, etc.).
- Hygienisation step and limit values for pathogens and heavy metals and vector control (including odour).
- Requirement for land application, where used in agriculture for food production and landscaping
- Dewatering requirement to prevent pollution from storage, reduce transport and space needed for storage, and prevent excess energy requirement for downstream treatments (drying and/or incineration).
- Framework for landfilling restrictions, long term storage (e.g. 3 years) should be regarded as landfilling.
- Maximum application rate (example tonne dry matter/ha) to agricultural land to avoid dumping.
- Monitoring requirement and reporting heavy metal concentrations, in this way indirectly monitor the ingress of industrial discharges in sewerage system.
- Intermediate storage including infrastructure to prevent pollution and timeline before final disposal to prevent dumping.
- Energy and GHG (greenhouse gas) accounting for the sludge treatment to final disposal.

Further it is recommended that each ULBs have a sludge master plan, funded to achieve the legislation and the political goals and priorities of the city.

2. Status of STPs and STP Sludges in India

Table 1 depicts the distribution of STPs based on various technologies deployed in India broken down by capacity and number of STPs in each segment.

Table 1: Technology and capacity distribution of STPs in India (CPCB, 2021)

Sl. No.	Technology	Capacity in MLD	Number of STPs
1.	ASP	9,486	321
2.	EA	474	30
3.	SBR	10,638	490
4.	MBBR	2,032	201
5.	FAB	242	21
6.	UASB	3,562	76
7.	WSP	789	67
8.	OP	460	61
9.	Any Other	8,497	364

2.1 Status of different types of sludges in India

Table 2: shows the tonnage of different types of sludges generated in India (tonnes per day dry solids)

State	PS-IC	PS-AU	SS-IC	SS-AU	MS-IC	MS-AU	Total Sludge (IC)	Total Sludge (AU)
Andhra Pradesh	0	0	89	31.2	90.9	27.4	179.9	58.6
Bihar	0	0	102.2	0	36.5	0	138.7	0
Chandigarh	0	0	50.7	33.8	2	2	52.7	35.8
Chattisgarh	0	0	0	0	19.4	1.8	19.4	1.8

State	PS-IC	PS-AU	SS-IC	SS-AU	MS-IC	MS-AU	Total Sludge (IC)	Total Sludge (AU)
Daman & Diu	0	0	5.4	1.6	0	0	5.4	1.6
Goa	0	0	23.8	3.8	0	0	23.8	3.8
Gujarat	0	0	476.2	342.9	328.6	313	804.8	655.9
Haryana	0	0	292.7	184.5	79.1	73	371.8	257.5
Himachal Pradesh	0	0	7	5.4	44.7	14.7	51.7	20.1
J&K	0	0	23.7	31.9	18.1	6.3	41.8	38.2
Jharkhand	0	0	76.5	1.1	65.4	0	141.9	1.1
Karnataka	0	0	342.2	157.6	167.4	143.2	509.6	300.8
Kerala	0	0	0.7	0.7	27.9	12.2	28.6	12.9
Madhya Pradesh	0	0	12.8	11.5	0	0	12.8	11.5
Maharastra	0	0	792.8	422.8	808.1	195.8	1600.9	618.6
Mizorum	0	0	2.1	0.1	0	0	2.1	0.1
NCT Delhi	0	0	29.9	20.2	695.4	382.9	725.3	403.1
Odisha	0	0	47.8	0	28.5	3.2	76.3	3.2
Puducherry	0	0	10	5.4	0	0	10	5.4
Punjab	0	0	293.1	212.5	52.5	43.2	345.6	255.7
Rajasthan	0	0	127.7	39	116	76	243.7	115
Sikkim	0	0	7.2	3.4	0	0	7.2	3.4
Tamil Nadu	0	0	72.1	20.7	279	222.3	351.1	243
Telangana	0	0	135.3	106.3	22	14.6	157.3	120.9
Tripura	0	0	1.9	0.4	0	0	1.9	0.4
Uttar Pradesh	0	0	543.9	203.5	247.7	58.1	791.6	261.6
Uttarakhand	0	0	107.6	20.2	3.2	0.9	110.8	21.1
West Bengal	0	0	153	13	54	22.7	207	35.7

- *MS-AU: Mixed sludge based on actual utilization of treatment capacity*
- *MS-IC: Mixed sludge based on installation capacity*
- *SS-AU: Secondary sludge based on actual utilization of treatment capacity*
- *SS-IC: Secondary sludge based on installation capacity*
- *PS-AU: Primary sludge based on actual utilization of treatment capacity*
- *PS-IC: Primary sludge based on installation capacity*

3. Sludge Treatment and Management

Generally, sludge from STPs consists of two types: primary sludge from the primary physical wastewater treatment and secondary sludge (mainly waste activated sludge — WAS) from biological wastewater treatment. The most common steps in sludge management is thickening, stabilization, dewatering and final disposal (Wang et al., 2017) — see Figure 1 and 2.

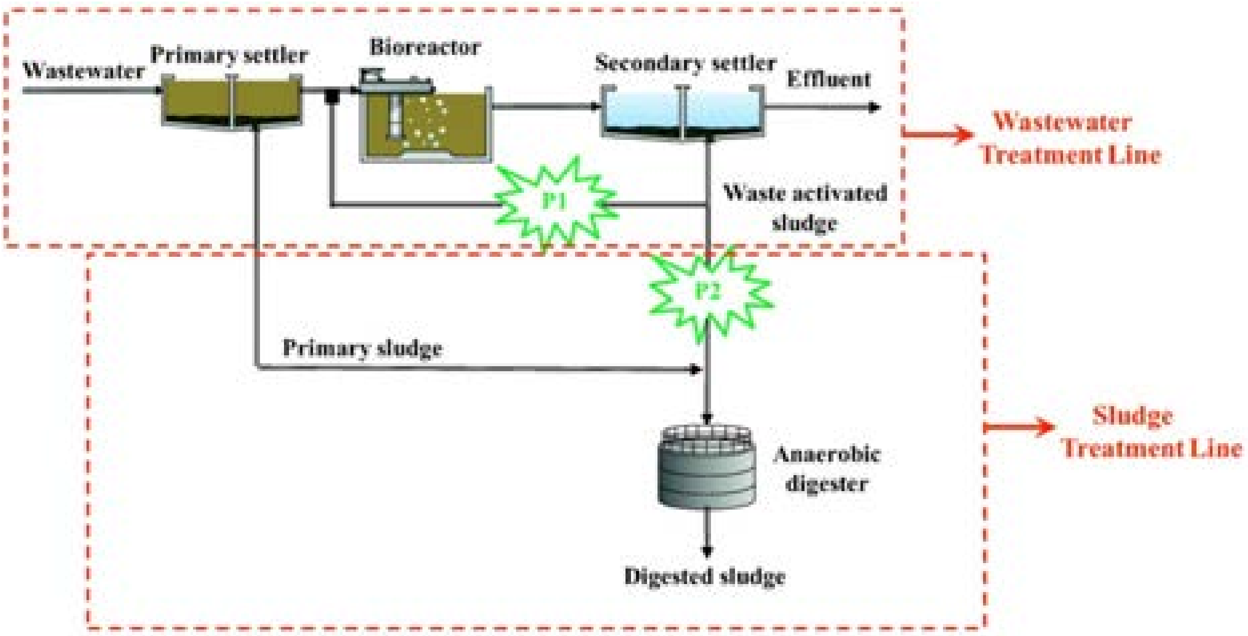


Figure 1: Potential locations for sludge reduction technologies in a typical wastewater treatment plant (WWTP). P1 indicates the location integrated into wastewater treatment line. P2 indicates the location applied in sludge treatment line (Wang et al., 2017)

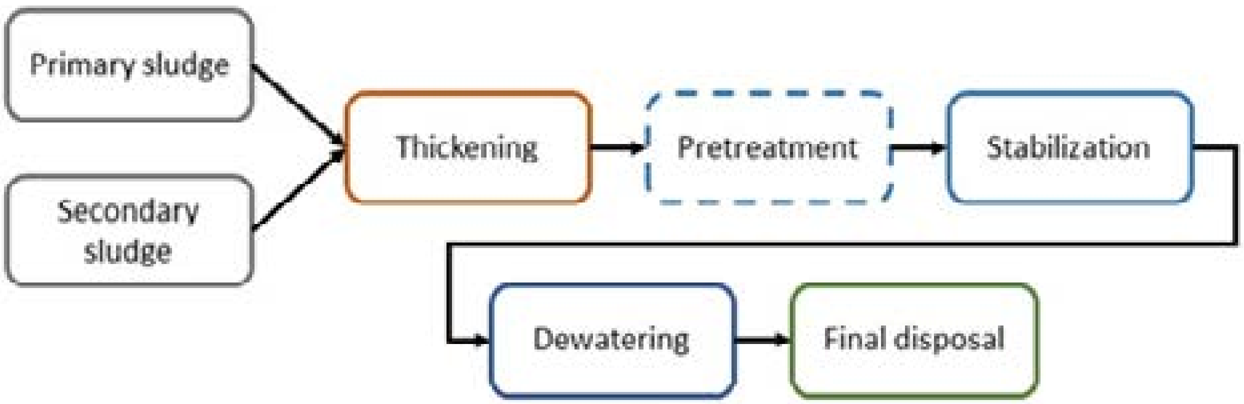


Figure 2: The main steps in the sludge management chain. The use of pretreatment depends largely on the choice of stabilization technology and is therefore shown with a dashed line

The technologies presented in the Table 3 are used in different stages of the sludge management chain.

Table 3: Summary of sludge treatment technologies

Stage	Technology
Thickening	Gravity thickening, dissolved air flotationand drum rotation
Pre-treatment	Physical, chemical, and biological technologies
Stabilization	Anaerobic digestion Advanced Anaerobic digestion Composting Alkaline stabilisation
Dewatering	Drying Thermal Destruction
Final Disposal	Application in agriculture, landfilling, and reuse for production of cement, bricks, and asphalt

3.1 Thickening

Thickening is the first step of sludge treatment and is a process of reducing free water content in sludge. One of the purposes of the process is to reduce the volume of material which reduces the off-site transport and storage requirement.

Untreated sludge from sewage treatment plants (STPs), after thickening, contains ~95 per cent water (~5 per cent solids).

To dewater sludge from ~95 per cent down to ~80 per cent water (~20 per cent solids) a condition chemical, like polymers, is added prior mechanical separation. This makes the sludge particles into flocs which make it easier to separate the water and solids by centrifuges, belt-presses, chamber filter presses, or others.

3.2 Pre-treatment

The pre-treatment can be applied to primary, secondary, or mixed sludge. Different pre-treatment methods are available, and they can be divided into various categories such as thermal, chemical, mechanical, biological, physical, and combined (e.g., thermochemical, physicochemical). The physical, thermal and their combination are most used and studied.

3.3 Stabilization

a. Anaerobic Digestion (AD)

There are two pathways for biological treatment of sludge, anaerobic digestion and composting (aerobic) to be turned into treated sludge or biosolids. AD is a mature technology and one of the most widely used for sludge stabilization. For example, around 66 per cent of sewage sludge produced in UK and 90 per cent in Germany is treated using AD (Tao et al., 2017).

- AD occurs in an oxygen-free environment in e.g., meso- or thermophilic conditions and produces biogas (mixture of methane (CH_4), carbon dioxide (CO_2) and small quantities of other gases) through by biological activity.

AD is a mature technology and one of the most widely used for sludge stabilization. For example, around 90 per cent in Germany is treated using AD

- Reviewing world-wide tenders for STPs in cities, almost all include AD as required sludge treatment, whether the resulting digested sludge (biosolids) go to agriculture, incineration, landfill or other end-use.

b. Advanced Anaerobic Digestion

Pre-treatment combined with anaerobic digestion is called advanced anaerobic digestion - AAD. Most commonly used Class A technologies within advanced anaerobic digestion are:

- Thermal Hydrolysis process (THP) + Anaerobic Digester
- Temperature-phased Anaerobic Digestion (TPAD)
- Pasteurization + Anaerobic Digester

A schematic of AAD with pre-treatment is shown in Figure 3 and in Figure 4 a picture of a plant with thermal hydrolysis pre-treatment is illustrated.

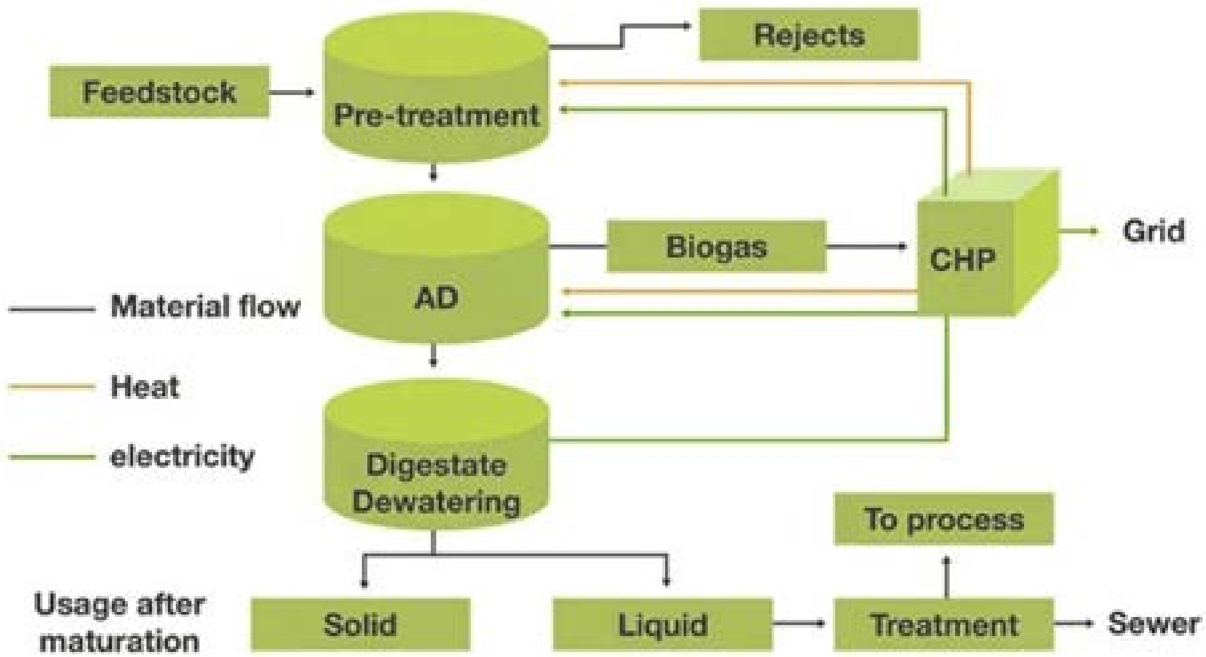


Figure 3: An illustration of anaerobic digestion. Besides CHP energy recovery, the biogas may also be upgraded into biomethane to replace fossil fuel.
Image Credits: surreycc.gov.uk

Figure 4: An illustration of a sludge treatment plant using THP and advanced anaerobic digestion. This plant treats 250 tonnes of sludge (on a dry basis) per day from a 500 MLD STP. ***Image Credits: Elliot Hobbs, Minworth STP, Birmingham, UK***

c. Composting

Composting of organic waste requires conditions that ensure fast degradation and safe sanitation of the organic material. The aerobic composting process can be done mesophilic at 37 °C (e.g. vermicomposting with the use of earthworms) and thermophilic over 55 °C.

- Thermophilic processes are most effective in degradation of organic material from 12 - 30 days. The high-rate composting phase is characterized by high thermophilic microbial respiration at temperatures above 45 °C.

Under optimally run composting, easily degradable organic contaminants will be highly reduced. For persistent organic compounds the reduction can be rather low.

For smaller STPs, the two options for sludge treatment, composting or sending the sludge to a sludge treatment centre with anaerobic digestion. Composting may be performed in closed composting reactors (in-vessel) or outdoors with shelters. however, the process requires space and machinery to turn the composting heaps, see Figure 5.

Figure 5: Sludge composting using a compost turner, which allows maximum space utilisation at the composting site. ***Photo credit: cnhydraulicpress.com/***

d. Alkaline stabilization (liming)

Lime is one of the most common materials used for sewage sludge stabilization. Application of lime increases the pH value of lime-sludge mixture for extended periods (Samaras et al., 2008), thereby reducing the availability of heavy metals and lowering the environmental risk (Wong and Selvam, 2006). Additionally, it prevents odor problems (Wong and Fang, 2000). However, through the alkaline stabilization only Class B of biosolids can be achieved (Bean et al., 2007).

3.4 Dewatering

Dewatered untreated sludge usually contains between 18-22 per cent solids depending on type of sludge and method of dewatering. Dewatering is a key-treatment to many subsequent processes as storage, transport, land application as fertiliser/ soil conditioner, sludge drying, pyrolysis and incineration. Dewaterability is dependent on the technology used for sludge treatment.

Figure 6 shows differences in nature and "stackability" of sludge after dewatering which reflects different sludge treatment technologies.

Figure 6: Different nature of dewatered biosolids depending on type of sludge, digestion technology and dewatering equipment. Volume to area ratio (m^3 storage/ m^2 occupied-area) for storing same volumes of different sludges (solid biosolid between 1.50 and 0.80; plastic biosolids between 0.8 and 0.60; liquid biosolids < 0.30) (Spinosa, 2007)

3.4.1 Drying

Drying is essentially the evaporation of water (most of it) from dewatered sludge. Thermal drying to 90 per cent dry solids is required to achieve Class A standards in the US.

In most cases the sludge is digested first, and the biogas are used to heat the dryer. Anaerobic digestion also reduces the volume of sludge to be dried and consequently, the energy requirement. Evaporation of water requires a lot of energy, but this is offset to some extent by reduced hauling costs and has to be evaluated in comparison to other options.

Two different drying technologies are solar drying in greenhouse and thermal drying (Figure 7). Solar drying needs extensive ventilation to ensure the moisture emissions. Generally thermal drying uses biogas generated from the anaerobic treatment and external fuel to achieve Class A biosolids with 90 per cent solids.

3.4.2.Thermal Destruction

The sludge thermal destruction technologies that are being considered are: Pyrolysis, Gasification, and Incineration.

Drying is essentially the evaporation of water (most of it) from dewatered sludge. Thermal drying to 90 per cent dry solids is required to achieve Class A standards in the US

Figure 7: Solar drying in greenhouses (left) and thermal dryer (right).
Credit photo: suezwatertechnologies.com

Pyrolysis

A subsequent process after dewatering and drying is pyrolysis. Pyrolysis is a thermal process. Pyrolysis of organic substances produces volatile products (gas and oil) and leaves char, a carbon-rich solid residue. Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization. Pyrolysis is considered the first step in the processes of gasification or combustion. There are different process designs for pyrolysis:

- Slow pyrolysis
- Intermediate pyrolysis
- Fast pyrolysis
- Hydro-pyrolysis

Gasification

Gasification is a process that converts organic or fossil-based carbonaceous materials at high temperatures (>700°C), without combustion, with a controlled amount of oxygen and/or steam into carbon monoxide, hydrogen, and carbon dioxide.

Incineration

Fluidized bed is the preferred technology for incineration of sludge. Since the calorific value of most dewatered sewage sludge is not sufficient for self-sustaining combustion in a fluidized bed incinerator, the sludge must be dried before mono-combustion to increase the calorific value. Combustion is carried out at temperatures of 850-950 °C.

In the case of mono-incineration, the process will be maintained if the sludge has a higher content than 55 per cent DM. At lower dry matter contents the process must be supplied with external fuel or a separate drying step before the incineration. The calorific energy for digested sludge with different water content is given in Table 4.

Fluidized bed is the preferred technology for incineration of sludge

Table 4: Calorific energy in different sludge and dry matter content

Type of sludge	Calorific energy in MJ/kg wet sludge	Dry matter (%)
Mechanical dewatered digested sludge	1-3	20-35
Partly dried digested sludge	4-7	40-85
Completely dried digested sludge	up to 12	>85

4. General Perceptions/(mis) Understandings around STP Sludges

4.1 Sludge has a lot of energy generation potential

- A general perception created by the consultants, vendors and businesses engaged in handling sludge is that sludge has biogas potential and can be utilised for energy generation potential in a profitable manner.
- Yes, it is true that there is energy trapped in sludges but the quantum of it is what matters most.
- The anaerobic digester remains the main energy generator and the aeration tank the main energy consumer in a STP, and both must be optimised to reach the zero-energy goal. The more biogas derived from sludge treatment (anaerobic digester) the more carbon neutral energy will be produced. In India, STPs operate aeration tanks with long solids retention time (SRTs) resulting in excessive use of air. This also digests the sludge partially/extensively aerobically in the aeration tank resulting in higher air demand. Higher use of air results in higher electrical consumption. Biological treatment of STPs in India must be optimised by operating at lower and appropriate retention time to minimise energy use and improve effluent quality. Recommended SRT for biological systems to achieve less than 10 mg nitrogen /L is 6 -10 days depending on

sewage characteristics and temperature. Lower retention times result in lower consumption of air and thus saves energy for aeration. In addition, lower retention times result in younger sludge with higher volatile solids and increased sludge quantities, which will yield more biogas (and energy) when digested in an anaerobic digester. However, this may have an adverse impact on the solid-liquid separation and quality of treated effluent.

Clarification

Therefore, to propagate the theory that digesting sludge will produce enough biogas that can fund the operation of the plant is not advisable. At best there will be a partial reduction in the operational cost of the plant.

4.2 Treated sludge can be used as a fertilizer

There are several studies worldwide of the benefits of converting sludge to a fertiliser / soil conditioner product. Organic carbon is food for soil microbes, it builds soil tilth, it enhances erosion resistance and increases water-holding capacity and increases the ability to retain nutrients.

The average organic carbon content in soil, an index for Indian soil health, is as low as 0.3-0.4 per cent, according to Indian Council of Agricultural Research. This is well below the acceptable 1-1.5 per cent carbon content. Indian soil needs addition of a tremendous amount of organic carbon and biosolid is perceived to be potential carbon source for these soils. Composted biosolid contains more carbon due to use of bulking material to produce compost compared to digested biosolids. Digested biosolid may contain higher percentage of nutrients such as nitrogen and phosphorus compared to sludge compost.

However, the more stable the added carbon (stable humic) is, the more effective organic fertiliser is to increase soil carbon.

Application of 10 to 20 tons of digested biosolids per hectare is usually acceptable to apply every five to ten years. This application

Indian soil needs addition of a tremendous amount of organic carbon and biosolid is perceived to be potential carbon source for these soils

rate has to be verified and has to be within the requirement for the plant nutrition for the different crops. Biosolids typically have too little nitrogen (~1.5 per cent) compared to the phosphorus content (~2 per cent), and to achieve a more balanced fertiliser more nitrogen should be applied. If the sludge management plan involves a strategy for land application of the biosolid, field trials should be performed to educate farmers and biosolids contractors.

High quality biosolids may even be packaged and sold as a soil product for private gardens.

Clarification

At best sludges are soil enhancers as they cannot match the level of NPK present in the chemical fertilizers.

4.3 Class A standards should be applied uniformly across the country

Different countries around the world have different sludge regulations. However, it is common to regulate the sludge disposal route depending on the hygienic standards of the sludge. For example, the US, the UK and South Africa have defined sanitation into three classes of treated sludge or "biosolids". Norway defines only one class, meaning biosolids must be sanitised if used in agriculture or green areas e.g., parks, road slopes, golf course or top cover at landfills.

- Class A biosolid has gone through a full pathogen kill and is suitable to be used for agricultural purposes.
- Class B biosolids have reduced numbers of pathogens, however it is not safe to be used in food production. This biosolid may be used in areas with low public access and be part of road slides or land reclamation projects.
- Class-C sludge is not treated and has to go to landfill with certain restrictions or to be thermally destroyed. Since landfilling of sludge should be avoided and only be an emergency option, drying and thermal destruction is the only option for untreated sludge.

Beside hygienic standards, sludge may have high levels of contaminants of unwanted heavy metals which should not be spread as a fertiliser / soil conditioner

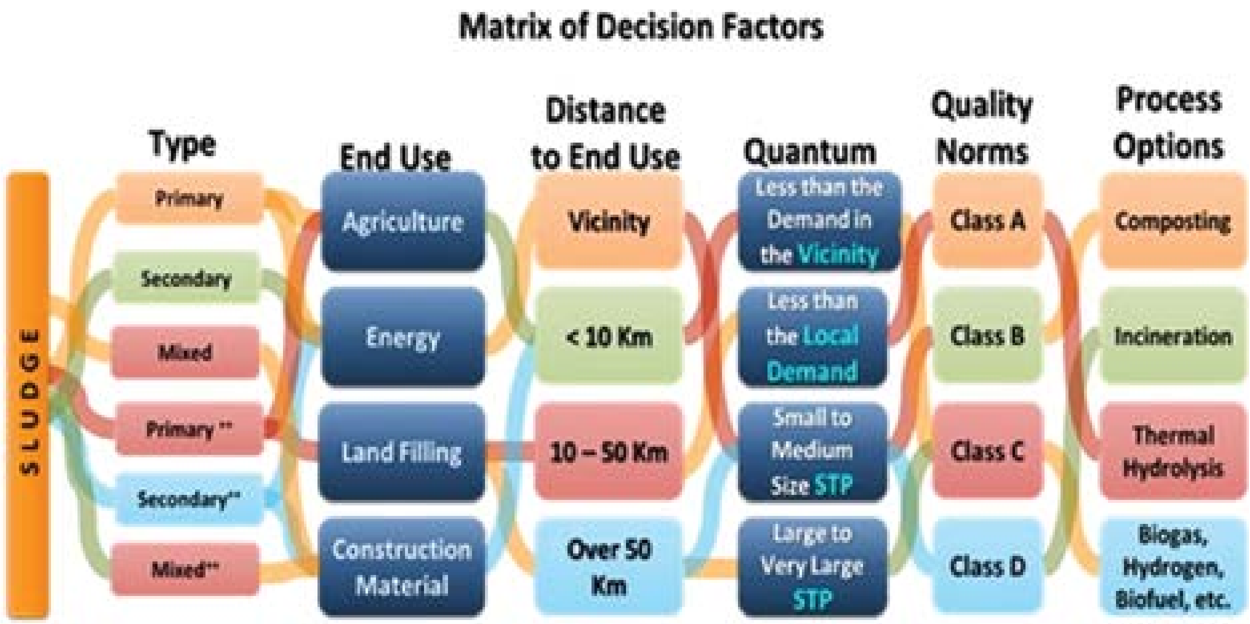
The biosolids regulations also demand vector reduction, like risk of flies and rodents. One such option is to reduce the biodegradable organics to a minimum through biological processes. Beside hygienic standards, sludge may have high levels of contaminants of unwanted heavy metals which should not be spread as a fertiliser / soil conditioner. The option route for this kind of sludge should be the same as Class C sludge, in other words, thermal destruction.

Clarification

Standards need to be defined for each city and location, and blanket standards will not work in the Indian context.

5. A Framework to Approach Sludge Management

As urban local bodies (ULB) get into their planning for creating a solution for sludge management, the matrix presented above



will help them in designing the optimum solution. The five critical factors that determine the solution design are:
(1) The type of sludges being produced
(2) What is the potential of intended end-use of the treated sludge
(3) What is the distance
(4) What is the quantum of the output
(5) Whether there are any quality norms legislated

The processing options and technological choices adopted will depend upon the matrix above as the ULB will also have to look at availability of financing and the overall economics of the optimum solution.

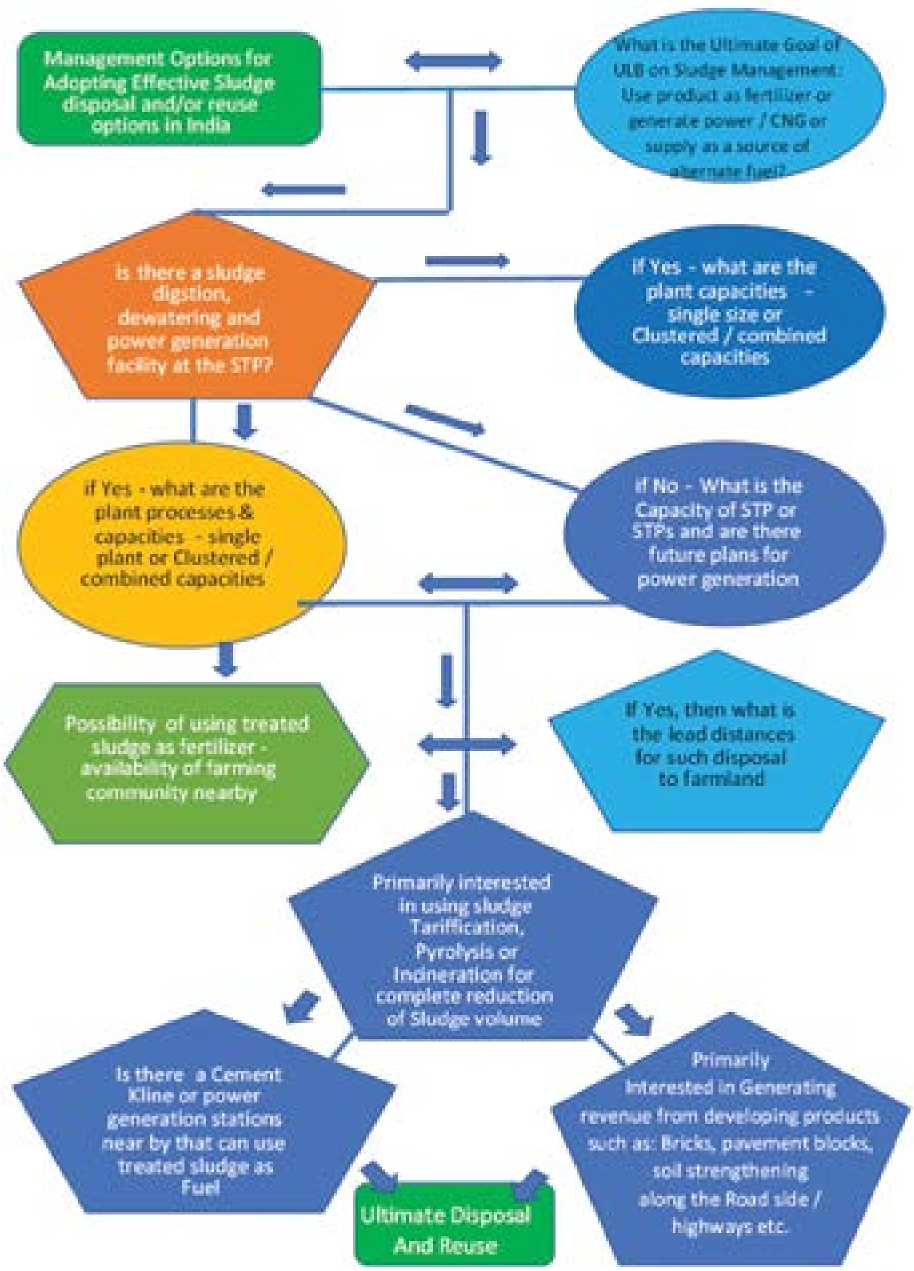
Sludge has to be disposed of safely in a sustainable manner to minimise/ eliminate landfilling

Therefore, every ULB should proceed in developing their sludge management plan. Why should a municipality have a sludge management plan? The reason is that sewage treatment plants (STP) generate sludge in very large amounts continuously, which is a problem and the sludge needs to be managed and disposed of but in doing the approach must be to recover any resource/value that is trapped in the sludges. This will help lower the operational cost of management of sludge for the ULB.

Untreated sludge or poorly treated sludge has the risk of spreading diseases and odour. If it is flooding there is a risk of polluting water if the sludge is stored close to the waterbody. The runoff from storage or landfill can flow into a waterbody or leachate from landfill or storage may reach groundwater. Landfilling requires huge space and becomes the breeding ground for spreading pollution and diseases. In addition, unstabilised sludge will emit greenhouse gases. So, sludge has to be disposed of safely in a sustainable manner to minimise/ eliminate landfilling. Organic waste in a landfill will emit greenhouse gases and enhance leachate of contaminants from the landfill.

Sludge is a source for green energy production, biogas. Biogas should be utilised, preferably replacing fossil fuel. However, if this is not economically feasible, the energy in biogas should be utilised to sanitise the sludge or as energy for drying it. Excess biogas should be transformed into electricity and heat or upgraded to fuel quality.

A decision tree for sludge management and planning is shown in figure below.



Composting is an alternative for smaller amounts of sludge. Advanced anaerobic digestion may be applied for STP lager than 50 to 100 MLD. Since the volume of sludge produced (before thickening) is between 1 and 2 per cent of the wastewater flow, centralised sludge treatment is recommended for multiple STPs. This provides an advantage for economies of scale. So, for better utilisation of the produced biogas and the investment cost, a centralised sludge centre should be considered for STPs between 5-50 MLD. Recommended distance from a STP to a sludge treatment centre should not be more than 50 km, however longer distance may also be considered depending on the transport infrastructure, cost and alternatives. Some surveys and measures have to be performed before any decisions are done:

- **First:** Measure the amount of raw sludge that is produced in a STP and to specify the proportion of primary sludge and secondary sludge (WAS).
- **Second:** Measure the quality of sludge regarding heavy metals. If there are known industries that contaminate the sewage this should be banned to have discharges to the sewage system or obligated to treat the wastewater separately.
- **Third:** To survey the local options for utilisation of treated sludge (biosolids). The most cost-effective disposal option is land application of biosolids. Biosolids contain plant nutrients and organic material beneficial for agriculture and soil in general. This option requires a high hygienic standard because no transmissible diseases should be allowed to be spread. If land application of biosolids is not feasible, thermal destruction should be assessed. The investment cost and operational cost of drying before thermal destruction is dependent on the amount of biosolids and the water content.
- **Fourth:** Survey the possibility for sustainable use of the biogas and choose sludge treatment technology and projects that produce biogas in an amount that has the potential for energy production (CHP) or replacing fossil fuels.
- **Fifth:** Investigate the locations or facilities already in place at

If there are known industries that contaminate the sewage this should be banned to have discharges to the sewage system or obligated to treat the wastewater separately

the STPs whether there is space, capacity and infrastructure for anaerobic digestion and sludge handling.

- **Sixth:** Perform a life cycle cost assessment from sludge production to utilisation, including storage, transport, e.g., drying and land application / thermal destruction. Identify the main cost drivers from sludge treatment and handling.

6. Economic and Financing Framework

Financing of sludge management will have multiple models based on the capital expenditure (CAPEX) and operational expenditure (OPEX), the size of the project and the capacity of the municipality to pay.

Many ULBs are unable to proceed further as they don't know the total lifecycle costs and how they can get value for money. This requires modelling across four segments:

- What end-use solution the ULB is intending
- Commercial model available for the end-use
- PPP structures based on risk appetite of the ULB
- Financing options for State and for the contractor

Comparison has to be done on operational aspects and total lifecycle costs (TLCs) in a like for like manner across various technologies. The first model that will need to be prepared is the commercial framework which includes:

- What is the resource recovery possible from implementation of a sludge management plan for every city? This includes energy (gas) recovery, water recovery, soil-conditioner recovery, or possibility of torrefying the biomass to sell as fuel to thermal power plants. What is the current practice and cost of disposal, and plans /regulations that require a change of this?

- The second level of analysis that needs to be done is the availability of tariff based or off-take based markets for each of the resources. So, for instance, will the gas be used for captive consumption to produce electricity thereby reducing the total operational expenditure for electricity consumption or will it be exported to the grid? Similar studies will be needed for other resources.

- The third level of study is around creation of a market where a market doesn't exist such as for the soil-conditioner, as there is a possibility of enhancing the NPK values of the soil-conditioner which will fetch a greater price in the market. The option of paying the farmer to allow use of biosolid to improve soil organic matter may also be considered as a national social well fare scheme and cost of these compared with other options of sludge processing.

- Based on the analysis of these, a commercial model emerges which will determine the ULB's ability to pay for the sludge treatment processes across the city.

- The PPP models available to ULB are as follows:
  - Fully funded by the State and operated by the contractor
  - Partially funded by State (viability gap funded) and contributions from contractor with O&M operations
  - Hybrid annuity model
  - Concession given by State and project fully funded by contractor who will recover their investments from the O&M operations paid for by a combination of tipping fee and resource recovery/monetisation
- The financing options for the ULB are as follows:
  - Fully funded by State government
  - Partially funded by Central and State Government
  - Development Finance Institution funded via State Government
  - State Government issued green bond
  - Impact sludge bond issued by a third party with guarantees from State / Central Government

The option of paying the farmer to allow use of biosolid to improve soil organic matter may also be considered as a national social well fare scheme and cost of these compared with other options of sludge processing

- The financing options for the contractor are as follows:
  - Establishment of an alternative investment fund (AIF) dedicated for sludge management. The fund would partner with a number of operators and provide both equity and debt for the projects. The contractors would have to provide for some equity should they win the tendered bids.
  - A sludge focused Infrastructure Investment Trust (InvIT) that will buy out the projects from the developers and the contractors continue to operate them.
  - Plain vanilla equity and concessionary debt from various investors and lenders.
- The final piece of the puzzle is via the generation of carbon credits that would bring in additional capital and thereby viability for the projectst. The option of to the farmers for improving soil organic matter may also be appropriately accounted for in working out carbon credits.

Issue of market for soil-enhancer

A common misconception is that India spends billions of dollars every year in importing urea/fertilizers from other nations. The country then makes the fertilizers available to farmers at a highly subsidised rate. Proponents of selling treated sludge residues as soil-enhancer make the case of the huge fertilizer market in India and the operational cost of sludge operations can be hugely subsidised by selling the soil-enhancer. But there are two major fallacies in that argument and these are:

- That the farmers have the ability to pay for the soil-enhancer
- That the funds spent by government on procuring urea and fertilizer from the international markets are readily available also for the soil-enhancer

The only way this market can develop is if one or more select fertilizer companies become market makers by aggregating the production of sludges from various STPs nationally. These aggregators would have to sign long-term off-take agreements with the operators of the sludge treatment plants. They will go on to collect, transport, further process sludges, package, market and distribute the soil-enhancer.

They will also have to take the responsibility of securing subsidies from the government in order to make their operations commercially viable.The government will establish a floor and a ceiling price in considering the subsidy levels for this product.

Figure 8 illustrates the structure of this market mechanism for soil-enhancer.

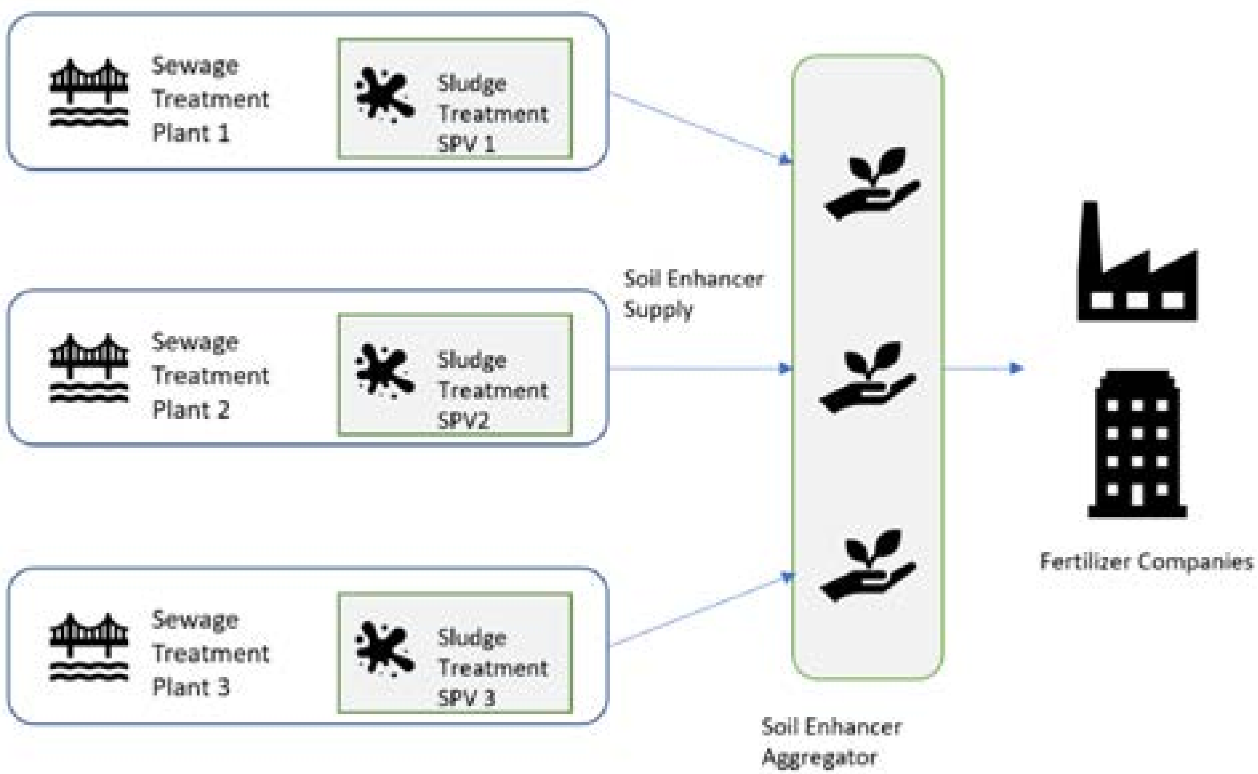


Figure 8: Market mechanism of soil enhancer

Creating a pooled risk facility of sludge treatment

- This framework is for the various municipalities coming together with a view to develop capacity and capabilities to raise finance from global capital markets.
- The finance is raised via long-dated Sludge bonds with 20+ year tenors the proceeds of which will be used to construct (VGF) and pay for the O&M fee of the plants.
- The pooled risk entity aggregates the assets and guarantees from various state governments and urban local bodies.
- The risk entity issues a bond that would get a backstop guarantee from the central government.

The economic model consists of the following components:

1. A number of Urban Local bodies are invited to join the pooled vehicle.
2. Initially they would contribute a single asset but as they build confidence, more and more assets can be contributed into the risk entity.
3. A manager would be selected based on its credentials and the one that is able to place the bonds in domestic/global markets as well as manage the securities provided by the various local bodies.

Figure 9 depicts how the facility can operate in the Indian context.

The finance is
raised via long-dated Sludge bonds with 20+ year tenors the proceeds of which will be used to construct (VGF) and pay for the O&M fee of the plants

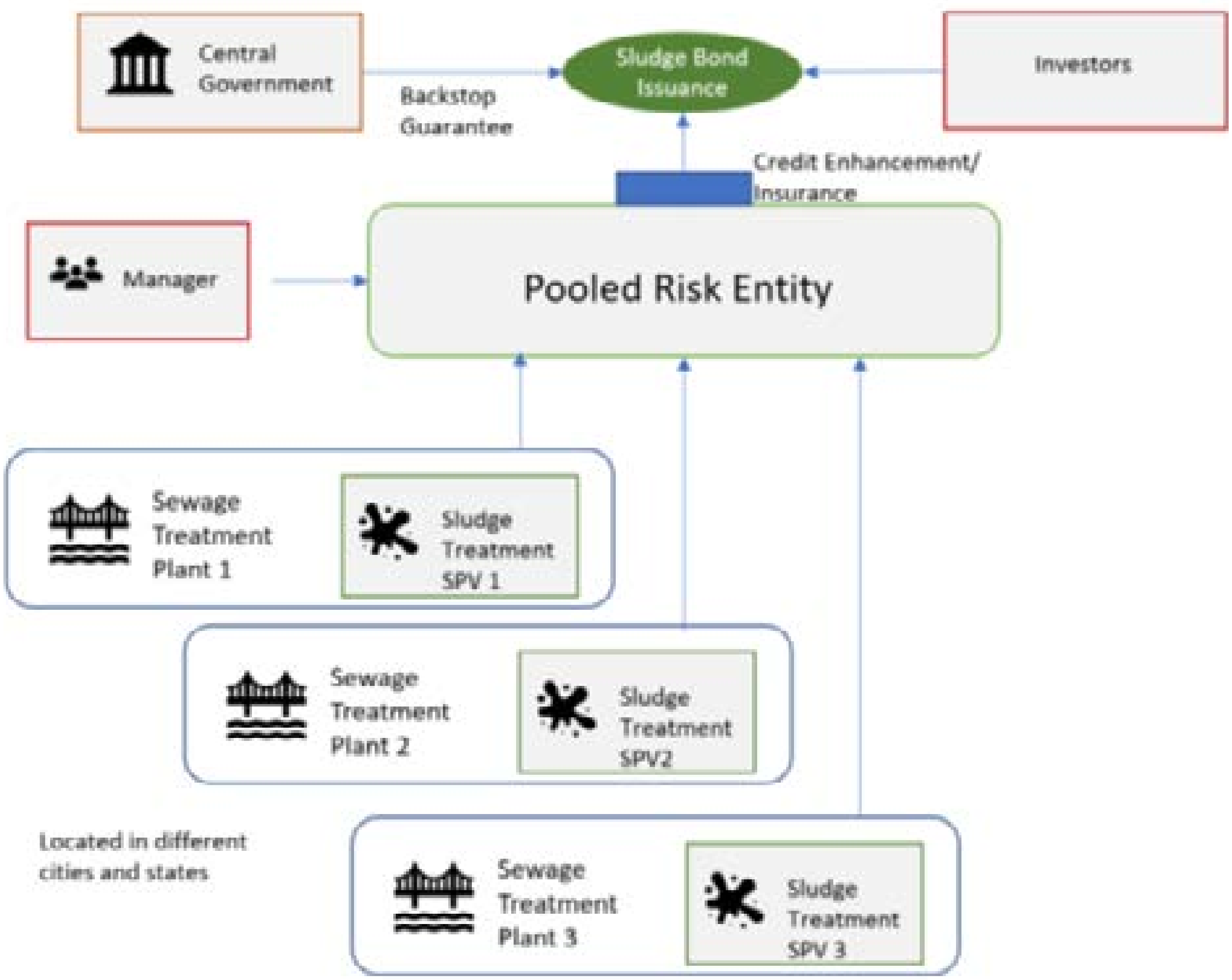


Figure 9: Potential facility to operate in Indian context

7. Policy Recommendations

Based on the analysis listed out in this discussion paper, the following steps, policies and enablers are recommended for implementation in India to address the issue of sludge management.

7.1 STP Sludges should be hygienised and predominantly used for “top-soil” rejuvenation as the most prolific end-use.

The nation experiences an average annual soil erosion rate of over 16 tonnes per hectare, and an annual gross loss of over 5000 million tonnes each year. Nearly a third is lost to the sea and the balance is predominantly shifted resulting in conversion of cultivable lands to waste-lands.

The need for conservation measures is crucial, with an estimated nearly 150 million hectares out of the reported area of over 300 million hectares requiring intervention. It has been reported that nearly 20 percent of the country’s total geographical area has undergone this transformation into wastelands.

It is therefore imperative that top-soil rejuvenation is kept as a national-priority and this objective must be taken up in a “mission-mode”.

Other use cases such as creating energy briquettes, construction under-lay will be of relevance where processing for soil-enhancement is not an option.

7.2 Liability for one department is an asset for another department.

The STP sludges and biodegradable municipal solid waste produced in urban areas has to be dealt with an environmentally friendly manner. This requires huge capital investment as well as high

The standards cannot be uniform across the nation as they very much depend on the end-use classification and characteristics of sludges being produced across the nation

ongoing operations and maintenance costs. The landfill sites are also big emitters of methane, one of the most significant contributors to greenhouse gas emissions and more significantly more potent than carbon.

There must also be a total ban on sending STP sludges to land-fill as it defeats the very purpose.

The challenge for urban local bodies is to be able to generate enough revenues to cover the costs of capital expenditure and operations for waste management. However, if the residual biodegradable urban waste, after adequate treatment and processing for pathogen elimination, is used for top-soil rejuvenation, then not only the resource recovery process becomes an asset to the nation but is also able to cover the costs through the market created for a quality soil-enhancing product.

7.3 Agronomic Values for "soil-enhancing" material can be enhanced by mixing STP sludges with biodegradable municipal solid waste.

In treatment of STP sludges, when an alkaline process is utilised, the blended pathogen free material has a very high level of pH for agronomic applications and uses in India. If this material is blended using other organic wastes such as organic waste from the Municipal Solid Waste ("MSW") stream then the pH levels are lowered to near neutral range. That MSW organic waste material should be sourced from existing city composting firms who are not able to achieve a full compost of their raw material streams. This creates a market for the compost as well.

The augmentation of macro and micro-nutrient in the STP waste using other organic waste-streams is also very important. Of particular importance is the level of organic carbon that needs to be returned back to the soil. If the STP sludges are produced from a plant that utilises digesters, then the residual carbon needs to be augmented. This can be done by adding other waste streams.

The challenge for urban local bodies is to be able to generate enough revenues to cover the costs of capital expenditure and operations for waste management

7.4 Presence of heavy metals in sludge streams

As per the study," Comprehensive characterisation of variably processed sewage sludge in Ganga Basin to classify its suitability of safe disposal", 1st Progress Report of the study lead by the Indian Institute of Technology, Roorkee for the National Mission for Clean Ganga (NMCG, Department of Water Resources, River Development and Ganga Rejuvenation (Do WR, RD & GR), Ministry of Jal Shakti, GoI, the samples of dewatered sludges tested satisfy the parameters of US EPA Class B Biosolids and are not far away from meeting the US EPA Class A Biosolids standards. Further dilution, provided it confirms to the established and agreed standards, can help the material meet higher standards as well. However, the samples do not qualify for the Indian Fertilizer Control Order (FCO) standards on N-P-K requirement and in a few cases where domestic sewage is ingresses with industrial wastes forheavy metals.

It is important to realize that the STP sludges are an important material for enhancement of Soil Organic Matter (SOM) and Soil Carbon (SC) that can substantially improve soil microbiology and thereby indirectly supplement nitrogen content through atmospheric nitrogen fixation in the root zone.

The market-making

will require providing a channel to market the end product to fertilizers

As summarised in this report, the uniformity of standards is a function of what the market for the final treated sludge is. Each city would have to create its own sliding scale metric based on the presence of industrial effluent streams in the wastewater stream.

7.5 Pathogens

The report of the IIT Roorkee led study further confirms that the dewatered sludges satisfy the US EPA Class B norms on fecal coliforms.

Further under Indian Climatic Conditions (mostly in Arid and Semiarid regions) pathogens are unlikely to survive and the fear of contamination of agricultural fields, particularly those which are not used for the produce that are not consumed unprocessed, is over stretched.

7.6 Pathway to FCO compliance product

Since the FCO product requirements are stringent, these are largely assessed from a chemical fertilizer lens and do not take into account the issue of top-soil rejuvenation. Therefore, there is a need to build a scaffolding around the FCO compliance regime to support the initiative of top-soil-rejuvenation.

This will entail conducting scientific testing of application of sanitised STP sludges on various soils, creating an interim or proxy compliance route and finally a full certification by FCO on the final product.

7.7 Accuracy of data collection at generation point

a. The management of sludge includes its generation, treatment, transport, beneficial reuse or disposal along with its monitoring and reporting. The minimization of sludge production and assurance of quality should be the prime concern at the source point itself.
b. The accurate data should be in place at the source of generation itself and following points should form a part of the report of every WWTP.
c. The design parameters and capacities along with actual flow and raw sewage data for WWTPs' on yearly basis should be reported and maintained by every municipal corporation of every state.
d. The raw water parameters in WWTPs should also include testing for heavy metals concentration.
e. A register should be maintained to note the dry solid production and concentration in "tonnes per day – TPD" from each WWTP to assess the volumes of sludge produced from each site.
f. Sludge sampling should be done on a monthly basis so as to have quality assurance of sludge.
g. The cost and distance of disposal of sludge from WWTPs should be reported.

The subsidy mechanism should also take into account on making avail of the benefits of any carbon-credits

7.8 Defining hygienisation standards

The CPHEEO Manual on Sewage Treatment has, in 2013, distinguished between Sludge being readily suitable or being unsuitable as soil additive depending on its faecal coliform content, and also of Sludge being hazardous when heavy metal contents are high. The use of sludge as agricultural fertilizer has also been limited by standards set by the Ministry of Chemicals and

De-watering process and digesting of STP sludges is made mandatory as part of the STP process rather than a separate bolt-on module which is either inefficient or is complex to retrofit in an existing STP

Fertilizers. In light of these norms and the above shortcomings in existing sludge management practices, it is imperative that comprehensive policy measures are adopted to mitigate the mounting challenge of managing increasing sludge generation in the country.

The standards however cannot be uniform across the nation as they very much depend on the end-use classification and characteristics of sludges being produced across the nation.

7.9 Mechanism for market creation

There has to be a joint initiative of urban local bodies, department of fertilizer and department of agriculture to create a market for treated STP sludges. The market-making will require providing a channel to market the end product to fertilizers. The following efforts will be required:

- Communicating the benefit of the soil-enhancer product to the farmers such as issues related to odour, consistency and efficacy.
- Demonstrating measurable benefits to the farmers.
- Establishing a product price that includes all elements of the value chain including: processing, production, bagging, storage & transport, marketing-margin for the distribution companies.
- Creating a joint subsidy mechanism to unlock subsidies from various departments to make the product financially viable.

- The subsidy mechanism should also take into account on making avail of the benefits of any carbon-credits.
- Substantial public expenditure for top soil rejuvenation for 10-15 years on the lines of the support provided under various schemes such as MGNREGA, SBM, Namami Gange, etc. for rejuvenation and conservation of rivers.

7.10 Making de-watering mandatory and optimal approach to stabilisation and energy efficiency to be addressed on a case by case basis.

It is imperative that the full solution to sludge management are looked at and not just parts of the process. The dewatering part must be made mandatory. The stabilisation and energy efficiency components have to be addressed based on how much residual carbon is left in the sludges as this needs to be prioritised for returning back to the soil.

Although, the more recent projects take into account operational efficiencies that the plants can achieve through gas capture that in the end helps reduce the overall power consumption of the STP, and therefore would take on the benefits offered by various technologies.

More recent projects take into account operational efficiencies that the plants can achieve through gas capture that in the end helps reduce the overall power consumption of the STP

7.11 Develop sludge management plans for the ULBs based on the matrix outlined earlier in this document. This would entail:

a. Standards of hygienisation (Class A or Class B)
b. Sludge reduction in % tonnage DM per year (efficiency of digester)
c. Biogas production and plan for biogas utilisation
d. Sludge tonnage dewatered sludge per year
e. The cost for anaerobic digestion and any pre-treatment (CAPEX and OPEX)
f. The handling (CAPEX and OPEX) cost of sludge per tonne after dewatering including if required drying, intermediate storage and transport to final destination (land application or thermal destruction)

Conducting scientific

testing of application of sanitised STP sludges on various soils, creating an interim or proxy compliance route and finally a full certification by FCO on the final product

g. Total sludge treatment cost (per tonne raw sludge dm) plus handling cost of biosolids per tonne (above)
h. Climate footprint (climate greenhouse gas) per tonne sludge delivered to final destination
i. Land footprint
j. Plan for sustainable sludge management
k. Joint-master-planning

- As demonstrated in the Sludge-Matrix, each city/ town would have its own unique characteristics of the volumes and qualities of STP sludges produced. Also, the vicinity to markets will determine the cost-benefit analysis of the "soil-enhancer" product marketing and distribution companies.
- Further, the city/town should look at dewatering hubs into which the septage cleaning industry can also integrate. This would also offer an opportunity to bring the manual scavengers into main-stream process and formal economy. They can be provided with equipment, training either by the State or enable creation of a micro-enterprise around the value chain.

7.12 Commercial Demonstration Projects

NMCG and other departments of Government of India and respective State Governments are required to take-up pilot projects.

cGanga is preparing a number of such projects with technologies that are validated through the ETV process. The projects will establish operational and commercial parameters, but most importantly provide the foundation necessary for **"Mission Top-Soil Rejuvenation".**

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