आवासन और शहरी कार्य मंत्रालय
भारत सरकार
MINISTRY OF HOUSING AND
URBAN AFFAIRS
GOVERNMENT OF INDIA

सत्यमेव जयते

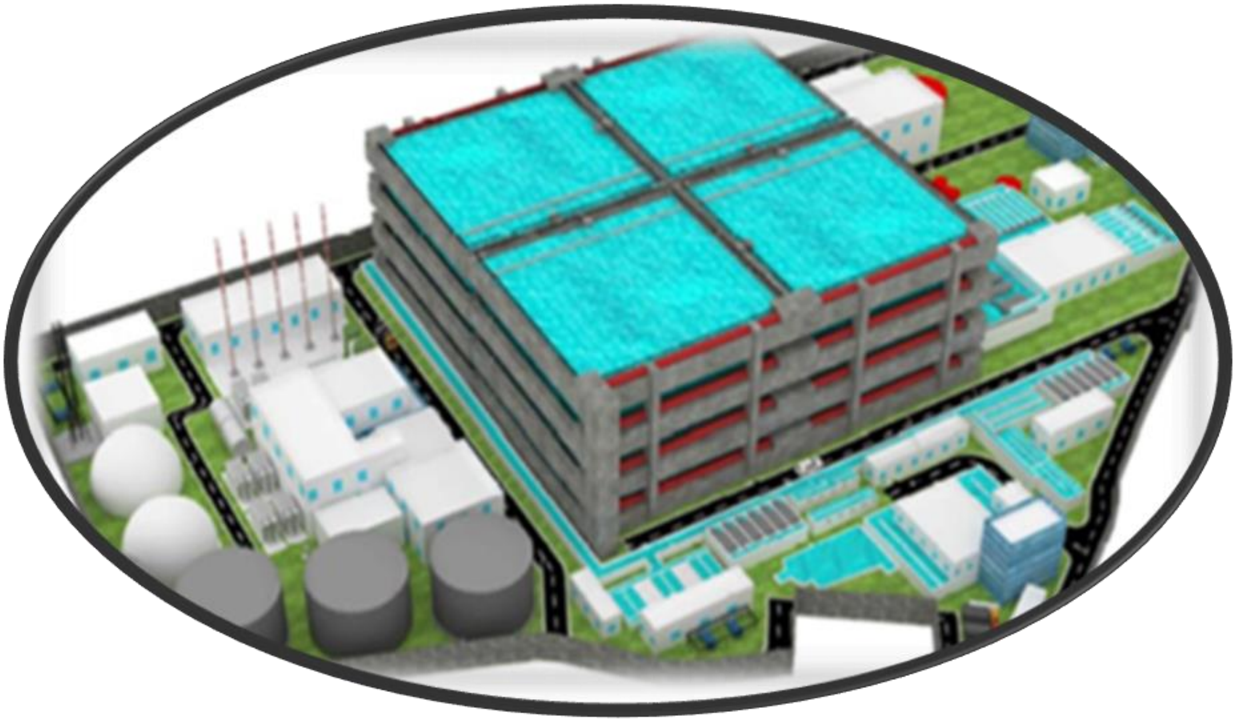
स्वच्छ भारत
एक कदम स्वच्छता की ओर

Swachh Bharat Mission - Urban

ADVISORY ON

MULTI-STOREY SEWAGE TREATMENT PLANTS

(FEASIBILITY ANALYSIS)



Central Public Health and Environmental Engineering Organization (CPHEEO)

MINISTRY OF HOUSING & URBAN AFFAIRS

Government of India

www.sbmurban.org | November 2024

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Executive Summary

CPHEEO has brought out this advisory on setting up of Multi-storey/underground STPs for urban areas with land constraints. The multi-storey/underground STPs are suitable for urban areas, where the population is relatively dense and the land area is limited and there is a demand for urban landscape. Sewage inflow has increased because of urbanization and enhanced living standards, giving rise to the necessity to treat a large volume of sewage within a limited area. Due to rising land prices and advanced urbanization, enlargement of existing sewage treatment sites and development of new sites in urban areas is a difficult task. Thus, the construction of multi-story/underground facilities for sewage treatment commenced as a circumstantial requirement.

Multi-storey/underground STPs have advantages in saving land and pipeline network investment as compared to conventional STPs, making it an attractive option for ULBs. In the advisory, advantages of multi-storey/underground STPs have been discussed. Salient features of some case studies on multi-storey/underground STPs are given highlighting their strengths and weaknesses. The potential safety hazards of multi-story/underground STPs cannot be ignored, but it can be significantly controlled by providing deodorization and ventilation equipment.

As per a study conducted in Osaka, Japan, the multi-story/underground STPs are lower than the one-story conventional STPs in main construction cost but higher in retaining wall and earthwork expenses. Thus, the overall construction cost is almost equal for both types of facilities. Further, the structural occupancy area per unit treatment capacity for multi-story STP facilities in Osaka, Japan can be reduced upto 46% in comparison to the conventional one-story STP and are equally efficient in treatment performance to conventional STPs.

Therefore, construction of multi-story/underground STP facilities can be suitably considered for setting of new STPs and retrofitting of the existing STPs by ULBs for urban areas with land constraint.

CHAPTER – 1

1. Introduction

Over the past few decades, the expansion of urbanization and population growth in India, coupled with issues such as land scarcity, land acquisition, and geotechnical glitches, significantly challenged the development and management of STPs in urban areas. To enhance efficient land utilization, construction of multi-storey STP is an innovative, environment-friendly, resource-intensive, and sustainable approach. Using modern technologies and shifting from single-storey conventional STPs to multi-storey STPs reduces the land requirement which is one of the most critical infrastructures for the development of urbanization. In multi-storey/underground STPs, the occupied land requirement can be reduced by about 54% compared to conventional STPs.

Various sewage treatment processes used in above-ground conventional single-storey STPs are generally not used in multi-storey/underground STPs due to factors such as large area requirement, huge sludge output. Thus, the approaches with small footprints, high treatment efficiency, and less residual sludge are widely used in multi-storey STPs. The selection of a reasonable, established, and promising sewage treatment technology is critical for the long-term development of the multi-storey STPs. Various high performing technologies like Sequential Batch Reactor (SBR), Moving Bed Biofilm Reactor (MBBR), and Membrane Bioreactor (MBR) etc., can be adopted for multi-storey STPs.

A multi-storey STP structure can be made underground, semi-underground or above-ground. In general, underground multi-storey STPs usually consist of a double-layer underground design. The second floor is used as the pool layer of sewage and sludge treatment structures, and the first floor underground serves as the operational management layer and the auxiliary building layer. The ground floor above the underground structures can be used to construct buildings such as comprehensive office buildings, parking lots, sports fields and other functional buildings or green park spaces. The underground multi-storey STPs have significant advantages in saving land cover, controlling noise pollution and odor, and ecological landscaping, compared with the conventional STPs. A comparative of landscaping effects between single-storey conventional STP and underground multi-storey STP is exhibited in Fig. 1.1.

Fig. 1.1: Comparative of landscaping effects between single-storey conventional STP and multi-storey underground STP (Giwa and Ali, 2023)

The above-ground landscape of the underground multi-storey STPs increases the value of the above-ground space, thereby offsetting the relatively high construction, operation, and maintenance costs generated by underground construction. In semi-underground design, the sewage treatment facilities are all underground, and the repair and maintenance buildings, office and living areas are on the ground. Whereas, in above-ground multi-storey STPs, structure is built together, compact, stacked above in layers, reducing the plant area results in less land utilization.

Therefore, with the continuous development of India's economy, the rapid increase in the urbanization and the increasing need for a better quality of living environment, the value of multi-storey/underground STPs will become more obvious in the future.

1.1 Objectives

- To provide guidance on the feasibility of multi-storey STPs in India.
- Land area and the cost comparison of multi-storey STPs with the conventional single-storey STPs.
- To provide guidance on the operational performance of multi-storey STPs.

CHAPTER – 2

1. Multi-storey STPs: Global scenario

In recent years, multi-storey STPs have gained more and more attention globally in urban sewage treatment because of their advantages in utilizing less land area, less noise pollution and odor, and better landscape than conventional single-storey STPs. The application of multi-storey STPs established in the world has a history of more than 80 years. Finland built the world's first underground STP in 1932; most of Sweden's STPs are underground and multi-storey. In addition, countries like Japan, South Korea, Netherlands, United Kingdom, Norway, France, Switzerland, Monaco, and the Czech Republic have built underground multi-storey STPs, which have successfully resolved the contradiction between sewage treatment, environmental pollution, and urban land use, and achieved great results in economic and social benefits. Some examples of multi-storey (underground, semi-underground and above-ground) STPs are given below in Table 2.1.

Table 2.1: Examples of multi-storey (underground, semi-underground and above-ground) STPs

Multi-storey STPs		Country
Underground (Giwa and Ali, 2023)	Hayama STP	Japan
	Kashima STP	
	Sendai Kamo STP	
	Busan STP	South Korea
	Daegu Jisan STP	
	Yongin STP	
	Bromma STP	Sweden

	Loudden STP	
	Marseille STP	France
	Antipu STP	
	Wiggin McKee Center STP	Finland
	Veas STP	Norway
	Dokhaven STP	Netherlands
	Xinqi STP	England
	Kunming Ninth STP	China
	Guilin Pingle STP	
	Shenzhen Buji STP	
	Hong Kong Stanley STP	
	Beijing Daxing Tiantanghe STP	
	Nanpian in Wenzhou STP	
Semi underground (Giwa and Ali, 2023)	Gifu STP	Japan
	Incheon STP	South Korea
	Geneva STP	Switzerland
Above-ground	Osaka STP	Japan
	Yannawa STP, Bangkok	Thailand
	Rishikesh STP, Uttrakhand	India
	Pune Cantonment STP, Maharashtra	India

	Dharavi STP, Mumbai, Maharashtra	India

Sweden developed an underground multi-storey STP more than 70 years ago. In 1942, Stockholm, the capital of Sweden, took advantage of the local superior geological conditions and advanced rock excavation technology to build underground multi-storey STPs. The entrance of the underground STP adopts an ingenious architectural art, which greatly beautifies the city's appearance and at the same time increases the city's green area. Most of the STPs in Sweden adopt this construction model.

Korea is also at the forefront of the world in the application of underground multi-storey STPs. With the rapid development of social economy, South Korea is facing various problems such as higher requirements for effluent water quality, shortage of urban land, and increasing requirements for the living environment of people around the plant. In recent years, to save land, most of the newly built underground multi-storey STPs in South Korea have adopted the underground construction model, which is said to account for about 50% of all STPs in South Korea.

The Dokhaven STP in **Netherlands** is in Rotterdam, the second largest city in the Netherlands. It is an underground multi-storey STP with only a control room built on the ground. This STP has been in operation for 28 years and was built in 1987.

As compared to the rest of the world, the underground multi-storey STPs developed late in **China**. Underground STP projects have been developed in Beijing, Shanghai, Guangzhou, Kunming, Hefei, Qingdao, Suzhou, Guilin, Xiamen, Shijiazhuang, Wenzhou, Taiyuan, and other cities so far. Nearly 40 underground STPs have been put into operation or are under construction. The total processing capacity of the plants is about 4.9 million tons/day. The construction of underground multi-storey STPs in China is booming and playing an important role in the field of sewage treatment.

A multi-storey underground STPs are more extensively adopted worldwide in comparison to semi-underground and above-ground STPs. Underground multi-storey STPs are preferred due to two primary reasons: to prevent the impact of extremely cold weather on the sewage treatment effect, such as in Sweden, Finland, Norway, and other Nordic countries; and to save urban land resources, such as in Singapore, Japan, South Korea, the Netherlands, and other countries.

With the continuous development of the urban economy and the need for improvement for a better quality of living environment, the STPs previously built in the city center now face several problems and thus need to be renovated and relocated, the cost of which is huge. The underground multi-storey STPs can be built in the center of the city and because of its closed design, it can prevent noise, odor and other pollution, all of which make them suitable for future urban development needs. A list of about 50 multi-storey underground STPs globally in chronological order (Sun et al., 2019) is given in **Annexure**.

A comparison of the underground multi-storey, semi underground multi-storey, conventional above-ground single-storey and above-ground multi-storey STPs in relation to different parameters is described in Table 2.2.

Table 2.2: Comparison of underground multi-storey, semi underground multi-storey, conventional above-ground single-storey and above-ground multi-storey STPs (Giwa and Ali, 2023)

Parameters	Underground multi-storey STPs	Semi underground multi-storey STPs	Conventional above-ground single-storey STPs	Above-ground multi-storey STPs
Design form	▪ STP and maintenance floor are underground, and a park is built on the ground.	▪ STP facilities are built semi-underground, and the top of the pool is sealed with a cover.	▪ Above-ground STP facilities with an open access pool.	▪ Above-ground STP facilities with an open access pool.

Land use	▪ Structures are built together, compact, stacked down in layers, results in less land utilization.	▪ Land utilization rate is relatively low.	▪ Land utilization rate is relatively high.	▪ Structures are built together, compact, stacked up in layers, results in less land utilization.
Noise pollution	▪ Equipment's are laid all underground, and mechanical noise and vibration does not affect the buildings and residents on the ground.	▪ Selecting low-noise equipment, and closed equipment's conducive to noise reduction, which has little impact on nearby residents.	▪ Take noise reduction measures but cannot completely avoid the impact of noise on the life of nearby residents.	▪ Equipment's are laid all above-ground, and mechanical noise and vibration affects the buildings and nearby residents.
Odor	▪ Fully enclosed underground comprehensive treatment of sewage, odor, and sludge, without impact on the environment.	▪ Pool body is covered and sealed, and the odor is collected and processed, eliminating the impact on the environment.	▪ It cannot completely avoid the impact on the environment	▪ It cannot completely avoid the impact on the environment.

Sealed cap	▪ Pool is stacked up and down in layers, multi-column network, and the structure is complex.	▪ Top portion of the pool is covered, mostly with light-weight structures such as fiberglass.	▪ No sealing cap	▪ Pool is stacked up and down in layers, multi-column network, and the structure is complex.
Construction difficulty	▪ Underground depth can be more than 10 meters, requiring deep foundation, pit support, and the construction is difficult.	▪ Buried depth is about 3 meters underground, the excavation volume is small, and the construction difficulty is relatively less.	▪ Above-ground structure and the construction difficulty is relatively less.	▪ Above-ground height can be more than 10 meters, requiring deep foundation, and the construction is difficult.
Construction Investment	▪ Investment per ton of water is about CNY 5000-6000	▪ Investment per ton of water is about CNY 2500-3000	▪ Investment per ton of water is about CNY 2000-2500	--
Floor area	▪ 0.4~0.5 m^2/ton of water	▪ 1~2 m^2/ton of water	▪ 1~2 m^2/ton of water	--
Construction period	▪ 12-18 months	▪ 8-10 months	▪ 6-8 months	--

CHAPTER – 3

3. Overview of different types of multi-storey STPs

A brief overview of different types of multi-storey STPs like fully underground multi-storey STPs, semi-underground multi-storey STPs, and above-ground multi-storey STPs, have been discussed below to understand the feasibility of multi-storey STPs.

3.1 Fully underground multi-storey STPs

In fully underground multi-storey STPs, structure is built together, compact, stacked down in layers, reducing the plant area results in less land utilization. Thus, sewage plant and maintenance floors are below ground. Some of the examples of fully underground multi-storey STPs, like1) Multi-storey STP in Shenzhen Buji, China, 2) Multi-storey STP in Kunming, China, 3) Multi-storey STP in Beijing Daoxianghu, China, and 4) Multi-storey STPs in Kidwai Nagar (East), New Delhi are explained below:

3.1.1 Multi-storey STP in Shenzhen Buji, China

The Shenzhen Buji STP is China's first completely underground STP with a park on the ground. Its construction began in April 2008 and its operation started in April 2011. The designed sewage treatment capacity is 200,000 tons/day. The planned land of the Shenzhen Buji STP is narrow, long, and irregular. An underground design is adopted to effectively save the land resources and improve land use efficiency.

The main structure is located underground, and the upper space is built as a leisure park. The construction area of the leisure park is about 4.30 hectares. The thickness of the top layer of the underground structure is 1.5 meters and deep-rooted large tropical plants are planted therein. The overall construction of the plant environment and leisure park landscape can not only coordinate with the surrounding topography but also be integrate with the street park and the green belt, thereby embodying the harmonious concept of integration of man and nature.

The HYBAS process is a composite process involving biofilm and activated sludge. It has the advantages of an activated sludge process and a fluidized bed biofilm. The two are combined in the same pool and equipped with a double-layer secondary sedimentation. The pool not only operates stably and ensures that the effluent water quality reaches the standard of Class A or above, but also effectively save the land used for project construction; thus, the actual land occupation per ton of water of the project is only 0.23 m^2/ton/day, which is much smaller than that of the same scale STP in the urban sewage treatment project, whose land occupation index according to the project construction standard was 0.75 m^2/ton/day.

Fig.3.1: Multi-storey STP in Shenzhen Buji, China with a leisure park on the ground (https://en.cccltd.cn/yw/dcs/Ecology_and_Environment_Protection/202109/t20210901_142175.html)

Highlights

- China's first completely underground STP with a leisure park on 4.30 hectares on the ground embodying the harmonious concept of integration of man and nature.
- A multi-storey STP based on a composite process involving biofilm and activated sludge.

3.1.2 Multi-storey STP in Kunming, China

Kunming Ninth STP was put into operation in 2014. Its operation improved the overall sewage treatment capacity of Kunming which has increased to 1.91 million tons per day, effectively reducing the pollution load discharged into Dianchi Lake. The STP covers an area of 2.8 hectares, with a treatment capacity of 100,000 tons per day, a service area of 22.85 square kilometers, and a population of nearly 300,000. The whole underground double-layer design is adopted for this plant. Kunming Ninth STP adopts the Membrane Bioreactor (MBR) treatment process. The MBR process has advantages of high treatment efficiency, compact equipment, and a small footprint.

Highlights

- A multi-storey STP based on MBR treatment technology.
- The sewage treatment facilities and maintenance units are located on the second floor and the first floor of the basement, respectively. Only one office building is on the ground level, and the other spaces are built in the surrounding open landscape parks, thereby achieving environmental harmony.

3.1.3 Multi-storey STP in Beijing Daoxianghu, China

The Beijing Daoxianghu reclaimed STP is in the northwest of Haidian District, Beijing. Its construction officially started in August 2013 and was put into operation in 2016. Its treatment capacity is 1,60,000 tons per day, the service area is about 34.5 km^2. The investment in the first phase of the project is about CNY 480 million, and the treatment capacity is 80,000 tons/day. This plant is currently the largest underground STP and the largest reclaimed STP in the northern region of China. The plant adopts A/A/O denitrification and phosphorus removal technology. The treated reclaimed water is used for water landscaping of the garden of the plant area, and on the other hand, it is used for water replenishment of water bodies.

Highlights

- A reclaimed STP, upgraded to multi-storey STP based on the A/A/O denitrification and phosphorus removal technology.

- The plant covers an area reduced from the original 17 hectares to the current 4.47 hectares, a reduction of nearly three quarters after the transformation.

3.1.4 Multi-storey STPs in Kidwai Nagar (East), New Delhi, India

3 nos of multi-storey STPs at Kidwai Nagar (East) Complex, New Delhi were developed based on SBR technology (Fig 3.2) of capacity 1500 KLD: 2 nos and 650 KLD: 1 no.

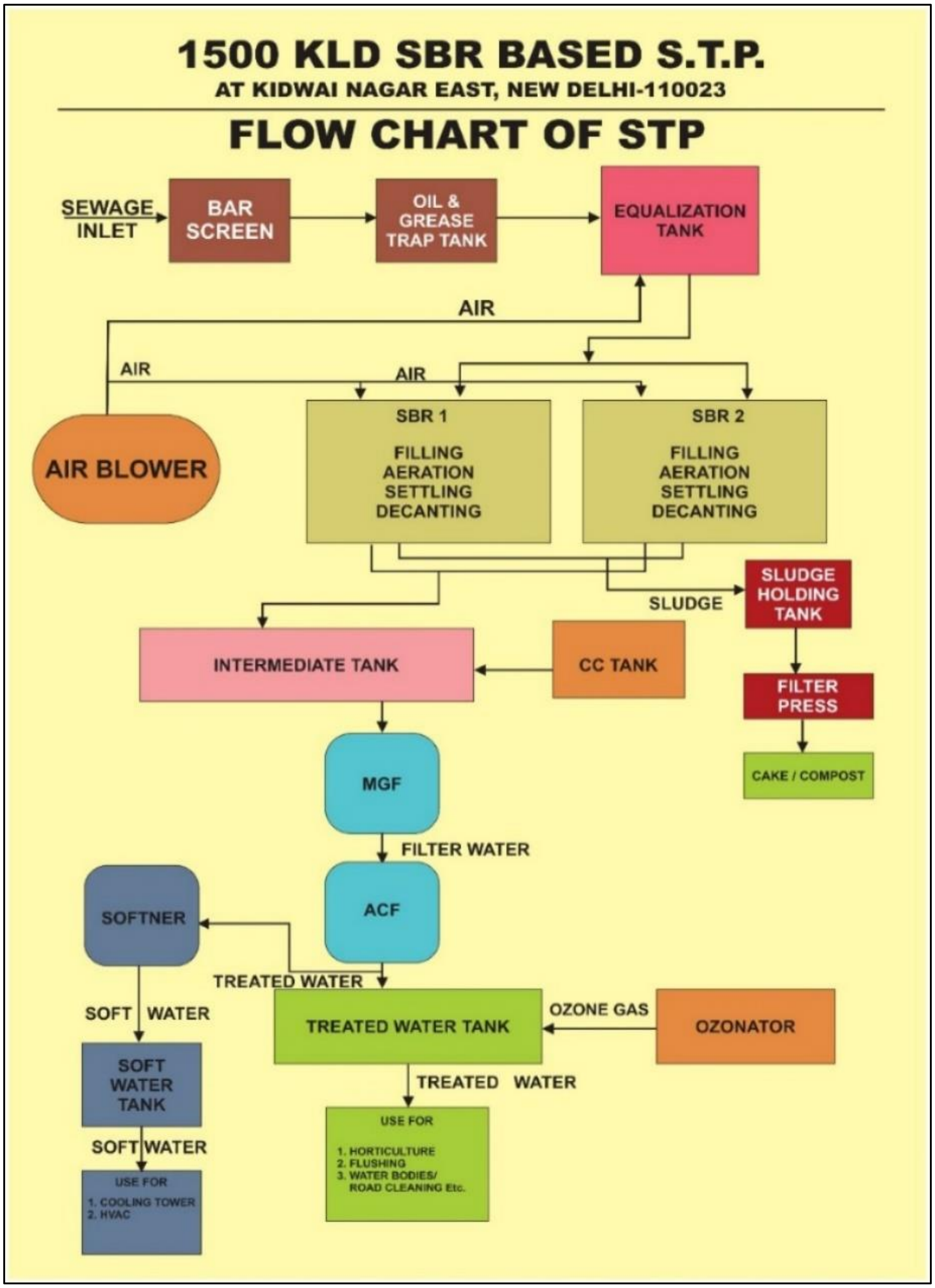


Fig. 3.2: Flow chart of Multi-storey STP (1500 KLD) in Kidwai Nagar (East) complex, New Delhi, India

Highlights

- A multi-storey STPs based on SBR technology.
- Appropriate deodorization and ventilation arrangement to control odour and gaseous pollutants.

3.1.5 Multi-storey Pantai 2 STP in Kuala Lumpur, Malaysia

For more than 50 years, Pantai Dalam, one of the oldest settlements in Kuala Lumpur, Malaysia has been known as the home of the Pantai STP, an open-air oxidation pond that served as one of the most critical sewage treatment facilities in Kuala Lumpur. The unfortunate by-products of this service are the water pollution and unpleasant odour that emanate from the facility. Under the 10th Malaysia Plan, the Pantai 2 STP was built to replace the original facility. This new state-of-the-art mechanized underground STP has proved to be a model for innovation in concept, design, engineering and construction and transforming its surrounding environment.

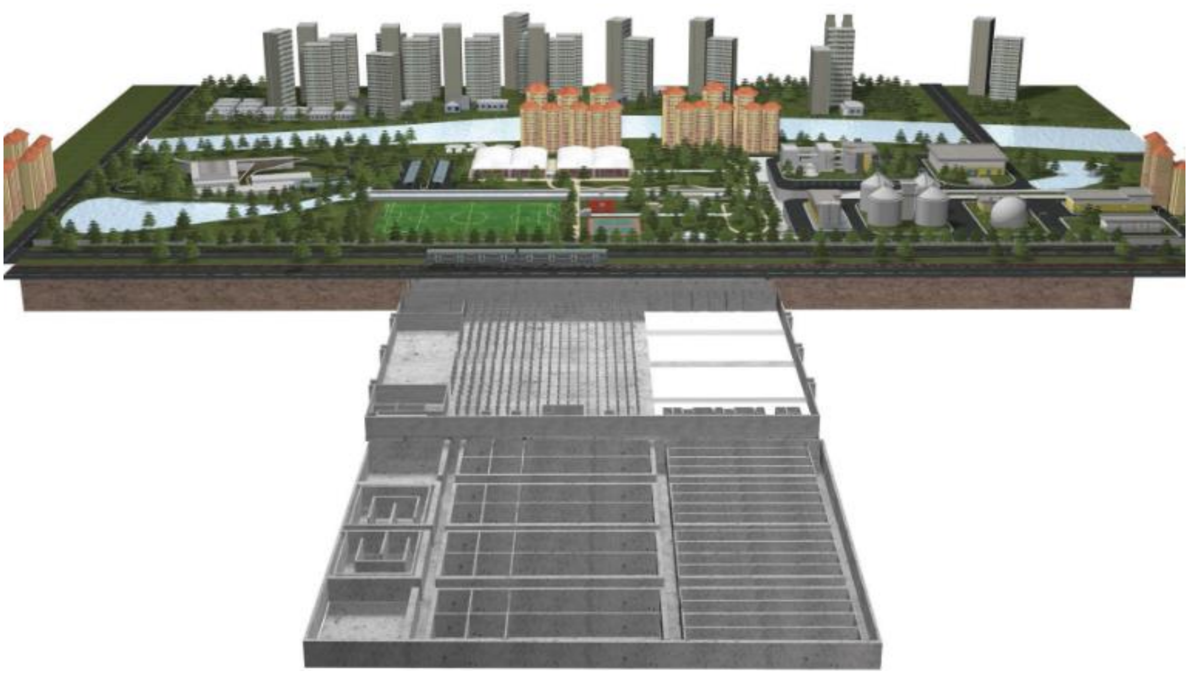
The Pantai catchment area covers 6,700 hectares in the central and south-western parts of Kuala Lumpur with a 320,000 m^3 per day capacity to serve a population equivalent to 1.423 million.

This mega STP was constructed on the same site where the previous oxidation ponds were. It comprises two main parts: the sludge treatment facility above ground and the fully underground multi-layered sewage treatment facility that goes 17 metres deep. At the ground level, there is also a 12-hectare public park named Pantai Eco Park with waterways and abundant greenery, as well as recreational facilities and covered parking.

This plant uses advanced anaerobic-anoxic-oxic (A^{2}O) liquid treatment process using microorganisms to break down sewage material. It results in better quality effluents, more efficient and effective removal of contaminants such as nitrogen and phosphorus from wastewater, more stable operating systems, minimal production of sludge, and smaller footprint. Odour scrubber systems are provided at this plant to treat odorous gases from the sewage and sludge treatment. The Pantai 2 underground multi-storey STP is built with sustainability in mind, capitalizing on renewable resources for energy and water to reduce wastage and pollution (Fig 3.3).

Aerial view of Pantai 2 multi-storey underground STP

(https://www.constructionplusasia.com/my/pantai-2-sewage-treatment-plant/)



The fully underground sewage treatment facility goes 17 metres deep

(https://www.constructionplusasia.com/my/pantai-2-sewage-treatment-plant/)

Bio effluent pool provides natural light to the plant below
(https://www.constructionplusasia.com/my/pantai-2-sewage-treatment-plant/)

The skylight naturally brightens up the underground plant
(https://www.constructionplusasia.com/my/pantai-2-sewage-treatment-plant/)

Above ground facilities include a community centre, sports facilities and a 12-hectare public park (https://www.constructionplusasia.com/my/pantai-2-sewage-treatment-plant/)

Fig. 3.3: Multi-storey Pantai 2 underground STP in Kuala Lumpur, Malaysia

A bio-gas generator converts the methane gases produced during the sludge treatment process to generate up to 700 kilowatts of auxiliary power. Together with solar panels installed atop the parking lots, it supplies 10 to 15 % of the plant's power needs. The aquatic skylight over the underground passageway provides natural lighting for the space below with energy savings of up to 30 kilowatts a day, while the wastewater source heat pump facilitates heat exchange with effluent to generate a cooling load of 1,200 kilowatts, which drives the air-conditioning system for the administration building and community centre.

Highlights

- A multi-storey STPs based on anaerobic-anoxic-oxic (A^2O) process.
- A sludge treatment facility above ground and underground multi-layered facility that goes 17 metres deep. At the ground level, there is also a 12-hectare public park with waterways and abundant greenery.

3.1.6 Multi-storey Changi NEWater plant in Singapore

Singapore is an economically developed and highly urbanized island country with very scarce freshwater resources. Changi water reclamation plant collects and treats used water from the eastern half of Singapore. The treated used water is then channeled to the NEWater Plant on its rooftop to be further purified into NEWater. NEWater is the brand name given to reclaimed potable water produced by Singapore's Public Utilities Board, Singapore's National Water Agency under the Ministry of Environment and Water Resources.

The Changi water reclamation plant is part of the S$3.65 bn deep tunnel sewerage system (DTSS). DTSS is an important component of Singapore’s water management strategy. It allows every drop of used water to be collected, treated and further purified into NEWater, Singapore’s own brand of reclaimed water. The DTSS is Singapore’s answer to its long term used water needs. This super-highway for the collection, treatment and disposal of Singapore’s used water comprises a 48 km tunnel that stretches from Kranji in the northern part of Singapore to Changi in the eastern part, a centralized water reclamation plant, 60 km of link sewers and a 5 km long deep-sea outfall. The deep tunnel works entirely by gravity, eliminating the need for pumping stations, thus reducing the risks of used water overflows. At the heart of the DTSS is the Changi water reclamation plant, one of the largest used water treatment facilities in the world. Sited on 32 hectares of land about one-third the size of a conventional plant, the Changi water reclamation plant features a state-of-the-art, compact and covered used water treatment facility that was commissioned in 2008 with an initial treatment capacity of 800,000 m^3 per day and expanded to 2,400,000 m^3 per day.

The Changi NEWater plant purifies the secondary effluent of an urban STPs using a two-stage microfiltration membrane (MF) and reverse osmosis (RO) process to produce NEWater for industrial use and to supplement drinking water sources. The quality of the NEWater is superior to the drinking-water standards of Singapore and the World Health Organization. The Changi NEWater Project is considered the pillar of Singapore’s water sustainability and currently meets 30% of the total water demand in the country (Fig 3.4).

Changi water reclamation plant is built partially underground and stacked for maximum compactness and land use (https://www.siww.com.sg/spotlight-2023/programme/technical-site-visits/changi-water-reclamation-plant-n-sembcorp-newater-plant)

An inside view of deep tunnel sewerage system (https://www.water-technology.net/projects/changi-reclamation/)

Influent pumping station at Changi Water Reclamation Plant. The 50 m deep has two pumping stations and a coarse screen shaft (https://www.water-technology.net/projects/changi-reclamation/)

Sembcorp NEWater Plant, Changi (https://www.siww.com.sg/spotlight-2023/programme/technical site-visits/changi-water-reclamation-plant-n-sembcorp-newater-plant)

Fig. 3.4: Multi-storey Changi NEWater plant in Singapore

Highlights

- The Changi water reclamation plant is part of the S$3.65bn deep tunnel sewerage system (DTSS).
- Changi NEWater plant purifies the secondary effluent of urban STPs using a two-stage microfiltration membrane (MF) and reverse osmosis (RO) process to produce NEWater for industrial use and to supplement drinking water sources.

3.2 Semi-underground multi-storey STPs

In semi-underground multi-storey STPs, the sewage facilities are built semi-underground, and the top of the pool is sealed with a cover. Some of the examples of semi-underground multi-storey STPs, like 1) Multi-storey STP in Beijing Xiaojiahe, 2) Multi-storey STP in Nanpian, Wenzhou, China are explained below:

3.2.1 Multi-storey STP in Beijing, Xiaojiahe, China

The Beijing Xiaojiahe reclaimed STP carried out an in-situ upgrade based on the original Xiaojiahe STP**.** The upgrading project started in 2013. The plant adopted a semi-underground construction model, wherein all sewage treatment facilities are buried underground, and offices, and living areas are built on the ground to minimize the harmful impact on the environment. The greening rate of the plant area becomes greater than 30%. Compared with the area of the original sewage treatment pool which only accounted for 15% of the plant area, the area of the sewage treatment pool of the reconstructed underground STP has increased by nearly 4 times. After the transformation, the sewage treatment adopts the "A^2O-energy-saving MBR" technology. The pulse aerator produces pulse bubbles to prevent the membrane pores from clogging. It greatly reduces the required blast volume, and saves the electricity required for water treatment by 0.15 kWh, making the energy consumption of the process less than 1/3 of the membrane aeration energy consumption compared with the traditional MBR process, and thus save electricity.

Highlights

- A reclaimed STP, upgraded to multi-storey STP based on A^2O-energy-saving MBR technology.

- The original 20,000 tons/day treatment capacity was upgraded to 80,000 tons/day after transformation.

3.2.2 Multi-storey STP in Nanpian, Wenzhou, China

Nanpian STP has a total land area of 8.72 hectares and a total sewage treatment scale of 80,000 tons/day. The construction started in early 2013 and it started operating in 2015. The Nanping treatment plant is the first high standard, full deodorization, garden STP in the Zhejiang Province.

It follows the semiunderground design, wherein the sewage treatment facilities are all buried underground, and the repair and maintenance buildings, office and living areas are unified on the ground. The above-ground area is covered with garden-style greening, except for the roads. This plant adopts the Biological Aerated Filter (BAF) process.

Highlights

- A multi-storey STP based on BAF process.
- A green roof is added on the roof of the main plant building and the comprehensive buildings give a new impression of STP to the people as a green park full of vitality, completely overturning their previous views of STPs as being dirty and smelly.

3.3 Above-ground multi-storey STPs

In above-ground multi-storey STPs, structure is built together, compact, stacked above in layers, reducing the plant area results in less land utilization. Thus, sewage plants and maintenance floors are above-ground.

Some of the examples of above-ground multi-storey STPs, like 1) Multi-storey STPs in Osaka, Japan, 2) Multi-storey Yannawa STP in Bangkok, Thailand, 3) Multi-storey STP of 7.5 MLD in Rishikesh, Uttrakhand, 4) Multi-storey 20 MLD STP in Pune Cantonment, Maharashtra and 5) Multi-storey 418 MLD STP in Dharavi, Mumbai, Maharashtra are explained below:

3.3.1 Multi-storey STPs in Osaka, Japan

Due to rising land prices and advanced urbanization, enlargement of sewage treatment sites in Osaka, Japan is extremely difficult. Sewage inflow has increased because of urbanization and enhanced living standards, giving rise to the necessity to treat a large volume of sewage with limited treatment area. The construction of multi-story facilities for sewage treatment commenced as circumstances requirement. Structure occupancy area per unit treatment capacity for multi-storey facilities in Osaka can be reduced to 46% in comparison to that of the conventional one-story type.

The study performed in Osaka indicated that the required area for the treatment of 1 m^3/day was less than 0.29 m^2. To reduce the occupied area of the STPs in Osaka, it was suggested to use two or three-story sedimentation tanks and multi-storey aeration tanks. The multi-story sewage treatment facility in Osaka is a good reference when enlargement of STP site is difficult. The Osaka Wastewater Treatment Plant utilizes the Activated Sludge Process (ASP). For reasons of function and curtailment of construction cost, multi-story sewage treatment facilities in Osaka employ a structure in which the upper and lower layers are hydraulically unified, with no hydraulic pressure occurring on the intermediate slab between the layers. The structural diagram of two-storey and three-storey final settling tanks is shown in Fig. 3.5 and Fig. 3.6.

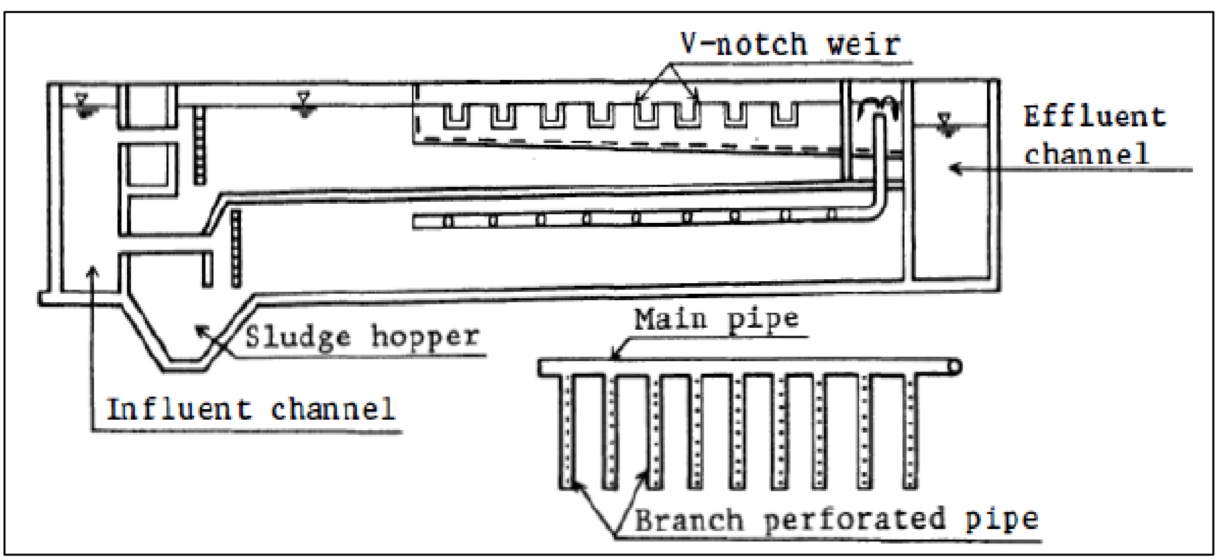


Fig. 3.5: Two-storey settling tank in above-ground multi-storey STP in Osaka, Japan (Yuki et al.,1991)

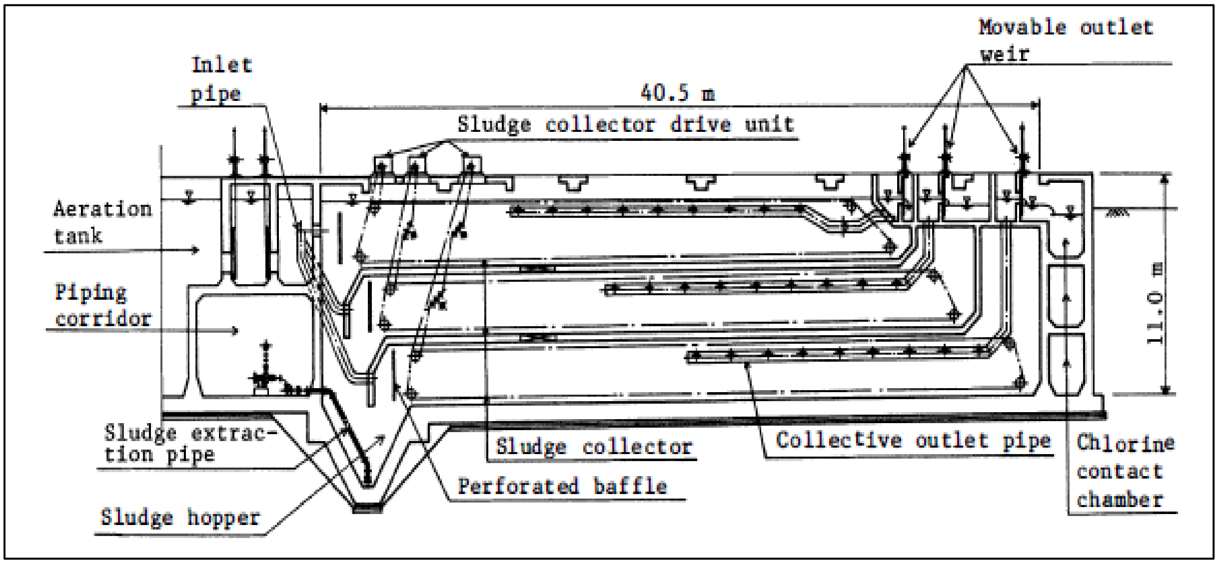


Fig. 3.6: Three-storey above-ground final settling tank in multi-storey STP in Osaka, Japan (Yuki et al.,1991)

The multi-storey final settling tanks employ multi-storey chlorination tank structures to enhance land utilization efficiency. For the same purposes, efforts were made to further deepen aeration tanks; tank depth has increased gradually from the initial 4.5 meters to the present 10 meters, almost equal to the depth of three-storey final settling tanks (Fig. 3.7).

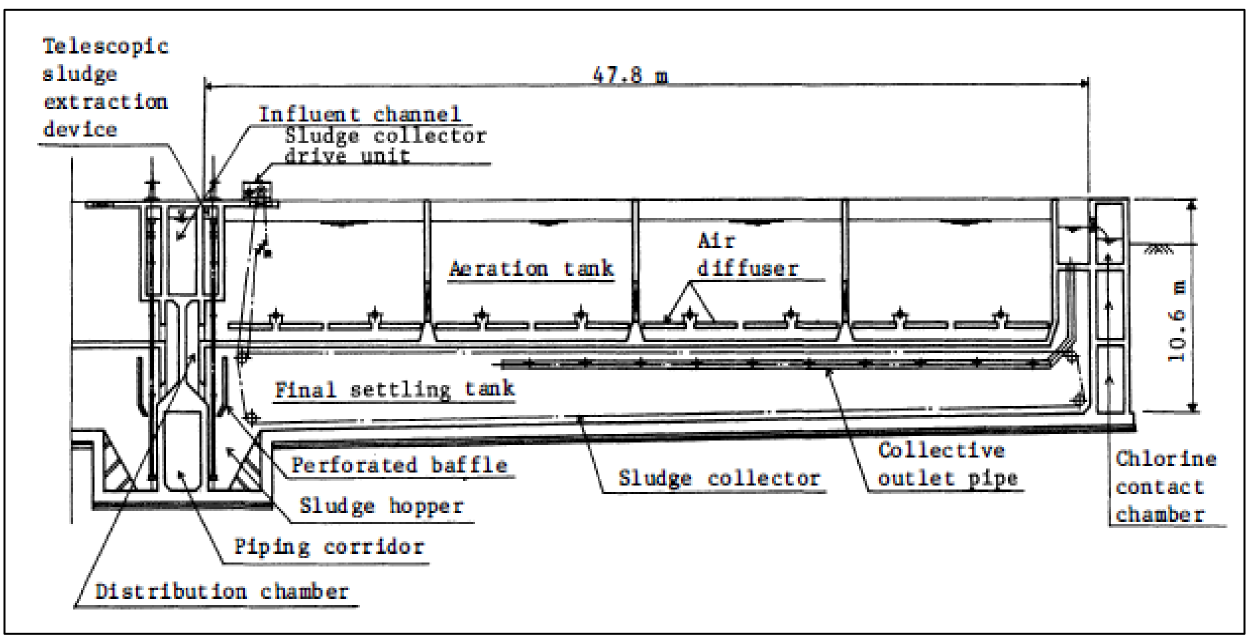


Fig. 3.7: Aeration tank vertically combined with final settling tanks in above-ground multi-storey STP in Osaka, Japan (Yuki et al.,1991)

Highlights

- To enhance effective land utilization, construction of multi-storey STPs has been promoted in Osaka, Japan.
- It is observed that structure occupancy area per unit treatment capacity for multi-story STP facilities in Osaka can be reduced to 46% in comparison to the conventional one-story STP type.

3.3.2 Multi-storey Yannawa STP in Bangkok, Thailand

The Yanawa multi-storey STP is located close to the residential area in Bangkok, Thailand (Fig 3.8).

Fig. 3.8: Yanawa multi-storey STP in Bangkok, Thailand (Vazin et al., 2022)

This STP was commissioned in the year 2000. The plant covers 30 square kilometers area and serves a population of 500,000 people in its first phase. SBR technology was chosen for this multi-storey STP. The STP consists of four SBR tanks, each stacked on top of each other due to space constraints. Each tank comprises six identical chambers with dimensions of 60 x 17.5 meters and a depth of 4.7 meters. One of the most important features of this STP is its proper odor control, which has enabled it to be built in an urban area without any odor emission problems. This consists of a conventional four-way distribution chamber based on overflow weirs. Downstream of each overflow weir is a wet well which is dedicated to one floor of the four-storey SBR plant. Each wet well is provided with submersible pumps and they lift the wastewater to a distribution manifold to ensure equal distribution into the six compartments on a floor of the STP plant, that make up a single SBR basin.

Highlights

- Due to the limited land availability and strict environmental compliances, the importance of odor emission control and process flexibility in critical conditions of hydraulic and organic fluctuations, the design of a multi-storey STP was accepted for this plant.

3.3.3 Multi-storey STP in Rishikesh, Uttarakhand, India

The multi-storey STP of 7.5 MLD capacity based on Moving bed biofilm reactor (MBBR) technology started in the year 2019 at a cost of Rs. 12.50 crore in Rishikesh, Uttarakhand. The total land area covered by the project is 990 m^2 (Fig.3.9).

Fig. 3.9: Multi-storey STP in Rishikesh, Uttarakhand, India

Highlights

- A multi-storey STP based on MBBR technology under Namami Gange Programme offered a highly competitive solution in terms of both capital and running cost.

3.3.4 Multi-storey STP in Pune Cantonment, Pune, Maharashtra

A double-storey 20 MLD STP based on SBR technology was developed in an area of 5,665 m^2 (1.40 acres) at 900 Boottee Street, Pune Cantonment, Maharashtra. The plant started in year 2018 with an expenditure of Rs 32.0 crore.

The project site is in a thickly populated area, where space is very limited. To address this issue, the technology provider had designed a plant in such a way that SBR basins were built one above the other in a two-storey structure instead of having all the basins at the same level on the ground (Fig. 3.10).

Fig. 3.10: Multi-storey STP in Pune Cantonment, Maharashtra, India

Highlights

- A multi-storey STP based on SBR technology offered a highly competitive solution in terms of both capital and running cost.

3.3.5 Multi-storey STP in Dharavi, Mumbai, Maharashtra, India

It is situated in the heart of Mumbai and is surrounded by Asia`s biggest slum area with a dense population. The land required for a single level conventional STP is about 500 sqm/MLD. In view of limited land availability in Dharavi, *i.e.*, 51,350 sqm (122.8 sqm/MLD), multi-storey STP construction based on SBR technology was proposed with an optimum footprint area (Fig 3.11).

The estimated cost of the project is about Rs. 4,775 crores. The design build cost is about Rs. 2,764 crores and O&M cost for 15 years is about Rs.1,610 crores. The project involves design, construction, operation and maintenance of a 418 MLD Dharavi multi-storey STP facility, along with 209 MLD tertiary treatment facility, to fulfil the growing need of recycling and reusing wastewater under Mumbai Sewage Disposal Project, Stage II.

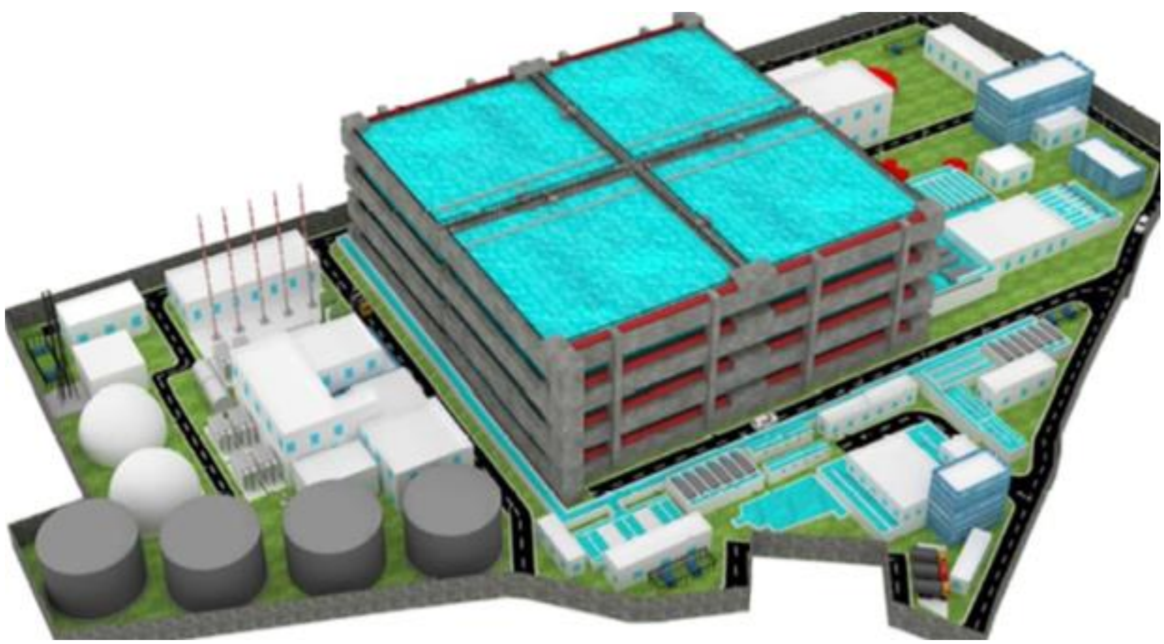


Fig. 3.11: Layout of multi-storey STP in Dharavi, Mumbai, Maharashtra, India (www.welspunenterprises.com)

Highlights

- A multi-storey STP based on SBR technology (Project under execution).

CHAPTER – 4

4. Findings and Observations

As a new technology there are various doubts regarding the viability of multi-storey STPs in India. In this report, the viability of multi-storey STPs supported with the findings and the observations pertaining to land area and construction cost, treatment performance, potential risks and safety hazards, water backflow and sewage leakage and above-ground landscaping are discussed as below:

4.1 Land area and construction cost

The construction of a multi-storey STP requires deep foundation pit excavation and a layered layout, which is difficult and costly. The multi-storey STP occupies a limited area, so it is necessary to choose a process and corresponding equipment with a compact structure, high treatment efficiency, which requires higher operation and maintenance cost, thus increasing the overall cost of the process equipment, operation, and maintenance.

In underground multi-storey STPs there is always a need to add deodorization and ventilation equipment, whose operating cost is also high. In general, the investment cost of a multi-storey STP is higher than that of an above-ground conventional STP of the same scale. The plan land of the above-ground conventional STP includes not only the construction land (15.00–49.10 ha), *i.e.*, the land used for the sewage treatment structures, and the road inside, but also the greenbelt land (1.50–7.50 ha) which usually covers the surrounding area away from the STP.

The underground multi-storey STPs need much less land for construction. On the one hand, all the sewage treatment structures are arranged compactly based on integration and common-wall technology. On the other hand, no greenbelt is needed because all the noise and odor-producing units are covered, and the gaseous pollutants are collected and treated underground.

Taking the sewage treatment scale of the STPs into consideration, it can be found that the area covered for the treatment of per m^3 sewage ranges from 0.57 m^2/m^3 to 0.83 m^2/m^3 in the above-ground conventional STP, which is more than 2 times that of the underground multi-storey STP, ranging between 0.23 m^2/m^3 and 0.29 m^2/m^3. What cannot be ignored is that, except for less land occupation for the construction of the underground multi-storey STP, another apparent advantage is the use of the above-ground space.

Related data showed that 98% of the total above-ground space of the underground multi-storey STP can be used for green land or the arrangement of communal facilities, and no more than 2% is needed to be used for the functional units such as central control rooms, and laboratories.

The construction investment of the underground multi-storey STP is usually higher than that of the above-ground conventional STP with the same treatment scale, for the need of deep excavation and underground layout. Moreover, due to the limitation of underground space, a sewage treatment process with compact structure, high efficiency, and high operation and maintenance requirement is usually required, leading to the higher equipment investment requirement in the underground STP in comparison to that of the above-ground STP.

Due to noise, odor and visual issue generated during sewage treatment, the location of the above-ground conventional STPs are usually chosen in the suburb far away from residential and business areas, which leads to a great increase of the length of the pipeline network, while the underground multi-storey STPs can be built near the residential area of the city center, where sewage is collected, treated and reused. Therefore, the investment in pipeline network is almost zero.

For the addition of deodorization in the underground STP, the ventilation and lighting equipment's power consumption increases the overall cost. It leads to an increase in the operation cost of underground multi-storey STP (0.20–0.24 $/m^3$), which is a little higher than that (0.15–0.17 $/m^3$) of the above-ground conventional STP.

4.1.1 Land area and cost comparison of multi-storey with Conventional STPs

Example 1: Multi-storey STPs in Osaka, Japan

The introduction of multi-storey settling tanks and deep aeration tanks in multi-storey STPs in Osaka, Japan is aimed in enhancing land utilization efficiency. To quantitatively determine their results, sewage treatment facility structures occupancy area per unit treatment capacity in Osaka, Japan is shown in Table 4.1.

Table 4.1: Area occupied by sewage treatment facility structures in Osaka, Japan (Yuki et al.,1991)

Facilities	Details	Structure Occupancy Area (m^2) per treatment capacity 1000 m^3/day
Primary settling Tank	One-storey	33
	Two-storey	19
Aeration tank	Water depth 4.5 m	76
	Water depth 6.0 m	54
	Water depth 10.0 m	36
Final settling Tank	One-storey	55
	Two-storey	30
	Three-storey	21

The occupancy area includes inlet/outlet channels and other structures unified with the sewage treatment facilities but does not include machinery buildings. Calculation based on the values, conventional water treatment facilities comprising **a single-storey primary settling tank, a 4.5 m deep aeration tank and a single-storey final settling tank, require 164 m^2 of land area per thousand m^3 per day of treatment capacity, while the combination of a two-storey primary settling tank, a 10 m deep aeration tank and a three-storey final settling tank, currently considered standard in Osaka, requires only 76 m^2, or almost 46% of the conventional occupancy area.**

For sewage treatment facilities with treatment capacity of 200,000 m^3/day, construction cost is compared between the one-storey type and the multi-storey type in Table 4.2. Construction costs differ by structure, with no considerable difference present in machinery and electricity equipment cost when comparing one-story structure with multi-storey STP structures.

Table 4.2: Comparison of construction cost between the multi-story and one-story STP structures in Osaka, Japan (Yuki et al.,1991)

Structure Type*	Main Structure (Including Foundation Piles)	Retaining Wall and Earthwork (including installation of Temporary Staging)	Construction Cost (Million yen)
Multi-storey	3,340	1,110	4,450
One-storey	4,180	420	4,600

*(*Capacity of 200,000 m^3/Day)*

Thus, multi-story STP facilities are lower than the one-story conventional STP type in main structure construction cost but higher in retaining wall and earthwork expenses; the overall construction cost is almost equal for both types of facilities. Structure occupancy area per unit treatment capacity for multi-story facilities can be reduced to 46% that of the conventional one-story STP type.

Example 2: Comparison of area covered and construction cost between the Multi-storey 7.5 MLD STP at Rishikesh and Single-storey 7.0 MLD STP, Ramnagar, Distt. Nainital, Uttarakhand

In Rishikesh, Uttarakhand, a multi-storey STP of 7.5 MLD capacity based on MBBR technology started in the year 2019 at a cost of Rs. 12.50 crore. The total land area covered by the project is 990 m^2.

A comparative study was done with another STP which is almost of similar capacity (7.0 MLD) but not multi-storey based on SBR technology started in the year 2021 at a cost of Rs. 11.70 crore at Ramnagar, Uttarakhand. The total land area covered by the project is 5,936 m^2. It is observed that the cost of the two STPs is almost the same, but the land area covered by the second is huge in comparison to multi-storey STP.

Multi-storey 7.5 MLD STP at Chandreshwar Nagar, Rishikesh		
Year of commissioning	Area	Cost (in Rupees)
2019	990 m^2	12.50 crore
Single-storey 7 MLD STP Transport Nagar, Ramnagar, Distt. Nainital		
Year of commissioning	Area	Cost (in Rupees)
2021	5,936 m^2	11.70 crore

Example 3: Comparison of area covered and construction cost between the Multi-storey 20 MLD STP at Pune Cantonment, Maharashtra and Single storey 23.5 MLD STP at Sangli, Maharashtra

A double-storey 20 MLD STP based on SBR technology has been developed at 900 Boottee Street, Pune Cantonment, Maharashtra on an area of 5,665 m^2 (1.40 acres). The plant was commissioned in 2018. The cost of the project was Rs 32.0 crore.

A comparative study was done with another STP which is almost of similar capacity (23.5 MLD) but not multi-storey based on SBR technology started in year 2018 at a cost of Rs. 28.20 crore at Sangli, Maharashtra. The total land area covered by the project is 10,724 m^2 (2.65 acres). It is observed that the cost of the two STPs is almost the same, but the area covered by the second is double in comparison to the multi-storey STP.

Multi-storey 20 MLD STP at Pune Cantonment, Maharashtra		
Year of commissioning	Area	Cost (in Rupees)
2018	5,665 m^2	32.0 crore
Single-storey 23.5 MLD STP Sangli, Maharashtra		
Year of commissioning	Area	Cost (in Rupees)
2018	10,724 m^2	28.20 crore

4.2 Treatment performance of multi-storey STPs

It is generally believed that multi-storey STP facilities are inferior in treatment performance in comparison to conventional one-storey STP facilities. To break this myth, examples are given here in support of the effective performance of multi-storey STPs in comparison to conventional one-storey STPs.

Example 1: Operational performance of Multi-storey STPs in Osaka, Japan

In Osaka, Japan multi-storey STP facilities are running for over the years. From the generated data through operations, it is observed that multi-storey facilities are not inferior in treatment performance in comparison to conventional one-storey STP facilities, and no maintenance and control problem exists in multi-storey STP structures.

Annual average values of operational performance of various multi-storey STP facilities in Osaka, Japan is shown in Table 4.3. It is depicted from the results that the operational performance of multi-storey STPs in Osaka, Japan is satisfactory.

Table 4.3: Operational performance of Multi-storey STPs in Osaka, Japan (Yuki et al.,1991)

Multi-storey STPs	Water Quality					
	Primary Settling Tank Inlet		Primary Settling Tank Outlet		Final Settling Tank Outlet	
	SS (mg/l)	BOD (mg/l)	SS (mg/l)	BOD (mg/l)	SS (mg/l)	BOD (mg/l)
A	250	190	73	97	7	7.1
A'	190	160	63	92	4	8.1
B	93	140	66	110	8	6.5
C	110	120	66	76	5	4.8

- *All primary settling tanks are two-story structures except in one-story A'.*
- *A and A': Three-story final settling tank with aeration tank 9-10 meters in depth*
- *B: Aeration tank vertically combined with final settling tank*
- *C: Two-story final settling tank with aeration tank 6 meters in depth*

Example 2: Operational performance between the Multi-storey 7.5 MLD STP at Rishikesh and Single-storey 7.0 MLD STP, Ramnagar, Distt. Nainital, Uttrakhand

The operational performance of both the STPs is satisfactory (Table 4.4). It is concluded from the data generated that multi-storey facilities are equally efficient in treatment performance to above-ground single-storey conventional STP, and no maintenance and operational problems exist in multi-storey STPs.

Table 4.4: Operational performance of Multi-storey STP (Rishikesh) and Single-storey conventional STP (Ramnagar) in December 2023 (M/s RK Engineers, Lucknow)

STP details	Sampling Point					
	Inlet			Outlet		
	pH	BOD (mg/l)	TSS (mg/l)	pH	BOD (mg/l)	TSS (mg/l)
Multi-storey 7.5 MLD STP at Rishikesh (Operated by Uttarakhand Pey Jal Nigam)	7.22	150	147	7.48	9.2	10
Single-storey 7.0 MLD STP Ramnagar, Distt. Nainital (Operated by Uttarakhand Jal Sansthan)	6.90	220	280	7.57	9.0	10

4.3 Potential health risks and safety hazards

The toxic and harmful gases generated during the sewage treatment processes are treated in airtight conditions and disposed-off before being discharged into the atmosphere in fully enclosed underground design, but there is a risk of odorous gas leakage, which can affect the health of underground workers. It is usually pointed out that hydrogen sulfide, ammonia, and volatile organic compounds, for example methyl mercaptan and methyl sulfide, produced in the sewage treatment process of underground multi-storey STPs can cause serious harm to human health. The noise pollution in the sewage treatment process also has an impact on the health of workers. The potential safety hazards of multi-storey underground STPs cannot be ignored but it can be significantly controlled by providing deodorization and ventilation equipment.

4.4 Water backflow and sewage leakage

Water backflow and sewage leakage may occur, resulting in danger for the multi-storey underground STPs being flooded in case of electricity cut-off or heavy rainfall**.** It can be significantly controlled by gates installation to ensure the prevention of waterlogging.

4.5 Above-ground landscaping

The reduction in construction and operating cost of underground multi-storey STPs is important for the widespread application of underground multi-storey STPs. Except for the technological innovation in the field of sewage treatment, landscape on the above-ground space is the important method to compensate some part of the total investment. The ecological value of the STP includes the indirect ecological value and the explicit ecological value generated by the landscape design on the above-ground space in multi-storey underground STPs.

The ecological value of underground STPs lies mainly in the above-ground landscape. The above-ground landscaping of the underground multi-storey STP reflects the concept of sustainable development. While controlling pollution, this enhances the ecological environment while increasing the comfort of the surrounding residents. It may also certainly increase the value of the surrounding land price, unexpectedly. For example, the ground landscape can be used for community gardens, urban parks, etc. The above-ground landscape design of the underground multi-storey STP can increase the value of the above-ground space and its surrounding land, thereby compensating for the relatively high construction, operation, and maintenance costs generated by the underground construction, driving social and economic development around the STP, and promoting environmental harmony and social development.

In 1942, the capital of Sweden, Stockholm, built the first modern underground STP using local superior geological conditions and advanced excavation techniques. They arranged the entire floor into a park. The entrance of the underground STP, using clever architectural art, greatly enhanced the city's appearance, and at the same time increased the green area of the city, which attracted worldwide attention.

In China's Shenzhen Buji STP, the STP is in the central urban area, which is less than 50 meters away from residential buildings. The ground space of the underground STP has a leisure park, to meet the needs of the surrounding residents, and to attract people from the surrounding residential areas, thus increasing the price of the land around. As shown in Table 4.5, the price of commercial housing near the Buji underground STP is higher than that far away, which may be closely related to better recreational and healthy living environment. This is a good example of the ecological value of the ground landscape of underground multi-storey STPs.

Table 4.5: Commercial housing price around the China's Shenzhen Buji underground multi-storey STP (Sun et al., 2019)

Distance (m)	Price ($/m^2)
0–100	7,077±354
100–200	6,907±311
200–500	6,723±212
500–1,000	6,369±354
>1,000	6,086±424

Underground multi-storey STPs can be built in urban areas, where the population is relatively dense and the land area is limited, the landscape design also needs to pay attention in combination with urban functional areas, make full use of public landscape space, and promote harmonious coexistence between man and nature.

Taking the Pantai underground multi-storey STP in Malaysia as an example, its landscape design is clear, reasonable, and compact. The underground multi-storey STP provides nearly 140,000 m^2 of leisure parks bringing satisfaction and enjoyment to the surrounding residents.

The Qingshan plant is the first underground multi-storey STP in Guiyang, China. The plant was commissioned in 2015. It provides a beautiful above-ground landscape and provides a solution to the increasing amount of sewage in urban areas with shrinking land resources reflecting the concept of sustainable development (Fig 4.1).

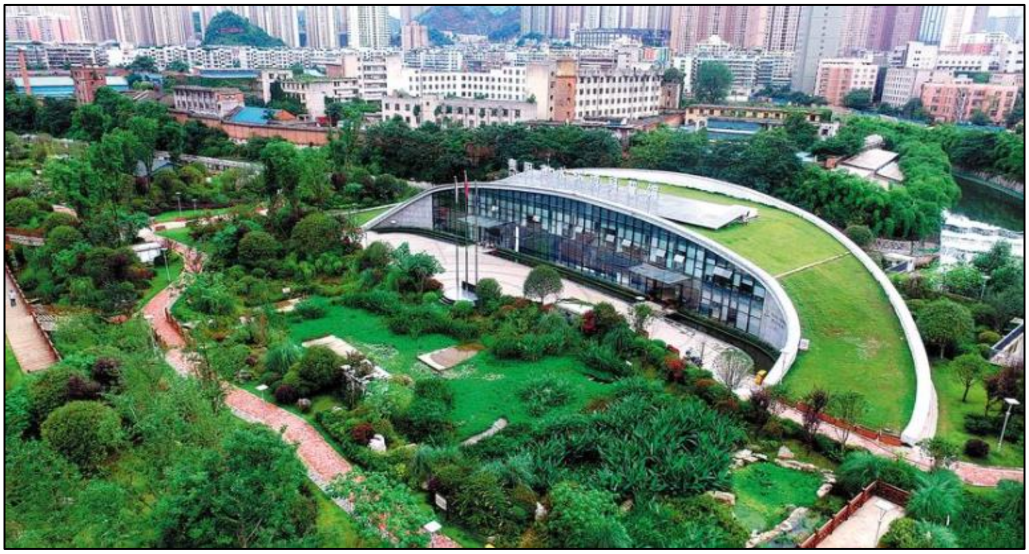


Fig. 4.1: An aerial view of the Qingshan plant, the first underground multi-storey STP in Guiyang, Guizhou Province, China (https://www.chinadailyhk.com/article/242387)

The Huaifang Water Reclamation Plant was constructed to meet the upgrading standards for wastewater treatment and improve water ecological environment in the southern part of Beijing, China. In 2015, SUEZ worked with Beijing Drainage Group to upgrade the plant to the biggest underground MBR-based STP in Asia. The strategies to reduce impact on surrounding environment involved putting wastewater treatment facilities underground and building an above-ground ecological wetland park with reclaimed water (Fig 4.2).

Fig. 4.2: An aerial view of the Huaifang Water Reclamation Plant, Beijing, China with an above-ground ecological wetland park (https://infra.global/projects/huaifang-water-reclamation-plant)

CHAPTER – 5

5. Conclusion and Way Forward

Due to rising land prices and advanced urbanization, enlargement of existing sewage treatment sites and development of new sites in urban areas is a difficult task for ULBs. Thus, the construction of multi-story/underground facilities for sewage treatment commenced as a circumstantial requirement.

As a novel, environment-friendly and resource-saving sewage treatment method, multi-storey/underground STPs have significant advantages in saving land and pipeline network cost, in improving urban landscape and ecological environment compared with the conventional STPs.

Its advantages compensate for its relatively high construction and operating cost to a certain level. The potential safety hazards of underground multi-storey STPs cannot be ignored but it can be significantly controlled by providing deodorization and ventilation equipment.

No lamella/tube or plate setters should be used in primary and secondary settling tanks under land constraints. Instead, multistorey arrangements should be preferred.

The engineering design of a multi-storey/underground STP is more complex in comparison to the conventional above ground single-storey STP. They require more resources and costs from planning, construction, environmental assessment, operation, and maintenance, and moreover, higher technical requirements. These issues can be resolved with experience, and continuous technological advancement. Therefore, improving the technical level, reducing the cost, and improving safety are important means for the sustainable development of multi-storey STPs in India.

Consequently, the multi-storey/underground STPs can be considered as a sustainable technology for setting up new STPs and retrofitting of the existing STPs to meet the growing demand on limited urban land area by ULBs.

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Annexure

List of 50 multi-storey underground STPs globally in chronological order (Sun et al., 2019)

STPs	City	Country	Completion year	Treatment Technology
ReDokhaven	Rotterdam	Netherlands	1987	AS
Kashima	Shimane	Japan	1992	AS
Viikinmäki	Helsinki	Finland	1994	AS
Stanley	Hong Kong	China	1995	AS
Hayama	Kanagawa	Japan	1999	AS
Bromma	Stockholm	Sweden	1999	AS
Noval	Eastburn	England	2000	AS
Bekkelaget	Oslo	Norway	2000	AS
Neihu	Taipei	China	2002	AS
Daegu	Daegu	Korea	2002	A/A/O
Toulon	Toulon	France	2002	A/A/O
Ukima	Tokyo	Japan	2003	A/A/O
Yongin	Yongin	Korea	2005	AS
Incheon	Incheon	Korea	2005	A/A/O
Dihua	Taipei	China	2007	Multiple A/O
Geolide	Marseille	France	2008	BAF
Jingxi	Guangzhou	China	2010	MBR

Biological Island	Guangzhou	China	2010	SBR
Buji	Shenzhen	China	2011	A/A/O
Kunming No.10	Kunming	China	2012	MBR
Jingang	Zhangjiagang	China	2012	A/A/O + MBR
Kunming No.9	Kunming	China	2013	MBR
Guxian	Yantai	China	2013	A/A/O
Industrial Park	Suzhou	China	2013	MBR
Qingshan	Guiyang	China	2014	A/A/O
Madi River	Guiyang	China	2014	A/A/O
South 3rd Ring	Zhengzhou	China	2014	A/A/O
Anning	Kunming	China	2014	A/A/O
Taiping	Kunming	China	2014	A/A/O
High-tech District	Tsingtao	China	2014	MBBR
Shiwuli River	Hefei	China	2014	A/A/O
Kunming No.11	Kunming	China	2015	A/A/O
Kunming No.12	Kunming	China	2015	SBR
Zhengding	Shijiazhuang	China	2015	MBR

Binhu District	Hefei	China	2015	MBR
Busan	Busan	Korea	2015	A/A/O + MBR
Henriksdal	Stockholm	Sweden	2015	MBR
Taozi Bay	Yantai	China	2016	MBR
Tiantang River	Beijing	China	2016	A/A/O + MBR
Daoxianghu	Beijing	China	2016	MBR
Jinyang	Taiyuan	China	2016	A/A/O + MBR
Xiaojia River	Beijing	China	2016	A/A/O + MBR
Gunagan	Guangan	China	2016	A/A/O
Bishui	Beijing	China	2017	Multiple A/O
Nanxiang	Shanghai	China	2017	A/A/O
Kuige	Guangan	China	2018	A/A/O
Sanqiao	Guiyang	China	2018	A/A/O
Huaifang	Beijing	China	2019	MBR
Pantai No.2	Kuala Lumpur	Malaysia	2020	A/A/O
Changi No.2	Changi	Singapore	2020	A/A/O + Anammox

AS = Activated Sludge, A/A/O= Anaerobic/Anoxic/Oxic, A/O= Anoxic/Oxic, MBR = Membrane Bioreactor, MBBR = Moving Bed Biofilm Reactor, SBR = Sequencing Batch Reactor