EU-India

Technical Cooperation on Environment

Sewage Treatment in Greater Mumbai

March-2018

IVL Swedish Environmental Research Institute, Sweden

Danish Technological Institute, Denmark

Shriram Institute for Industrial Research, Delhi, India

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EU Project on Technical Cooperation
for
Environment in India

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PREFACE

The EU-India Project on Technical Cooperation for Environment has an overall aim to contribute towards sustainable and inclusive development of India by means of capacity building of stakeholders. The focus of the project is on two priority themes viz. Sewage Treatment and Solid Waste Management. Both the thematic areas are having synergies with the National Action Plan of Climate Change and the *Swachh Bharat Mission* of the Government of India. The NCT of Delhi and Mumbai, which are two mega-cities of India are identified as pilot-cities for implementation of project activities in accordance with 10 work packages. The project started in October-2014 and will continue till September-2018. During interaction and intense deliberations with stakeholders comprising of municipal corporations, central ministries, regulatory bodies and NGOs during the year 2015 together with extensive site visits and situation analysis, following two areas of training were identified:

- Solid Waste Management with particular focus on waste processing technologies
- Sewage Sludge Management

Considering the priorities of stakeholder on above areas, Two International Training through Study Tours to Europe were organised during June-2016 and one during June-2017 for wide-spectrum of stakeholders comprising of Implementers, Policy-makers, Regulators, Private actors and Non-government Organisation. Though many countries of EU are having *par excellence* waste (liquid and solid) management practices, Sweden, Denmark and Germany were selected as a “pilot-locations” for study tours considering best practices in many areas of Sewage Treatment and Sludge Management. In addition, brief site visit was also made to Denmark during June-2016.

This document namely “Sewage Treatment in Greater Mumbai” illustrates the status of Sewerage Projects and Sewerage Operations in Greater Mumbai. Various aspects pertaining to Sewerage Operations including Wastewater Treatment are analysed vis-à-vis regulatory requirement as per the Environment (Protection) Act and Rules. The European Best Practices including the learnings from Europe in context to Sewage Treatment and Sludge Management are also discussed in this documents, which would help authorities to develop future benchmarks. This document would further help Municipal Corporation of Greater Mumbai to develop necessary action plan to prepare future strategies with respect to Sewage Treatment and Sludge Management.

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1. Introduction

1.1 Background

The Government of India always endeavours to adopt the path of sustainable and inclusive development by means of increasing the use of green energy sources, energy efficiency and clean technologies. The EU-India Technical Cooperation for Environment has an aim to contribute towards India's sustainable and inclusive development objectives based on the local experience of both India and the EU through capacity building and skill development. The focus of the project is on two priority themes[1] viz. (1) Solid Waste Management and (2) Sewage Treatment in two pilot cities viz. Mumbai and the National Capital Territory of Delhi. The expected outcomes of the project includes:

- Enhanced technical and institutional capacity of Indian authorities to create an enabling environment promoting clean technologies;
- Enhanced human capacity through the transfer of the required skills and technical know-how for the use and development of clean technology in the local context;
- Increased awareness amongst public and private actors and the public at large, on environmentally friendly development activities.

The implementation strategy of the project has two main dimensions, the first of which comprises the provision of short-term international technical assistance across the lifetime of the project to help in building institutional capacity, generate knowledge, create linkages between European and Indian agencies and institutions, and ensure awareness-raising. The second dimension includes the use of exchange visits of personnel from designated link institutions (Europe to India and India to Europe), study visits to Europe, and deputation/training with relevant European bodies and institutions for "know how"/ and best practice transfer including technical training, training of master trainers and instructors etc. The project website is https://www.euprojectinindia.com, which gives detailed information.

1.2 Training Need Assessment

Subsequent to the Inception Phase of the project and to initiate the various activities under Work Packages[a] WP-2 & WP-3 of the Project Inception Report[2], the project consortium started interaction with various stakeholders to apprise about the aim and objective of the EU-India Technical Cooperation for Environment and also to understand immediate needs of training. Stakeholders, as mentioned below were contacted during the project execution.

- Ministry of Environment, Forests and Climate Change
- Ministry of Urban Development
- Municipal Corporation of Greater Mumbai
- North Delhi Municipal Corporation
- South Delhi Municipal Corporation
- East Delhi Municipal Corporation
- Delhi Jal Board
- Central Pollution Control Board
- Department of Environment/ DPCC, the Government of NCT of Delhi
- Maharashtra Pollution Control Board
- *Stree Mukti Sanghatana* and Mumbai First

[a] The Project is being executed as per 10 Work Packages defined in the Inception Report.

Interaction with stakeholders from time to time through various missions, helps the project consortium to identify training needs as per the requirement of WP-5 of the Project Inception Report[2]. Accordingly the project consortium starts the conceptualization of the delivery of training programme for the benefit of stakeholders.

1.3 Delivery of Training Programmes through Study Tours to Europe

Within above framework and as part of WP-6 "Training programs to encourage stakeholders to switch over to climate change and resource efficiency technologies" (Para 6.3: "Study tours to Europe and training by EU experts") of the approved Inception Report[2], the project consortium organized and delivered following training programmes through study tours to Europe:

- One week long Sludge Management Study Tour from June 4th-11th 2016 in Sweden and Denmark.
- One week long Solid Waste Management Study Tour from June 11th-18th 2016 in Sweden.
- One week long Solid Waste Management & Sewage Treatment Study Tour from June 17th-24th 2017 in Sweden and Germany.

Wide-spectrum of stakeholders comprising of Environmentalist, Engineers, Policy-makers and Technical Experts representing various organisations such as the Ministry of Urban Development, Government of India; Central and Maharashtra Pollution Control Boards; Department of Environment of the Government of National Capital Territory of Delhi; Municipal Corporation of Delhi (North, South and East); Delhi Jal Board; Municipal Corporation of Greater Mumbai; Private Sector and Non-government Organisation, participated in the study tours to Europe[3] during 2016-17.

Objectives of the Study Tours

The purpose of study tours was to build advanced capacity and develop synergies on sludge and solid waste management. These areas represent key challenges in India and to contribute towards the *Swachh Bharat Mission* and the National Action Plan on Climate Change. Main focus was

1. To understand technologies and processes for the pre-treatment of waste, material separation, and energy recovery, which are essential components for successful waste management in Europe.
2. To have insight of implementation of environmental policies in Europe including target setting, division of responsibilities, collaboration between private and public sectors etc. to facilitate review of EU policies and legislative framework to explore their applicability to India.
3. To witness the model of Information, Education and Communication (IEC), which is playing significant role towards effective implementation of policies and enforcement of rules and are essential pre-requisite for Better Environmental Management.
4. To explore opportunities for collaboration on technology development, process optimisation, compliance with norms, etc.

1.4 Consultation Workshops to deliver Technical Training

The objectives of the consultation workshops are to facilitate understanding of problems and perspectives at the implementation stage and to implement capacity building sessions on the thematic areas in accordance with the WP-4 (Consultation Workshops at City Level) of Inception Report[2]. Accordingly, four numbers of consultation workshops were organized to deliver technical training for stakeholders in Mumbai and Delhi viz. (i) Consultation Workshop on Solid Waste Management Processing Technologies at the Trident, Mumbai on February 2, 2017 (ii) Consultation Workshop on Sewage Treatment and Sludge Management Technologies at the Oberoi, Mumbai on March 15, 2017 (iii) Consultation Workshop on Landfill Mining on September 25, 2017 at SDMC Auditorium and (iv) Consultation Workshop on Remediation on Waste Dumpsites, at Bombay Exhibition Centre on September 28, 2017.

1.5 The Aim of Present Report

This report provides detailed information about present status and management practices of Sewerage Operations with particular references to the Wastewater Treatment Facilities (WWTF) in Greater Mumbai together with future plans. Current practices are compared with the applicable legislations together with illustrations of EU Best Practices of Wastewater Treatment. The contents of report are:

- General Aspects of Sewage Treatment
- Demography and Physiography of Mumbai
- Evolution of Sewerage System in Greater Mumbai
- Aspects of Wastewater Treatment in Greater Mumbai
- Quality of Sewage Treatment
- Mumbai Sewage Disposal Project-II
- Training and Capacity Building as part of EU India Project of Technical Cooperation for Environment.
- Operation and Maintenance Aspects of WWTF
- Way Forward

In order to prepare city specific Sewage Treatment Plan, it would be more appropriate to discuss overall status of the Management of Sewage in urban areas of India together with understanding of applicable rules and regulatory instruments. The Sewage Treatment Plan shall be in in line with the regulatory requirements being updated from time to time.

2. General Aspects of Sewage Treatment

2.1 Need for Sewage Treatment

The sanitation can be recognized as the conditions and processes related to public health, especially in context to water supply, dealing with human waste and maintaining overall hygiene. When untreated sewage accumulates and is allowed to become septic, the decomposition of its organic matter leads to nuisance conditions including the production of malodorous gases. The untreated sewage encompass numerous pathogens that dwell in the human intestine tract in addition to having variable range of toxic compounds. Not only this, sewage also contains nutrients, which not only stimulate the growth of aquatic plants but also are responsible for eutrophication. Keeping in view of this, the foremost step towards maintaining sanitation is to facilitate nuisance-free removal of sewage from its sources of generation followed by its treatment, reuse or dispersal into the environment in an eco-friendly manner to protect public health and environment.

2.2 Stakeholders Mapping[4-5]

The stakeholders for implementing the management of sewage are many and all have their own rules and regulations besides having their own limitations.

(a) Government of India

The GOI supports clear assignment of roles, responsibilities, resources, capacities, institutional incentives in relation to setting standards, planning, financing, implementation, knowledge development, capacity building, training, monitoring & evaluation and regulatory arrangements.

(b) State Governments

The State Governments ensure clear responsibilities of Urban Local Bodies (ULBs) as envisaged in the 74th Constitutional Amendment. The States also delegate ULBs with wide-ranging powers over agencies that currently carry out sanitation related activities in the city but are not directly accountable to them, such as parastatal agencies and Public Health Engineering Departments (PHEDs).

(c) Urban Local Bodies (ULB)

Under decentralized governance (74th Amendment), the ULB has some powers to frame bylaws in conformity with the State and Central Government policies and the Environment Protection Act. The ULB on its part has to frame policies for cost recovery, levying sanitation tax, promoting Public Private Partnership (PPP) and private sector participation, providing sewerage and sanitation services in slums, allotting appropriate funds, developing human resources, setting up mechanism for grievance redressal, enforcing awareness for public participation, construction and maintenance of drains.

(d) Jal Boards, PHEDs etc.

These agencies are responsible for implementing the infrastructure services from finances allocated by the State and Central Governments.

(e) Regulatory Bodies

Statutorily set-up authorities mainly for independently monitoring the works of other agencies, NGOs and ULBs, etc., for complying with announced set of rules and regulations by State Governments like the Pollution Control Boards (PCB).

(f) Non-Government Organizations (NGOs)

Independently set up voluntary groups, which are accorded recognition by State and Central Governments to receive grant money and conduct programmes mainly in capacity building among the people to take up micro level management functions on behalf of State Governments.

(g) Citizen/Communities

The population has so far been referred to as beneficiaries of services rendered by the above mentioned agencies. It has now been recognized that the population should instead be stakeholders and have a say before the implementation of infrastructure services in respect of the financial liabilities, which the population has to bear for availing of services to each household and the charges for its O&M by the ULBs.

2.3 Legal framework related to Sewage Treatment[4-10]

The legal framework for the sewerage and related sectors in India are updated from time to time to reflect new statutes that are enacted. Articles, constitutional amendments, acts, designated best-use, general standards, discharge standards, notifications and policies relevant to the sewerage sector are hereby covered briefly to have quick insight of the relevant requirement:

(a) The Easements Act, 1882

The Easements Act is perhaps the most important act for public services. Any vacant space of the ULB earmarked or proposed to be earmarked for sewerage components and lying un-utilized for a reasonably long period shall not be alienated anew by the ULB unless it is enacted by the state legislature under the relevant act. If such a land has been earmarked for a specific purpose at the time of town planning the same shall not also be questioned by the public later on.

(b) The 74th Constitutional Amendment

The 74th Constitutional Amendment, enacted by the Parliament in 1993, mandates the State Government to transfer responsibility of water supply and sanitation (WSS) services to the urban local bodies (ULBs) such as Nagar Panchayat (City council), Nagar Palika (Municipality) and Nagar Nigam (Municipal Corporation) in the ascending order of magnitude. This amendment is aimed to strengthen ULBs through devolution of powers towards decentralization. The Twelfth Schedule, which has been added to the 74th Constitutional Amendment, includes 18 functions in accordance with Article 243, which are inclusive of following:

- Water supply for domestic, industrial and commercial purposes
- Public health, sanitation conservancy and solid waste management
- Urban forestry, protection of the environment and promotion of ecological aspects
- Slum improvement and up-gradation

(c) Bureau of Indian Standards (BIS) Discharge Standards, 1973

The BIS discharge standards were issued as IS: 4764 in 1973. This standard is now inactive and national discharge standards, issued by CPCB and SPCB, are being adopted widely.

(d) Water (Prevention and Control of Pollution) Act, 1974, and its Amendments

The purpose of this Act is "to provide for the prevention and control of water pollution and the maintenance or restoring wholesomeness of water for the establishment, with a view to carrying out the purpose aforesaid by Boards for the prevention and control of water pollution, for conferring on and assigning to such Boards powers and functions relating thereto and for matters connected therewith." This is the Act that established the Central and State Boards and also the authority and power to constitute as many committees as it feels essential to carry out specific functions. The Act specifically prohibits 'any poisonous, noxious or polluting matter' into any stream or well. Consent from the State Board is required for issues of any type of new discharge into any new stream or well.

(e) Designated-Best-Use by Central Pollution Control Board, 1981

The Central Pollution Control Board (CPCB) has developed the concept of "designated best use". According to this concept, out of several uses a particular water body is put to, the use that demands the highest quality of water is called its "designated best use", and the water body is designated accordingly. In this context, each of the five defined "designated best uses", the CPCB has identified water quality requirements in terms of few water quality criteria.

Use based classification of surface waters in India[9]

Class	Designated Best Use	Criteria	Limits
A	Drinking water source without conventional treatment but after disinfection	pH	6.5 to 8.5
		Dissolved Oxygen (DO)	6 mg/l or more
		BOD	2 mg/l or less
		Total Coliform MPN/ 100 ml	50 or less
B	Outdoor bathing (organized)	pH	6.5 to 8.5
		Dissolved Oxygen (DO)	5 mg/l or more
		BOD	3 mg/l or less
		Total Coliform MPN/ 100 ml	50 or less
C	Drinking water source with conventional treatment followed by disinfection	pH	6.5 to 8.5
		Dissolved Oxygen (DO)	4 mg/l or more
		BOD	3 mg/l or less
		Total Coliform MPN/ 100 ml	5000 or less
D	Propagation of wild life and fisheries	pH	6.5 to 8.5
		Dissolved Oxygen (DO)	4 mg/l or more
		Free Ammonia	1.2 mg/l or less
E	Irrigation, industrial cooling, and controlled waste disposal	pH	6.5 to 8.5
		Electrical Conductivity	<2250 µmhos/ cm
		Sodium Absorption Ratio (SAR)	<26
		Boron	<2 mg/l

(f) Environment (Protection) Act, 1986

The provisions of this Act, passed in 1986, have strengthened the enforcement of the Water Act, 1974. The Act was enacted to "provide for the protection and improvement of environment and for matters connected therewith." This act defined the environment, which includes "water, air, and land and the inter-relationship which exists among and between "water, air, land, human beings, other living creatures, plants, micro-organisms and property". It also defined a hazardous substance as "any substance or preparation which, by reason of its chemical or physico-chemical properties, or handling, is liable to cause harm to human beings, living creatures, plants, microorganisms, property or the environment". This law enlists general powers of the central government which includes "all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environmental pollution". The law also included "the standards of quality of air, water, or soil for various areas and purposes, the maximum allowable limits of concentration of various environmental pollutants, procedures and safeguards for the handling of hazardous substances". Important points of the Act that are more relevant to sewerage and sanitation are as follows:

a. The Act empowers the Centre to take all such measures, as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environmental pollution.

b. The Central Government has the power of entry for examination, testing of equipment and other purpose and power to take samples of air, water, soil or any other substance from any place for analysis to ensure compliance with the Act.

c. The Act explicitly prohibits discharge of pollutants in excess of prescribed standards and prohibits handling of hazardous substances except in compliance with regulatory procedures and discharges.

d. Persons responsible for discharge of pollutants in excess of prescribed standards must prevent or mitigate the pollution on a continual basis and must report the discharge to government authorities at pre-determined time intervals.

e. The Act empowers the central government to establish standards for the quality of the environment in its various aspects, including maximum allowable concentration of various environmental pollutants for different areas.

f. Penalties for contravention are specified.

(g) General Standards for Discharge of Environmental Pollutants under the Environmental (Protection) Rules, 1986 (Amended to date)

Under the Environment (protection) Rules, the following standards related to the discharge of sewage and effluent have been stipulated in addition to standards for other environmental attributes.

a. Industry specific standards for emission/effluent discharge (Schedule I)

b. General standards for discharge of environmental pollutants (Schedule VI)

Schedule VI of the Environment (Protection) Rules, 1986 contains the General Standards for Discharge of Environmental Pollutants. The State Boards may specify more stringent standards for the relevant parameters with respect to specific industry or locations after recording the reasons in writing.

(h) Environment (Protection) Amendment Rules, 2017

The Environment (Protection) Amendment Rules, 2017 came into force on 13 Oct 2017 thereby entry at S.No. 105 in context to Sewage Treatment Plants, shall be inserted after S.No. 104 of the Environment (Protection) Rules, 1986, in Schedule-1, whereby the Effluent Discharge Standards for all mode of disposal, are revised with respect to the parameters such as pH, BOD, TSS and Faecal Coliforms, subject to the conditions as specified therein. These Standards shall apply to all STPs to be commissioned on or after the 1st June, 2019 and the old/existing STPs shall achieve these standards within a period of five years from date of publication of this notification in the Official Gazette. In case of discharge of treated effluent into sea, it shall be through proper marine outfall and the existing shore discharge shall be converted to marine outfalls, and in cases where the marine outfall provides a minimum initial dilution of 150 times at the point of discharge and a minimum dilution of 1500 times at a point 100 meters away from discharge point, then, the existing norms shall apply as specified in the general discharge standards[9].

(i) The Prohibition of Employment as Manual Scavengers and their Rehabilitation Act, 2013

The aforesaid act was notified by the GOI in September 2013. This Act prohibits manual cleaning of sewers and septic tanks, aims to eliminate insanitary latrines, and rehabilitate identified manual scavengers in alternative occupations.

(j) National Environmental Tribunal Act, 1995

The National Environmental Tribunal Act, 1995 was enacted to provide for strict liability for damages arising out of any accident occurring while handling any hazardous substance. The National Environment Tribunal established for effective and expeditious disposal of cases arising from such accidents, with a view to giving relief and compensation for damages to persons, property and the environment and for matters connected therewith or incidental thereto.

(k) Water (Prevention and Control of Pollution) Cess Act, 2003

This provides for the levy and collection of a cess on water consumed by certain industries, with a view to augment the resources of the Central and State Boards for the prevention and control of water pollution constituted under the Water (Prevention and Control of Pollution) Act, 1974. The various types of industries are specified in Schedule-I. The definition of “industry” in the earlier Act of 1997 has been amended to read as “industry includes any operation or process, or treatment and disposal system, which consumes water or gives rise to sewage effluent or trade effluent, but does not include any hydel power unit” and levy of cess for water used for domestic purpose has been duly authorized.

(l) Coastal Regulation Zone Notification, 2011

The Coastal Regulation Zone (CRZ) Notification, 2011 is based on three objectives: the need to protect the livelihood of fishermen families, protect the ecology of the coastal area and the ecological infrastructure, and to generate economic activities in the coastal area. The Notification tries to ensure:

a. Livelihood security to the fisher folk communities and other local communities, living in the coastal areas, to conserve and protect coastal stretches.

b. Development through sustainable manner based on scientific principles taking into account the dangers of natural hazards in the coastal areas by sea level rise due to global warming.

c. Declaration of the coastal stretches of the country and the water area up to its territorial water limit.

d. Restricting the setting up and expansion of any industry, operations or processes and manufacture or handling or storage or disposal of hazardous substances.

(m) Service level benchmarking on sewage management

The Millennium Development Goals (MDGs) enjoin upon the signatory nations to extend access to improved sanitation to 100% access by 2025. The Ministry of Urban Development has proposed to shift focus on infrastructure in urban water supply and sanitation sector (UWSS) to improve service delivery. The Ministry has formulated the set of Standardized Service Level Benchmarks for UWSS as per International Best Practice and brought out a "Handbook on Service Level Benchmarking" on water supply and sanitation sector in the year 2008.

Service Level Benchmarking: Sewage Management (Sewerage and Sanitation) [6]

S. No.	Indicator	Benchmark
1.	Coverage of toilets	100%
2.	Coverage of sewage network services	100%
3.	Collection efficiency of sewage network	100%
4.	Adequacy of sewage treatment capacity	100%
5.	Quality of sewage treatment	100%
6.	Extent of reuse and recycling of sewage	20%
7.	Efficiency in redressal of customer complaints	80%
8.	Extent of cost recovery in sewage management	100%
9.	Efficiency in collection of sewage charges	90%

2.4 National Urban Sanitation Policy [12]

The National Urban Sanitation Policy-2008 envision that *"All Indian cities and towns become totally sanitized, healthy and liveable and ensure and sustain good public health and environmental outcomes for all their citizens with a special focus on hygienic and affordable sanitation facilities for the urban poor and women"*. In order to achieve this vision, following key policy issues must be addressed:

- **Poor Awareness:** Sanitation has been accorded low priority and there is poor awareness about its inherent linkages with public health.

- **Social and Occupational aspects of Sanitation:** Despite the appropriate legal framework, progress towards the elimination of manual scavenging has shown limited success, Little or no attention has been paid towards the occupational hazard faced by sanitation workers daily.

- **Fragmented Institutional Roles and Responsibilities:** There are considerable gaps and overlaps in institutional roles and responsibilities at the national, state, and city levels.

- **Lack of an Integrated City-wide Approach:** Sanitation investments are currently planned in a piece-meal manner and do not take into account the full cycle of safe confinement, treatment and safe disposal.

- **Limited Technology Choices:** Technologies have been focussed on limited options that have not been cost-effective, and sustainability of investments has been in question.

- **Reaching the Un-served and Poor:** Urban poor communities as well other residents of informal settlements have been constrained by lack of tenure, space or economic constraints, in obtaining affordable access to safe sanitation. In this context, the issues of whether services to the poor should be individualized and whether community services should be provided in non-notified slums should be addressed. However provision of individual toilets should be prioritized. In relation to "Pay and Use" toilets, the issue of subsidies inadvertently reaching the non-poor should be addressed by identifying different categories of urban poor.

- **Lack of Demand Responsiveness:** Sanitation has been provided by public agencies in a supply-driven manner, with little regard for demands and preferences of households as customers of sanitation services.

Specific Goals of National Urban Sanitation Policy (NUSP), 2008

National Urban Sanitation Policy Goals

The overall goal of this policy is to transform Urban India into community-driven, totally sanitized, healthy and liveable cities and towns.

A. Awareness Generation and Behaviour Change

a. Generating awareness about sanitation and its linkages with public and environmental health amongst communities and institutions.

b. Promoting mechanisms to bring about and sustain behavioural changes aimed at adoption of healthy sanitation practices.

B. Open Defecation Free Cities

All urban dwellers will have access to and use safe and hygienic sanitation facilities and arrangements so that no one defecates in the open. In order to achieve this goal, the following activities shall be undertaken:

a. Promoting access to households with safe sanitation facilities (including proper disposal arrangements).

b. Promoting community-planned and managed toilets wherever necessary, for groups of households who have constraints of space, tenure or economic constraints in gaining access to individual facilities.

c. Adequate availability and 100 percent upkeep and management of Public Sanitation facilities in all Urban Areas, to rid them of open defecation and environmental hazards.

C. Integrated City-Wide Sanitation :

Reorienting Institutions and Mainstreaming Sanitation

a. Mainstream thinking, planning and implementing measures related to sanitation in all sectors and departmental domains as a cross-cutting issue, especially in all urban management endeavours.

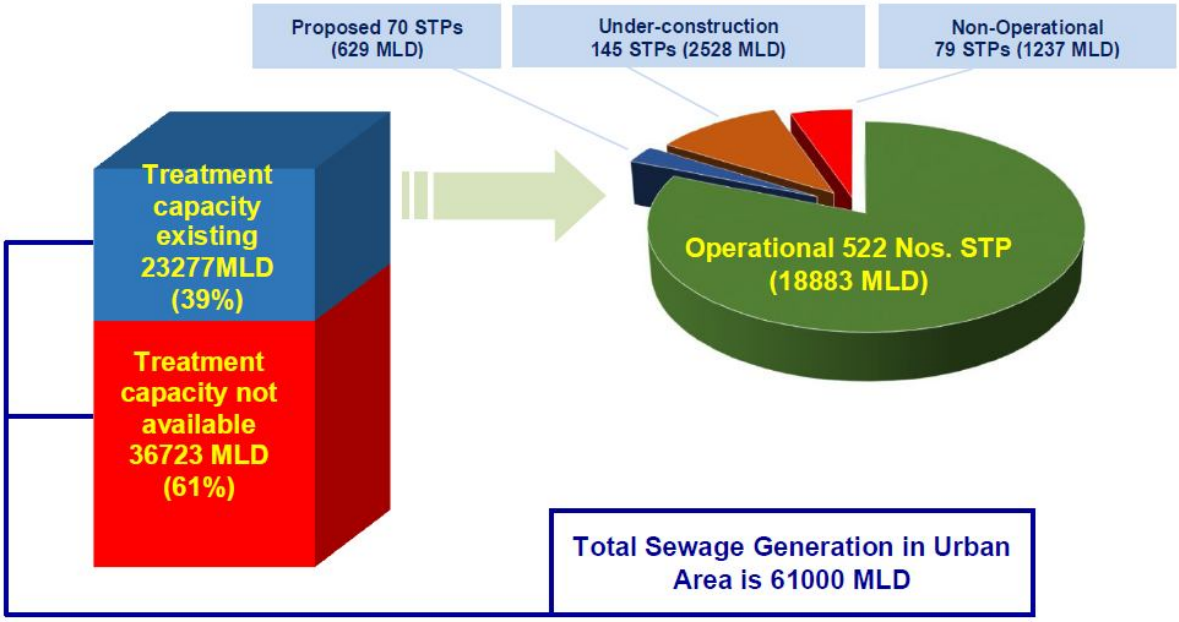
b. Strengthening national, state, city and local institutions (public, private and community) to accord priority to sanitation provision, including planning, implementation and O&M management.

c. Extending access to proper sanitation facilities for poor communities and other unserved settlements.

2.5 Sewage Treatment in India [12-13]

As per CPCB report on Inventorization of Sewage Treatment Plants[18], based on the data provided by SPCBs/PCCs, it has been estimated that 816 number of STPs are available with the total treatment capacity of 23,277 MLD in class-1 cities & class II towns. Out of 816 STPs, 522 STPs Operational, 79 STPs Non- Operational, 145 STPs under-construction and 70 STPs are proposed. It was also reported that maximum STPs are having Activated Sludge (ASP) based treatment technology. The estimated sewage generation in the country is 61000 MLD.

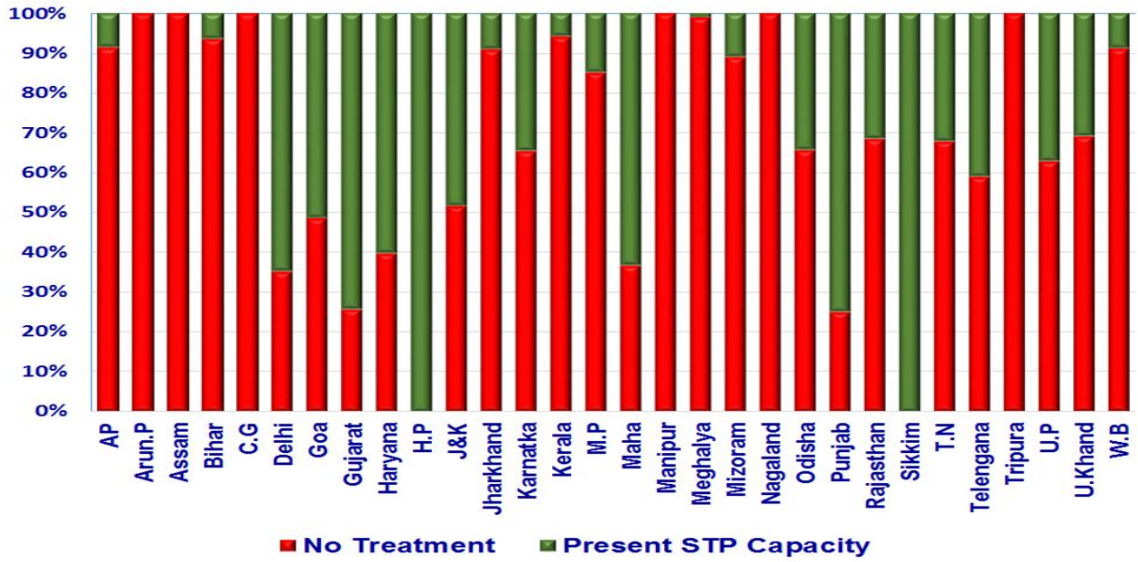
Figure-1: Status of Sewage Treatment in India



The CPCB report[13, 14] further envisages performance evaluation of 152 STPs under NRCD spread over 15 states in the country and having total treatment capacity of 4716 MLD. The study revealed that the actual treatment capacity utilization was only 3126 MLD (66%). Out of the 152 STPs, 30 STPs were non-operational and performance of 28 STPs not satisfactory. Out of the 152 STPs, the treated effluent from 49 STPs exceeded the BOD standards and with respect to COD, 7 STPs were found violating the general standards of Discharge. The large numbers of STPs created under Central Funding schemes such as the Ganga Action Plan and Yamuna Action Plan of National River Action Plan are not fully operated.

The untreated or partially sewage is the main cause of pollution of rivers and lakes. Census 2011 shows that only 32.7 per cent urban Indians are connected to a piped sewer system and 12.6 per cent (roughly 50 million urban Indians) still defecate in the open. The challenge is enormous and needs urgent intervention, which provides both sanitation facility and disposal. Large parts of the modern cities remain unconnected to the sewage system as they live in unauthorized or illegal areas or slums, where the state services do not reach.

Figure-2: State wise Status with respect to percentage of Sewage Treatment



Technologies of Sewage Treatment Plants

The Sewage Treatment Plants based on various processes such as aerobic, anaerobic and facultative are enlisted below [4,13,16] :

(a) Aerobic Treatment Process

The following treatment processes as also cited in the advisory issued by the Ministry of Urban Development in March-2012 titled "Recent Trends in Technologies in Sewage Treatment" fall under the classification of aerobic treatment

- Activated Sludge Process (ASP)
- Sequencing Batch Reactor (SBR)
- Moving Bed Bio Reactor (MBBR) / Fluidized Aerobic Bioreactor (FAB)
- Membrane Bio Reactor (MBR)
- BIOFOR – Biological Filtration and Oxygenated Reactor (BIOFOR)
- High Rate Activated Sludge BIOFOR-F Technology
- Submerged Aeration Fixed Film (SAFF) Technology
- Fixed Bed Biofilm Activated Sludge Process (FBAS)
- Fixed media like Rotating Biological Contactor (RBC)
- Oxidation Ditch (OD)

(b) Anaerobic Treatment Systems

The following treatment processes fall under the classification of anaerobic treatment.

- Up flow Anaerobic Sludge Blanket - UASB
- Anaerobic filter - AF
- Anaerobic fluidized bed

(c) Facultative Treatment Processes

The following treatment processes fall under the classification of facultative treatment.

- Aerated lagoon - AL
- Waste stabilization pond - WSP
- Eco Bio Block - EBB

Challenges in Sewage Management in India

The majority of towns and cities have no sewerage and sewage treatment services. Many cities have expanded beyond municipalities, but the new urban agglomerations remain under rural administrations, which do not have the capacity to handle the sewage. Management of sewage is worse in smaller towns. The sewage is either directly dumped into rivers or lakes or in open fields. In many cities and towns in India, major portion of sewage remains unattended leading to insanitary conditions in densely populated slums. This in turn results in an increase in morbidity especially due to pathogens and parasitic infections and infestations in all segments of population, particularly the urban slum dwellers. As per Root cause of sewage treatment gap may be due to following facts:

- Sewer networks for collection and transportation of sewage from households in cities and towns are too inadequate to carry it to the STP.

- The STP capacities are inadequate due to many reasons.

- Poor planning and implementation of sewerage and STP and other appropriate sanitation facilities by ULBs due to inadequate financial resources and lack of adequate capacity of ULBs in the country.
- Large portion of resources are being utilized on manning sewerage system by Urban Local Bodies (ULBs) for their operation and maintenance (O&M).
- Decline in the standard of services with respect to collection, transportation, treatment and safe disposal of treated sewage as well as measures for ensuring safeguard of public health, hygiene and environment.
- Cities and towns, which have sewerage and sewage treatment facilities, are unable to cope-up with the increased burden of providing such facilities efficiently to the desired level.
- Lack of institutional arrangements and capacity building to conceive planning, implementation, procurement of materials, operate and maintain the sewerage system and sewage treatment plants (STP) at the desired level of efficiency.

Immediate Areas of Attention

In major cities and in town, in particular the project pilot-cities Delhi and Mumbai, there is an intense need for

- Sludge Management
- Augmentation and Up-gradation of Treatment Facilities
- Optimization of existing system for better performance

Keeping in view of above, it is deemed essential to build the capacity of stakeholders to have acquaintance with the European Best Practices and exchange of knowledge so that processes can be optimized to address various issues pertaining sewage treatment and sludge management.

2.6 Waste Water Management in Europe[17-19]

The Urban Waste Water Treatment Directive (UWWTD) 91/271/EEC establishes minimum requirements for collection and treatment of urban wastewater and is one of the key policy instruments under the EU water *acquis.* Implementation of the UWWTD since its adoption in 1991 has, in particular, significantly reduced discharges of major pollutants such as organic load and nutrients, main drivers for eutrophication in waters[17,18].

The 8th Implementation Report covers more than 19,000 towns and cities ("agglomerations") above 2,000 inhabitants, generating a pollution corresponding to 495 million population-equivalents (Mpe).

"Population equivalents" or p.e., term used in the UWWTD, covers the organic pollution generated by the inhabitants of a village/town, and other sources such as non-resident population and agro-food industries[18].

The generated load or the "size" of the agglomeration is expressed in p.e. According to Article 2(6) of the Directive, "*one population equivalent (p.e.) means the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day"*[18].

The implementation status[17,18,19] of Directive as per the 8th Report SWD 2016 is as follows:

Article 3 : Collecting systems and individual or other appropriate systems

Most Member States collect a considerable part of their waste waters, with an average rate of compliance of 98 %. 20 Member States reach compliance rates of 100%.

Article 4 : Secondary or biological treatment

92% of the waste waters in the EU received secondary treatment in compliance with the provisions of the UWWTD. 16 Member States reached 90-100% compliance, another 5 had levels of compliance in the range of 50-90%. Even though the compliance rates in EU-13 Member States are still trailing behind, with an overall rate of 68%, there has been a substantial improvement in comparison to the previous Report, in which only 39% of the waste waters received appropriate secondary treatment.

Article 5 : More stringent or tertiary treatment and sensitive areas

Nearly 75% of the territory in the EU is now designated as sensitive area. 15 Member States have designated their entire territory as such, whereas 13 Member States have identified only certain water bodies as "sensitive". Figure-3 represents the compliance %age by EU 13, EU 15 and EU 28 countries with respect to Article 3, Article 4 and Article 5, whereas Figure 4 represents the compliance %age of member states.

Figure-3: Status of % Compliance: EU 13; EU 15 & EU 28

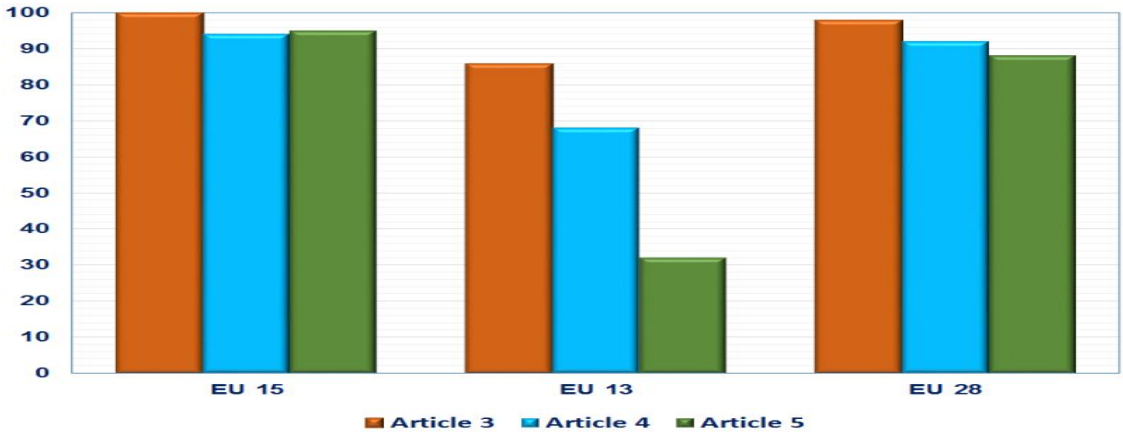
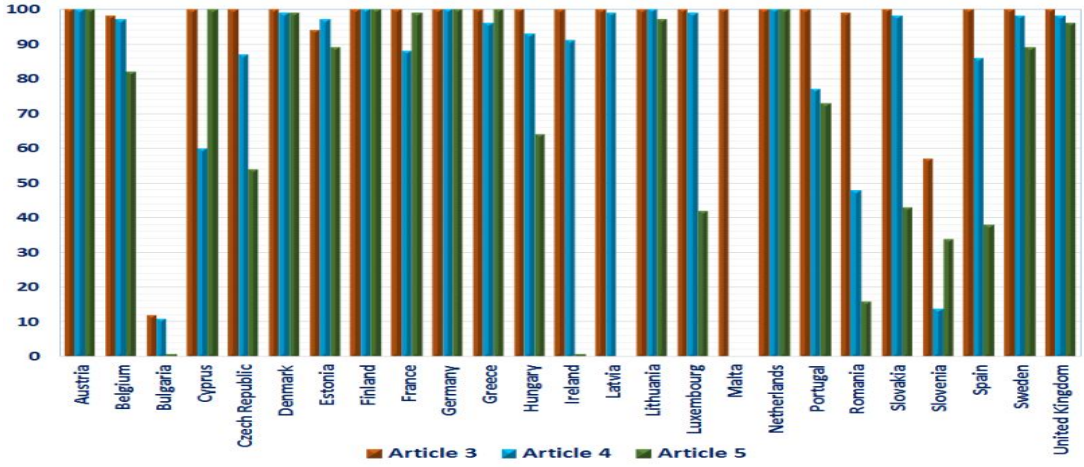


Figure-4: Status of %Compliance: EU Member States



EU-15: Austria, Belgium, Denmark, Finland, France, Greece, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden.

EU-13: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia (for certain interim deadlines).

The implementation of EU Directive can be summed-up as:

- The implementation of the UWWTD has significantly reduced organic and nutrient pollution load discharges in the EU and therefore plays a key role to achieve good environmental status of marine and fresh waters.

- Despite challenges such as substantial investment needs and long-term planning, high compliance rates are reached in EU-15. In EU-13, still significant compliance gaps exist, especially on treatment. Reinforced action and investments are needed to reach full compliance within reasonable time delays.

- Implementation programmes show that Member States plan significant investments to close the compliance gaps by constructing waste water infrastructure. Member States need to continue to collect the necessary information to timely identify future investment needs and operation costs, and to improve or maintain the performance of their current systems.

- Additional efforts are needed to improve the quality and the timeliness of the data reported on the implementation of the UWWTD. To this end, processes and tools are being revised and developed by the Commission in collaboration with EEA and Member States.

- Investments in innovative technologies are essential to make the water industry more resource efficient and also contribute to job creation and economic growth

Considerable efforts are needed in India to not only augment the sewage treatment capacity but also to ensure the adequacy and performance efficiency of sewage treatment on continual basis. In this context, EU countries are providing excellent showcasing example.

Further, Sewage Generation in a city depends upon its demographic profile and the management of Sewage and Sludge is dependent upon the type and magnitude of technical and socio-economic interventions of civic agencies and ULBs in addition to the physiographical features of the region.

Mumbai being a coastal mega city of India has diverse physical features. The Municipal Corporation of Greater Mumbai (MCGM) is responsible for the Treatment of Sewage in Mumbai.

3. Mumbai : Physiography and Demography

3.1 Physiography[20,21,22]

Location and Physical Features

The Greater Mumbai consists of two districts (Island and Suburban). The Island District is situated on the west coast of India between 18°52' and 19°04' north latitudes and 72°47' and 72°54' east longitudes. It is surrounded on three sides by water, the open Arabian Sea to the west and south and Thane creek to the east. Towards north it is bordered by Mumbai (Suburban) District, which is also a coastal District. It lies between 18°58' and 19°17' north latitudes and 72°46' and 72°60' east longitudes. It is surrounded by Arabian sea towards west, Thane District towards east and north and Mumbai Island District towards south. Physiographically, the both Island and Suburban Districts, falls under the Maharashtra littoral, the micro level division of Coastal Plains and Islands.

This island district, separated from the mainland of Konkan by the narrow Thane creek and a slightly wider Harbour Bay, is originally consisted of eight separate islands. These are (i) Salsette, (ii) Colaba, (iii) Old Woman, (iv) Apollo Bundar, (v) Mazagaon, (vi) Parel-Sewri-Sion, (vii) Mahim Baradbet (deserted island) and (viii) Worli. The land located in the North of Mahim creek is known as Salsette Island which together with Trombay area forms the Mumbai Suburban District. The District spreads from Bandra to Dahisar on the Western Railway side and Kurla to Mulund on the Central Railway side including Chembur and Chembur Camp.

The physiographic feature of Mumbai are broad and flat terrain flanked by north-south trending hill ranges, forming almost parallel ridges in the eastern and western part of the area. The Powai-Kanheri hill ranges are the other hills extending in the eastern and central part running NNE-SSW. The maximum elevation of the area is 450 m above mean sea level. Trombay Island has north-south running hills with maximum elevation of 300 m above mean sea level. Malabar, Colaba, Worli and Pali hills are the isolated small ridges trending north-south in the western part of the district. The Powai-Kanheri hills form the largest hilly terrain in the central part of the Salsette island are the feeder zone for the three lakes viz., Powai, Vihar and Tulsi. There are number of creeks, dissecting the area. Among these, Thane is the longest. Other creeks are Manori, Malad and Mahim, which protrudes in the main land and give rise to mud flangs and swamps. The area is drained by Mahim, Mithi, Dahisar and Poisar rivers. These small rivers near the coast, form small rivulets which inter-mingle with each other resulting in swamps and mud flats in the low lying areas. Two types of soils have been observed in the district viz., medium to deep black and reddish soil.

Hydrogeology

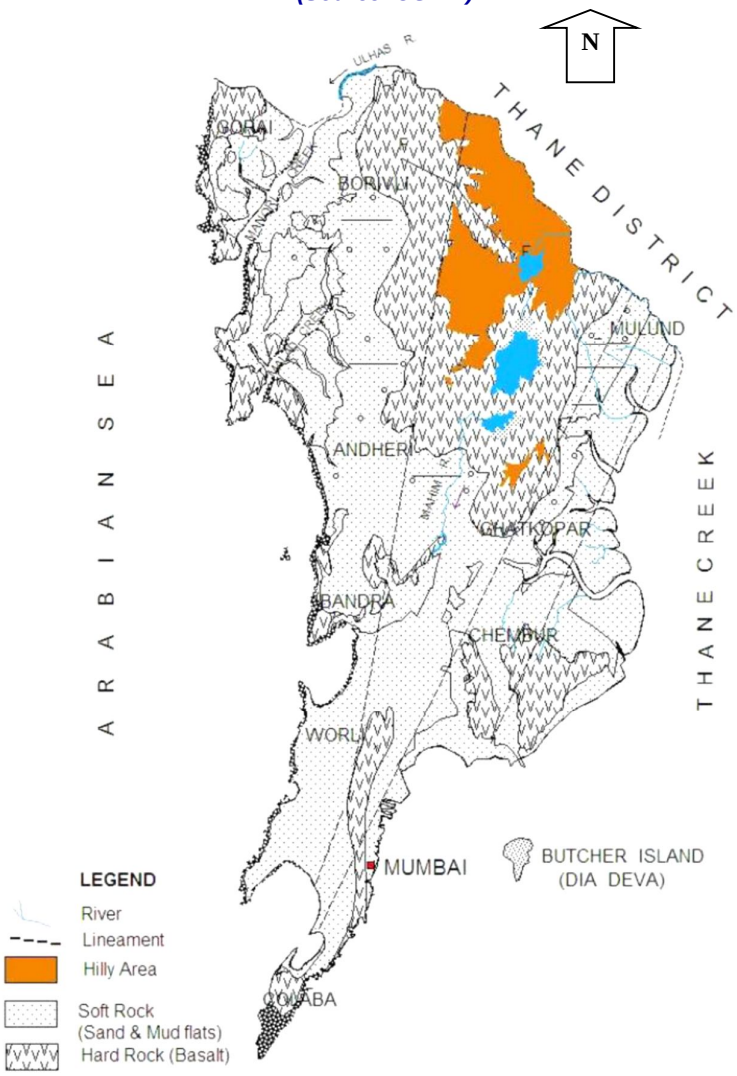
The entire district is underlain by basaltic lava flows of upper Cretaceous to lower Eocene age. The shallow Alluvium formation of recent age also occurs as narrow stretch along the major rivers flowing in the area.

Hard Rock Areas (Deccan Trap Basalt): The 'Pahoehoe' flows in the district consist of highly vesicular layer having closely spaced horizontal joints but the thickness is generally less. The vesicles are generally filled with secondary minerals and green earths. In such cases, these do not serve as aquifer.

However, such vesicular zones are weathered in most part of the area, thus, making these moderately permeable. But if, vesicles are not filled, these act as highly permeable aquifers. The simple and compound "Pahoehoe" flow comprises a basal vesicular zone, middle relatively massive portion followed by a vesicular top. The vesicles of "Pahoehoe" flows are generally not interconnected and thus there is a variation in water holding capacity from the base to the top of the flow.

Loose Formation Alluvium: River alluvium patches along the course of rivers and marine alluvium in the coastal area, form highly potential aquifer but with limited areal extent.

Figure-5: Hydrogeological Features of Greater Mumbai[22]
(Source: CGWB)



The ground water occurs under water table conditions in sandy / gritty layers. The alluvial fill of low lying areas underlain by weathered basalt has relatively better ground water potential.

Climate and Rainfall

The climate of Mumbai is characterized by an oppressive summer, dampness in the atmosphere nearly throughout the year and heavy south- west monsoon rainfall from June to September. The mean minimum temperature is 16.3°C and the mean maximum temperature is 32.2°C at Santacruze. The normal annual rainfall over varies from about 1800 to about 2400 mm. It is minimum in the central part of the district around Kurla (1804.9 mm). It gradually increases towards north and reaches a maximum around Santacruze (2382.0 mm).

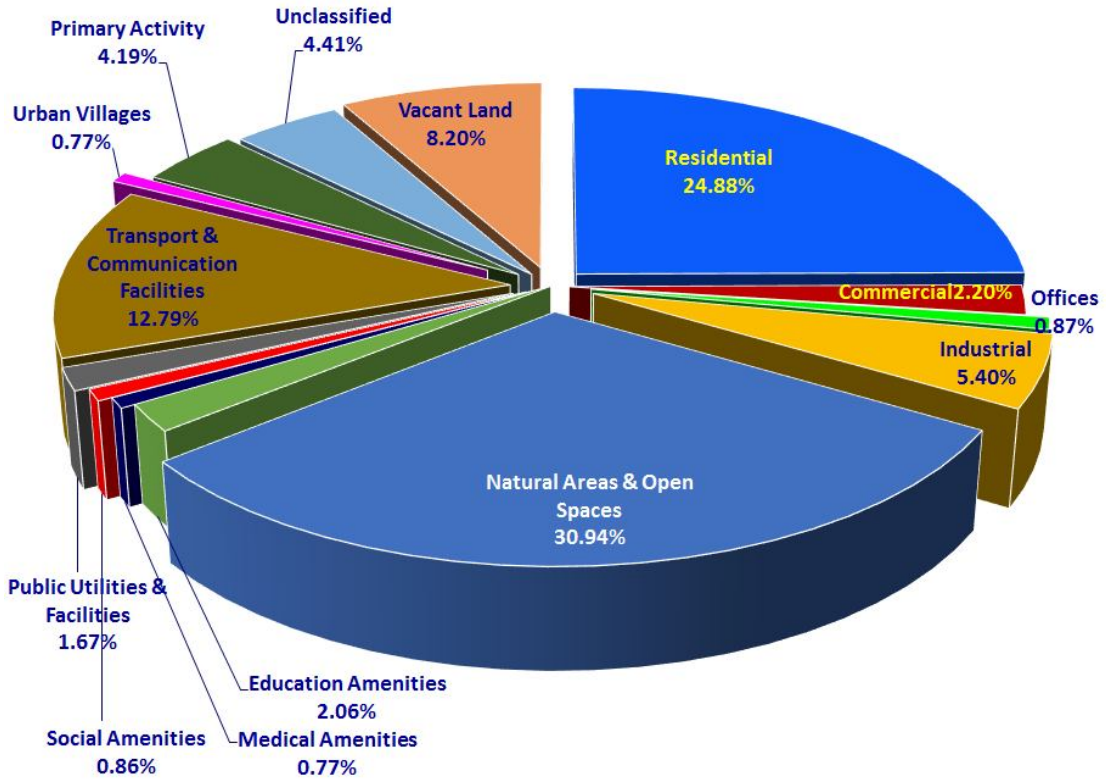
Drainage

Due to human interference, most of the surface drainage has been modified to the extent that there is practically no natural drainage. The original Mahim river, draining northern fringe of the Island District into Mahim Bay has been dammed in its upper reaches while the building of the Airport at Santacruz has blocked it in its mid stretches. The lower stretches, close to Mahim Bay, are carrying waste water. The entire District has so dense built up area and roads that have decreased percolation of run off into the ground so that even moderately heavy rains result in flooding of vast areas. The original relief features of Suburban District are hardly visible at present due to influence of human interference and action. Many low hills, which were present in the Salsette Island, have been levelled and built up. Due to the continuous increase in built up areas and asphalted and macadamised road surfaces, natural drainage during the heavy monsoon rains has been so adversely affected that vast areas and local depressions get readily flooded even with moderately heavy rains. The Dahisar river flowing westerly and draining the slopes of Kanheri is dammed at its upper reaches while below in the flat terrain it consists of local pits and depressions thereby holding drainages.

3.2 Existing Land Use (ELU)[21]

The Greater Mumbai's total area admeasures 458.28 sq km out of which 43.22 sq.km area is under Special Planning Authority (SPA). Hence, existing Land Use of 415.05 sq.km area under MCGM comprised of 65.34% (271.17 sq.km) developed area and 34.66% undeveloped area. The undeveloped area includes Natural Areas, Vacant Lands, Plantations and Salt Pans.

Figure-6: Existing Land Use (ELU-2012)[21]



In case of Developed Area, 38.08% is occupied by Residential uses, 8.27% by Industrial uses, 3.36% by Commercial uses & 1.33% by Offices. Amenities constitute 5.63%, Open Space 5.67% and Public Utilities &facilities 2.56%. Transport &Communication facilities constitute 19.57%, Roads occupy 13.79% of developed area and Railways occupy 2.97%. Together 33.43% of the developed area is under Amenities, Open Space, Public Utilities and Transport. The ELU 2012 shows presence of Natural Areas, which includes the Sanjay Gandhi National Park, mangrove forests, mud flats and creeks. Almost all of these natural areas are equally distributed between the Eastern and Western Suburbs. Only about 1% of the natural area is located in the Island City

3.3 Area under Coastal Regulation Zone[21]

According to the approved Coastal Zone Management Plan (CZMP) prepared under CRZ Notification, 1991 of MoEF&CC, the coastal stretches of Greater Mumbai are divided into following three zones.

CRZ-I This is an area between the Low Tide Line and High Tide Line. The North West coastal area like Gorai, Uttan, areas around Manori river, area where Mithi river meets Mahim creek and on eastern side Godrej Vikroli grassland and mangrove forest along Thane creek etc are demarcated as CRZ-I, which are environmentally sensitive zone. CRZ-I area covers 40.44 sq. km in Greater Mumbai. In addition to this, areas along coastal road and allied open space reservations are the new proposals within CRZ-I.

CRZ-II This is a coastal area within 500 m buffer from sea and 100 m or equal to the width of the creeks whichever is lesser that is already developed. The development is permissible in this zone only on landward side of the existing road or structure, provided the land use and FSI remain same as permissible prior to 13th Feb. 1991. CRZ-II covers 43.48 sq. km of area in Mumbai.

CRZ–III It includes areas that are relatively undisturbed and those do not belong to either CRZ-I or II which include coastal zone in the rural areas (developed and undeveloped) and also areas within municipal limits which are not substantially built. Within CRZ-III area up to 200 m from HTL on the landward side in case of seafront and 100 m along tidal influenced water bodies or width of the creek whichever is less is earmarked as "No Development Zone (NDZ)". CRZ-III covers 13.14 sq.km area in Mumbai. Significant CRZ-III area is located on North Western edges of the MCGM and some parts along Thane creek.

Figure-7: Area wise CRZ in Greater Mumbai[21]

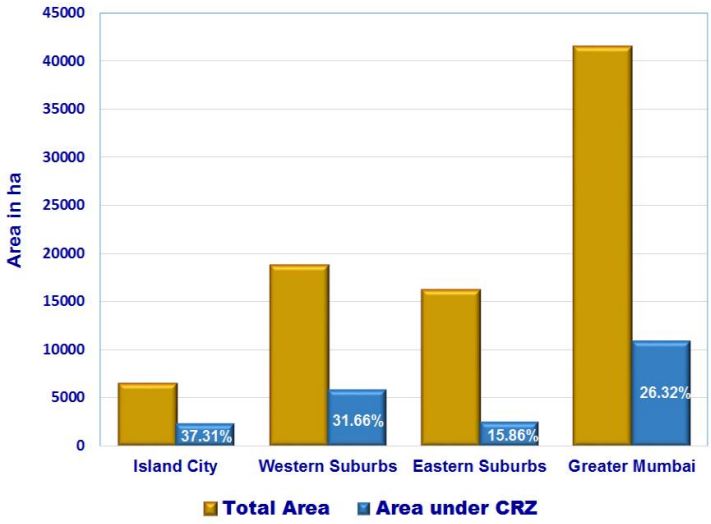
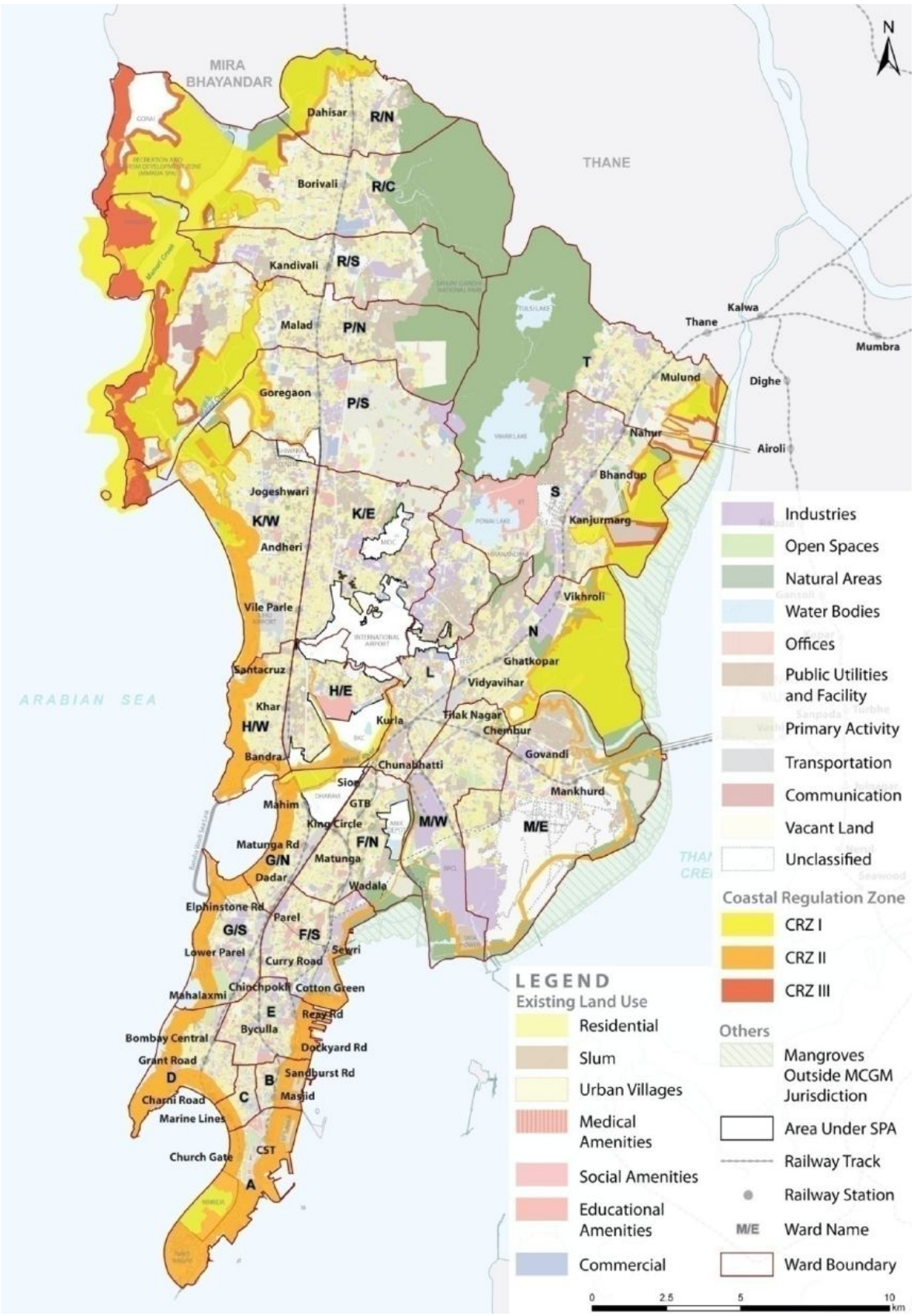


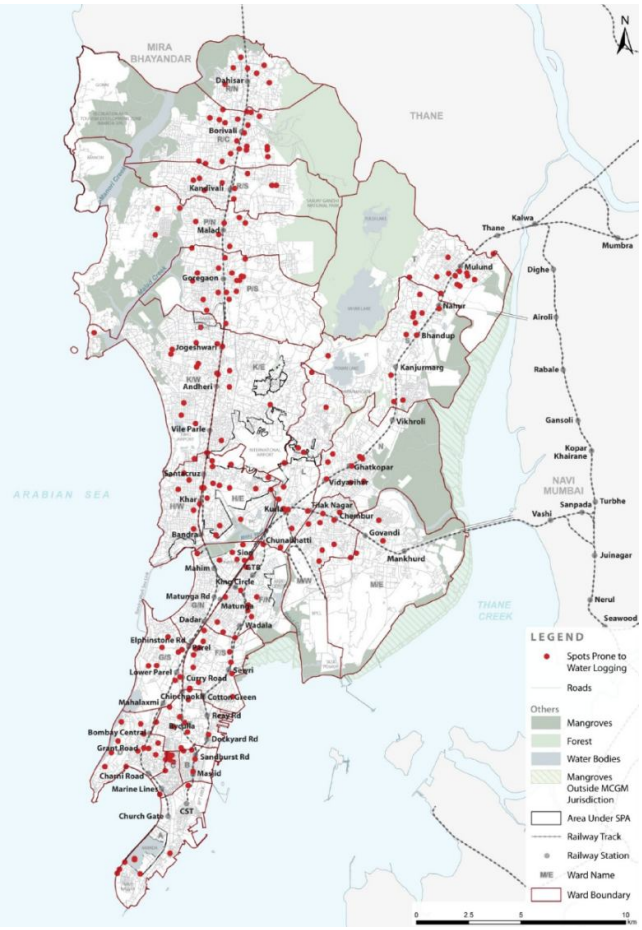
Figure-8: Existing Land Use & CRZ areas of Greater Mumbai[21]
(Source: DDP-2034)



3.4 Environmental Vulnerability[21]

Greater Mumbai areas are prone to three potential natural hazards of flooding, landslides and earthquake. Flooding is the major threat because of its greater impact on life and property.

Figure-9: Areas/ Spots prone to water logging [21]
(Source: DDP-2034)



Climate change risk

Increased intensity of climatic events like increased rainfall, floods, unseasonal rain or drought, intense heat, sea level rise, cyclonic storm surges and increasing outbreaks of tropical diseases and epidemics are predicted outcomes of climate change and global warming. Greater Mumbai's coastal location and a large population living in close proximity to the coast render it highly vulnerable to many climate change effects, especially sea level rise and flooding. Since Mumbai is only a few meters above sea level and has four rivers flowing through it further increases its vulnerability to flooding. MCGM has prepared a separate storm water drainage plan to deal with the risks of flooding.

Areas Prone to Landslides

Several areas around hill slopes in Greater Mumbai are prone to landslides. The risk is more during the monsoon. Areas around hill slopes in Ghatkopar, Bhandup and Kurla in the Eastern Suburbs are prone to landslides resulting in increased exposure of slopes to erosion and water infiltration. Slum populations residing on these hill slopes are at high risk.

Areas Prone to Flooding

Flooding is the major environmental vulnerability areas of Greater Mumbai owing to heavy annual rainfall. Estuarine setting, coupled with continuous reclamation in marsh lands and low lying areas in Greater Mumbai have led to an obstruction in the natural flow of water bodies and drains. Most of Greater Mumbai is on reclaimed lands that are almost flat, which makes the city naturally prone to flooding. Prime city locations are lower than high tide level. Similarly, low lying coastal edges and river floodplains are susceptible to flooding.

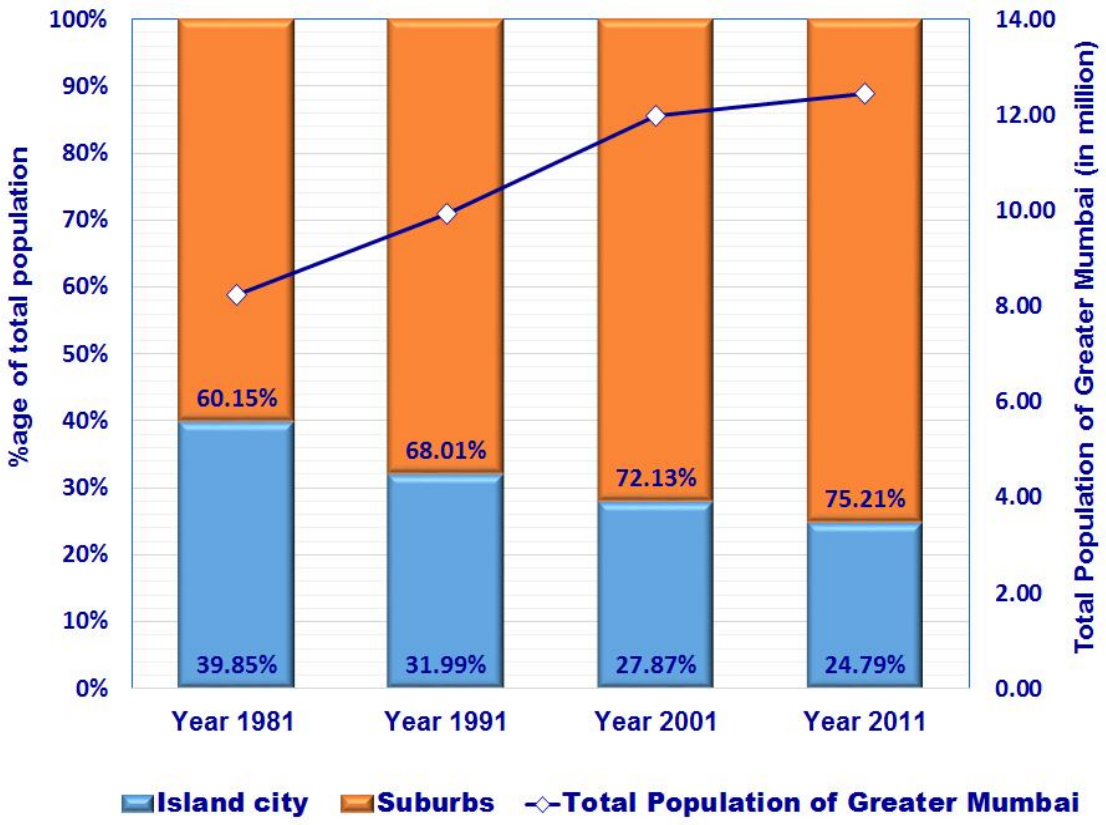
3.5 Demography of Greater Mumbai[20, 21]

The population of Greater Mumbai recorded in the 2011 Census is 12.44 million. Since 1991, the growth rate of the population of Greater Mumbai has reduced significantly. In 1991 the decadal growth rate dropped to 20.41 % from 38.07% in 1981. This further dropped sharply to 3.87% in 2011.

Population Distribution

Within Greater Mumbai, the population of the Suburban District is larger than that of the Island City. Further, the share of Suburban population has been increasing consistently since 1981 with City population showing the opposite trend.

Figure-10: Population distribution of Greater Mumbai[20, 21]

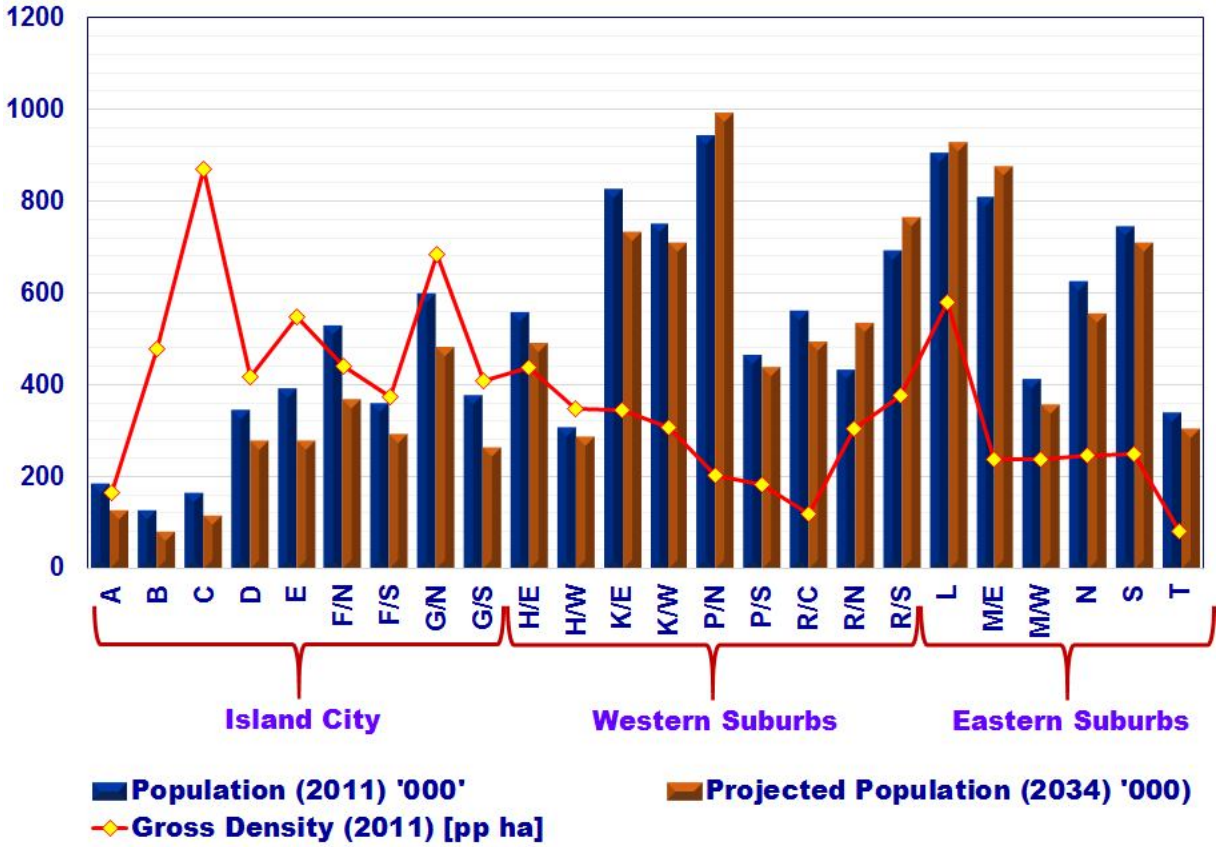


A comparison of the population trends in the Island City and the Suburban District indicates that the population in the Island City has reached near stability or marginal reduction since 1981. The absolute population in 2011 was recorded at about 3.08 million as against 3.28 million in 1981. On the other hand, the population in the Suburban District has grown consistently. It recorded a figure of 9.35 million in 2011 against 4.95 million in 1981. However, the decadal growth rate in the suburbs has recorded a decline from 70.97% in 1981 to 8.29% in 2011.

Ward Wise Population Distribution

The ward wise population for 2001 and 2011 is given below. The absolute population in the Island City has decreased while that in the Suburbs, both Eastern and Western has increased. The population is inclusive of SPA population. The Ward P/N in the Western Suburbs has the highest population 0.94 million among all 24 wards, holding 7.5% of the total population. Ward B in Island City on the other hand, has the lowest population of 127,290 among all 24 Wards.

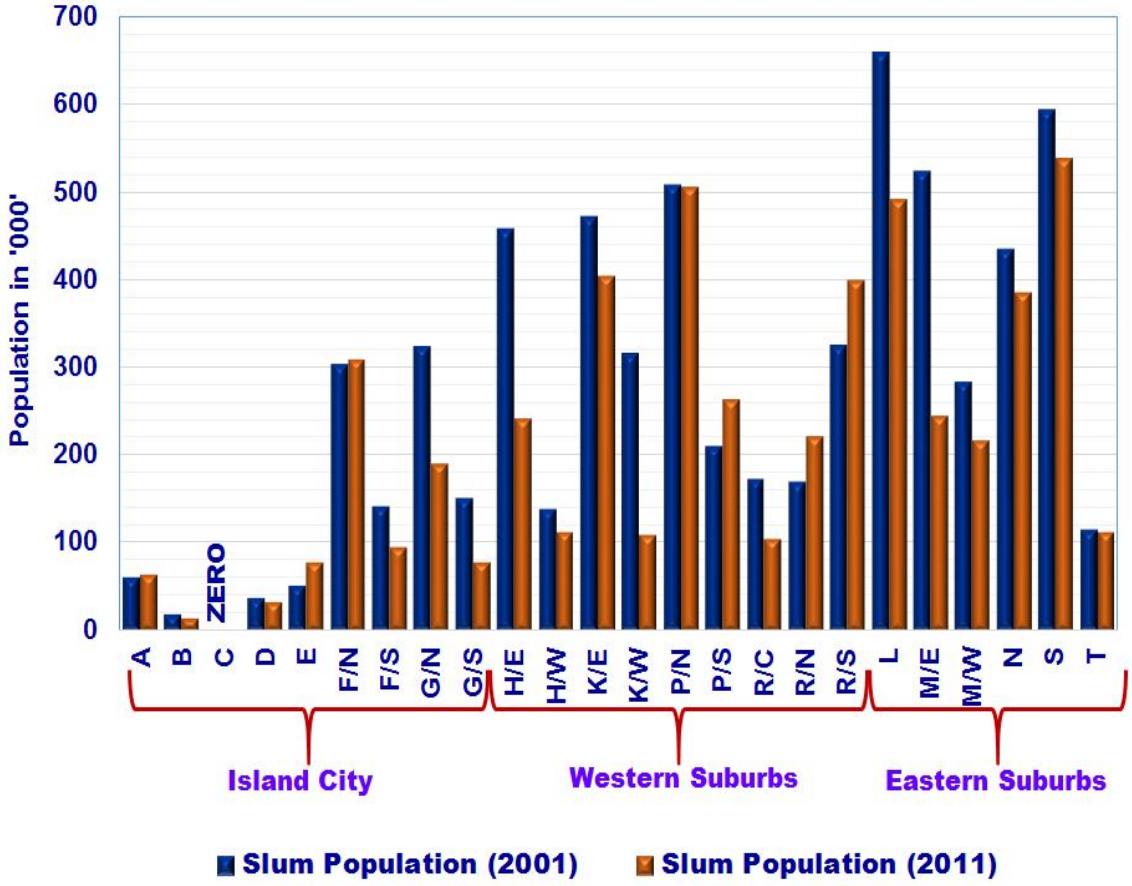
Figure-11: District wise & Ward wise population distribution in Greater Mumbai[20, 21]



Slum Population

In 2001 the slum population in Greater Mumbai constituted 52.52% of the total population (excluding the areas notified under SPAs). In 2011 this figure came down to 41.85% (including the areas notified under SPAs). However, the extent of slums has increased as per satellite images. Slums are mostly located along watercourses/creeks, on precarious hillsides, in low lying areas, on the periphery of forests and along railway tracks. Majority of them are in wards L, M/E.

Figure-12: District wise & Ward wise distribution of slum population in Greater Mumbai[20,21]



Wastewater Management Plan of any area or region is critically dependent upon the attributes like physical features, hydrogeology, climate & rainfall, drainage pattern, land use and population distribution as well as projections.

4. Evolution of Sewerage System in Greater Mumbai

4.1 Responsibility of Sewerage System in Greater Mumbai

The Municipal Corporation of Greater Mumbai (MCGM) a local authority for Brihanmumbai area formed under Mumbai Municipal Corporation Act, 1888 is responsible for providing municipal and civic services to the citizens of Greater Mumbai, including Sewerage Operations, Sewage Treatment and Sewage Disposal within the jurisdiction of Greater Mumbai.

Provision of MMC Act[29]

The Obligatory Duty of MCGM under MMC Act 1888, in context to Sewerage Operations are as follows[23]:

Section 61 (a):	The construction, maintenance and cleansing of drains and drainage works, and of public latrines, urinals and similar conveniences.
Section 61 (c):	Scavenging and the removal and disposal of excrementitious and other filthy matters, and of all ashes, refuse, and rubbish.

4.2 Evolution of Sewerage System in Greater Mumbai[23, 30]

The present Sewerage System of Mumbai is evolved after passing through long chronological events, as mentioned below:

- History commences with the old main drain constructed about by the end of 18th Century.
- The first sections of the sewerage system, were constructed in Zones-1 and 2 in 1860. By close of 1867, outlets with main sewer were laid.
- Captain Tulloch recommended a separate system for storm water and sewerage. Thereupon, Worli (Love Grove) outfall was constructed and completed in 1880 and by 1900 much of the city flow was directed towards Love Grove, to form the basic arrangement for Zone-2.
- In 1905, ejector stations at Mazgaon & Parel were constructed. In 1910, treatment plant was constructed at Dharavi. In 1938, treatment plant was constructed at Dadar and the expansion continued through to 1940, with improvements. New catchment areas formed at Dadar, Banganga and Malabar Hill under Zone-2 and at Dharavi under Zone-3.In Zones-4, 5, 6 and 7, as well as in the northern part of Zone-3, there were no facilities recorded prior to 1940, as these were all outside the then municipal boundary.
- After independence in 1947, relief works undertaken but it was inadequate to alleviate the problem due to very low population forecast. The municipal boundaries were extended in 1950 and again in 1957 to the present position. Pumping stations were constructed at Khar and Kurla in 1955 in Zone-3 and at Versova in 1959 in Zone-4.
- In 1960, primary treatment plants were constructed at Khar, Versova & Ghatkopar.

- Further pumping capacity was added in Zone-3 at Dharavi in 1964 nad at Kheradi in 1971. The first pumping station of Zone-5 was also built in 1971 at Malad.

- The studies carried out by Binnie & Partners in 1970 recommended that flows from all zones be directed through two long sea outfalls at Worli and Bandra. These were further expanded to seven zone by 1973. By 1979, eight new pumping stations were constructed.

- Consultant M/s Metcalf & Eddy was appointed in the year 1976 to review the proposed sewerage system with special context to oceanographic surveys, proposed landuse and to workout feasibility of the reuse of treated sewage.

- Revised development plans were submitted by 1979, consisting of provision of marine outfalls at Colaba, Love Grove and Bandra as well as aerated lagoons at Versova, Malad, Bhandup and Ghatkopar.

- In 1979, M/s Metcalf & Eddy in association with Environments Engineering Consultants prepared integrated Master Plan for Sewage Collection Disposal for the period up to 2005, which culminated into the Mumbai Sewage Disposal Project (MSDP)-I

- MCGM implemented Mumbai-I, Mumbai-II, and Mumbai- III during 1975 to 1996. Under these projects, 123 km of sewer lines were laid, 23 numbers of pumping stations constructed and 6 numbers of WWTF were constructed in addition to the construction of one pipe outfall and one aerated lagoon. These projects were implemented with the help of World Bank.

- Chronology of the development of the sewerage system vis-à-vis current status of pumping stations, is described below:

Sewerage Zone	Commencement Year of Sewerage System	Number of Pumping Stations in 1979	Pumping Stations in 2017 (numbers)
Zone-1 (Colaba)	1860	02 + 09 (ejector stations)	06
Zone-2 (Worli)	1860	08 + 02 (ejector stations)	17
Zone-3 (Bandra)	1900-1940	13	16
Zone-4 (Versova)	1959	01	02
Zone-5 (Malad)	1971	01	06
Zone-6 (Bhandup)	Post 1979	None	03
Zone-7 (Ghatkopar)	1950s	03	01
Total		**28 + 11 (ejector stations)**	**51**

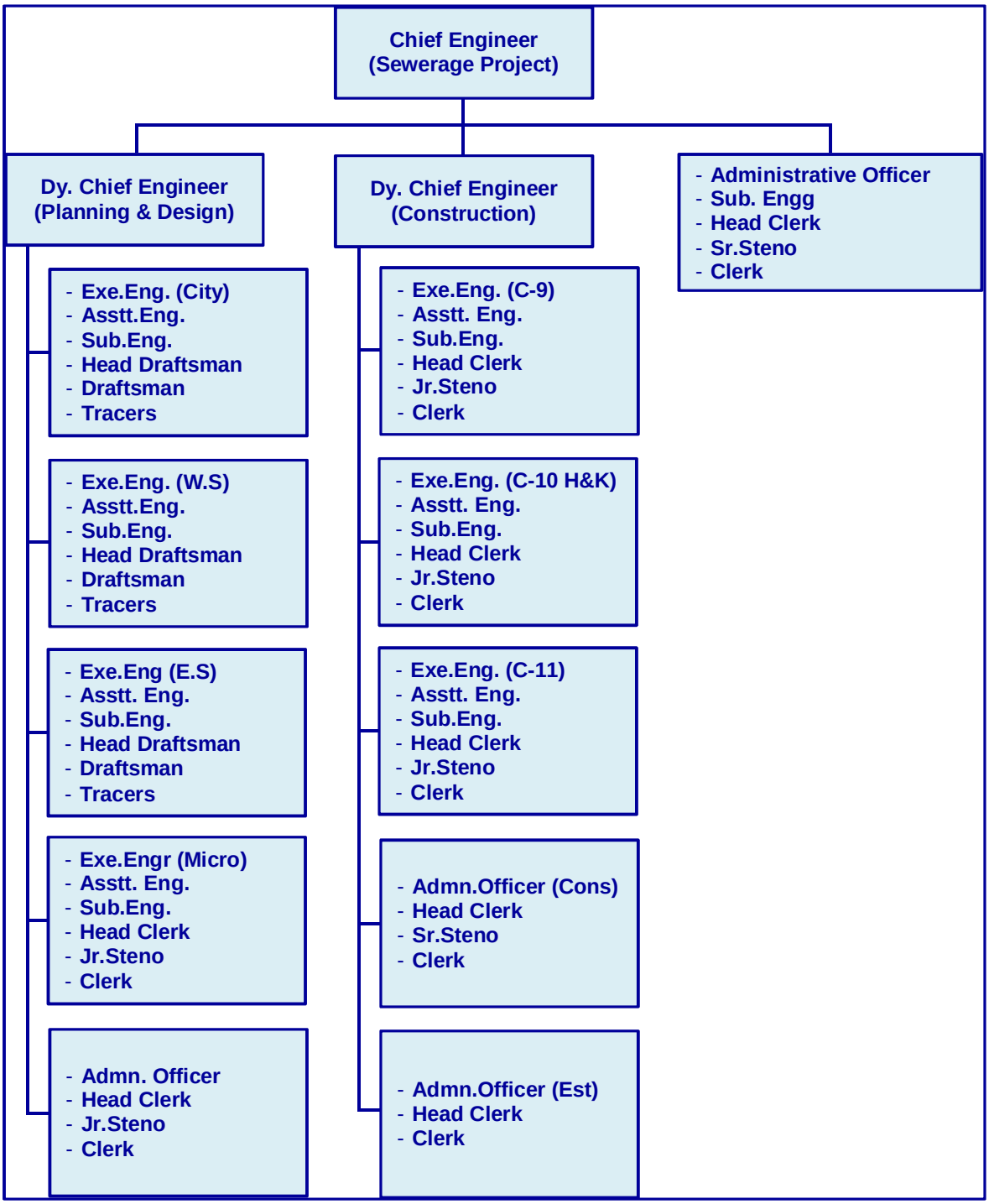
4.3 Institutional Setup for Planning, Implementation and Operation[21, 23-29]

Sewerage in Greater Mumbai is planned, implemented and operated by two departments of MCGM, namely Sewerage Project Department and Sewerage Operations Department. The Sewerage Project Department plans, designs and lays sewer networks across the city and thereafter on completion, the project is being handed over to the Sewerage Operations Department for operations and maintenance. The department also provides approvals for new connections.

(a) Sewerage Project Department[25,26]

The Chief Engineer (Sewerage Project) department is working under the control of Additional Municipal Commissioner (Projects) and Deputy Municipal Commissioner (Engineering) for its administrative functioning. Providing and laying sewer lines for carrying sewage flow generated in Greater Mumbai is the main function of Chief Engineer (Sewerage project) department.

Figure-13: Organizational Chart of Sewerage Project Department, MCGM[25]



Chief Engineer (Sewerage Project) is entrusted with planning, designing and construction of sewage conveyance lines leading to Pumping Stations and conveyance lines carrying sewage to the outfall and aerated lagoons. This department is bifurcated mainly in two sections viz. (i) Planning and Design and (ii) Construction. There are two numbers of Dy. Chief Engineers under the control of Chief Engineer (Sewerage Project), under whom other Executive Engineer, Assistant Engineers, Sub Engineers and other staff are working as shown in the above organizational chart.

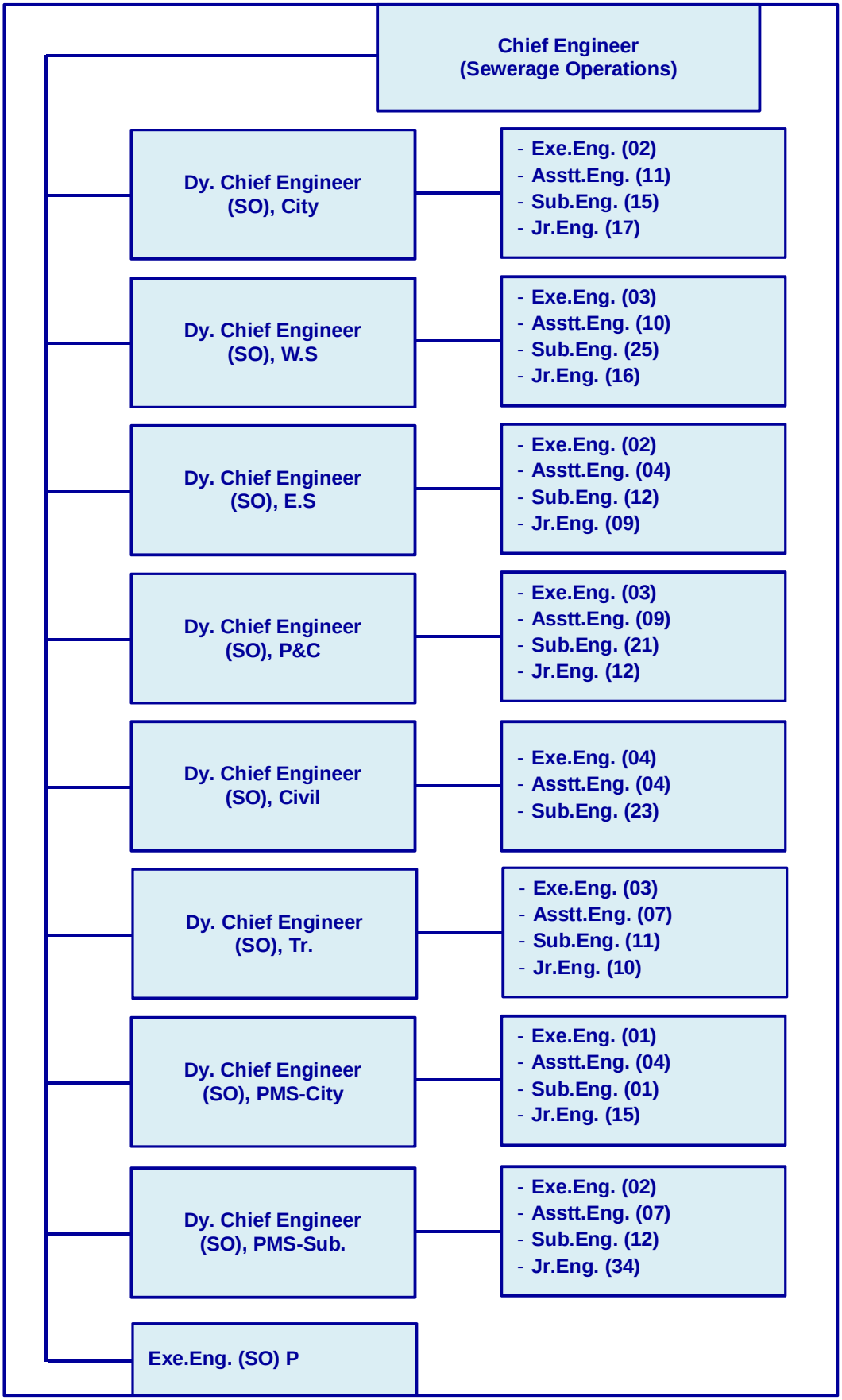
Staff Strength in Sewerage Project Department of MCGM[25]

Sl.	Designation	Filled in Post	Vacant Post
1.	Chief Engineer	1	0
2.	Dy. Chief Engineer	2	0
3.	Executive Engineer	7	2
4.	Administrative Officer	4	0
5.	Assistant Engineer	13	5
6.	Sub Engineer	62	17
7.	Jr. Engineer	0	64
8.	Sr. Steno	1	1
9.	Head Clerk	9	0
10.	Jr. Steno	0	6
11.	Clerk	21	19
12.	Head Draftsman and Draftsman	1	10
13.	Others	35	105
	Total	**156**	**229**

(b) Sewerage Operations Department[24,28]

The Sewerage Operations Department involves in operations and maintenance of the sewage collection, conveyance, pumping, treatment and disposal system brought in place by the Sewerage Projects and Mumbai Sewage Disposal Project departments. This department also undertakes remedial measures like upsizing of sewer, rising of manholes, shifting of vent shafts, replacement of faulty portion of sewer lines, etc. in addition to the execution of various rehabilitation works pertaining to old and dilapidated sewer lines. The department is also providing the vehicular transportation facilities to the Water Supply and Sewerage Division. The organizational chart of the Sewerage Operations Department is described as follows.

Figure-14: Organizational Chart of Sewerage Operation Department, MCGM[24]



The activities of the Sewerage Operations Department can be classified in four categories

(i) Sewers (a) Pipe sewers (size below 18 inches) and (b) Main sewers (size 18 inches & above).

(ii) Pumping, treatment and disposal.

(iii) Transportation Services.

(iv) Planning & Constructions of sewers such as

- Condition assessment of sewers.
- Rehabilitation of sewers.

The other responsibility of the department is the cleaning of the main sewer in accordance with the preventive maintenance schedule as part of preventive care by the Main Sewer sections. Most of the main sewer activities are mechanized to ensure adherence to all safety norms, while working on the system. The main sewer sections are equipped with following sewer cleaning machinery and workshops to ensure regular maintenance:

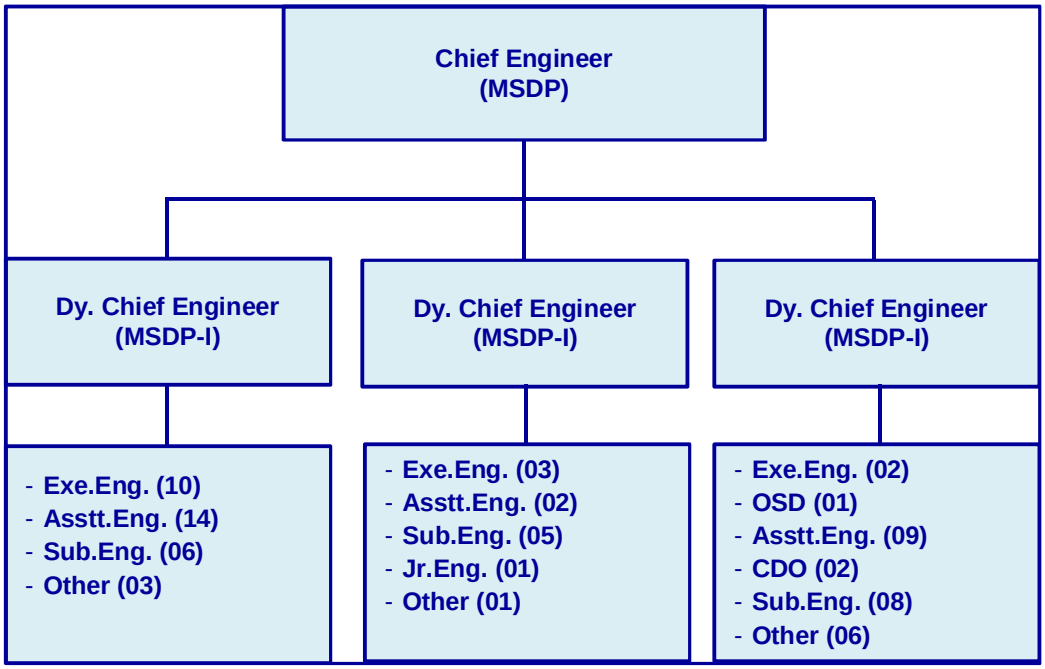
♦ Jetting Machine	:	06 numbers
♦ Suction Machines of 6.5 cu.m capacity	:	19 numbers.
♦ Suction Machine of 1.5 cu.m capacity	:	17 numbers
♦ Power Bucket Machine	:	36 numbers
♦ Power Rodding (Choke) Machine	:	32 numbers
♦ High Power Rodding Machine	:	01 number
♦ Recycling Machine	:	06 numbers

(c) Mumbai Sewerage Disposal Project Department[27]

The Mumbai Sewerage Disposal Project Department of MCGM is in existence since 1997. The obligatory duty of this department is to provide Sewerage Treatment Facilities as well as upgradation of pumping stations and to provide Community Sanitation Facility under Slum Sanitation Programme.

The department is functioning under the administrative control of Additional Municipal Commissioner (Projects) and Deputy Municipal Commissioner (Engineering) as the technical head. The Chief Engineer (MSDP) is the highest technical officer in charge of MSDP Department. The CE (MSDP) is assisted by Dy.Ch.Eng (MSDP-I), Dy.Ch.Eng (MSDP-II) & Dy.Ch.Eng (MSDP-III). The responsibilities of MSDP Department are planning, designing and construction of sewage treatment plants, pumping stations etc. and community toilet blocks in slums in various zones of the city.

Figure-15: Organizational Chart of MSDP Department, MCGM[27]



4.4 Planned Sewerage Projects[21, 23]

The Municipal Corporation of Greater Mumbai, has been implementing integrated Water Supply and Sewerage Projects since 1974 with the assistance of the World Bank. 25-years Master Plan for sewerage, which began in 1979, has been completed in 2004. Under the 1st Master Plan, following projects were completed:

(a) 1st Mumbai Water Supply and Sewerage Project, 1974-81 with expenditure amounting to Rs.2,129.90 million.

(b) 2nd Mumbai Water Supply and Sewerage Project, 1979-88 with expenditure amounting to Rs.7,151.50 million.

(c) 3rd Mumbai Water Supply and Sewerage Project, 1988-95 with expenditure amounting to Rs.4,674.20 million.

(d) Mumbai Sewerage Disposal Project (MSDP-I), 1995-2004 with expenditure amounting to Rs.11,818.60 million.

The main objective of the MSDP-I project was to strengthen the capacity of MCGM in all aspects of the management of the sewerage services.

Work Completed under MSDP-1

Under MSDP-1, work as per following description, is completed[30]

- Worli Outfall.

- Bandra Collector Tunnel.
- Bandra Outfall.
- Bandra Pumping Station.
- Bhandup lagoon
- Ghatkopar High Level Tunnel
- Ghatkopar lagoon
- Missing links re-established by micro-tunnelling method & some Conveyance System.
- Rehabilitation of 22.5 km of old sewer lines.
- More than 300 toilet blocks constructed.
- Master Plan for 2nd stage studies prepared.
- Consultancy services for Condition Assessment.
- O & M study.
- Topo survey.

Sewerage Master Plan-II

The Sewerage Master Plan-II for the period from 2005 to 2025 with a proposed expenditure of Rs. 5,570.4 Crores (year 2001 base) is to be implemented in five phases and covers slum areas. However, despite these projects being undertaken, connectivity to sewerage network and environmentally friendly means of disposal of sewage continues to be a challenge in Greater Mumbai[21].

Since a large portion of Greater Mumbai's population lives in slums, providing sanitation services continues to be a major challenge. As per Revised City Development Plan, MCGM, 2012, Greater Mumbai generates around 2,680 MLD of sewage. Out of this only about 1,700 MLD or 63% is collected. Currently 60% of the Greater Mumbai area covering 42% of population (including 2% of the slum population) is connected with piped sewer lines[21].

"The strengthening of Institutional Capacity on sustainable basis is essential to ensure the effectiveness of Sewerage System. In order to achieve this, it would be desirable to consider setting targets on continual basis for up-gradation of facilities together with human resources development through capacity building and training need analysis".

5. The Aspects of Sewage Treatment in Greater Mumbai

5.1 Zoning of Sewerage System in Greater Mumbai

The entire territory of Greater Mumbai is divided into seven sewerage zones namely Colaba, Worli, Bandra, Versova, Malad, Bhandup and Ghatkopar, for the convenience of the collection, treatment and disposal of the sewage. The treated sewage from Colaba, Worli and Bandra Zones, is disposed into the Arabian Sea through marine outfalls, whereas the treated sewage from Versova zones is discharged into the Malad creek and that from Bhandup and Ghatkopar zones, is discharge into the Thane creek.

The sewerage system of Greater Mumbai consists of[28]

- Approximately 1830 km sewer line and 65412 manholes for sewage collection and conveyance.
- Sewage Pumping Stations (SPS) includes 44 numbers satellite and 7 numbers terminal SPS.
- Preliminary Treatment of Sewage at four (04) zones namely Colaba, Worli, Bandra and Malad and Preliminary as well as Aerated Lagoons Treatment at three (03) zones namely Versova, Bhandup and Ghatkopar.
- Sewage disposal system/ outfall comprises of

- Colaba, Bandra and Love Grove (Worli) into the sea (Marine Outfall)

- Versova, Malad, Bhandup and Ghatkopar into the Creek Outfall.

Figure-16: Sewer Zones in Greater Mumbai[29]

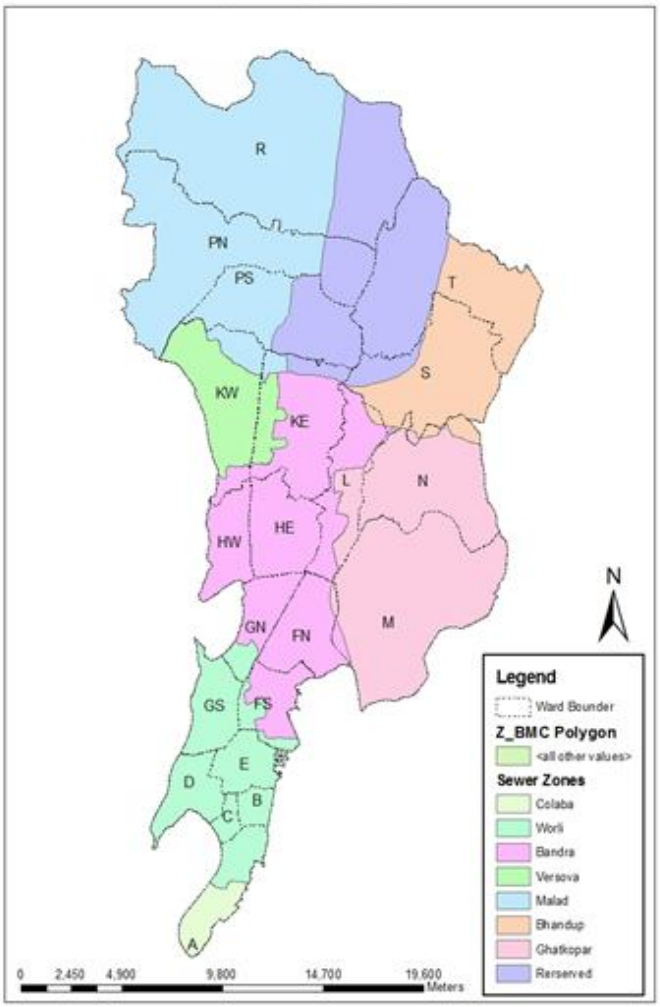
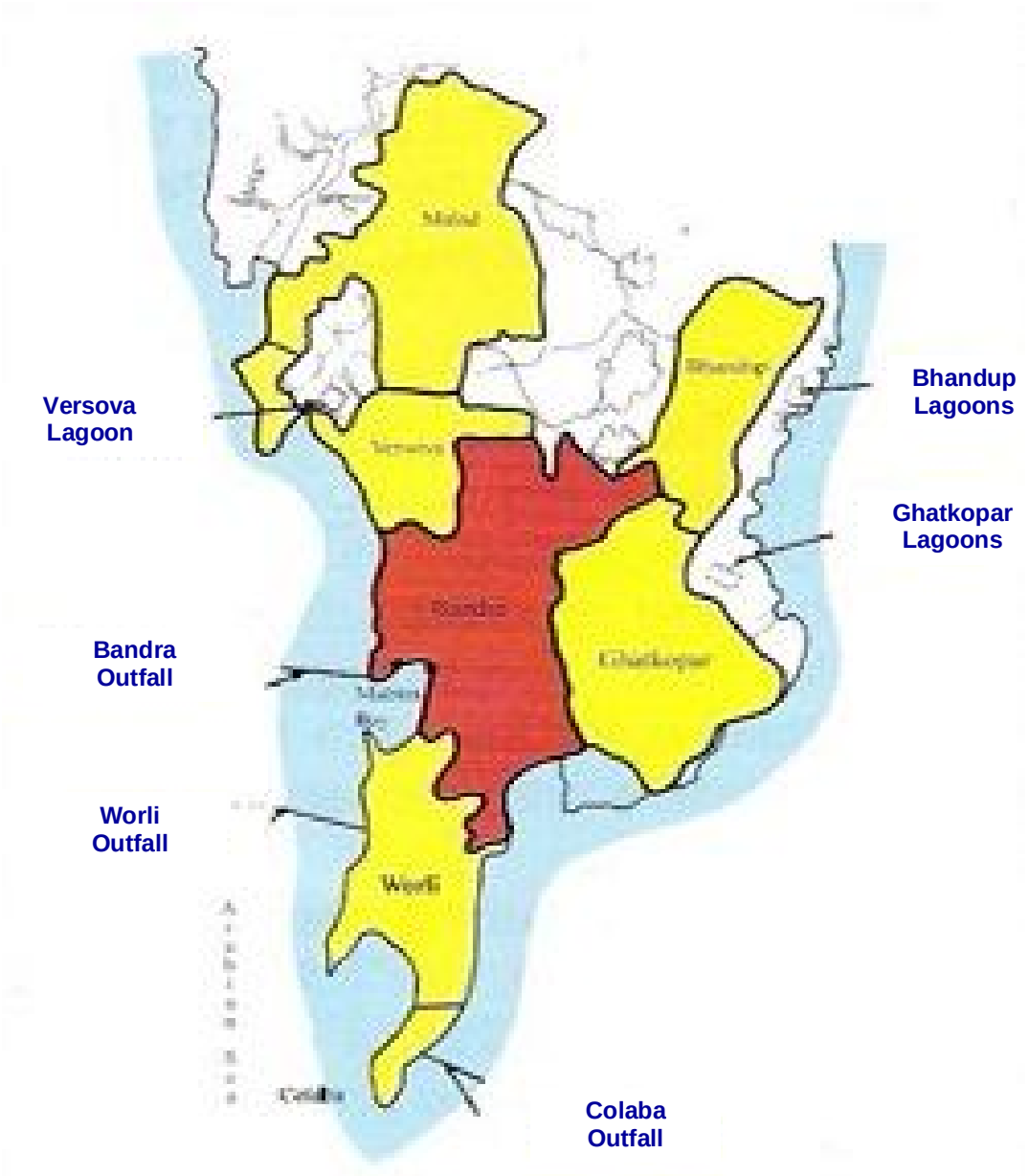


Figure-17: Drainage Zone within the Municipal Limits of Mumbai[29]



Description of Sewerage Zone in Greater Mumbai

The sewage collected through the sewerage network is conveyed to the Main Pumping Station and treatment facilities through a complicated network of sewers and satellite pumping stations, for treatment and disposal.

Zone-1 (Colaba) : It is relatively a small zone with the catchment area of 6 sq.km covering predominantly the military area. There are six (06) numbers of pumping stations in

this zone with about 40 km of sewers leading to preliminary treatment with the provision of 1.2 km short outfall into the harbor. The population in this zone is 200,000.

Zone-2 (Worli) : It is a densely populated zone with the catchment area of 44 sq.km with small hilly ridges at Malabar and Pedder Road. This zone is also having some redundant textile mills. There are 17 numbers of pumping stations in this zone with about 355 km of sewer leading to preliminary treatment in Love Grove WWTF. There is a provision of 3.4 km long sea outfall at Worli to facilitate discharge of effluent into the Arabian Sea. The population in this zone is 3.5 million.

Zone-3 (Bandra) : With catchment area of 77 sq.km with some major slum areas together with intense commercial activity, this is the densely populated area with 3.4 million population. The zone is having 16 numbers of pumping stations along with 350 km of sewers. The flow from Influent Pumping Station (IPS) passes to Bandra WWTF prior to discharge via Effluent Pumping Station (EPS). There is a provision of 3.7 km long sea outfall at Worli to facilitate discharge of effluent into the Arabian Sea.

Zone-4 (Versova) : It is relatively a small zone with the catchment of 21 sq.km inhibited by developed residential area. There are two (02) pumping stations, one at Versova village and other for final pumping. The 160 km sewer lead to preliminary treatment followed by aerated lagoons prior to final discharge of effluent into the Malad Creek.

Zone-5 (Malad) : With catchment area of 115 sq.km covering most of western suburbs, this is the largest zone with the population of 2.9 million. The zone has large low-lying areas in the west rising up to the hilly reserve area in the east. There are six (06) pumping stations and about 320 km of sewer, connected by a major intercepter sewer running along a planned north-south 100 ft road. A large final pumping station delivers flows from intercepter to WWTF prior to the final discharge of effluent into the Malad Creek.

Zone-6 (Bhandup) : It is a smaller zone with the catchment 43 sq.km in the northern part of eastern suburbs. The population of this zone is 1.2 million and there are state built housing in the low lying areas. However, there also exists major private development at Powai in addition to the slum development up onto the hills in the west. It consists of three (03) pumping stations and about 120 km of sewer leading to preliminary and aerated lagoon treatment of sewage at WWTF prior to the discharge of effluent into the Thane Creek.

Zone-7 (Ghatkopar) : The catchment area of this zone is 77 sq.km in the southern part of the eastern suburbs. The population of this zone is 2 million. There is large area of mangrove along the coast. There is also substantial unsewered development on both sides of the highway leading to Thane Creek bridge. In addition, a major hilly area in the southeast is occupied by Bhabha Atomic Research Centre. The coastal area in the south is occupied by the petroleum and chemical industries, which are responsible for handling their own waste. There is also substantial slum development in sewered and un-sewered areas. The sewered areas are mixed development with 155 km of sewer. There is one pumping station known as Ghatkopar pumping station leading to preliminary and aerated lagoon treatment of sewage at WWTF prior to the discharge of effluent into the Thane Creek.

5.2 Wastewater Treatment Facilities (WWTF) in Greater Mumbai[30]

The disposal of wastewater is an obligatory function performed by the Sewerage Operation Department of MCGM. The wastewater generated from day-to-day activities i.e sullage from household kitchen, baths and sewage from toilets etc. from houses, commercial areas and other establishments, is collected and conveyed by means of underground network of sewers, added by satellite pumping stations to the terminal facilities from where it is discharged into sea or creek after treatment in WWTF.

The total installed capacity of Seven (07) numbers of Waste Water Treatment Facilities in Greater Mumbai is 5579 Million Litres per Day (MLD), whereas the maximum quantity of sewage allowed as per MPCB consent is 2727.4 MLD. However, the average flow over the year is 1623 MLD, which indicates the average quantity of sewage collected. There are in total 51 numbers of Sewage Pumping Stations and total length of sewer is 1830 km. WWTF wise Installed Capacity, the average flow of sewage over the year (sewage collected) and consent granted by the MPCB, are described in figure-18.

Figure-18: Installed Capacity, Consent Obtained & Sewage Collection in WWTF in Greater Mumbai[30]

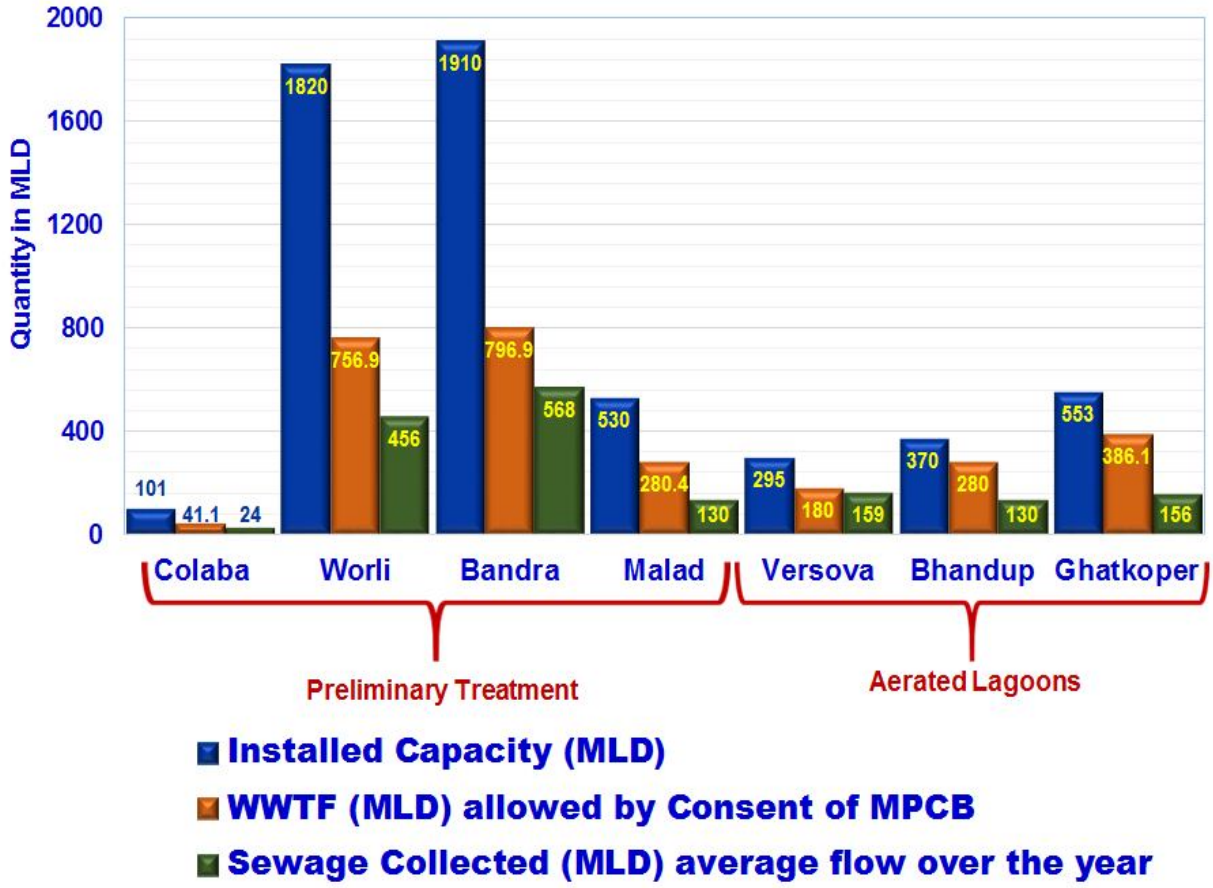
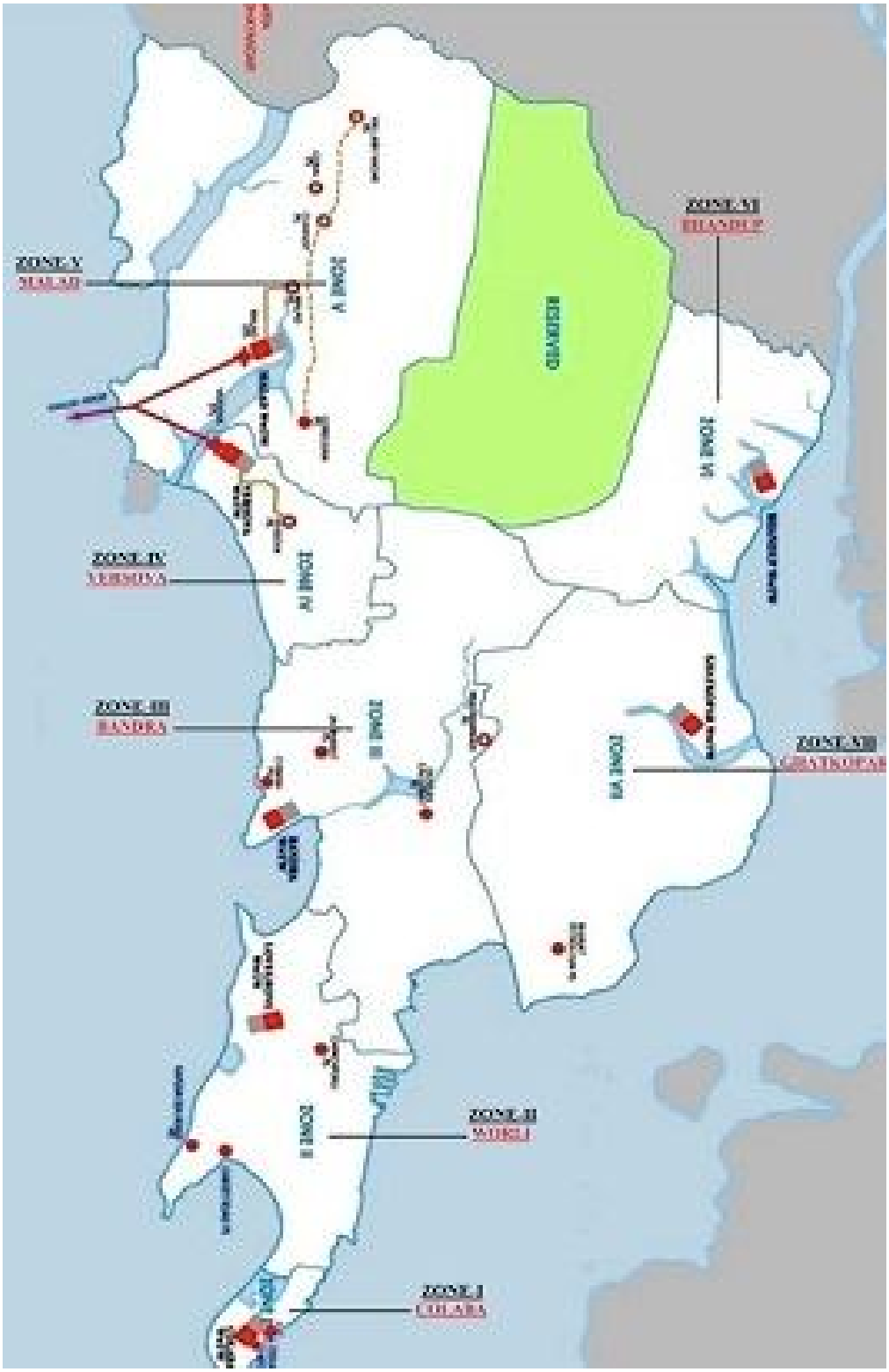


Figure-19: Sewerage Zone wise location of WWTF in Greater Mumbai[30]



(a) Description of the Major Components of WWTF in Mumbai[32-34]

Pumping Stations: The sewage pumping station consists of screens, dry well and wet well, pumps, piping main fitted with discharge valves and lines. The wastewater received at sub ground level is lifted up with the help of **Pumps** and then it is disposed off at adequate distance inside the sea via **Marine Outfalls** after getting rid of floating material and other inert solid material at **Screens** and **Grit Chambers**

Screens: The sewage from the various zones is collected by gravity at the respective pumping station through sewer lines. It is received at the inlet chamber or wet well prior to the bar screen which provide quiescent condition before its entry. The screen chambers with a mechanically raked screen are provided to remove large solid materials, floating matter, sub-merged objects and plastics from sewage before pumping. The process facilitates in protecting the system from blockage/ obstruction or damage of the pumps from solid materials, plastics and fabric, thereby ensure the removal/ minimization of interferences in the normal operations of pumping as well as other downstream treatment facilities in addition to preventing objectionable shoreline conditions, where disposal in the sea is practiced.

Grit Removal Facility: The grit chambers are designed as aerated grit chambers with the special design consisting of a spiral flow aeration tank provided with air diffusion tubes placed on one side of the tank. The compressed air and the geometry of the tank induce a spiral roll that provides a centrifugal force to facilitate in removal of solid material with higher specific gravity, while keeping organic material of lower specific gravity in suspension. The roll also sweeps the settled grit into a bottom hopper or collection trough. Typically, aerated grit chambers are designed to remove grit particles of 0.2 mm in diameter or larger with a specific gravity of 2.65.

Dry and Wet Well: The wet well is divided into two compartments to allow maintenance without total shutdown. An isolation gate is provided in the partition wall between two wet wells to allow flexibility of operation.

Pumps: Wastewater pumps are designed to handle solids below 100 mm diameter without clogging. Sewage then shall be pumped by submersible pumps into a common outlet channel which joins to WWTF through under gravity pipeline. Adequate gates are be provided to isolate any of the screen chambers or/and wet wells. In some of the pumping stations, pumps starts and stop automatically based on level in the wet well.

Knife Gate Valve and Pump Check Valves: All the valves on suction and discharge lines are be of knife gate type and be installed with a flange adaptor for ease of installation and removal for maintenance. The valve is operated by electric actuator. Check valves installed on the delivery pipe between the pump and gate valve reduce the possibility of water hammer throughout the system by controlling valve opening and closing speeds so the operation does not cause pressure surges in either direction. The operation of check valve is independent of flows.

Pipelines: Suction and discharge pipes are normally ductile iron (DI). Each discharge line starting from the pump and connecting to the main channel is DI double flange type. The velocity through the discharge pipe shall not exceed 3 m/sec. The type, diameter and length

of the pump discharge and force main piping are predetermined while designing. Pump stations generally include all piping through the last valve connected to the pump station end of the force main. Common pipe materials are stainless steel, ductile and PVC.

Liquid Level Sensors: One or more liquid level sensors suspended in the wet well report the fluid level. This data is used by the pump station controller to turn pumps on or off and, in the event of a problem, to turn on alarms and transmit alarm data. The type of sensors used is determined for the controller chosen for the pump station.

Flow Calculating & Metering: An easy and inexpensive way to accomplish Flow Calculating & Metering to measure the volume of fluid being pumped is by calculating the flow by multiplying the volume of water pumped with each pump start by the number of pump starts. An electromagnetic flow meter can be located in the force main. Transmission of flow data to a remote computer can also be done.

Control Panel & Electrical Power: Typically, the electrical controls of the pump station are located in a control panel within a weatherproof enclosure. Various devices supply power to the pumps, control the pumps, receive operational and fault data from sensors within the pumps and the wet well, report elapsed operational time for each pump and report operational status and alarm conditions both locally and to remote sites through telephone circuits, radio transmissions and other means.

Marine Outfall: A marine outfall is a conduit for conveying sewage out into the sea and discharging it through number of discharge pipes at the end. It can either be a pipe embedded in the sea bed or a tunnel deep under the sea bed. The marine outfall system, therefore, consists of effluent pumping stations, tunnel and diffusers with multiple risers and ports. Once the marine outfall is operational, it is cumbersome to find its functional and operational behavior in coastal region. Any breakage of diffuser will make compulsory closure of the system.

The philosophy of marine outfall is that it takes the sewage out into the sea to facilitate its dilution and dispersion by a large mass of sea water. The natural hydrodynamic and biological process of the sea then disperses and facilitate natural treatment of sewage without causing unacceptable pollution at the point of discharge. In general, the marine outfall shall have the pipe diameters of 3.5 m and pipe length of 3.5 km. It shall consists of a drop shaft on shore from which a tunnel is constructed on upward slope under the sea bed. The outer 240 m long section of the tunnel is provided with 10 riser pipes of 1 m diameter each capped just above the sea bottom above the layer of sediments suspended by waves. At discharge point, the direction of the sea current is such that the plume of sewage is taken away from the shore and spread on the wider area.

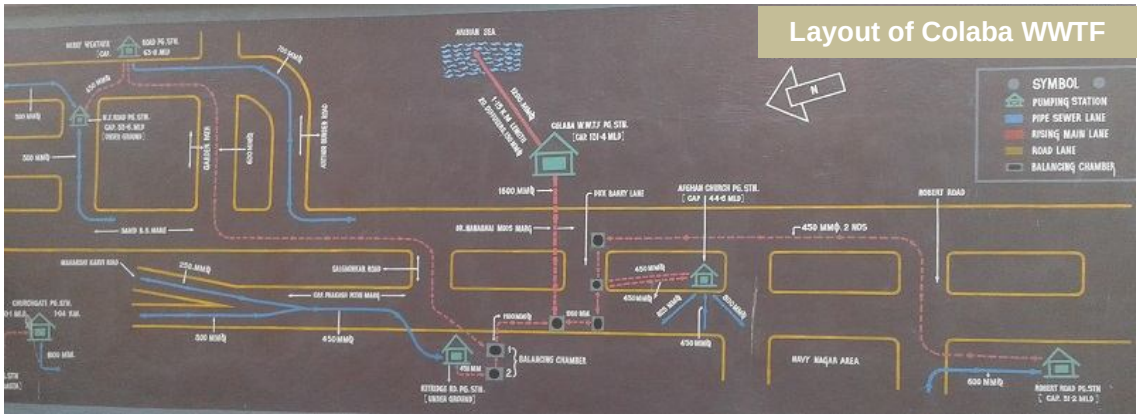
(b) Preliminary Treatment Facilities at various WWTF in Mumbai[29,30,32]

(i) Colaba WWTF

The Colaba WWTF based on preliminary treatment, was commissioned in the January-1988. The capacity of WWTF allowed by the consent is 41.1 MLD. However, the average dry weather flow (ADWF) is 24 MLD. It consists of two fine screens and two aerated grit chambers with a

rated peak flow capacity of 101 MLD. Treated effluent is discharged into a head chamber of marine outfall extending 1.15 km east towards Oyster Rock Battery in Mumbai Harbour.

Figure-20: Layout of Colaba WWTF [32]



The salient features of WWTF are as follows:

- The Influent Pumping Station of WWTF has 04 numbers of sewage pumps (M&P make) which are placed in Dry Well and are mounted vertically. The size of suction/ Delivery is 600/ 500 mm and discharge is 33.75 MLD with the head of 13.1 m.

- There are 04 numbers of motors (squirrel cage type induction) with 100 H.P rating and 970 RPM.

- 02 numbers of bar screens (FMC make) with 20 mm opening are located in the screen chamber.

- The marine outfall (M.S pipe encasing) is 1.15 km length and 1200 mm dia, has 20 numbers of outlet ports of dia 150 mm located in Arabian Sea.

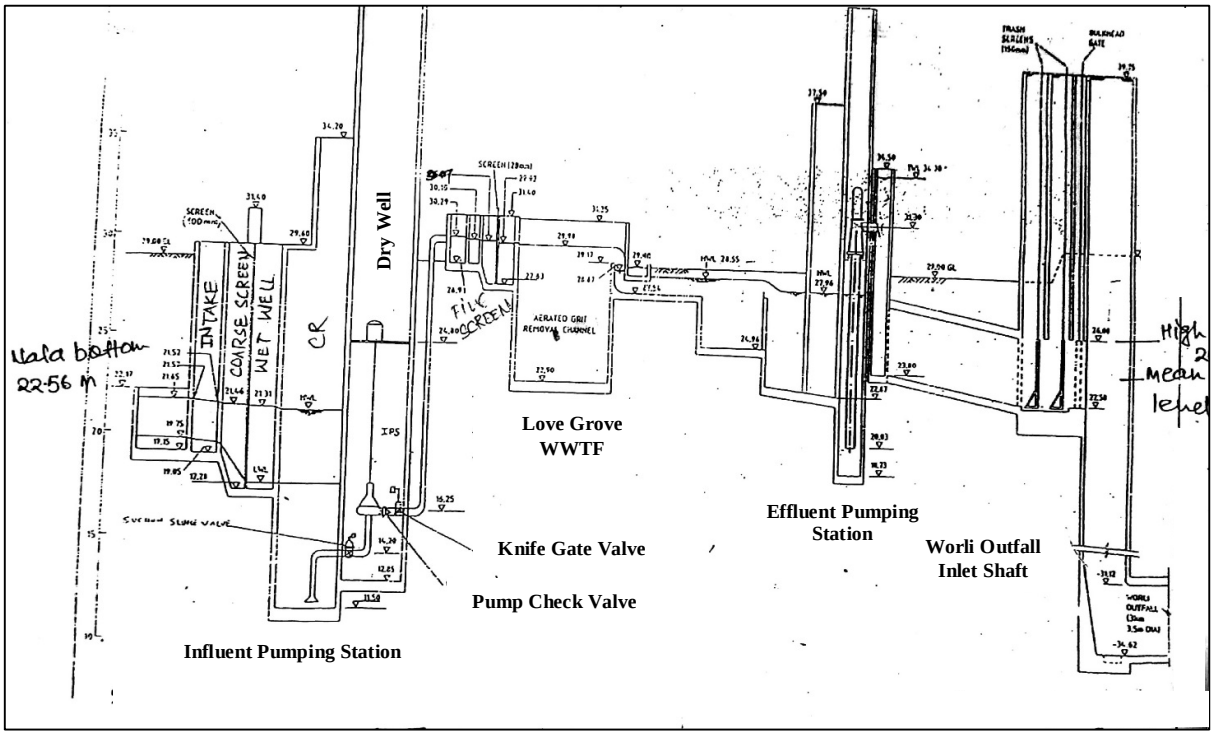
(ii) Love Grove WWTF, Worli

The Love Grove WWTF based on preliminary wastewater treatment, was commissioned in January-1991. The capacity of WWTF allowed by the consent is 756.9 MLD. However, the average dry weather flow (ADWF) is 456 MLD. The installed capacity of WWTF is 1820 MLD. The geocodes of plant location are 18°59’31.5”N and 72°42’55.2”E.

The salient features of WWTF are as follows:

- The influent Pumping Station of WWTF has 08 numbers of pumps (make EBARA, Japan) of centrifugal non-clogging type, are placed in Dry Well and are mounted vertically. The size of suction/ Delivery is 900/ 1200 mm. The discharge rate of pump is 3 m^3/d with head of 12.55 m. There are 04 numbers of motors (squirrel cage type induction) with 670 H.P rating and 330 RPM.

Figure-21: Layout of Love Grove (Worli) WWTF [32]



- The WWTF has 04 numbers of coarse screen (make FMC, UK) with 65 mm opening at the intake side of IPS, whereas at delivery side of IPS there are 08 numbers of fine screens with 20 mm opening. Bar screens (02 numbers) of 150 mm opening are located at the inlet shaft of the outfall. The trash racks (04 numbers) of 100 mm opening are located at Junction Box No. 6.

- The aerated Grit Chambers consists of 04 numbers of tanks (each having dimensions 34.5 m x 7 m x 5.1 m). The length of aerated area is 27.5 m, the detention time is 2 to 5 minutes. The air is supplied at the rate of 0.36 m^3/min/meter length. There are 03 numbers of compressors (twin lobe type make Usha) each having the capacity of 1500 m^3/hour with discharge pressure 0.7 kg/m^2. The quantity of grit removed per day is 4 cu.m. The trash is being dumped at Deonar dumping ground.

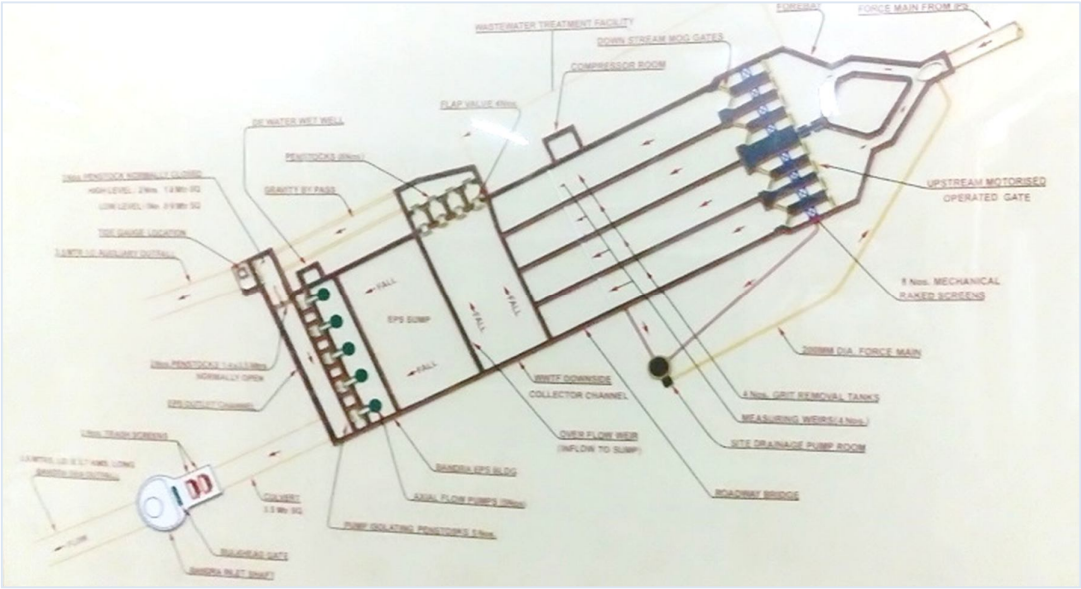
- The effluent Pumping Station of WWTF has 05 numbers of pumps (make HITACHI, Japan) of centrifugal non-clogging type, are placed in Wet Well and are mounted vertically. The discharge rate of pump is 6 m^3/d with the head of 5.86 m. There are 05 numbers of motors (squirrel cage type induction) with 777 H.P rating and 367 RPM.

- The length of the marine outfall is 3.5 km with the dia 3.5 m. It consists of deep tunnel in sea bed with 10 numbers of outlet ports with the dia 220 to 280 mm.

(iii) Bandra WWTF

The Bandra WWTF based on preliminary wastewater treatment, was commissioned in May-2003. The capacity of WWTF allowed by the consent is 796.9 MLD. However, the average dry weather flow (ADWF) is 568 MLD. The installed capacity of WWTF is 1910 MLD. The geocodes of plant location are 19°02'42.1"N and 72°49'35.3"E.

Figure-22: Layout of Bandra WWTF [32]



The salient features of WWTF are as follows:

- The influent Pumping Station of WWTF has 08 numbers of pumps (make SULZAR) of submersible type, are placed in Dry Well and are mounted vertically. The size of suction/ Delivery is 1600/ 1500 mm. The discharge rate of pump is 311 MLD with the head of 31.8 m. There are 08 numbers of motors (ABB Slip ring type) with 1500 kW rating and 422 RPM.

- The WWTF has 08 numbers of fine screen (make Voltas) with 20 mm opening in addition to 02 numbers of trash racks with 150 mm opening.

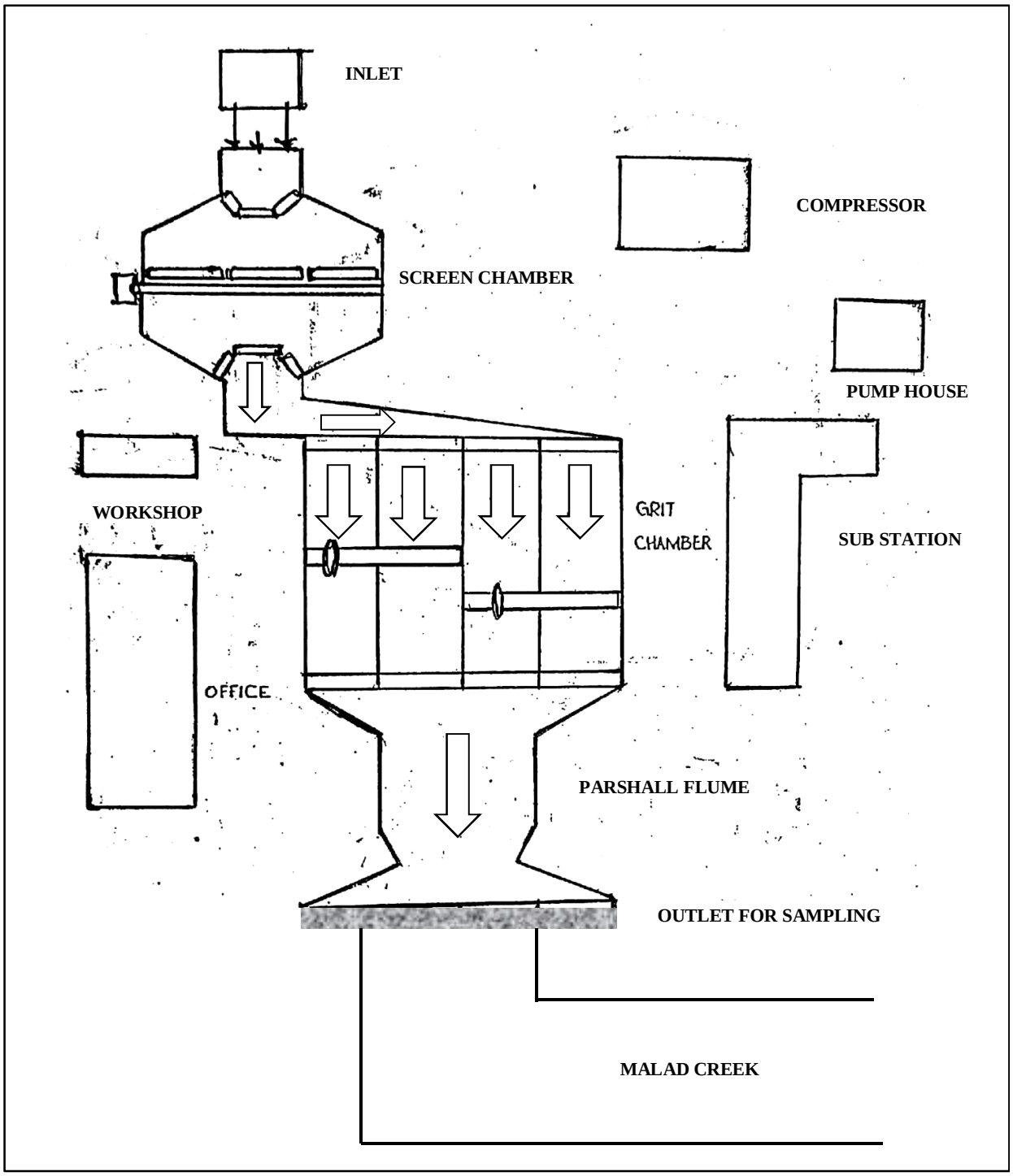
- The aerated Grit Chambers consists of 04 numbers of tanks (each having dimensions 27 m x 6 m x 8 m). The length of aerated area is 27 m, the detention time is 2 to 5 minutes. The air is supplied at the rate of 0.36 m^3/min/meter length. There are 03 numbers of compressors (twin lobe type make Kay International) each having the capacity of 1500 m^3/hour with discharge pressure 0.45 kg/m^2. The quantity of grit removed per day is 0.5 cu.m. The trash is being dumped at Deonar dumping ground.

- The effluent Pumping Station of WWTF has 05 numbers of pumps (make HICO) of submersible and are mounted vertically. The discharge rate of pump is 497 MLD with the head of 4.41 m. There are 05 numbers of motors (squirrel cage type; WICO make) with 516 H.P rating and 245 RPM. The length of the marine outfall is 3.5 km with the dia 3.5 m.

(iv) Malad WWTF

The Malad WWTF based on preliminary wastewater treatment, was commissioned in October-1997. The capacity of WWTF allowed by the consent is 280.4 MLD. However, the average dry weather flow (ADWF) is 130 MLD. The installed capacity of WWTF is 530 MLD. The geocodes of plant location are 19°10’51.0”N and 72°49’29.0”E.

Figure-23: Layout of Malad WWTF [32]



The salient features of WWTF are as follows:

- The influent Pumping Station of WWTF has 06 numbers of pumps (make Kirloskar) of mixed flow type, are placed in Dry Well and are mounted vertically. The size of suction/ Delivery is 5500/ 6000 mm. The discharge rate of pump is 106 MLD with the head of 16.2 m. There are 06 numbers of motors (Shinko, Japan; Squirrel cage type) with 367 H.P rating and 593 RPM.

- The WWTF has 03 numbers of fine screen (make Triveni) with 20 mm opening.

- The aerated Grit Chambers consists of 04 numbers of tanks each having the capacity of 60 MLD. The length of aerated area is 23.9 m, the detention time is 15 minutes. The air is supplied at the rate of 22 m^3/min. There are 02 numbers of compressors (twin lobe type make Usha) each having the capacity of 22 m^3/min with discharge pressure 0.9 kg/m^2. The quantity of grit removed per day is 0.5 cu.m. The trash is being dumped at Deonar dumping ground.

- The effluent is discharged into Malad Creek.

(c) WWTF based on Aerated Lagoons in Mumbai[29,30,32]

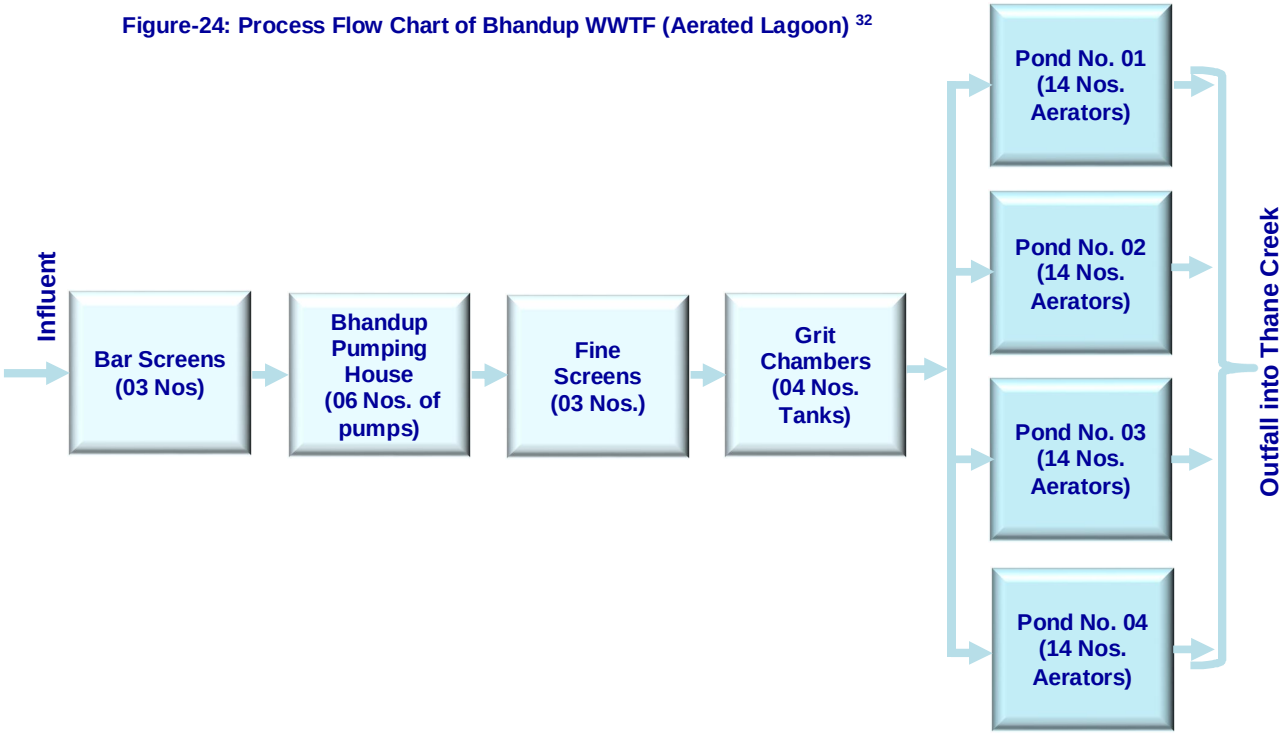
The Aerated Lagoons are part of Aerobic Suspended Growth System, which do not have Sludge Recirculation facility in contrary to Activated Sludge Process, which employ sludge recirculation. In both the cases, the sewage containing waste organic matter is aerated in an aeration basin in which micro-organisms metabolize the soluble and suspended organic matter. Part of organic matter is synthesized into new cells and part is oxidized into carbon dioxide and water. In activated sludge process, the new cells formed in the reactor are removed from the liquid stream in the form of a flocculant sludge in settling tank. A part of this activated sludge is recycled to the aeration basin and the remaining forms waste or excess sludge. **In Aerated Lagoons**, the microbial mass leaves with the effluent stream or may settle down in areas of the aeration basin where mixing is not sufficient.

The WWTF facilities at Versova, Bhandup and Ghatkopar are based on Aerated Lagoons. Aerated lagoon consists of the constructed tank either single cell or three cell, which receives preliminary treated waste water after grit chamber. Mechanical surface aerators are provided for effective aeration. The outlet of the Aerated lagoon joins the receiving water body. Other than aerators, there is no mechanical part in the aerated lagoon system. Adequate stand-by aerators are provided in case of the failure of some and hence there will not be any significant risk in operation of the system.

(i) Bhandup WWTF (Aerated Lagoon)

The Bhandup WWTF based on Aerated Lagoon treatment, was commissioned in June-2002. The capacity of WWTF allowed by the consent is 280 MLD. However, the average dry weather flow (ADWF) is 130 MLD. The installed capacity of WWTF is 370 MLD. The geocodes of plant location are 19°08’38.0”N and 72°57’40.5”E.

Figure-24: Process Flow Chart of Bhandup WWTF (Aerated Lagoon) [32]



The salient features of Bhandup WWTF are as follows:

- The WWTF has 03 numbers of bar screens with 50 mm opening and 03 numbers of fine screen (make Voltas) with 20 mm opening.

- The aerated Grit Chambers consists of 04 numbers of tanks each having the capacity of 20.4 m x 4.27 m x 4 m. The length of aerated area is 20.4 m, the detention time is 3.2 minutes. There are 02 numbers of compressors (Rooters type make TMVT) each having the capacity of 2600 m^3/hr with discharge pressure 700-850 milibar. The quantity of grit removed per day is 1 cu.m. The trash is being dumped at Mulund dumping ground.

- Aerated lagoons consist of 4 Nos. of ponds each having following dimension
  - 207 x 133 m at bottom
  - 237 x 163 m at top
  - 231 x 157 m at water level

  Each pond is having 14 numbers of aerators of each having 50 HP capacity. The inlet gate to each pond is having 04 pipes of 700 mm dia each and outlet gate of each pond is having 03 pipes of 700 mm dia each. The retention time of wastewater in aerated lagoon is 36 hrs.

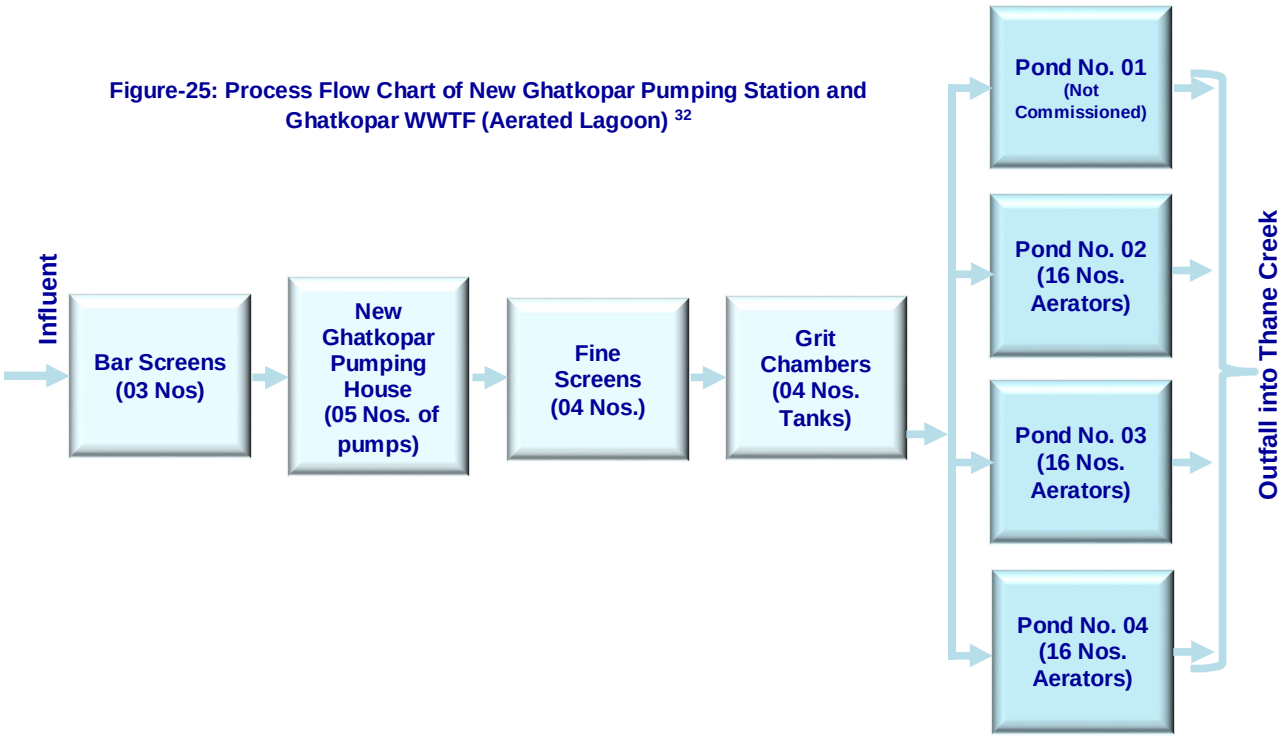
- The effluent Pumping Station of WWTF has 06 numbers of pumps (make Ebara) of radial type, are placed horizontally. The size of suction/ Delivery is 600 mm/ 600 mm. The discharge rate of pump is 72 MLD with the head of 18.8 m. There are 06 numbers of motors (Shinko, Japan; 3 Ph induction type) with 310 H.P rating and 593 RPM.

- The effluent is discharged into Thane Creek.

(ii) Ghatkopar WWTF (Aerated Lagoon)

The Ghatkopar WWTF based on Aerated Lagoon treatment, was commissioned in May-2003. The capacity of WWTF allowed by the consent is 386.1 MLD. However, the average dry weather flow (ADWF) is 156 MLD. The installed capacity of WWTF is 553 MLD. The geocodes of plant location are 19°04'51.5"N and 72°55'23.2"E.

Figure-25: Process Flow Chart of New Ghatkopar Pumping Station and Ghatkopar WWTF (Aerated Lagoon) [32]



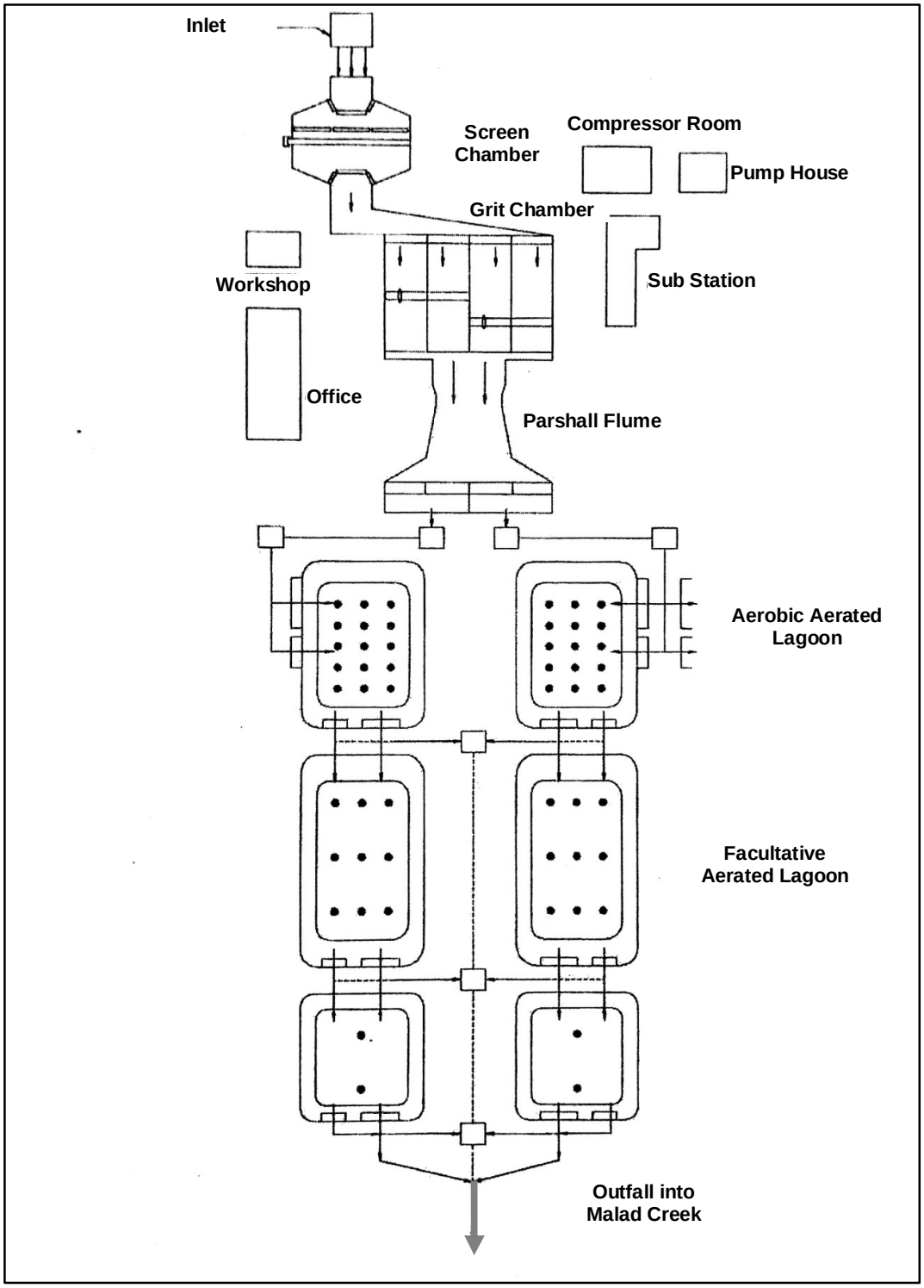
The salient features of Ghatkopar WWTF are as follows:

- The WWTF has 03 numbers of bar screens (make Triveni) with 100 mm opening and 04 numbers of fine screen (make Voltas) with 20 mm opening.
- The aerated Grit Chambers consists of 04 numbers of tanks each having the capacity of 22.5 m x 5 m x 6.47 m. The length of aerated area is 22.5 m, the detention time is 3.2 minutes. There are 02 numbers of compressors (Rooters type make TMVT) each having the capacity of 2600 m^3/hr with discharge pressure 700-850 milibar. The quantity of grit removed per day is 1 cu.m. The trash is being dumped at Deonar dumping ground.
- Aerated lagoons consist of 3 Nos. of ponds (Pond No. 2, Pond No.3 & Pond No.4) each having dimension of 150 x 250 m. Pond No. 1 is not yet commissioned. Each pond is having 16 numbers of aerators of each having 50 HP capacity. The inlet gate to each pond is having 04 pipes of 700 mm dia each and outlet gate of each pond is having 03 pipes of 700 mm dia each. The retention time of wastewater in aerated lagoon is 43 hrs.
- The effluent Pumping Station of WWTF has 05 numbers of pumps (make Sulzar) of non-clogging, single stage & bottom suction type. The size of suction/ Delivery is 1200 mm/ 900 mm. The discharge rate of pump is 138.24 MLD with the head of 25.3 m. There are 06 numbers of motors (Brush Electricals; slipring induction type motor totally enclosed fan cooled) with 713 H.P rating and 591 RPM. The effluent is discharged into Thane Creek.

(iii) Versova WWTF (Aerated Lagoon)

The Versova WWTF based on Aerated Lagoon treatment, was commissioned in December-1992. The capacity of WWTF allowed by the consent is 180 MLD. However, the average dry weather flow (ADWF) is 159 MLD. The installed capacity of WWTF is 295 MLD. The geocodes of plant location are 19°08'49.0"N and 72°48'55.7"E.

Figure-26: Plant Layout for Versova WWTF Lagoons [32]



The salient features of Versova WWTF are as follows:

- The Influent Pumping Station of WWTF has 06 numbers of pumps (make Kirloskar) which are vertically mounted. The size of suction/ Delivery is 400 mm/ 400 mm. The discharge rate of pump is 59 MLD with the head of 19.4 m. There are 06 numbers of motors (Shinko Electricals; slipring induction type motor) with 185 kW rating and 735 RPM.

- The WWTF has 03 numbers of fine screen (make Voltas) with 20 mm opening.

- The aerated Grit Chambers consists of 04 numbers of tanks each having the capacity of 45 MLD each. The length of aerated area is 17 m, the detention time is 13 minutes. There is 01 number of compressor (Twin Lobe) having the capacity of 21 m^3/min with discharge pressure 0.9 kg/m^3. The quantity of grit removed per month is 20 cu.m.

- WWTF consists of 3-stage lagoons with 2-streams. There are three (03) numbers of pond in each stream with following descriptions:
  - 1st Pond (aerobic) : 172 m x 120 m x 4.05 m
  - 2nd Pond (Facultative-I) : 210 m x 120 m x 4.05 m
  - 3rd Pond (Facultative-II) : 135 m x 120 m x 4.05 m

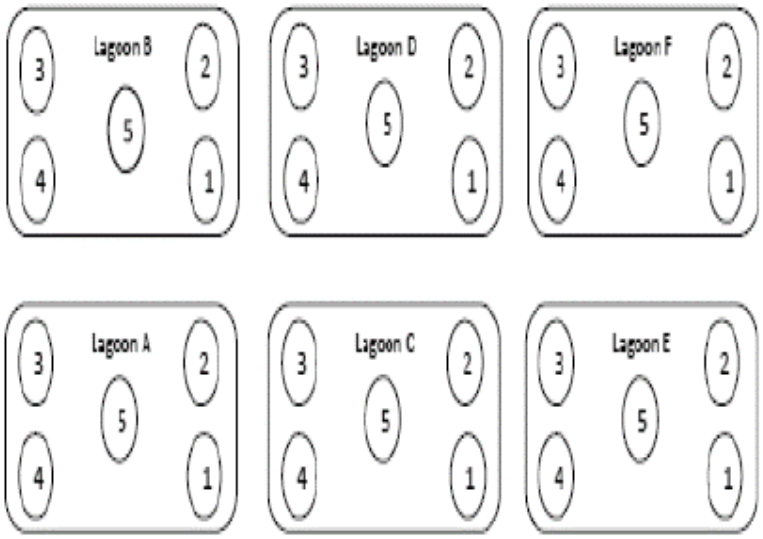
  The retention time of sewage in lagoon is 4.3 days.

- The effluent is discharged into Malad Creek.

Sludge Accumulation at Versova Lagoon

The sludge being generated at Versova lagoon has not been disposed-off since the commissioning of plant. The accumulated sludge quantity at Versova lagoon is approximately 100,000 m^3. The IIT, Mumbai[36] has carried out composition and characteristics of settled sludge/ sediment at the ponds of Versova lagoons. The study is reported based on collection of 189 samples from the bed of the six lagoons (marked A, B, C, D, E & F) upto the depth of 2.1 m (at an interval of 0.3 m) as shown in following figure.

Figure-27: Sampling Boreholes Locations at Versova WWTF Lagoons [36]
(*IIT Mumbai Study*)



The study of IIT reveals following findings[36]:

The following are some basic recommendations for utilization of the sediments lying in Versova Lagoons.

(a) The sewage sludge of the 'Versova Lagoons' being a good source of organic matter, can provide beneficial soil conditioning and essential nutrients to the plants. Application of sewage sludge in agriculture will reduce the environmental and economic considerations related to disposal in landfill and incineration. However, the pathogenic activities present in the sludge may affect the soil-plant system adversely, which might further pose a serious risk to human health.

(b) The utilization of vermicomposting technology seems to be one of the feasible options for dealing with the lagoon sediments having heavy metal contamination (when exposed to extreme climatic conditions). As heavy metals are non-degradable, the removal technologies readily available in the market can be expensive and might even inhibit soil fertility. Chemical immobilization under these circumstances may be useful for immobilizing the heavy metals, but for a certain period of time. Under these prevailing conditions, vermicomposting is an economic and sustainable process for conversion of these sediments into bio-fertilizers. However, the requirement of the land and related infrastructure would be prohibitive.

(c) Landfilling is one of the most common disposal techniques adopted for utilizing the sediments and sludges from such treatments plants. However, for a city like Mumbai, where the land is scarce and its cost extremely high disposal of sludge and sediments in the existing landfill becomes critical. Further, sun drying and dumping these materials in the open areas, might lead to serious health hazards due to their high pathogenic activity. Hence, the landfilling combined with vermicomposting seems to be an option for accelerated decomposition of the material.

(d) Keeping in mind the high values of organic carbon associated with the sewage sludge and sediments, incineration appears to be the most preferable and manageable way of handling these materials. The leftover residues from the incineration process can be used as manmade resource (e.g aggregates) in construction industry, restoration and reclamation purposes.

(e) The high organic matter in the Versova Lagoon welcomes Pyrolysis of the sludge and sediments as another option for sludge handling and utilization. Pyrolysis leads to the chemical decomposition of the organic materials (PCB, dioxins, PAH etc.) leaving a gaseous component and a solid residue containing carbon and ash. As the system is heated, energy gets consumed during the pyrolytic process, under such condition, a very high moisture content in the sediments can increase the treatment cost substantially.

(f) Further, for treatment of the supernatant water in the farthest lagoons, it is advisable to install an additional filtration unit (viz., a vertical sand filter) to reduce the biological load of the system before disposing the semi-treated water into the creek. The sand required in such case, can be the residue of either incineration or pyrolysis, due to its high ion exchange capacity. However, these ion exchange filters should be periodically replenished, to maintain the rate of exchange/ absorption of heavy metals and microorganisms.

(g) State-of-the-art technologies such as 'Gamma irradiation' could be quite effective for 'sterilizing the sediments and sludge' lying in the lagoons. Gamma irradiation involves high-

energy photons, which are emitted from an isotope source, to produce electron disruptions throughout a material. The disruptions caused due to these high-energy photons results in damage of the DNA and other cellular structures, in living cells. At the molecular level, these changes result in annihilating the organisms or render them incapable of reproduction. The materials (viz., sediments and sludge) rich in biological load can thus be sterilized by gamma irradiations and used for commercial purposes for production of bricks and aggregates.

Future Opportunity:

Understanding the siltation pattern (based on the characteristics of the sediments excavated) and assess the load of silts depositing in the lagoons and advice a remedy to prevent siltation and reduce further deposition to certain extent and suggest frequency of adoption of the recommended methodology for its desiltation.

Radiation Processing for Stabilization of Sewage Sludge[37]

The sludge as generated by a sewage treatment plant is having disagreeable odour in addition to the presence of high level of pathogens, limiting the reuse of this waste, which is otherwise a rich source of nutrients like nitrogen and phosphorous. The fact of the matter as evident by the available literature is that the conventional sewage treatment plants typically involves the anaerobic digestion process for stabilization of sewage sludge. The processing of the sludge to reduce odour and pathogens, therefore, is essential to decide modalities for its beneficial utilization. Thus, there exists a need for further upgradation of treatment technologies that can supplement the existing process to ensure removal of the pathogenic bacterial with a high degree of reliability. The radiation treatment of sludge generated by STP provides an efficient, simple and reliable method to make sludge free from pathogens, which can be further upgraded to produce value added bio-fertilizer with adequate quantity of available nutrients. The high energy gamma radiation from Cobalt-60 has the ability to inactivate the pathogens with a very high degree of reliability, in a clean and effective way. The pathogens present in the sewage sludge can be effectively removed by exposing the sludge to high-energy radiation source.

Effects of Radiation Processing on metabolism of pathogens

The metabolic effects of ionizing radiations, as reported in the literature are well known and includes: (i) Damaging of living cells by breaking down vital bio-molecules (ii) Production of highly reactive free radicals by the radiolysis of the aqueous medium thereby attacking and destroying the cells and (iii) Breakdown of genetic materials like DNAs of a cell to render it non-reproducing. Studies have established that a dose of 2-3 kGy destroys about 99.9% of all the viable bacteria and fungus present. Parasite eggs are almost totally inactivated, though viruses are not eliminated at this level of irradiation. However, higher doses of upto 10 kGy may be required to bring down some of the more resistant species of microorganisms.

6. Performance of WWTF in Greater Mumbai

6.1 Objective of Sewage Treatment[43, 44]

The objective of sewage treatment is to reduce the polluting substances to comply with the standards laid down by the Ministry of Environment, Forests and Climate Change (MoEF&CC), Government of India. The State Pollution Control Boards (PCB) cannot relax the standards, but can prescribe more stringent standards specific to the discharge environment. The characterization of treated effluent together with influent as well as effluent of intermediate stage/s, has an overall aim to provide performance data of STP/ WWTF, based whereupon not only the compliance obligations can be ensured but also necessary corrective actions can be envisaged in case effluent does not meet the regulatory requirements.

6.2 Parameters of Interest for STPs/ WWTF[4-6, 43, 44, 45]

The design of a sewage treatment plant/ WWTF is dependent upon the quality and quantity of the waste to be treated. Sewage Operation Department of MCGM is undertaking characterization of influent and effluent of WWTF at Dadar Laboratory of MCGM. The important characteristics of domestic sewage are as follows:

(a) Organic Matter in terms of BOD

Organic matter is the most important polluting constituent of sewage in respect of its effects on receiving water bodies. It is mainly composed of proteins, carbohydrates and fats. Organic matter is commonly measured in terms of Biochemical Oxygen Demand (BOD). If untreated sewage is discharged into natural water bodies, biological stabilization of organic matter leads to depletion of oxygen in water bodies.

The BOD test has its widest applications in measuring waste loading to treatment plants and in evaluating the BOD-removal efficiency of the systems. The test measures the molecular oxygen utilized during a specified incubation period for biochemical degradation of organic material (carbonaceous demand).

- The limit of BOD in accordance with the general limits for discharge of effluent into Marine Coastal Areas as per the Environmental (Protection) Rules 1986; Schedule-VI: Part-A amended to date, is 100 mg/l.

- The Maharashtra Pollution Control Board (MPCB) Standard of BOD for discharge of effluent into Creek is 50 mg/l.

- The limit of BOD as per the MPCB Standard for Primary Water Quality Criteria of Class SW-II Water is ≤ 3 mg/l.

General Limits for Discharge of Effluent as per Environmental (Protection) Rules 1986; Schedule-VI: Part-A amended to date[38-41].

Sl.	Parameters		Inland Surface Water	Public Sewers (A)	Land for Irrigation	Marine coastal areas
1.	Colour and odour		(B)	-	(B)	(B)
2.	Suspended Solids, Max		100	600	200	(C), (D)
3.	Particle size of suspended solids		(E)	-	-	(F), (G)
4.	pH value		5.5 to 9.0	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
5.	Temperature ^{o}C, Max		(H)	-	-	(H)
6.	Oil and grease, Max		10	20	10	10
7.	Total residual chlorine, Max.		1.0	-	-	1.0
8.	Ammoniacal nitrogen (as N), Max.		50	50	-	50
9.	Total Kjeldahl nitrogen (as N), Max.		100	-	-	100
10.	Free Ammonia (as NH_3), Max.		5.0	-	-	5.0
11.	Biochemical Oxygen Demand		30	350	100	100
12.	Chemical Oxygen Demand, Max.		250	-	-	250
13.	Arsenic (as As), Max.		0.2	0.2	0.2	0.2
14.	Mercury (as Hg), Max.		0.01	0.01	-	0.01
15.	Lead (as Pb), Max.		0.1	1.0	-	2.0
16.	Cadmium (as Cd), Max.		2.0	1.0	-	2.0
17.	Hexavalent chromium (as Cr+6), Max.		0.1	2.0	-	1.0
18.	Total chromium as (Cr), Max.		2.0	2.0	-	2.0
19.	Copper (as Cu), Max.		3.0	3.0	-	3.0
20.	Zinc (as Zn), Max.		5.0	15	-	15.0
21.	Selenium (as Se), Max.		0.05	0.05	-	0.05
22.	Nickel (as Ni), Max.		3.0	3.0	-	5.0
23.	Cyanide (as CN), Max.		0.2	2.0	0.2	0.2
24.	Fluoride (as F), Max.		2.0	15.0	-	15.0
25.	Dissolved Phosphates (as P), Max.		5.0	-	-	-
26.	Sulphide (as S), mg/l, Max.		2.0	-	-	5.0
27.	Phenolic compounds (as C_6H_5OH), Max.		1.0	5.0	-	5.0
28.	Radioactive materials, Max	Alpha emitters, micro curie/l	10^{-7}	10^{-7}	10^{-8}	10^{-7}
		Beta emitters, micro curie/l	10^{-6}	10^{-6}	10^{-7}	10^{-6}
29.	Bio-assay test		(I)	(I)	(I)	(I)
30.	Manganese (as Mn), Max		2.0	2.0	-	2.0
31.	Iron (as Fe), Max		3.0	3.0	-	3.0
32.	Vanadium (as V), Max		0.2	0.2	-	0.2
33.	Nitrate Nitrogen (as N)		10.0	-	-	20.0

Note:

(A) These standards shall be applicable only if such sewer leads to a secondary treatment including biological treatment system; otherwise the discharge into sewers shall be treated as discharge into inland surface waters.

(B) All efforts should be made to remove colour & unpleasant odour as far as practicable.

(C) For process wastewater 100 mg/l

(D) For cooling water effluent 10% above total suspended matter of influent.

(E) Shall pass 850 micron IS Sieve

(F) Floatable solids max. 3 mm

(G) Settleable solids max. 850 microns

(H) Shall not exceed 5°C above the receiving water temperature

(I) 90 % survival of fish after 96 hours in 100 % effluent

MoEF&CC notified Environment (Protection) Amendment Rules, 2017 vide G.S.R 1265 (E) dated 13.10.2017 to amend Environment (Protection) Rules 1986, Schedule-I [42].

Parameter	Location	Concentration not to exceed
pH	Anywhere in the country	6.5-9.0
Bio-chemical Oxygen Demand (BOD)	Metro Cities*, all State Capitals except in the State of Arunachal Pradesh, Assam, Manipur, Meghalaya Mizoram, Nagaland, Tripura Sikkim, Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and Union territory of Andaman and Nicobar Islands, Dadar and Nagar Haveli Daman and Diu and Lakshadweep	20
	Areas/ regions other than mentioned above	30
Total Suspended Solids (TSS)	Metro Cities*, all State Capitals except in the State of Arunachal Pradesh, Assam, Manipur, Meghalaya Mizoram, Nagaland, Tripura Sikkim, Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and Union territory of Andaman and Nicobar Islands, Dadar and Nagar Haveli Daman and Diu and Lakshadweep	<50
	Areas/ regions other than mentioned above	<100
Faecal Coliform (FC), MPN/100 ml	Anywhere in the country	<1000

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

Note:

(i) All values in mg/l except for pH and Fecal Coliform.

(ii) These standards shall be applicable for discharge into water bodies as well as for land disposal/applications.

(iii) The standards for Fecal Coliform shall not apply in respect of use of treated effluent for industrial purposes.

(iv) These Standards shall apply to all STPs to be commissioned on or after the 1st June, 2019 and the old/existing STPs shall achieve these standards within a period of five years from date of publication of this notification in the Official Gazette.

(v) In case of discharge of treated effluent into sea, it shall be through proper marine outfall and the existing shore discharge shall be converted to marine outfalls, and in cases where the marine outfall provides a minimum initial dilution of 150 times at the point of discharge and a minimum dilution of 1500 times at a point 100 meters away from discharge point, then, the existing norms shall apply as specified in the general discharge standards.

(vi) Reuse/Recycling of treated effluent shall be encouraged and in cases where part of the treated effluent is reused and recycled involving possibility of human contact, standards as specified above shall apply.

(vii) Central Pollution Control Board/State Pollution Control Boards/Pollution Control Committees may issue more stringent norms taking account to local condition under section 5 of the Environment (Protection) Act, 1986".

(i) WWTF based on Aerated Lagoons in Greater Mumbai

The trend of BOD in influent and effluent of Aerated Lagoons at Ghatkopar, Bhandup and Versova is discussed as follows:

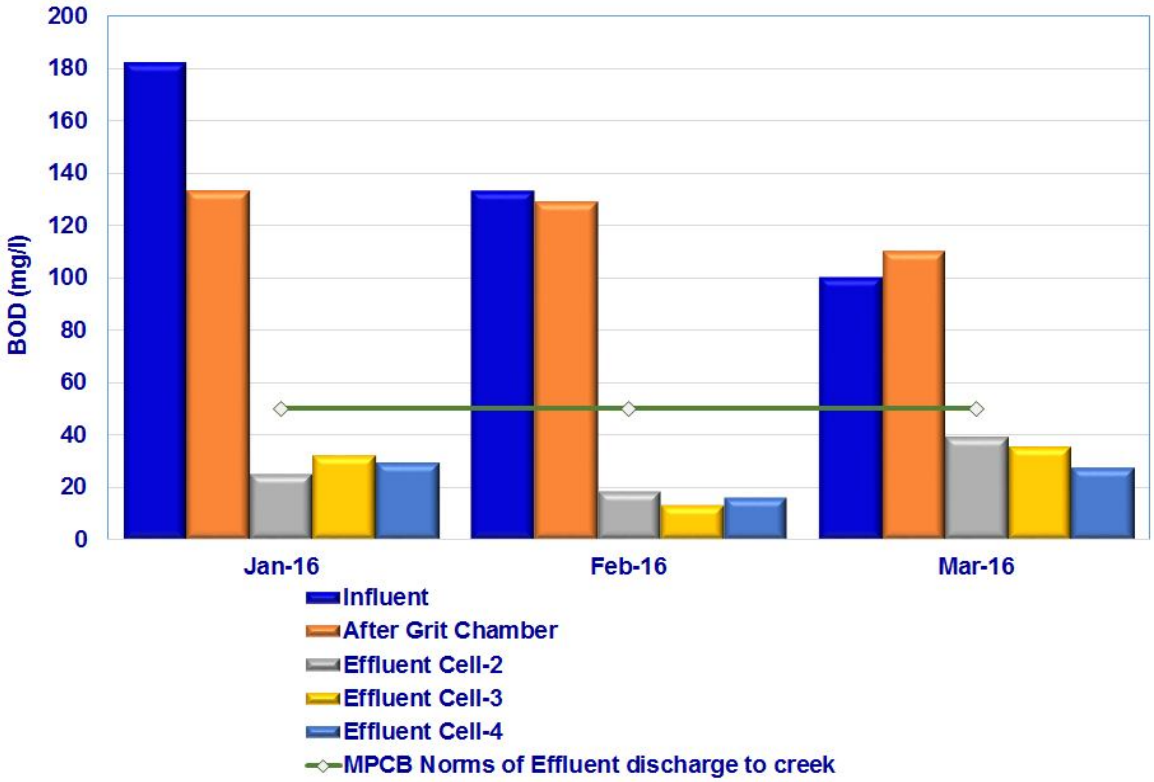
Ghatkopar Aerated Lagoon

The MCGM Dadar laboratory reports analysis results at following locations[45]

- Ghatkopar lagoon Influent
- Effluent after Grit Chamber
- Effluent from Cell

The influent BOD from January to March-2016 is reported ranging between 100 to 182 mg/l, whereas BOD in the effluent of Grit Chamber has been given in range of 110 to 133 mg/l. The effluent BOD from Cells has been reported ranging between 16 to 39 mg/l.

Figure-28: Trend of BOD in Influent and Effluent of Ghatkopar Lagoon[45]



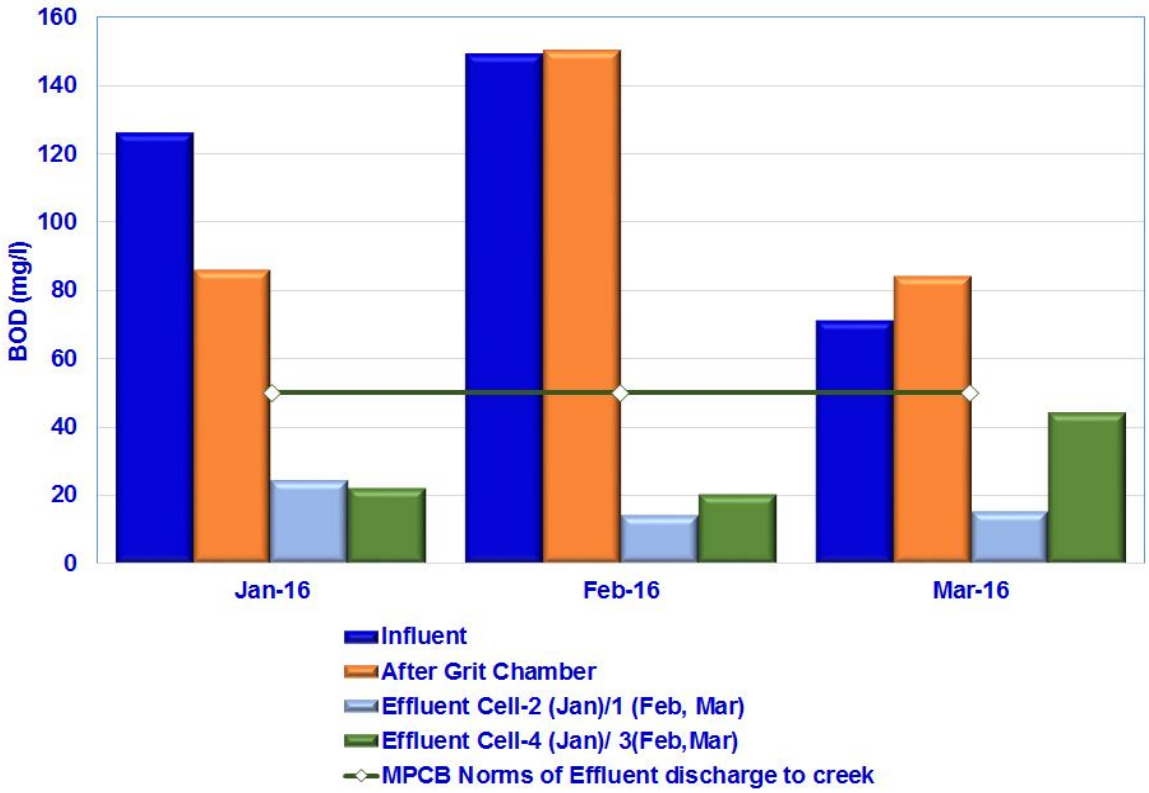
Bhandup Aerated Lagoon

The analysis results for following locations are being reported[45]

- Bhandup lagoon Influent
- Effluent after Grit Chamber
- Effluent from Cell

The influent BOD from January to March-2016 is reported ranging between 71 to 126 mg/l, whereas BOD in the effluent of Grit Chamber has been given in range of 84 to 150 mg/l. The effluent BOD from Cells has been reported ranging between 14 to 44 mg/l.

Figure-29: Trend of BOD in Influent and Effluent of Bhandup Lagoon[45]



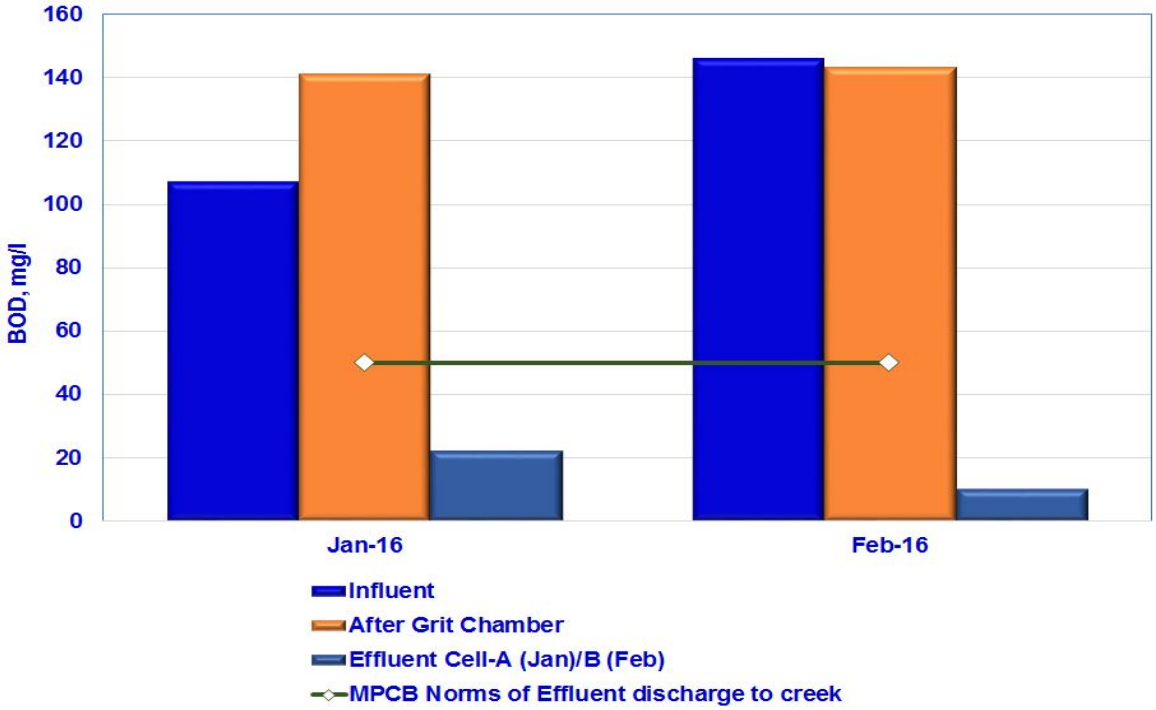
Versova Aerated Lagoon

The analysis results for following locations are being reported[45]

- Versova lagoon Influent
- Effluent after Grit Chamber
- Effluent from Cell

As indicated in figure-30 the influent BOD during January and February-2016, is reported as 107 and 146 mg/l respectively, whereas BOD in the effluent of Grit Chamber during the corresponding period has been reported 141 and 143 mg/l respectively. The effluent BOD has been reported ranging between 10 to 22 mg/l.

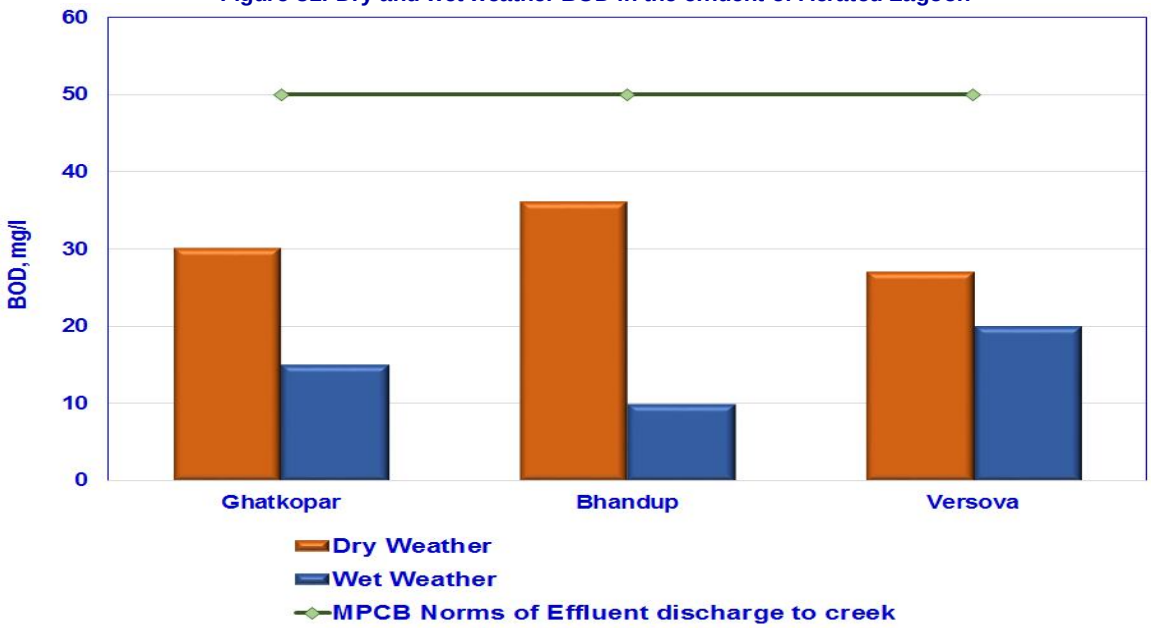
Figure-30: Trend of BOD in Influent and Effluent of Versova Lagoon[45]



Dry and Wet Season Aerated Lagoon (Ghatkopar, Bhandup and Versova) [30]

As indicated in figure-31, dry season BOD of Aerated Lagoons effluent is reported ranging between 27 to 36 mg/l, whereas the wet season BOD is reported varying between 10 to 20 mg/l.

Figure-31: Dry and wet weather BOD in the effluent of Aerated Lagoon[30]



(ii) WWTF based on Preliminary Treatment in Greater Mumbai[45]

The trend of BOD in influent and effluent of WWTF at Colaba, Love Grove-Worli, Bandra and Malad, which are based on preliminary treatment only, indicates the influent BOD varying between 104 to 182 mg/l.

Figure-32: BOD in marine outfalls of WWTF[45]

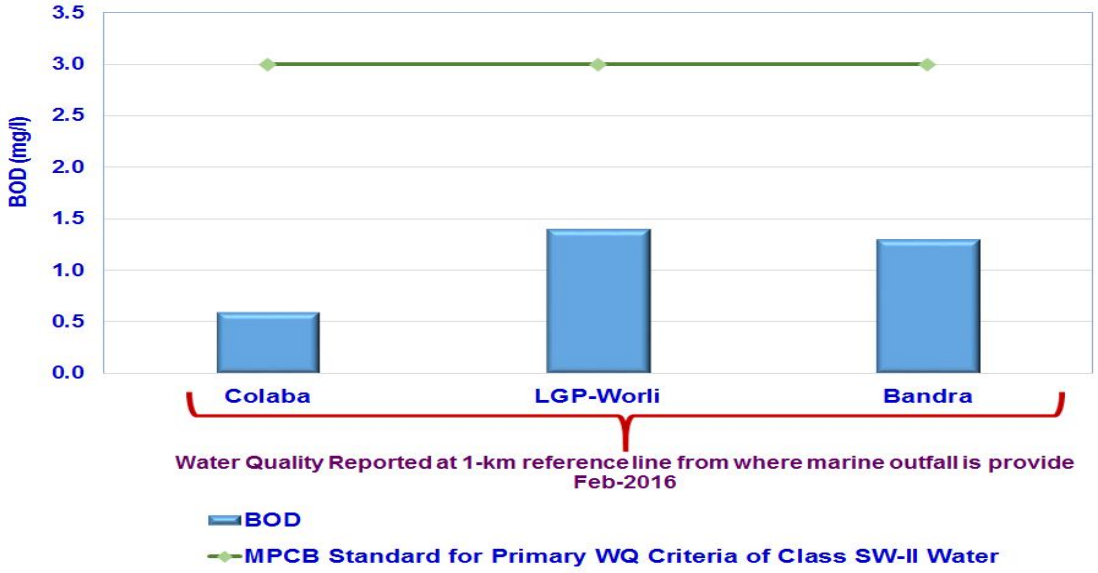
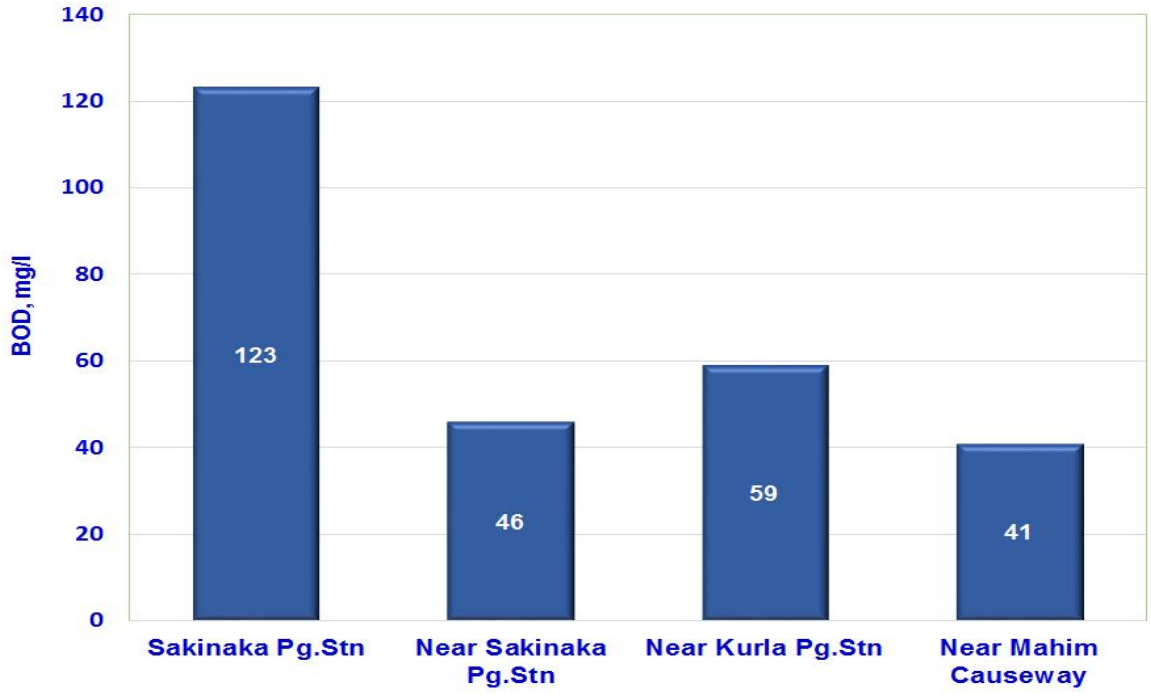


Figure-33: BOD at various locations on Mithi River[45]



- As indicated in figure-32, the BOD of marine outfall of Colaba, Love Grove and Bandra is reported in range of 0.6 to 1.4 mg/l during February-2016.

- BOD values are also reported at various locations on the course of Mithi River (figure-33), where it has been found varying between 41 to 123 mg/l.

(b) Chemical Oxygen Demand (COD)

The COD test is often used as a measurement of pollutants in wastewater and natural waters by means of chemically digestion. The limit of COD in accordance with the general limits for discharge of effluent into Marine Coastal Areas as per the Environmental (Protection) Rules 1986; Schedule-VI: Part-A amended to date, is 250 mg/l.

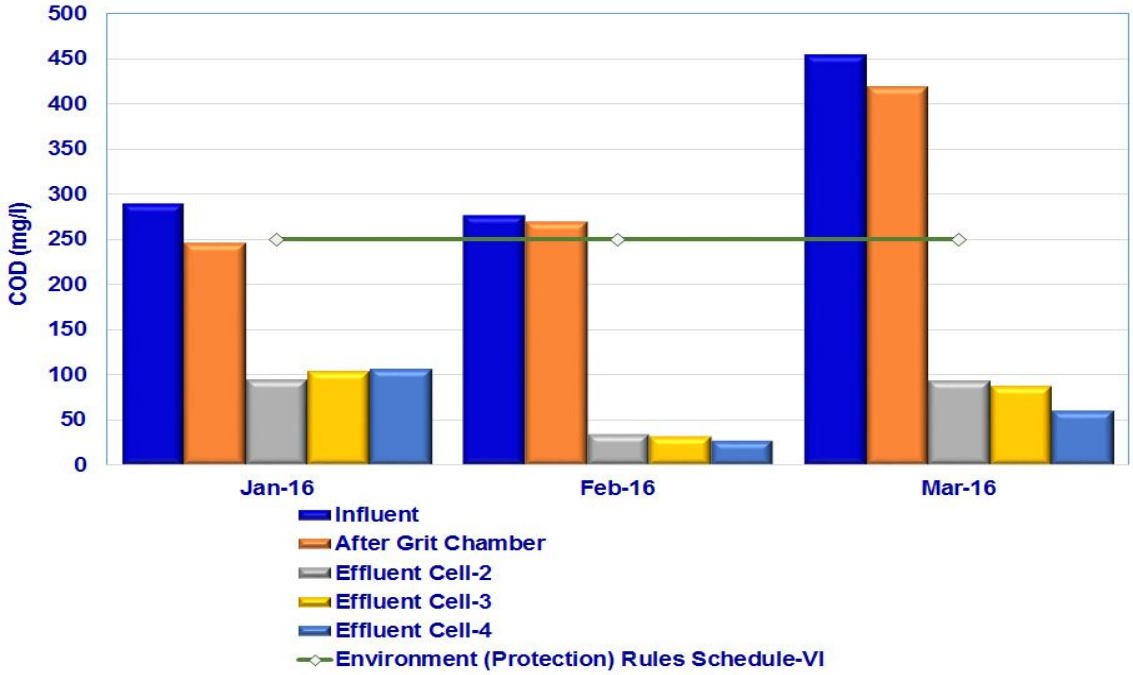
(i) WWTF based on Aerated Lagoons in Greater Mumbai

The trend of COD in influent and effluent of Aerated Lagoons at Ghatkopar, Bhandup and Versova is discussed as follows:

Ghatkopar Aerated Lagoon

The influent COD from January to March-2016 is reported ranging between 276 to 454 mg/l, whereas COD in the effluent of Grit Chamber has been given in range of 246 to 418 mg/l. The effluent COD has been reported ranging between 27 to 105 mg/l.

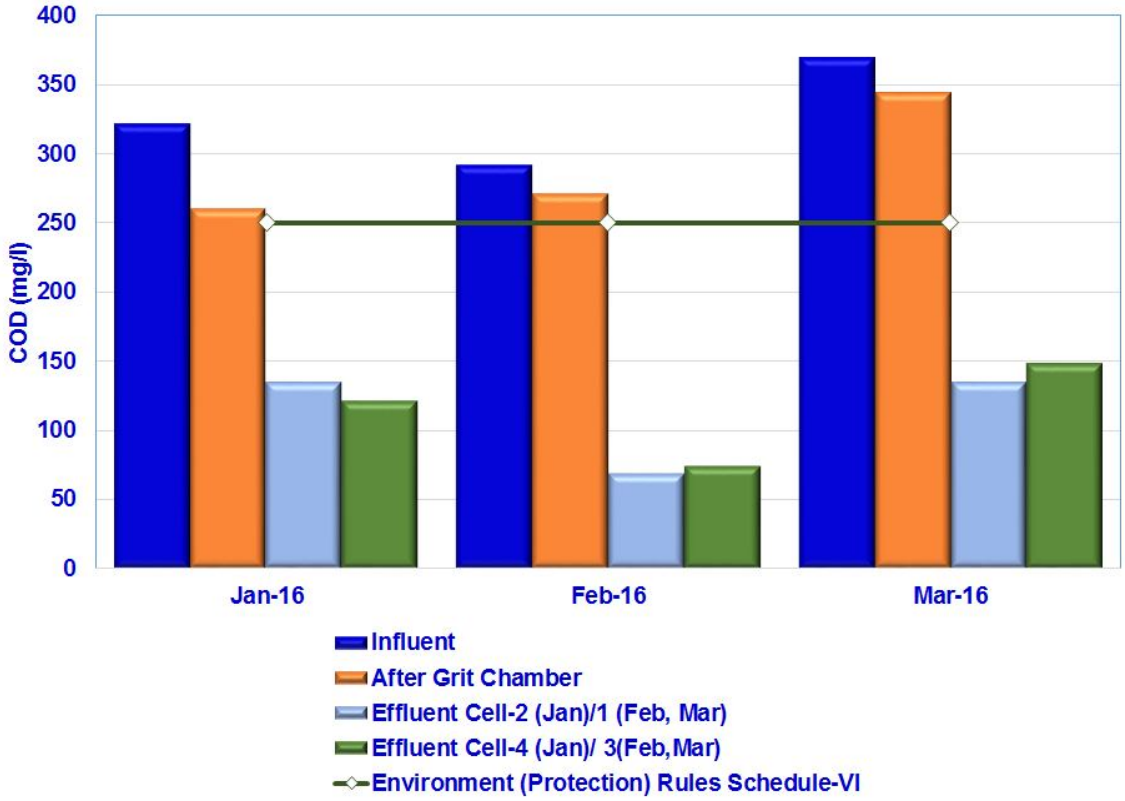
Figure-34: Trend of COD in Influent and Effluent of Ghatkopar Lagoon[45]



Bhandup Aerated Lagoon

As shown in figure-35, the influent COD from January to March-2016 is reported ranging between 291 to 369 mg/l, whereas COD in the effluent of Grit Chamber has been given in range of 260 to 344 mg/l. The effluent COD has been reported ranging between 68 to 148 mg/l

Figure-35: Trend of COD in Influent and Effluent of Bhandup Lagoon[45]



Versova Aerated Lagoon

As indicated in figure-36, the influent COD during January and February-2016 is reported as 483 and 220 mg/l respectively, whereas COD in the effluent of Grit Chamber during the corresponding period has been reported 479 and 213 mg/l respectively. The effluent COD from has been reported ranging between 71 to 131 mg/l.

Figure-36: Trend of COD in Influent and Effluent of Versova Lagoon[45]

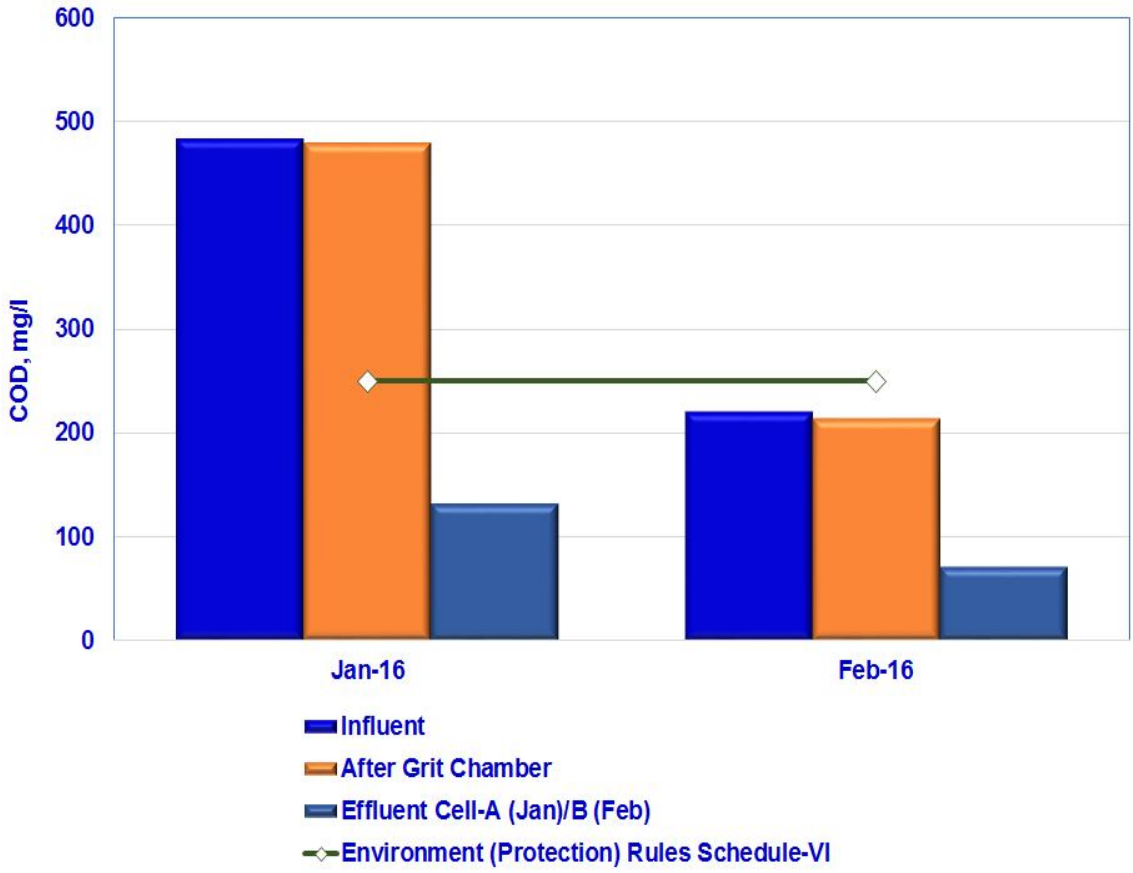
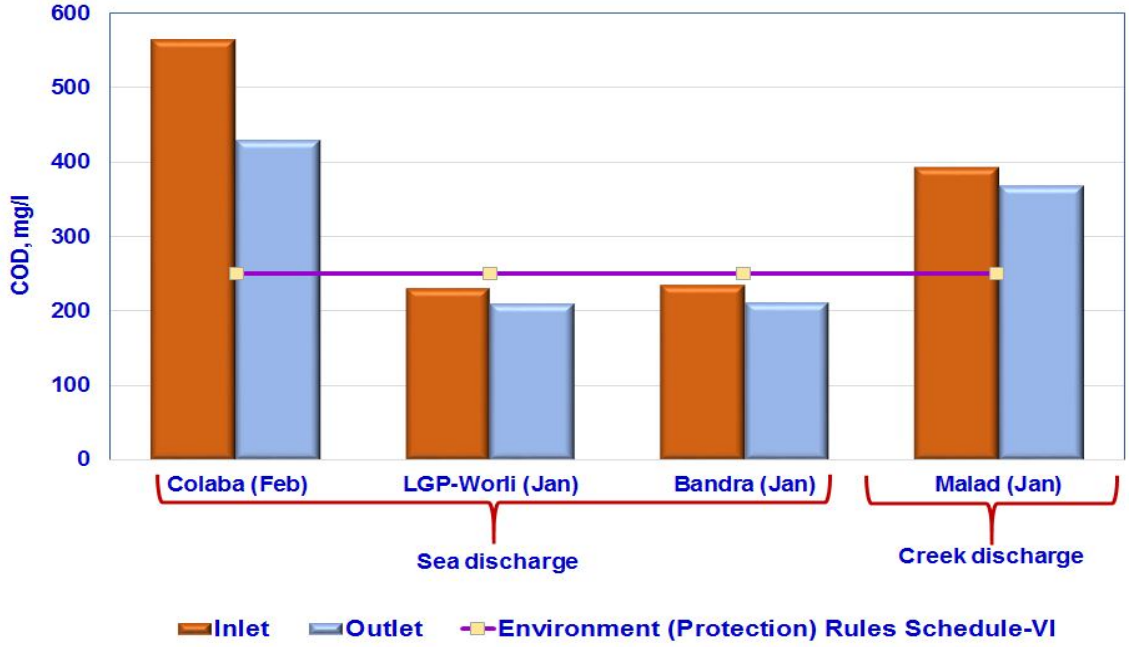


Figure-37: COD in influent & effluent of Colaba, Worli, Bandra and Malad WWTF[45]



The trend of COD in influent and effluent of WWTF at Colaba, Love Grove-Worli, Bandra and Malad, which are based on preliminary treatment only, indicates the influent COD varying between 231 to 564 mg/l, whereas effluent BOD is ranged between 210 to 429 mg/l as shown in figure-37.

(c) Dissolved Oxygen

Dissolved oxygen (DO), as such, does not have any significance as a sewage characteristics. However, it is the most important pollution assessment parameter of the receiving water bodies. Stabilization of organic matter, when discharged untreated or partially treated in receiving waters, leads to depletion of their dissolved oxygen. Nutrients (nitrogen and phosphorus) addition due to discharge of untreated or treated sewage may lead to algal growth. During day time, algae undergo photosynthesis process and the oxygen released by this process is much more than their respiration requirements resulting in a net addition of dissolved oxygen to water. However, during night time photosynthesis process is stopped whereas respiration requirement continues. This leads to depletion of dissolved oxygen in waters. The limit of Dissolved Oxygen as per the MPCB Standard for Primary Water Quality Criteria of Class SW-II Water is ≥ 4 mg/l.

(i) WWTF based on Aerated Lagoons in Greater Mumbai[45]

Dissolved Oxygen in influent has been reported Below Detection Level (BDL), whereas in effluents it is reported ranging between 0.5 to 5.4 mg/l during January to March-2016.

(ii) WWTF based on Preliminary Treatment in Greater Mumbai[45]

In all the samples of influent and effluent after preliminary treatment i.e. screening and grit removal, reported from January to March-2016, DO is reported Below Detection Limit.

(iii) DO in Marine Outfalls and Mithi River[45]

- In marine outfall of Colaba, Love Grove and Bandra, DO is reported in range of 6.14 to 6.44 mg/l during February-2016.
- DO values are also reported at various locations on the course of Mithi River, where it has been found Below Detection Limit.

(d) Suspended Solids

Suspended solids represent that fraction of total solids in any wastewater that can be settled gravitationally. Suspended solids can further be classified into organic (volatile) and inorganic (fixed) fractions. Organic matter is present in the form of either settleable form or non-settleable (dissolved or colloidal) form. If the organic fraction of suspended solids present in sewage is discharged untreated into streams, it leads to sludge deposits and subsequently to anaerobic conditions.

- The Maharashtra Pollution Control Board (MPCB) Standard of TSS for discharge of effluent into Creek is 50 mg/l.
- The MPCB Standard for Primary Water Quality Criteria of Class SW-II Water is prescribed for Turbidity (≤ 30 NTU).

(i) WWTF based on Aerated Lagoons in Greater Mumbai

The trend of TSS in influent and effluent of Aerated Lagoons at Ghatkopar, Bhandup and Versova is discussed as follows:

Ghatkopar Aerated Lagoon

As indicated in figure-38, the TSS in influent from January to March-2016, are reported ranging between 204 to 246 mg/l, whereas TSS in the effluent of Grit Chamber have been given in range of 210 to 252 mg/l. The TSS in effluent have been reported ranging between 13 to 69 mg/l.

Bhandup Aerated Lagoon

As shown in figure-39, the TSS in influent from January to March-2016, are reported ranging between 201 to 273 mg/l, whereas TSS in the effluent of Grit Chamber have been given in range of 203 to 245 mg/l. The TSS in effluent have been reported ranging between 34 to 48 mg/l.

Versova Aerated Lagoon

As indicated in figure-40 the influent TSS during January and February-2016, are reported as 268 and 278 mg/l respectively, whereas TSS in the effluent of Grit Chamber during the corresponding period have been reported 252 and 274 mg/l respectively. The effluent TSS have been reported ranging between 28 to 33 mg/l.

Figure-38: Trend of TSS in Influent and Effluent of Ghatkopar Lagoon[45]

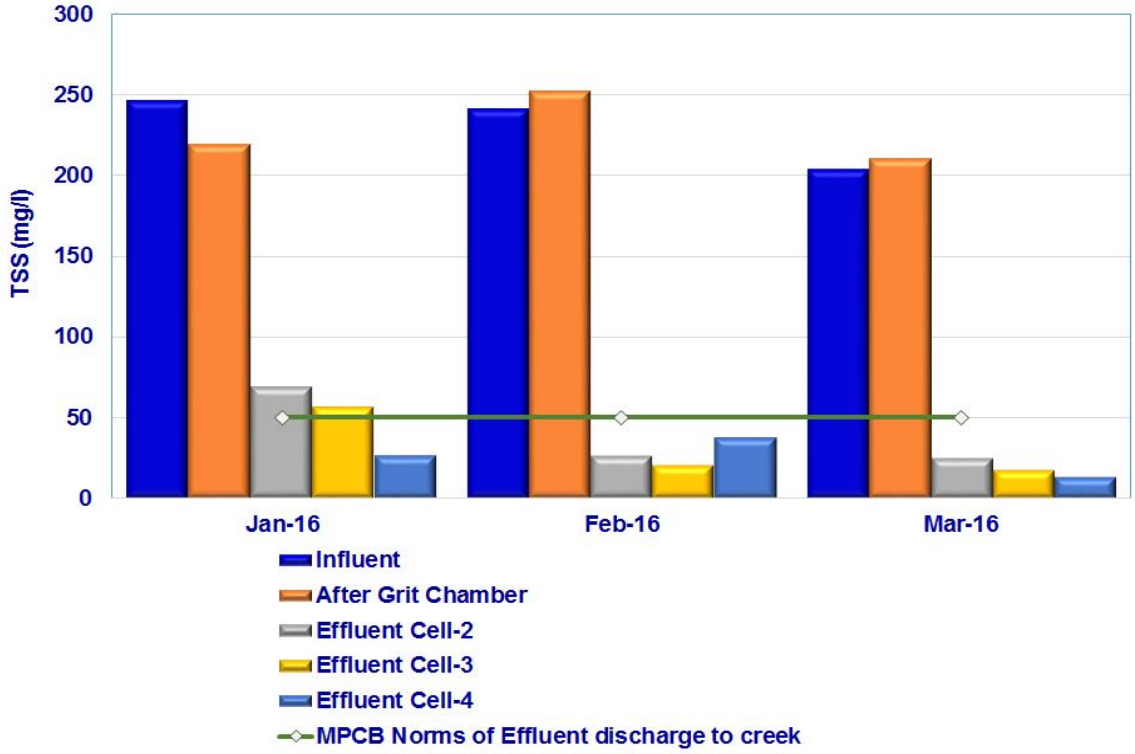


Figure-39: Trend of TSS in Influent and Effluent of Bhandup Lagoon[45]

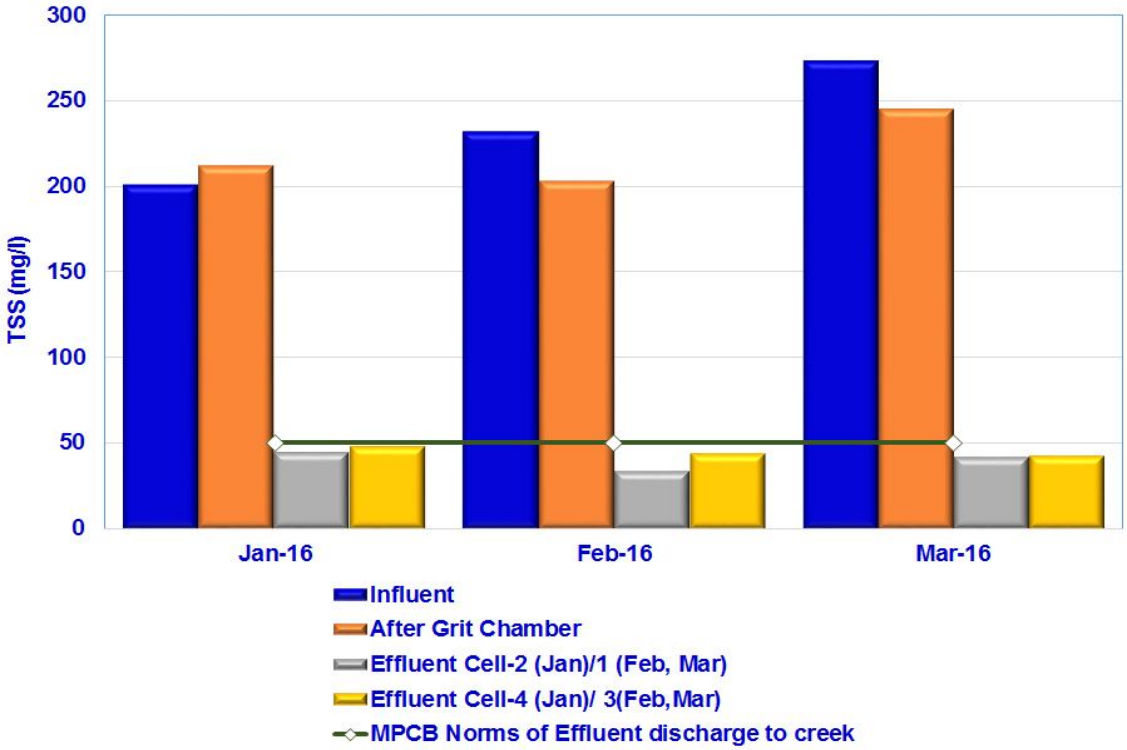
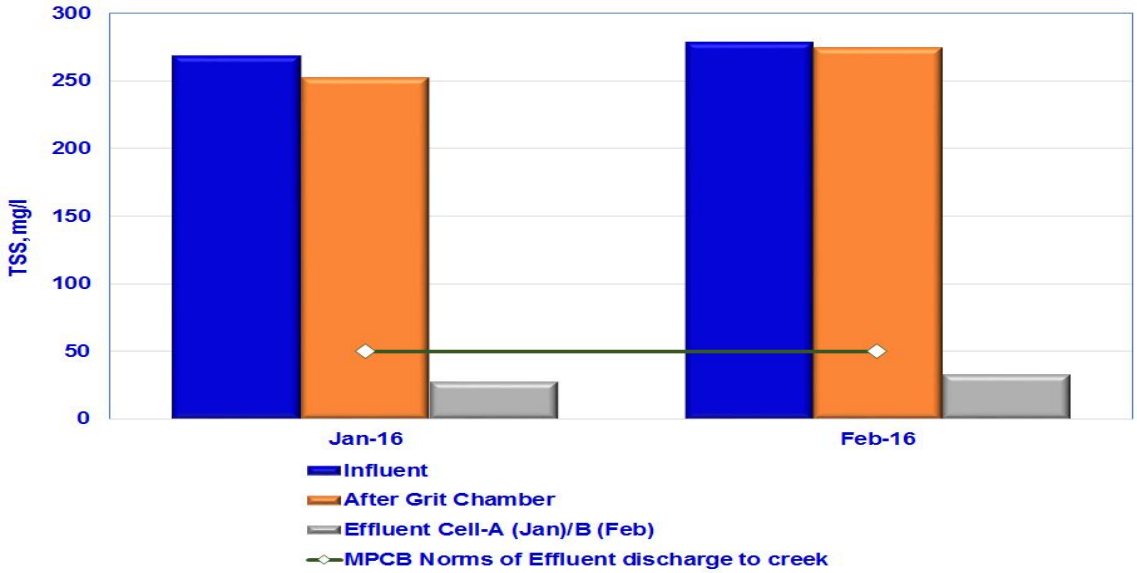


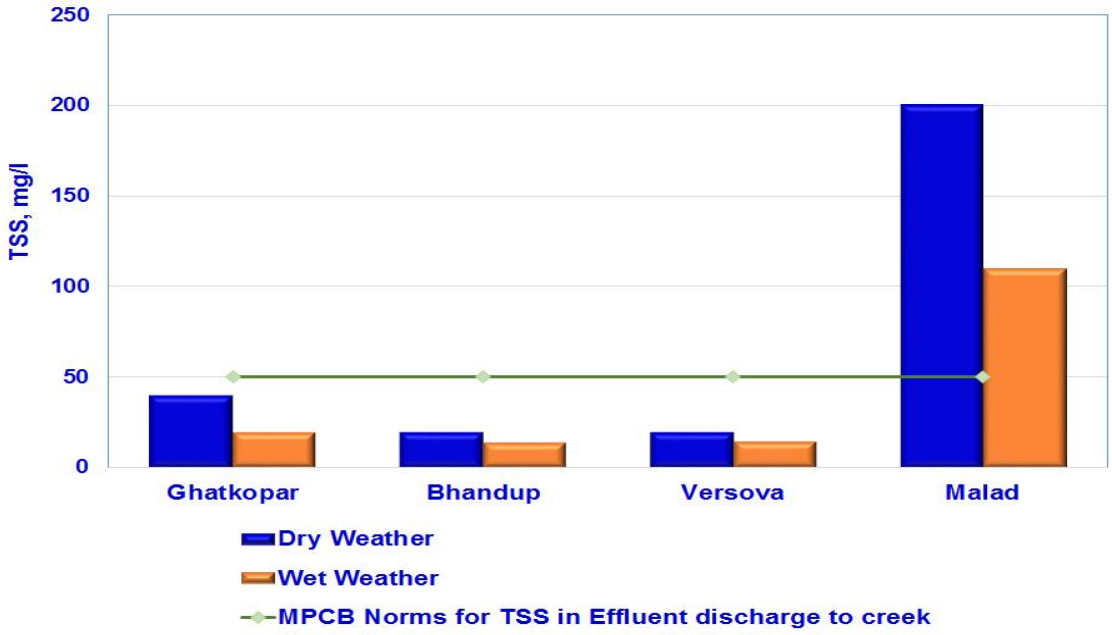
Figure-40: Trend of TSS in Influent and Effluent of Versova Lagoon[45]



Dry and Wet Weather [30]

TSS during dry weather are reported in range of 20 to 40 mg/l at Aerated Lagoons (Ghatkopar, Bhandup and Versova) and 200 mg/l at Malad, whereas same at the corresponding locations during wet weather are reported 14 to 20 mg/l and 110 mg/l respectively as shown in figure-41.

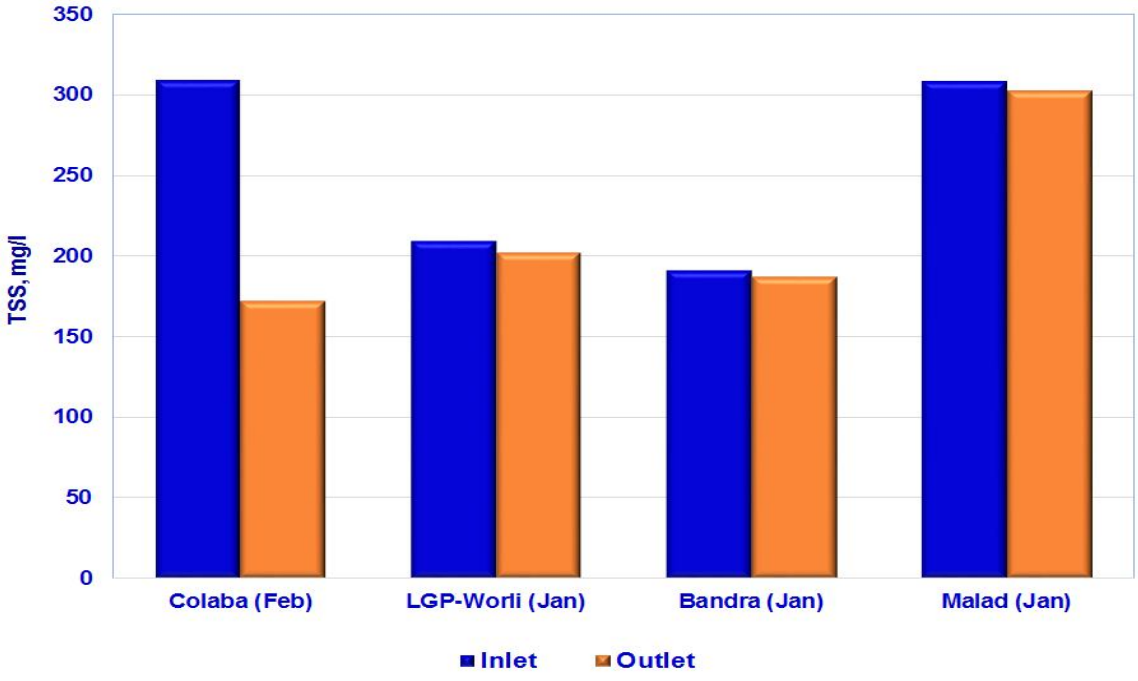
Figure-41: Dry and wet weather TSS in the effluent [30]



(ii) WWTF based on preliminary treatment[45]

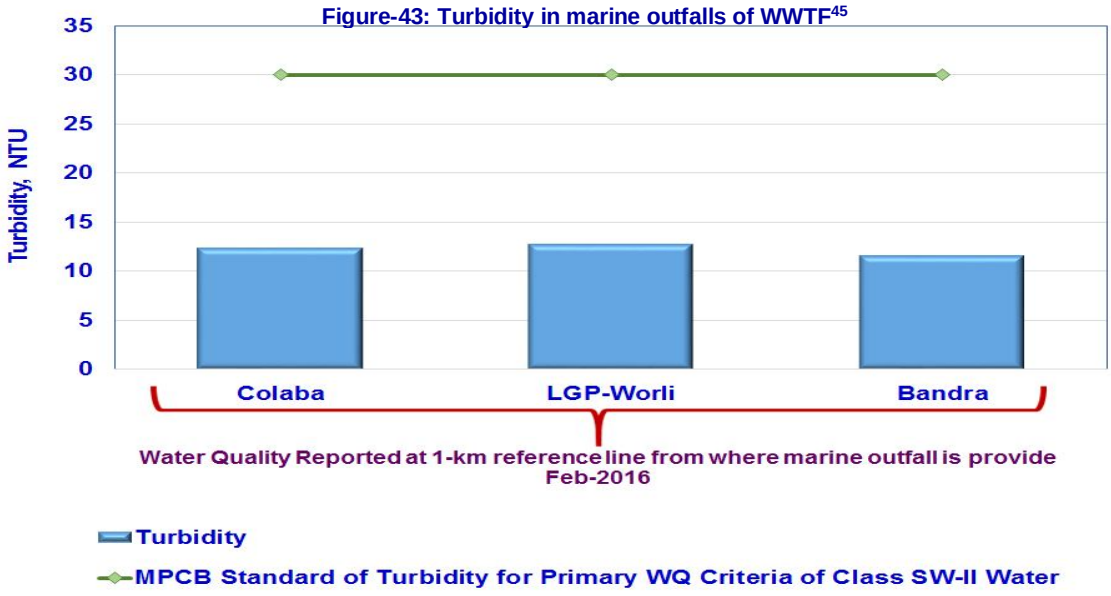
The trend of TSS in influent of Colaba, Worli, Bandra and Malad, as shown in figure-42 are reported in range of 191 to 309 mg/l during January & February-2016, whereas same in the effluent of corresponding locations are reported ranging between 172 to 302 mg/l.

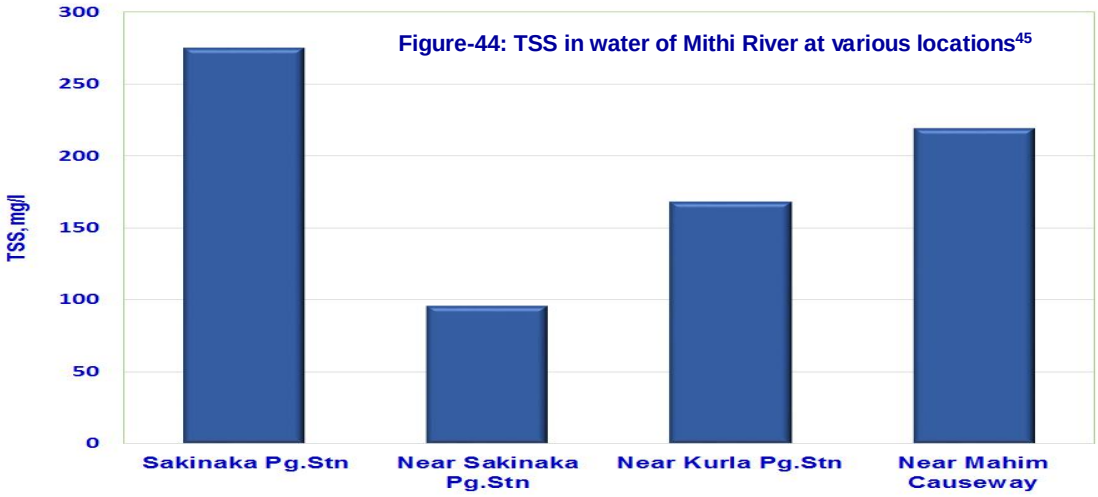
Figure-42: TSS in influent & effluent of Colaba, Worli, Bandra and Malad WWTF[45]



(iii) Turbidity (NTU) in Marine Outfall and TSS in Mithi River[45]

- As indicated in figure-43, the Turbidity at marine outfall of Colaba, Love Grove and Bandra is reported in range of 11.6 to 12.4 NTU during February-2016.
- The TSS values, as shown in figure-44, are also reported at various locations on the course of Mithi River, where these have been found varying between 96 to 275 mg/l.





Quality Control Laboratory has the significant role in providing accurate, reliable and dependable data to ensure the effectiveness of Wastewater Treatment Facility. The training of QC laboratory staff is an essential requirement not only for updation of their knowledge and skill but also towards development of capability towards interpretation of data and information.

7. Mumbai Sewerage Disposal Project Stage-II

7.1 Background of MSDP Stage-II [21, 23, 33,]

The original island city of Mumbai consisted of seven islands namely Apollo Bunder, Malabar, Cumbala, Mazgaon, Worli, Mahim, and Parel-Dharavi-Sion. The idea of reclaiming submerged land emerged as back as early as middle of 16th Century. The first work of construction of Vellard between Worli and Mahalaxmi was done in the year 1772. Major areas of island city were reclaimed by the year 1860. These areas were Wadi Bunder, Chinch Bunder, Curnac Bunder, Mint Road, Elphinstone Road, Tank Bunder, Clerk Road, Mahalaxmi, Seweree, and Frere Estate. There are several areas that were subsequently filled up and reclaimed. After independence major reclamations were carried out at Back Bay reclamation and Nariman Point. This was also accompanied by development of suburban areas.

Sewerage System Development

Mumbai has historically separate systems for sewerage and storm water disposal. The history of sewerage system of Mumbai started with the laying of main drain in the 18th Century, discharging at the Great Beach Worli. As the urban area increased, sluices were constructed in 1842 at Love Grove. By 1867, the outlets with main sewer were laid at Colaba. In 1880 all sewage was taken to Love Grove, where an outfall was constructed to discharge partially treated sewage into the sea. Between 1890 to 1905, five ejector stations were constructed to pump sewage from low lying areas to gravity sewer. The sewerage network and system was extended from time to time as per demand and need. In 1910, treatment plant was constructed at Dharavi. In 1938, treatment plant was constructed at Dadar.

Post-independence, as suburban areas developed the sewerage system was also extended to suburban areas. In 1960, primary treatment plants were constructed at Khar, Versova & Ghatkopar.

In the year 1962, a High Level Committee undertook study of Water Supply Resources and Sewerage and integrated project was commissioned. Accordingly, in the year 1969, World Bank was approached to finance development of Water Supply & Sewerage System of the City. M/s Binnie & Partners were appointed as Consultants, in the year 1970, to prepare feasible Development Plan for the sewerage system. The Consultants submitted their report in 1971 and suggested a complete sewerage system plan consisting of conveyance system, construction of Pumping Stations and Sewage Treatment in the form of secondary treatment at 3 locations. Higher priority was given to Water Supply Works and initially sewerage works were restricted to laying of some sewers and construction of few pumping stations.

On World Bank advice, M/s. Metcalf & Eddy Consultants were appointed in the year 1976 to review the proposed sewerage system with special reference to oceanographic surveys, proposed landuse and feasibility of reuse of sewage. The consultants, in association with Environmental Consultants, carried out extensive studies and prepared integrated Master Plan (in 1979) for Sewage Collection, treatment and Disposal for the period up to 2005. The

plan consisted of marine outfalls at Colaba, Love Grove and Bandra and aerated lagoons at Versova, Malad, Bhandup and Ghatkopar for sewage disposal apart from conveyance system and pumping stations. These recommendations were accepted & implemented under Bombay–I, II, III & B.S.D.P-I (now known as MSDP) with the assistance of World Bank. As a part MSDP-I the work of preparation of Master Plan for 2025 was also taken in hand and was prepared in 2002. This plan is accepted for implementation which is now known as MSDP-II. The present sewerage system is detailed below:

Zone 1 – Colaba covers an area of 574 ha. Contains six pumping stations and about 32 km of sewers leading to preliminary treatment and the short pipe outfall to Colaba Harbor. The capacity of Colaba WWTF is 41 MLD.

Zone 2 – Worli covers and area of 3891 ha. Contains sixteen pumping stations and about 339 km of sewers leading to preliminary treatment and the new, 3 km long sea outfall at Worli, discharging to the Arabian Sea. The capacity of Worli WWTF is 756 MLD.

Zone 3 – Bandra covers an area of about 7730 ha. having sixteen pumping stations and about 326 km of sewers. Flow from the IPS will pass to Bandra preliminary treatment works prior to discharge via the EPS and a 3.5 km long sea outfall to the Arabian Sea. The capacity of Bandra WWTF is 796 MLD.

Zone 4 – Versova covers an area of about 2140 ha. There are only two stations, a final pumping station one small pumping station at Versova village. The 146 km of sewers lead to preliminary and three stage aerated lagoon treatment, discharging to Malad Creek. The capacity of Versova WWTF is 180 MLD.

Zone 5 – Malad covers an area of over 11500 ha. There are six pumping stations and about 300 km of sewers. A final pumping station delivers flows from the interceptor to preliminary treatment, which discharges to Malad Creek. The capacity of Malad WWTF is 280 MLD.

Zone 6 – Bhandup covers an area of 4274 ha. There are three pumping stations and about 105 km of sewer leading to preliminary and single stage aerated lagoon treatment discharging into Thane Creek. The capacity of Bhandup WWTF is 230 MLD.

Zone 7 – Ghatkopar serves an area of about 7730 ha. There are 3 pumping stations and 136 km of sewers leading to preliminary and single stage aerated lagoons treatments discharging into Thane Creek. The capacity of Ghatkopar WWTF is 386 MLD.

Sewage collection system comprising of gravity underground sewer network and online satellite pumping stations are grouped in such way that the entire quantity of sewage collected from that zone is delivered to the terminal point located in that respective zone. The summary of existing sewerage infrastructure is given below:

1.	Area of the city	: 437 Sq.Km
2.	Population of the city (2011 Census)	: 1,24,00,000
3.	Length of Sewer Lines	: 1915 kms.
4.	No. of Sewage Pumping Station	: 51 Nos.
5.	No. of Waste Water Treatment Facilities	: 7 Nos.
6.	No. of Outfall	: 3 Nos.
7.	No. of Lagoons	: 3 Nos.
8.	No. of Street Connections	: 2,95,000 Nos
9.	No. of Manholes	: 77,000
10.	Size of Smallest Sewers	: 6" dia.
11.	Size of Maximum Sewers	: 6' dia. & 6' X 9' ovoid sewer
12.	Average quantity of sewage handled	: 1700 MLD

The Sewerage Master Plan prepared in 1979 by Metcalf & Eddy Inc. formed a basis for the conveyance and disposal of sewage in Greater Mumbai area upto the year 2005. The work under this state of Master Plan were completed under MSDP-I. However, further environmental impact assessment studies concluded that water quality in coastal regions and creeks will require additional measures for protection in order to comply with the national standards. The population rise and associated escalation in water consumption, also necessitated the additional disposal facilities. The second 'Sewerage Master Plan' was prepared in the year 2002, presently known as Mumbai Sewage Disposal Project (Stage-II). The scope of MSDP Stage-II covers the wastewater management plan upto the year 2031.

The overall objective of the project is to bring out the improvements in the collection of non-point discharges as well as to expand the sewage network that will lead to increased wastewater collection and discharge as point sources. The MSDP Stage-II also includes provision of sanitation facilities to entire slum population, improvement of sewerage conveyance system, rehabilitation of sewers, upsizing of sewer and laying new trunks sewers, placing/expansion/ refurbishment of pumping stations and transfer of flows, new sewage pumping stations, rehabilitation/ extension and new wastewater treatment works, disposal of treated effluent through outfalls including recycling, provision of new/ upsize sewer lines, rehabilitation of manholes and transfer schemes i.e. transfer of sewage in pipeline. The rationale of the MSDP Stage-II is, therefore, to provide improved environment, while minimizing the impact of wastewater on the natural environment. These objectives are to be achieved through increasing the reliability of wastewater collection together with effectiveness of treatment and disposal.

7.2 The Objectives of the MSDP Stage-II [21, 23, 33, 34]

The major objectives of MSDP Stage-II are

- To minimize the impact of wastewater on the natural environmental through augmenting wastewater collection together with enhancing effectiveness of treatment and disposal.

- To facilitate the collection of wastewater from non-point pollution sources.

- To envisage progressive improvements in the water quality at discharge points with implementation of enhanced level of treatment by 2031/2034.
- To expand the sewerage network together with collection efficiency that will lead to the gradual increase of flows at influent pumping stations for proper disposal to receiving water bodies.

With the implementation of MSDP Stage-II, there will be new additions/ augmentations of sewerage infrastructure, which would facilitate the MCGM to comply with the prescribed discharge standards.

7.3 The Implementation Plan of MSDP Stage-II [23, 27, 33, 34]

The Mumbai Sewage Disposal Project Stage-II Master Plan finalised in 2001 addressed the waste-water collection, treatment and deposal requirement of the area under the management of the Municipal Corporation of Greater Mumbai (MCGM) to the year 2025. The design horizon for the flows and loads was revised by MCGM to correspond to the 1999 Water Supply Master Plan with a design horizon of 2031. At this design horizon, the population of Greater Mumbai is projected to reach 16.5 million and the average daily water-water flows from domestic and other sources about 5175 MLD.

The system included area sewerage, Trunk sewers, intermediate and terminal pumping station, augmentation of existing treatment plant, new plant and a new marine outfall.The entire sewerage system within the MCGM area is divided into seven zones based on the drainage topography of the area. At present, preliminary treatment exists at Bhandup WwTF for that zone with screening and grit removal facilities followed by single stage lagoons. The sewage is then discharged into Thane Creek. As per Master plan, the existing Bhandup WwTF will have to be upgraded to provide secondary treatment by the addition of primary tanks ,aeration tanks with fine pore aeration and secondary settling tanks. Sludge handling and treatment. The new treatment works are to be located in existing lagoon area.

Figure-45 MSDP Stage-II Priority Work[34]

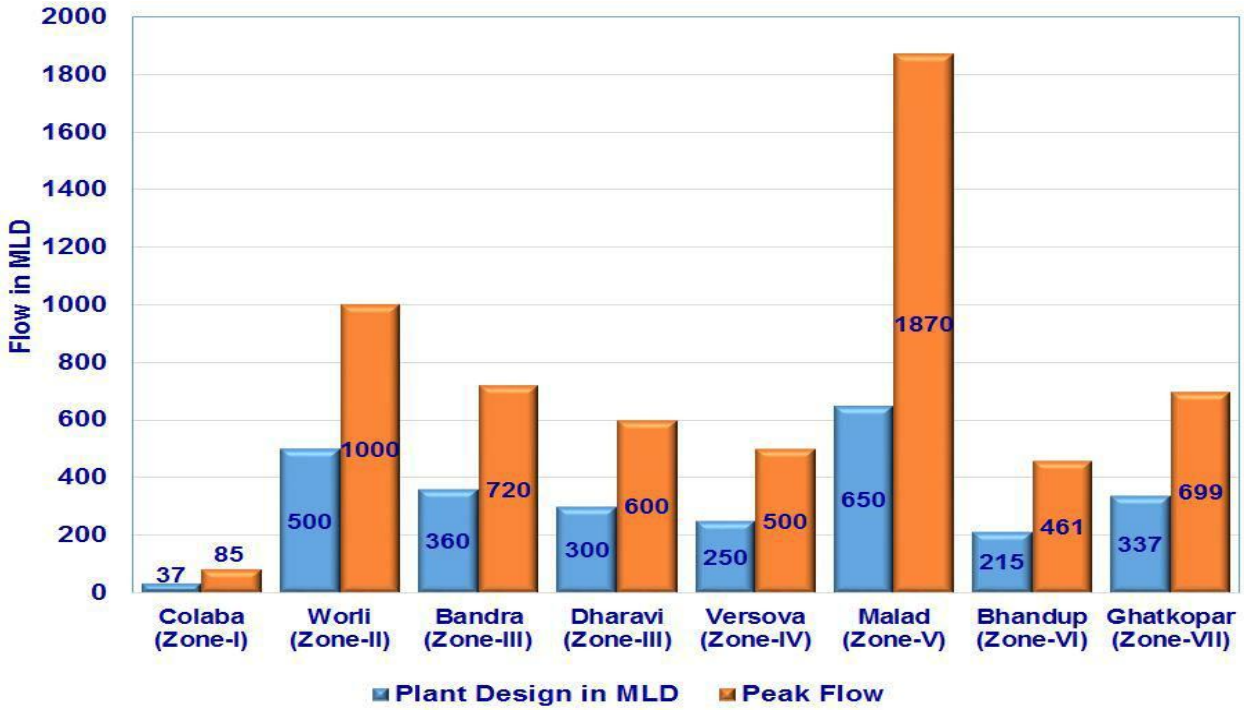
The major work consists of

- **Up-gradation of WWTF in Mumbai.**
- **Recycle/ reuse of treated sewage**

7.4 Extension and Up-gradation of Treatment Plants [23, 27,30,33,34]

The extension and up-gradation of treatment plants at various locations are designed based on flow prediction for 2031. Biological process such as lagoon, activated sludge process etc. are considered for designing at Average Dry Weather Flow (ADWF). Effluent quality of the treated wastewater from WWTF is based on Central Pollution Control Board (CPCB) and Maharashtra Pollution Control Board (MPCB) discharge standards. In MSDP Stage-II priority works, the proposed designed flow and peak flow are shown in following figure.

Figure-46: Proposed Capacity of WWTF in Greater Mumbai[30]



The overall plan of MSDP-II consisted of coverage of sewerage network to entire city and suburbs, rehabilitation and augmentation of existing sewer lines, rehabilitation of sewage pumping stations/ providing new pumping stations. The major work under MSDP-II is upgradation of waste water treatment facilities. The project was initiated because the 1979 Master Plan, which was developed on the philosophy of seven zones each with treatment works and long sea outfalls into the Arabian Sea and Harbour, only covered the period upto 2005. The broad category of priority works identified under MSDP stage II are:

- New sewer lines
- Upsizing of sewers
- Rehabilitation of sewers
- Area sewers
- Pumping stations
- Waste water Treatment Facilities
- Marine outfalls

The broad objective of the MSDP Stage-II is to provide a healthier and improved environment for people living in the city, while minimising the impact of wastewater on the natural environment. This will be achieved by increasing the quality and reliability of wastewater collection, treatment and disposal using affordable and sustainable technologies over the duration of the planning period i.e. by the year 2025. Accordingly the works are categorised above are planned and taken in hand and being carried out. The up-gradation of wastewater treatment facilities is, however, yet to be carried out/ completed, which now is a major focus. After resolving issues such as environment clearances, land inadequacies, technology and CRZ clearance for Malad WWTF, MCGM, has now prioritised WWTF project works based on studies and reports and discharge norms set out by CPCB/ MoEF&CC.

The study under Master Plan 2002 undertook the Regional Overview and this report covers the Mumbai Regional Area (MMR) and identification of impacts of the MRA on the water quality in creeks, coastal waters around Mumbai. The impacts of the discharges from the MMR and the MCBM area were assessed using water quality models by NEERI for further recommendations. The future wastewater flows are assessed after considering the water supply to the area. It was then predicted that in 2025 the water demand in the MMR will be 11,718 MLD. In 2025 the wastewater flow from the MMR is predicted to be over 5600 MLD (ADWF) and the BOD load nearly 760 tonnes. The MCGM will contribute about half the flow in 2025.

Despite the improvements in treatment in MCGM jurisdiction, overall pollution (BOD) load generated by the MMR in 2025 will be greater than as in year 2000. NEERI used the information from the report to determine the assimilative capacity of Thane Creek. The results of NEERI's water quality modelling showed that assimilative capacity is limited and the quality of the creek will deteriorate under the predicted loads; hence NEERI recommended that all domestic/municipal discharges should be given secondary treatment upto acceptable norms i.e. BOD<20 mg/l, DO> 2 mg/l and faecal coliforms less than 1 x 10^5 counts/ 100 ml. The detailed Environmental Impact Assessment Study was carried out by NEERI which indicated that MCGM. has to plan and implement measures to bring the pollution levels in and around Mumbai to the acceptable limits of Government of India/International Standards.

As such MCGM has planned up-gradation of waste water treatment facilities in 7 sewerage zones as major activity in line with the standards set out by Central and State Pollution Control Boards. As a part of project MCGM has already awarded the work of construction of Colaba WWTF of 37 MLD capacity. The work consists of Influent Pumping Station, screen and grit removal facility, secondary / biological treatment plant, tertiary treatment, disinfection facility and effluent pumping station. The discharge standards are set out as per CPCB directives dated 9/10/2015 with BOD/ TSS/ Feacal Coliform norm of 10/10 mg/l and MPN Coliform 230. It is also planned that tertiary treatment facility will be provided in 4 phases with additional disinfection facility to facilitate reuse of treated waste water for industrial/ non-potable purpose.

MoEF&CC/ CPCB in October-2017 has notified new norms of BOD/ TSS of 20/50 mg/l and Faecal Coliform MPN 1000 and MCGM has planned WWTF up-gradation works in line with the directives which is tabulated below:

Zone No. / Name	WWTF Capacity in MLD	Treatment Configuration
(2) Worli	500	Biological treatment and disinfection to achieve treated waste water to meet discharge norm of BOD/ TSS as 20/ 50 mg/l and faecal coliform limit to MPN 1000 for discharge in to sea and creek of Mumbai and BOD / TSS of 10/5 mg/l and FC (Nil) after tertiary treatment and further disinfection to facilitate reuse of treated waste water for industrial and non-potable purpose. Initially upto 20% of sewage is proposed to be reused in phases as per demand.
(3) Bandra	360	
Dharavi	325 (250+75)*	
(4) Versova	240 (180+60)*	
(5) Malad	650 (450+150)*	
(6) Bhandup	323 (215+108)*	
(7) Ghatkopar	505 (337+168)*	

* to be implemented in two phases as detailed.

It is also planned to construct gravity sewer tunnels (Area Sewers) for certain areas which will facilitate elimination of sewage pumping stations.

Figure-47: STP Locations in Greater Mumbai[62]

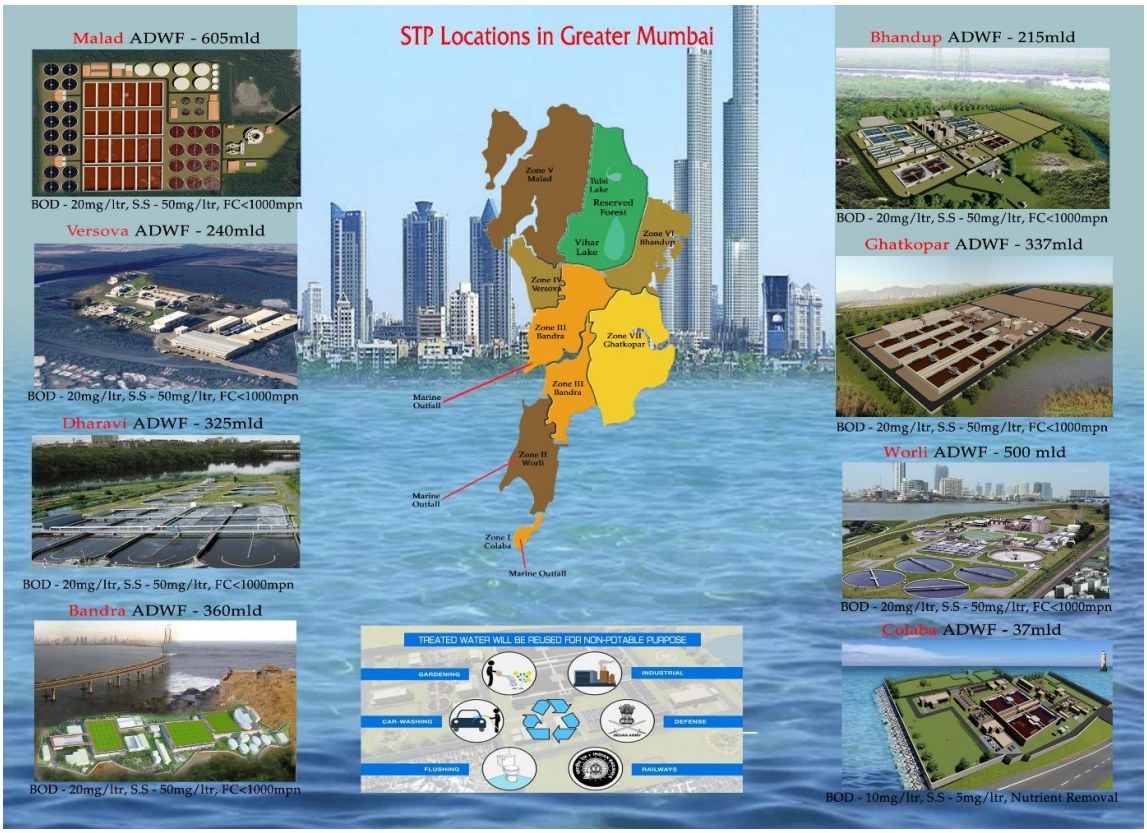


Figure-48: Proposed STP at Colaba[62]

Figure-49: Proposed STP at Worli[62]

Figure-50: Proposed STP at Bandra[62]

Figure-51: Proposed STP at Bhandup[62]

Figure-52: Proposed STP at Dharavi[62]

Figure-53: Proposed STP at Ghatkopar[62]

Figure-54: Proposed STP at Malad[62]

Figure-55: Proposed STP at Versova[62]

Figure-56: Reuse and Recycling Plan of Treated Effluent[62]

Benefits of Projects

On completion of these priority works following benefits are expected:

- Effective and Efficient sewerage infrastructure i.e. collection, conveyance, pumping and treatment.
- Improved sanitation and therefore improved Health and Environmental conditions in Mumbai.
- Meeting the standards laid down by CPCB/ MPCB and MoEF&CC.
- Recycle and reuse of treated effluent which will help increased availability of fresh water for potable purpose and to meet the increased demand for the same.
- Elimination of certain seven sewage pumping stations due to provision of deep sewer tunnels.

8. Recommended Standard Operation and Maintenance Procedures

8.1 Objectives of Operation and Maintenance[5, 44, 47]

Operation and Maintenance (O&M) is essential requirement needed to sustain the sewerage and treatment systems, which are otherwise created at huge costs. Preventive maintenance is a set procedure whereby each component of the system goes through a systematic check to facilitate various components of the system into the dependable use. The preventive maintenance issues are inclusive of parameters of checking along with maintenance schedule, which are needed to ensure the effective operation of the system. The overall aim is to save costly equipments through preventive maintenance, which otherwise ends up as "breakdown repairs." Hence to ensure improved efficiency, O&M plays vital role.

Purpose of "Operation and Maintenance Procedures"

The purpose of O&M Procedures is to lay down methods for operation, maintenance and trouble-shootings of IPS, WWTF and EPS for Municipal Corporation of Greater Mumbai. The scope of O&M Procedures, therefore, includes

- Procedures for day-to-day operation and maintenance of IPS and EPS.
- Trouble-shootings for identification and off-setting the problems.
- Procedures for Optimization of Sewage Treatment Operations (Particularly be applicable with the up-gradation of WWTF under MSDP Stage-II).

Sewage Pumping Station (SPS) or Influent Pumping Stations (IPS) handle sewage/ storm water either for lifting the sewage so as to discharge into another gravity sewer to be followed by treatment of sewage in WWTF and finally discharge through Effluent Pumping Stations (EPS). Sewage Pumping Stations with following details are meant to feed various WWTF:

Essential Components of Sewage Pumping Stations

A typical SPS must have following components:

(a) Coarse and fine screens	:	To remove floatables, rags, paper etc. from raw sewage
(b) Grit Channel	:	To remove indestructible solid matter, grit etc. from raw sewage
(c) Wet well (sump well)	:	Wet well or sumps accommodates raw sewage from where pumping can be done through suction pipes.
(d) Dry well (Pump room)	:	To accommodate pumps & motors
(e) Rising mains	:	The sewage after being pumped, is taken to the high leveled gravity sewers through rising mains.

8.2 Functional Requirements of SPS [5, 44,46,47,49]

(a) Ventilation

Keeping in view of the fact that toxic gases may emanate from sewage, it is necessary to ensure proper and adequate ventilation for hazard free working at SPS, which is mandatory for both medium and large scale sewage pumping installations.

- Normally 8 to 10 air changes per hour are recommended as per the CPHEEO manual. In case of dry wells, upto 4 m depth natural inlet with exhaust fans can be used.

- Forced inlet & outlet may be used both in case of wet well and the dry well (having the depth more than 4 m below ground level).

- Ventilation design must have the provision for the dissipation of the heat generated from the electric motors, especially during hot weather.

(b) Safety Measures

In order to ensure safe operations at Sewage Pumping Stations, following measures are to be envisaged:

- Appropriate railing shall be provided around all manholes and openings where covers are left open during operation.

- Safety guards shall be provided on and around all mechanical equipment where operators generally comes in contact with the belt drives, gears, rotating shafts or other moving parts of the equipment.

- Staircases are to be provided in preference to ladders particularly for dry well access.

- SPS are to be essentially equipped with telephones with relevant contact numbers on display to make immediate contact in case of emergency.

- Pumping stations must have essential safety gadgets like fire extinguishers, face masks, first-aid boxes etc.

- All electrical equipment and wiring shall be properly insulated and grounded. Switches and control should be of non-sparking type. All wiring and devices in hazardous areas should be explosion-proof.

- Adequate lighting shall essentially be provided at the plinth and at all working levels of the pumping stations. Glares and shadows shall be avoided in the vicinity of machinery and at floor openings.

(c) Operation of Pumps

(i) There should not be any dry running of pumps. Centrifugal pumps must be started only after priming.

(ii) Helical rotor pumps, although are self-priming, being of positive displacement type and need rubber-stator to be wetted before start.

(iii) It should be ensured that the direction of the motor agrees with the arrow on the pump.

(iv) Pumps should be operated only within the recommended range of parameters specified.

(v) Operation near to the shut-off head of the pump shall be totally avoided, as re-circulation within the pump may cause overheating.

(vi) Whether a pump should be started with the delivery valve open or closed has to be decided based on their power characteristics.

- Pumps of low and medium specific speeds draw more power as the flow increases. In order to minimize the load on the motor at the time of starting, such pumps are to be started with the delivery valve closed.

- The pumps of high specific speed draw more power at shut-off and hence to be started with the delivery valve open.

- While stopping, the position of delivery valve should be as at the time of starting.

(vii) When pumps are to be operated in parallel, these should be started and stopped with time-lag between two pumps, which should be adequate enough to let the pressure-gauge stabilize.

(viii) The delivery valve shall be operated gradually to avoid surges.

(ix) Pumps should be started and stopped sequentially but with minimum time-lag as possible, while operated in series.

(x) It has to be ensured that air-vent of the pump next in sequence, is to be opened before starting the pump.

(xi) The stuffing box should let a drip of leakage to ensure that no air is passing into the pump and that the packing is getting adequate water for cooling and lubrication. The stuffing box is to be grease-sealed and adequate refill of grease is to be maintained.

(xii) The running of both the duty pumps as well as those standbys are to be so scheduled that all pumps are in ready-to-run condition.

(d) Maintenance of Pumps

The check-list of maintenance schedule to ensure regular and smooth operation of SPS encompasses routine checks as well as comprehensive checks semi-annually and annually.

(i) Routine Checks (daily/ weekly)

- Leakage through packing
- Bearing temperature
- Whether any undue noise or vibration
- Pressure, voltage and current readings

(ii) Comprehensive Checks (Quarterly/ semi-annually)

- Free movement of the gland of the stuffing box.
- Cleaning and oiling of the gland-bolts.
- Inspection of packing and re-packing.
- Alignment of the pump and the drive
- Cleaning of oil-lubricated bearing and replenishing fresh oil. If bearing are grease-lubricated, the condition of the grease should be checked and replaced to correct quantity, if necessary. An anti-friction bearing should have its housing so packed with grease that the void spaces in the bearings and the housing be 1/2 to 2/3 filled with grease. A fully packed housing will cause the bearing to overheat and hence will reduce its life.

(iii) Annual Inspection

- Cleaning and examination of all bearing for flaws developed, if any.
- Examination of shaft-sleeves for wear or scour.
- Checking Clearances
- Clearances at the wearing rings should be within the limits recommended by the manufacturer. Excessive clearances mean a drop in the efficiency of the pump. If the wear is on one side, it means mis-alignment. Not only that the misalignment should be corrected, but also the causes for the disturbance of the alignment should be investigated and the clearances have to be redeemed to the values recommended by the manufacturers.
- All instruments and flow meters shall be re-calibrated.

- Pumps should be tested to ascertain whether proper performance is being obtained.

- In the case of vertical turbine pumps, the inspection can be bi-annual.

(e) Facilities for maintenance and repairs

- Consumables and lubricants (Adequate stock of such items as gland packing, belts, lubricating oils, greases etc. shall be maintained).

- Replacement spares (To avoid downtime, a stock of fast moving spares shall be maintained. A set of recommended spares for 1-2 years of trouble free operation shall be kept along with the pumps).

- Repair workshop : The repair workshops shall be equipped with

  - Tools such as bearing pullers, clamps, pipe wrenches and other relevant equipment.

  - General purpose machinery such as welding set, grinder, blower, drilling machine and other relevant equipment.

8.3 Trouble-shootings for Pumps [5, 44, 46,47,48,49]

Trouble-shootings means detecting the trouble, investigating the cause and taking necessary remedial action for rectification. Detection of trouble is prompted by noticing possible deficiencies. Guidelines for diagnosing the causes of trouble likely to arise during operation of pumps together with the corrective actions, are essentially required to offset deficiencies. The trouble-shooting details for pumps are, hence outlined here below for various deficiencies.

I. Check Chart for Centrifugal Pump Troubles

Deficiency	Causes
♦ **No flow from pump**	- Pump not primed or priming inadequate - Suction lift too high - Air pocket in suction - Suction inlet open - Reverse rotation - System head too high - Speed too low - Discharge line clogged - Improper parallel operation
♦ **Less flow from the pump**	- Priming inadequate/ improper - Inadequate margin on NPSHr (Net Positive Suction Head Required) - Suction lift too high - Excess air/ gas in liquid - Air pocket in suction line

Deficiency	Causes
	- Air leaks into suction - Air through stuffing box - Foot-valve too small or clogged - Suction inlet open - Speed too low - System head is high - Improper parallel operation - Ingress of foreign matter. - Wearing rings worn - Impeller damaged - Casing gasket defective
♦ **Less pressure**	- Speed too low - Reverse rotation - System head too high - Viscosity variation - Improper parallel operation - Wearing rings worn - Impeller damaged - Casing gasket defective
♦ **Loss of prime after starting**	- Priming inadequate/ improper - Suction lift too high - Excess air/gas in liquid suction line - Air pocket in suction line - Air leaks into suction - Air through stuffing box - Suction inlet open - Block in lantern connection or lantern out of position
♦ **Excess Power**	- Speed too high - Reverse rotation - System head is high/ low - Denser liquid - Viscosity variation - Ingress of foreign material - Misalignment - Shaft bent - Rubbing in running - Wearing rings worn - Poor fitting of packing - Incorrect packing - Gland too tight
♦ **Leakage through packing**	- Lantern out of position - Misalignment - Shaft bent

Deficiency	Causes
	- Scouring of shaft - Poor fitting of packing or incorrect packing - Shaft runs eccentric - Rotor out of balance - Poor cooling to packing - Packing spills into pump - Dirt/ grit at lantern
♦ **Packing life is less**	- Block in lantern connection or lantern out of position - Misalignment - Shaft bent - Bearing worn - Scouring on shaft - Poor fitting of packing or incorrect packing - Shaft runs eccentric - Rotor out of balance - Gland too tight - Poor cooling to packing - Packing spills into pump - Dirt/ grit at lantern
♦ **Vibration or noise**	- Priming inadequate/ improper - Suction lift too high - Foot-valve too small or clogged - Suction inlet open - Ingress of foreign material - Misalignment - Slack foundation - Shaft bent - Rubbing in running - Bearing worn - Impeller damaged - Shaft runs eccentric - Rotor out of balance - Axial thrust not balanced - Over lubrication or poor lubrication - Wrong fitting of bearing - Dirt, rusting, water or condensation in bearing
♦ **Fast wear of bearing**	- Misalignment - Shaft bent - Rubbing in running - Bearing worn - Shaft runs eccentric

Deficiency	Causes
	- Rotor out of balance - Axial thrust not balanced - Over lubrication or poor lubrication - Wrong fitting of bearing - Dirt, rusting, water or condensation in bearing
♦ **Overheat or seizure**	- Pump not primed - Inadequate margin on NPSHr (Net Positive Suction Head Required) - Improper parallel operation - Misalignment - Rubbing in running - Bearing worn - Shaft runs eccentric - Rotor out of balance - Gland too tight - Axial thrust not balanced

II. Check Chart for Reciprocating Pump Troubles

Deficiency	Causes
♦ **Liquid end noise**	- Insufficient suction pressure - Partly loosing prime - Shocks in system - Improper piping - Air in liquid - Over-pressure/ over speed - Broken or worn valve or obstruction in valve - Worn packing
♦ **Power end noise**	- Main bearing lose - Worn bearing - Low oil level - Plunger loose
♦ **Overheating of Power end**	- Over-pressure/ over speed - Low oil level - Main bearing tight - Inadequate ventilation - Driver misaligned

Deficiency	Causes
♦ **Water in crank case**	- Condensation
♦ **Leakage from crank case**	- Worn seals
♦ **Fast wear of packing or plunger**	- Dirty liquid and environment - Foundation not rigid or leveled - Loose packing
♦ **Pitting at valve seat**	- Cavitation - Dirty liquid - Corrosion
♦ **Valves hang up**	- Valve binding - Broken valve spring
♦ **Leakage at cylinder valve**	- Over pressure/ over speed - Water hammer - Loose cylinder plug - Damaged O-ring seal
♦ **Loss of prime**	- Insufficient suction pressure - Lift too high - Leaking suction - Required accelerator head high

III. Check Chart for Rotary Pump Troubles

Deficiency	Causes
♦ **No flow**	- Priming improper - Suction partly open - Strainer clogged - Leaky footvalve - Suction lift too high - Air leaks into suction - Reverse rotation - Low speed - Pump worn
♦ **Less flow**	- Air leaks into suction - Inadequate liquid supply - Excessive pressure - Bent drive shaft - Coupling off-balance - Relief valve chatters

Deficiency	Causes
♦ **Pump runs noisy**	- Excessive pressure - Grit/ dirt in liquid - Pump runs dry - Strain from piping - Corrosion
♦ **Rapid wear**	- Strainer clogged - Suction lift too high - Air leaks into suction - Suction line under-sized - Low speed - Pump worn - Air leak at packing - Relief valve semi-open
♦ **Excess power**	- Priming improper - Suction partly open - Air leaks into suction - Suction line undersized - Inadequate liquid supply

8.4 Maintenance for Electrical Equipment[5, 44, 46,47,48,49]

(a) Facilities required for maintenance and repairs

In order to ensure smooth functioning of equipment, following needs to be envisaged:

- Adequate stock of consumables such as the lubricating oil and transformer oil should be maintained.
- To avoid downtime, stock of fast moving spares and that are likely to be damaged by the short circuit should be maintained.
- Tools such as crimping tools, soldering, brazing and other to be required in routine maintenance must be readily made available all the time.
- Routine test equipment such as megger, AVO meter (multi meter), tong tester, vibration tester, noise level tester, tachometer must be readily available.

(b) Preventive maintenance

In order to ensure smooth functioning, it is always advisable to follow a schedule of maintenance of the equipment. The schedule covers recommendations for checks and remedial actions to be observed at different periodicity.

I. Routine Checks (Daily)

(i) Motors

- Check bearing temperatures
- Check for any undue noise or vibration

(ii) Panel, circuit-breaker, Starter

- Check the phase-indicating lamps
- Note readings of voltage, current, frequency and others
- Note energy-meter readings

(iii) Transformer Sub-station

- Note voltage and current readings

II. Monthly Checks

(i) Motors

- Nothing special other than daily checks

(ii) Panel, circuit-breaker, Starter

- Examine contacts of relay and circuit breaker. Clean, if necessary.
- Check setting of over-current relay, no volt coil and tripping mechanism and oil in the dash-pot relay.

(iii) Transformer Sub-station

- Check the level of the transformer oil.
- Check that the operation of the Ground Operated Dis-connectors (GOD) and of OC.
- Check temperature of oil and windings
- Clean radiators to be free of dust or scales
- Pour 3 to 4 buckets of water in each earth pit

III. Quarterly Checks

(i) Motors

- Blow away dust and clean any splashing of oil or grease.
- Check wear of slip ring and brushes; smoothen contact- faces or replace, if necessary. Check

spring-tension. Check brush-setting for proper contact on the slip ring.

- Check cable connections and terminals and insulation of the cable near the lugs; clean all contacts, if insulation is damaged by overheating investigate and rectify. All contacts should be fully tight.

(ii) Panel, circuit-breaker, Starter

- Check fixed and moving contacts of the circuit breakers/ switches. Check and smoothen contacts with fine glass papers or file.
- Check condition and quantity of oil/ liquid in circuit breaker, auto transformer starter and rotor controller.

(iii) Transformer Sub-station

- Check condition of H.T bushing.
- Check the condition of the de-hydrating breather and replace the silica gel charge, if necessary. Reactivate old charge for reuse.

IV. Semi-annually Checks

(i) Motors

- Check condition of oil & grease, replace if necessary. Avoid excessive greasing
- Test insulation by megger.

(ii) Panel, circuit-breaker, Starter

- Nothing special

(iii) Transformer Sub-station

- Check di-electric strength and acid test of transformer oil and filter, if necessary.
- Test insulation by megger.
- Check continuity for proper earth connections.

V. Annual Checks

(i) Motors

- Examine bearings for flaws, clean and replace if necessary.
- Check end-play of bearings and reset by lock-nuts wherever provided.

(ii) Panel, circuit-breaker, Starter	♦ All indicating meters should be calibrated
(iii) Transformer Sub-station	♦ Check resistance of earth pit/ earth electrode

(c) Trouble-shootings for Electrical Equipment

Guidelines for diagnosing the causes of trouble likely to arise during operation of pumps together with the corrective actions required to offset deficiencies. The trouble-shooting details for electrical equipment are hence outlined here below for various deficiencies.

Deficiency	Causes
♦ **Motor gets overheated**	- Check whether voltage too high or too low. - Change tapping of transformer, if HT supply is availed. Otherwise approach power supply authorities for correction of the supply voltage. - Check whether air ventilation passage of motor is blocked. Clean the passage. - Check whether the motor bearings are improperly lubricated or damaged. - Check bearings for damage and lubrication. - Check whether the cable terminals at the motor are loose. Tighten the terminals.
♦ **Motor gets overloaded**	- Check for any friction. - Check whether characteristics of pump (i.e the related driven equipment) are of overloading type. - Check for any vortices in the sump. - Check that there is no short-circuiting or single phasing. - Check whether any foreign matter has entered the air gap causing obstruction to the smooth running of the motor.
♦ **Starter/ Breaker Trips**	- Check whether the relay is set properly. Correct for setting, if necessary. - Check whether motor is getting overloaded.

Deficiency	Causes
	- Tripping can also be due to short-circuiting or single-phasing. - Oil in dashpot relay may be either inadequate or of low viscosity. - Check that there is no loose connections. - Check whether the timer setting of auto transformer starter are proper.
♦ **Vibration in motor**	- Check for rigidity of supporting frame and foundation. - Check alignment of pump and motor. - Check that the nuts on foundation bolts are tight. - Check if rotor has an imbalance. - Check for resonance from supporting structure or foundation or from critical speed of rotor or from vibration of adjoining equipment.
♦ **Cables get overheated**	- Check whether the cable is undersized. Change the cable or provide another cable in parallel. - Check for loose termination of joint. Fasten the termination and make proper joint. - Check whether only a few strands of the cable are inserted in the lug. Insert all strands using anew lug, if necessary.

8.5 Unit Operations, Processes, Functions and Devices[5, 44, 46,47,48,49]

Unit wise operational process as well as details pertaining to equipment/ devices are given below. ASP Operations will be applicable to MCGM after up-gradation under MSDP Stage-II.

Unit Operations and Processes	Functions	Devices/ Equipment
Screening	♦ Operational process of STP starts with screening. ♦ Removal of large floating suspended and settleable solids and hence to protects pumps & other equipments from damage.	♦ Bar racks and screens of various descriptions ♦ Motors ♦ Conveyer ♦ LT Panels
Grit Removal	♦ Removal of inorganic particles such as sand, gravel, grit etc. to prevent damage to the pumps and to prevent their accumulation in sludge digester. ♦ Grit removal is necessary to protect the moving mechanical equipment and pump elements from abrasion. ♦ Removal of grit also reduces the frequency of cleaning of digesters and settling tanks.	♦ Rack Classifier and agitators. ♦ Grit chamber ♦ Motors ♦ Gear box and control mechanism ♦ LT Panels
Primary Sedimentation	Primary sedimentation of sewage also reduces the organic load on secondary treatment units. It removes ♦ Inorganic suspended solids ♦ Free oil and grease and other floating material	PSTs of varying capacities equipped with : ♦ Motors ♦ Pumps ♦ Gear box and control mechanism ♦ LT Panels
Activated Sludge Process (Aeration Tank)	Conversion of colloidal, dissolved and residual suspended organic matter into settleable biofloc and stable organics : ♦ The sewage containing waste organic matter is aerated in the aeration basin in which micro-organisms metabolize the soluble and suspended organic matter.	ASP units equipped with ♦ Aerator Fans ♦ Motors ♦ Pumps for return sludge ♦ Gear box and control mechanism ♦ LT Panels

Unit Operations and Processes	Functions	Devices/ Equipment
	♦ Part of the organic matter is synthesized into new cells and part is oxidised into carbon dioxide and water. ♦ The new cells formed in the ASP are removed from liquid stream in the form of flocculent sludge in settling tank. A part of this activated sludge is recycled to the aeration basin and the remaining forms waste or excess sludge. ♦ The suspended soilds concentration in the aeration tank liquor, also called mixed liquor suspended solids (MLSS) is generally taken as an index of the mass of active micro-organisms in the aeration tank. ♦ The aeration equipment shall provide adequate mixing in the aeration tank to keep solids in suspension.	♦ Aerator Fans ♦ Motors ♦ Pumps for return sludge ♦ Gear box and control mechanism ♦ LT Panels
Secondary Settling	♦ Secondary settling assumes considerable importance in the ASP as the efficient separation of the biological sludge is necessary not only for ensuring final effluent quality but also for return of adequate sludge to maintain the MLSS level in the aeration tank. ♦ The secondary settling tank of the ASP is particularly sensitive to fluctuations in flow rate and on this account it is recommended that the units be designed not only for average overflow rate but also for peak overflow rates.	♦ Motors

Unit Operations and Processes	Functions	Devices/ Equipment
Sludge digester, Gas mixer & booster and Gas holders	♦ Organic sludges are important by-products of conventional ASP based STP. ♦ The settleable solids that are organically present in raw sewage and those synthesized and bio-flocculated during biological treatment are removed in settling tank as sludge. ♦ Sludge thickening or de-watering is adopted for reducing the volume of sludge prior to loading into sludge digesters. ♦ Sludge digestion can be achieved biologically under anaerobic/ aerobic conditions. ♦ The primary purpose of a gas holder is to adjust the difference in the rate of gas production and consumption as well as to maintain uniform pressure.	♦ Digesters ♦ Motors ♦ Pumps ♦ Gas Compressors ♦ Gas holders ♦ LT Panels

8.6 STP/ WWTF Operation and Maintenance[5, 44, 46,47,48,49]

(a) General Maintenance (Preventive and Corrective)

The objective of STP Operation and Maintenance is the systematic planning to take appropriate steps to prevent breakdown well in advance so that major breakdowns can be prevented. Preventive maintenance which constitute work and precautions to be taken to prevent breakdown. Corrective maintenance which involves carrying out repairs after the breakdown. The preventive maintenance is much more economical than the corrective maintenance and provides uninterrupted service which is essential to achieve the basic objectives of the sewage treatment. The proper maintenance does not start at repairs but at the time of planning, selection and the installation of machinery. In fact much of the preparation starts at the planning stage itself. If due care is not taken in properly forming specification and selection, it would not only result into poor performance but also causes the frequent breakdowns. The basic requirements of successful operation and maintenance of STP are:

(i) Operating staff must have thorough knowledge of availability and functioning of plant, machinery and equipments provided in the STP.

(ii) Operating staff must have thorough knowledge of the processes of treatment.

(iii) STPs to be equipped not only with proper and appropriate tools but also have adequate stock of spare parts and chemicals.

(iv) STPs must have the provision of the assignment of specific maintenance responsibilities to operating staff.

(v) There shall be the provision of systematic and periodic inspection and strict adherence to servicing schedule.

(vi) There shall be the provision of training of all operating staff in proper operating procedures and maintenance practices.

(vii) Good housekeeping is one of the essential requirement of STP operation.

(viii) STPs must have procedure for proper logging of all operation/ maintenance activities.

(ix) STPs must have adequate supply of water for drinking and other uses.

(x) There shall be strict adherence to safety precautions and procedures.

(b) Operation & Maintenance : Treatment Units

In order to ensure better plant operation, it would be essential that the operational, maintenance and laboratory staff of STP shall be fully conversant with the characteristics and composition of sewage being treated together with expected and achieved results at each stage of the treatment process. Operation and preventive maintenance of several treatment units and the frequency of cleaning, lubrication of mechanical equipment etc. are to be strictly adhered to if optimum results are to be expected.

Treatment Unit/s	Operation & Maintenance
Screening	♦ Manual screens to be cleaned as often as required to prevent backing up of sewage. ♦ Mechanical screens should be kept promptly lubricated as per the instructions of manufacturers. The entire mechanism should be thoroughly cleaned and to be coated with the appropriate anticorrosive paint. Periodic inspection of mechanical and automatic screens is essential to ensure that the equipment is functioning properly.

Treatment Unit/s	Operation & Maintenance
	♦ Screen chambers should be hosed at least once a day to keep them clean and the walls should be scrubbed at least once a week. ♦ Prompt and hygienic disposal of screening in the environmentally acceptable way is necessary. Burial or composting with city refuse or trenching under earth cover are the prominent ways to handle screenings ♦ Daily record of operations should be maintained to show frequency of cleaning, volume of wet screening removed and power consumption of mechanical operated/ automatic screens.
Grit Chambers	♦ The frequency of grit removal should be adjusted such that the storage space shall not be occupied more than 50 percent at any time. ♦ In manual cleaning operation, the flow has to be shut off, the chamber to be emptied by gravity or pumping and the grit hauled by using long handled shovels, buckets and wheel barrows. The operator must always use gum boots and hand gloves. ♦ Inspection of mechanically cleaned grit chambers consists of checking of washed grit, lubrication of mechanical equipments as per manufacturer schedule and routine inspection. ♦ Grit to be disposed-off safely at predetermined disposal sites, providing adequate earth cover. ♦ The record of operation should show the dates of cleaning, amount of grit removed and flow through the chambers between cleanings.
Sedimentation Tanks	**Sludge** ♦ The sludge removal frequency to be maintained in such a way to prevent the development of septic conditions. ♦ Sludge from the primary sedimentation tanks is to be drawn from the sludge sump by means of a pump discharging into digesters. ♦ Sludge from secondary settling tanks to be pumped partially into the aeration tanks and partially to PST. While drawing the sludge, the operator should adjust pumping capacity according to the quantities required for feeding the digester or returned to aeration tank or primary sedimentation tanks. ♦ Excessive sludge pumping and withdrawal of watery sludge to be avoided.

Treatment Unit/s	Operation & Maintenance
	♦ In sedimentation tanks provided with mechanical sludge scrapers, sludge to be withdrawn continuously or at predetermined intervals. ♦ If automatic starting and stoppage of pumps is involved, the setting of this equipment should be periodically checked. **Bulking and Rising of Sludge** ♦ The quick settleability of sludge is an important factor in the efficient performance of the activated sludge plant. ♦ The SVI is an index of sludge settleability. SVI values in range of 50-150 ml/g are considered satisfactory in plants operating with MLSS ranging between 1500-4000 mg/l. ♦ Sludge with poor settling characteristics is termed bulking sludge. Sludge bulking results in poor efficiency due to the presence of excessive suspended solids and also in rapid loss of MLSS from aeration tank. ♦ Sludge bulking is generally due to inadequate air supply, low pH or septicity and also due to growth of filamentous organisms. ♦ When sludge bulking occurs, the suggested remedies are: (i) reduction in rate of sewage flow into aeration tanks (ii) reduction in ratio of return sludge (iii) increase in air supply (iv) dilution of incoming sewage. **Skimming** ♦ Floating materials getting collected on the surface of primary sedimentation tanks are to be removed by skimming devices to be operated mechanically. ♦ In case, mechanical skimmers are not provided or out of order, manual removal of skimmings is recommended once in a day. ♦ The skimmer device should be inspected periodically together with the lubrication of moving parts. **Structure and Mechanical Equipment** ♦ The side walls of the settling tanks should have adequate finishing so as to minimize the accumulation of solids, grease, oil and aquatic growth. ♦ Accumulations, if any, to be removed periodically by brushing and hosing.

Treatment Unit/s	Operation & Maintenance
	♦ Dark floating matter and rising bubbles on the surface indicate improper cleaning and inadequate sludge removal. ♦ Inlet and outlet channels should be kept clean and hosed at least once in a week. ♦ All baffles should be cleaned of any sticky materials and stringy growth on the surface and edges. ♦ The bearings, transmission gears, traction rollers etc. are to be properly lubricated as per the lubricating schedule. ♦ Each clarifier has to be de-watered at least once in a year to inspect the submerged portions of the mechanism such as flight scrapper, squeezers etc. in addition to repairing/ replacement of worn- out part.
Aeration Tanks	**Operational Variables of Aeration Tank** ♦ The operational variables in an activated sludge plant include rate of flow of sewage, air supply, MLSS control, aeration period, DO in aeration, settleability, rate of return sludge and sludge condition. ♦ Effective control/ optimization of aeration tank variables shall be maintained and operators must have adequate knowledge of these variables. ♦ Inspection of mechanical aerators has to be done for bearings, bushes, transmission gears, which shall be lubricated as per the schedule of manufacturer. ♦ The whole unit to be inspected thoroughly once in a year including replacement of worn out parts and coating with anti-corrosive paint to achieve desired efficiency. **Sewage Flow** ♦ Since the activated sludge treatment is biochemical in nature, the condition of the aeration tank to be maintained uniformly all the time. ♦ Sudden increase in rate of flow or slug of flow to be avoided. **Air Supply** ♦ Frequent checks of DO at various points in the aeration tank and at the outlet end, which should not be less than 1 mg/l, will help in determining the adequacy of air supply.

Treatment Unit/s	Operation & Maintenance
	♦ The uniformity of air distribution can also be checked by observing bubbles of air at the surface, which should be evenly distributed over the entire surface area of the tank. Uneven distribution indicates clogging of diffusers. ♦ Air flow meters should be checked periodically for air supply and pressure to control over-aeration or under-aeration. ♦ Mechanical or surface aerators to be kept free from fungus or algal growths by periodic cleaning. **Control of Mixed Liquor Suspended Solids (MLSS)** ♦ Control of the concentration of solids in the mixed liquor of the aeration tank is an important operating factor. ♦ It is essential to keep the MLSS constantly in range of 50-150 ml/g. ♦ The test of MLSS to be done preferably twice in a day (both during peak and lean flow). ♦ The MLSS will be minimum during peak flow and maximum during the lean flow. **Return Sludge** ♦ The return sludge pump to be operated according to the increase or decrease in return sludge rate of flow required to maintain the desired concentration of MLSS in the aeration tank based on SVI. ♦ The SVI value of over 200 indicates sludge bulking. ♦ The prompt removal of excess sludge from aeration tank is essential to ensure that the sludge is fully aerobic. ♦ The excess sludge is to be taken to digester directly or through PST. **Foaming** ♦ Foaming or frothing is some time seen in the activated sludge plant, when the sewage contain materials which reduce the surface tension such as synthetic detergent. ♦ Foaming can be controlled by decreasing the air supply or addition of the anti-foam agent.

Treatment Unit/s	Operation & Maintenance
	♦ The presence of synthetic anionic detergents in sewage also interferes with the oxygen transfer thereby reduces aeration efficiency.
Sludge Digestion	**Digestion Operation** ♦ Pumping capacity and pumping hours of the sludge from settling tanks to the digester shall be recorded on daily basis. ♦ The alkalinity and pH value of sludge is to be measured at the time of pumping. ♦ The date & time of withdrawal of sludge, quantity drawn, quantity of sludge loaded on drying beds and the depth of loading shall be monitored. ♦ Raw sludge to be characterized for percent dry solids. The digested sludge to be analysed for total and volatile solids. ♦ Gas production to be measured on daily basis and gas samples to be analysed for methane concentration and calorific value. **Sludge Drying Beds** ♦ Sludge that is drawn to the beds generally contains 4-10% solids depending upon the type of sludge. ♦ Wet sludge to be applied to the beds to a depth of 20 to 30 cm. After each layer of dried sludge has been removed, the bed should be raked and levelled. Sludge should never be discharged on a bed containing dried or partially dried sludge. ♦ Removal of dried sludge from bed surfaces should be done with shovel, while taking care that sand is not to be removed . ♦ When the sand layer is reduced to as low as 10 to 15 cm, it may be clogged by organic matter and if found so during examination, the entire sand to be removed and the bed re-sanded to the original depth of 20 to 30 cm. ♦ The dried sludge cakes can be used as fertilizer.

(c) Maintenance of Records

Operational records of all units of STP are to be maintained on daily basis with respect to operation, maintenance (preventive and corrective).

8.7 Activated Sludge Process[5, 43,44,46,47,48,49,50]

The Activated Sludge Process of Sewage Treatment includes following steps:

- The sewage effluent from the PST is mixed with the activated sludge, which contains large numbers of highly active aerobic micro-organisms.
- The mixture enters the aeration tank, where the micro-organisms (coated around the sludge solids) and the sewage are intimately mixed with the large amount of air (through diffusers/ surface aerators/ fans/ blowers etc.) for about 4 to 8 hours.
- Suspended and colloidal matter in sewage tend to coagulate and form a precipitate, which settle down in the secondary settling tank.
- The settled sludge (containing mico-organisms) called activated sludge, is then recycled to the head of aeration tank, to be mixed again with the sewage being treated.
- New activated sludge is continuously being produced by this process and a portion of it being utilized and sent back to the aeration tank, whereas the excess portion is disposed-off properly along with the sludge collected during primary treatment, after digestion.

Process Optimization Parameters

Various parameters to be considered for optimization of activated sludge process of sewage treatment are described as follows.

(a) Aeration Tank Loading

Significant aspects which define the loading rates of an activated sludge plant, include

(i) Aeration Period or Hydraulic Residence Time (HRT)

The aeration period (t) empirically denote the loading rate at which the sewage is fed into the aeration tank. It can be estimated as follows:

$$\textbf{Aeration Period or Detention Period or HRT} = \frac{V \text{ in } m^3}{Q \text{ in } m^3/d} = \frac{V}{Q} \times 24$$

Where,

t = aeration period in hours

V = Volume of aeration tank

Q = Quantity of wastewater inflow into aeration tank (excluding quantity of recycled sludge)

(ii) BOD loading per unit volume of aeration tank (Volumetric BOD Loading)

It is the BOD load applied per unit volume of aeration tank. It is also known as organic loading.

Volumetric BOD loading or Organic loading $= \dfrac{Q.Y_o \text{ (gm)}}{V \text{ (m}^3\text{)}}$

Where,

V = Volume of aeration tank

Q = Quantity of wastewater inflow into aeration tank

Y_o = BOD_5 in mg/l (gm/m^3) of influent sewage

(iii) Food (F) to Micro-organism (M) Ratio (F/M Ratio)

F/M ratio is an important rational organic loading rate, adopted for an activated sludge process. It is a manner of expressing BOD loading with regard to the microbial mass in the system. The BOD load applied to the system in kg or gm is represented as food (F) and the Mixed Liquor Suspended Solids (MLSS) in the aeration tank is represented by M.

If Y_o (mg/l) represents the BOD of the influent sewage with flow Q m^3/day

Hence, BOD load applied to the aeration tank $= F = Q.Y_o$ gm/d

The total microbial mass in the aeration system (M) can be computed by multiplying the average concentration of solids in the mixed liquor of the aeration tank (MLSS) with the volume of the aeration tank (V).

$$\mathbf{M} = \text{MLSS} \times V = X_t.V$$

Hence, F/M ratio $= \dfrac{F}{M} = \dfrac{Q.Y_o}{V.X_t}$

F/M ratio for an activated sludge plant is the main factor controlling BOD removal. Lower the F/M value, the higher will be the BOD removal in the plant. The F/M ratio can be varied by varying the MLSS concentration in the aeration tank.

(b) Sludge Age

The sludge age is an operational parameter related to the F/M ratio. It is the average time for which particles of suspended solids remain under aeration. It, thus, indicates the residence time of biological solids in the system. While sewage passes through the aeration tank only once, the resultant biological growth and solids are repeatedly recycled from the secondary clarifier back to the aeration tank, thereby increasing the retention time of solids. The time period for which solids remain in the aeration tank is called Solids Retention Time (SRT) or Mean Cell Residence Time (MCRT) or Sludge Age.

The most common method of expressing Sludge Age, usually represented by θ_c in days and is estimated as the ratio of the mass of MLSS in the aeration tank relative to the mass of suspended solids leaving the system per day.

$$\textbf{Sludge age } (\Theta_c) = \frac{\text{Mass of suspended solids (MLSS) in the system (M)}}{\text{Mass of solids leaving the system per day}}$$

For a conventional activated sludge plant, with flow (Q), concentration of solids (X_t) and BOD_5 (Y)

Mass of solids in the reactor	=	V x MLSS = $V.X_T$
Mass of solids removed with the wasted sludge per day	=	$Q_w.X_R$
Mass of solids removed with effluent per day	=	$(Q - Q_w).\ X_E$
Hence, total solids removed from system per day	=	$Q_w.X_R + (Q - Q_w)\ X_E$
Sludge age (Θ_c)	=	$\dfrac{V.X_T}{Q_w.X_R + (Q - Q_w)\ X_E}$

Where
- X_T = Concentration of Solids in the influent of Aeration Tank (MLSS)
- V = Volume of Aeration Tank (in m^3)
- Q_w = Volume (in m^3) of wasted sludge per day
- X_R = Concentration of solids in the return sludge (in mg/l)
- Q = Sewage inflow per day
- X_E = Concentration of solids in the effluent

(c) Sludge Volume Index (SVI)

The term Sludge Volume Index is used to indicate the physical state of the sludge produced in a biological aeration system. It represents the degree of concentration of the sludge in the system, and hence decides the rate of recycle of sludge (Q_R) required to maintain the desired MLSS and F/M ratio in the aeration tank to achieve the desired degree of purification.

SVI is defined as the volume occupied in one milliliter by one gram of solids in the mixed liquor after settling for 30 minutes and is to be determined experimentally. The test method to be performed in the laboratory to compute SVI of an aeration system involves following steps:

- Collection of mixed liquor sample of wastewater from the aeration tank.
- One litre of mixed sample has to be taken in Imhoff Cone and allowed to stand for 30 minutes for settling of solids.
- Sludge volume (in ml) has to be recorded at the end of 30 minutes.
- Concentration of MLSS in terms of weight has to be measured by performing standard test for estimation of suspended solids (APHA method).

$$\textbf{SVI, ml/g} = \frac{\text{Volume of MLSS (ml/l)}}{\text{Weight of MLSS (mg/l)}} \times 1000$$

Relationship between Sludge Volume Index and Settling Characteristics of Sewage are given below:

SVI Value	Indication
Less than 50 ml/g	Pin floc Potential
50 to 100 ml/g	Good Range
100 to 150 ml/g	Filament Growth
150 to 200 ml/g	Bulking at high flows
200 to 300 ml/g	Bulking
More than 300 ml/g	Severe Bulking

(d) Sludge Recycle and Rate of Return Sludge

The MLSS concentration in the aeration tank is controlled by the Sludge Recirculation Rate and the sludge settleability and thickening in the secondary sedimentation tank. The relationship between sludge recirculation ratio is given by:

$$\frac{Q_R}{Q} = \frac{X_t}{X_R - X_t}$$

Where Q_R = Sludge recirculation rate in m^3/d
X_t = MLSS in aeration tank in mg/l
X_R = MLSS in the returned or waste sludge (in mg/l)

The settleability of sludge is determined by Sludge Volume Index (SVI). If it is assumed that the sedimentation of suspended solids in the laboratory is similar to that in the sedimentation tank, then

$$X_R = \frac{10^6}{SVI}$$

$$\textbf{Return Sludge Ratio} = \frac{Q_R}{Q} = \frac{X_t}{\frac{10^6}{SVI} - X_t}$$

(e) Excess Sludge Wasting

It involves:

- The sludge generated in the aeration tank has to be wasted to maintain a steady level of MLSS in the system.
- The excess sludge quantity will increase with increasing F/M and decrease with increasing temperature.
- In the case of domestic sewage, the excess sludge to be wasted will be about 0.35 –0.50 kg/kg BOD removed for the conventional system.
- Excess sludge may be wasted either from the sludge return line or directly from the aeration tank as mixed liquor. The latter procedure is to be preferred as the concentration of suspended solids will then be fairly steady in the waste stream providing better control on biomass wasted.

(f) Nitrification

Activated sludge plants are generally designed for the removal of only carbonaceous BOD. However, there may be incidental nitrification in the process. Nitrification though generally not desired, it may be required in specific cases such as (i) when concentration ammonia is in excess (ii) when removal of nitrogenous matter is required (to prevent eutrophication).

- Nitrification consumes part of the oxygen supplied to the system and reduce the DO level in the aeration tank.
- Nitrification will also lead to subsequent de-nitrification in the secondary settling tank thereby causing a rising sludge problem (also known as blanket rising).
- Nitrification is aided by low F/M and long aeration.

(g) Oxygen Requirement of the Aeration Tank

Oxygen is required in the activated sludge process in the aeration tank for oxidation of part of the influent organic matter, and also for endogenous respiration of the micro-organisms in the system. The total oxygen requirement may be computed by using following equation:

$$\textbf{O}_2\textbf{ required} = \left[\frac{Q\,(Y_o - Y_E)}{f} - 1.42.\ Q_w.\ X_t \right]$$

Where,

$$\mathbf{f} = \frac{BOD_5}{BOD_u} = \frac{\text{5 days BOD}}{\text{Ultimate BOD}} = 0.68$$

This formula represents the oxygen demand for carbonaceous BOD removal and does not account for nitrification. The extra requirement of oxygen for nitrification is theoretically found to be 4.56 kg O_2/ kg NH_3-N oxidized to NO_3-N.

(h) Operational Parameters and Optimization

The most important aspect in the operation of an activated sludge plant is the maintenance of proper F/M which can be achieved by increasing or decreasing the MLSS levels in the aeration tank to suit the influent BOD loads. The MLSS in the aeration tank can be regulated by controlling the rate of sludge return based on SVI to be determined experimentally. The quick settleability of sludge is an important factor in the efficient performance of the activated sludge plant. The SVI also is an important index of sludge settleability. SVI values of 50 to 150 are considered satisfactory.

Sludge with poor settling characteristics is termed bulking sludge. Sludge bulking results in poor effluent due to the presence of excessive suspended solids and also in rapid loss of MLSS from aeration tank. Sludge bulking is generally due to inadequate air supply resulting in low pH or septicity and growth of filamentous organisms. Sludge bulking is controlled by eliminating the causes and by application of chlorine either to the sewage or to the return sludge to control filamentous growths. Chlorine requirements in general range between 0.2 to 1.0 percent of dry solids weight of return sludge.

Various parameters for the process optimization are given below:

Process Parameter	Process Type (Flow Regime)		
	Conventional	Complete Mix	Extended Aeration
MLSS, mg/l	1500 to 3000	3000 to 4000	3000 to 5000
F/M (Kg BOD_5/ Kg MLSS)	0.3 to 0.4	0.3 to 0.5	0.1 to 0.18
HRT, h	4 to 6	4 to 6	12 to 24
Sludge Retention Time (θ_c in days)	5 to 8	5 to 8	10 to 26
Return Sludge Ratio, Q_R/ Q	0.25 to 0.5	0.25 to 0.8	0.25 to 1.0
Efficiency (%)	85 to 92	85 to 92	95 to 98
Kg O_2/ Kg BOD_5 removed	0.8 to 1.0	0.8 to 1.0	1.0 to 1.2

8.8 Aerated Lagoons[4, 44, 48]

Aerated lagoons are generally provided in the form of simple earthen basins with inlet at one end and outlet at the other to enable the sewage to flow through while aeration is usually provided by mechanical means to stabilize the organic matter. The major difference between activated sludge systems and aerated lagoons is that in the latter, settling tanks and sludge recirculation are absent. Aerated lagoons are of two principal types depending on how the microbial mass of solids in the system is handled.

- Facultative Aerated Lagoons are those in which some solids may leave with the effluent stream and some settle down in the lagoon since aeration power input is just enough for oxygenation and not for keeping all solids in suspension. As the lower part of such lagoons may be anoxic or anaerobic while the upper layers are aerobic, the term facultative is used.

- Aerobic Lagoons, on the other hand, are fully aerobic from top to bottom as the aeration power input is sufficiently high to keep all the solids in suspension besides meeting the oxygenation needs of the system. No settlement occurs in such lagoons and under equilibrium conditions the new (microbial) solids produced in the system equal the solids leaving the system. Thus, the solids concentration in the effluent is relatively high and some further treatment is generally provided after such lagoons. If the effluent is settled and the sludge recycled, the aerobic lagoon, in fact, becomes an activated sludge or extended aeration type lagoon.

A few typical characteristics of the above types of lagoons are given below:

Characteristics	Facultative Aerated Lagoons	Fully Aerobic	Extended Aeration System (For Comparison)
Detention time, days	3-5	2-3	0.5-1.0
Depth, m	2.5-5.0	2.5-4.0	2.5-4.0
Land required, m^2/person	0.15-0.30	0.10-0.20	-
BOD removal efficiency %	80-90	50-60	95-98
Overall BOD removal rate, K[1]	0.6-0.8	1-1.5	20-30
Suspended Solids in lagoon, mg/l	40-150	150-350	3000-5000
Desirable power level[2]	0.75	2.75-6.0	15-18
Power requirement, kWh/person/year	12-15	12-14	16-20

[1]Per day at 20 degree C for soluble BOD only; [2]in watts per cum of lagoon volume

Design Variables

For facultative aerated lagoons, the dispersed flow model just referred to gives the relation between influent and effluent substrate concentrations, S_0 and S, respectively and other

variables such as the nature of the waste, the detention time and the mixing conditions, as shown in the following equation.

$$\frac{S}{S0} = \frac{4ae^{1/2d}}{(1+a)^2e^{a/2d}-(1-a)^2e^{-a/2d}}$$

In which the term a = √1+4KΘd;

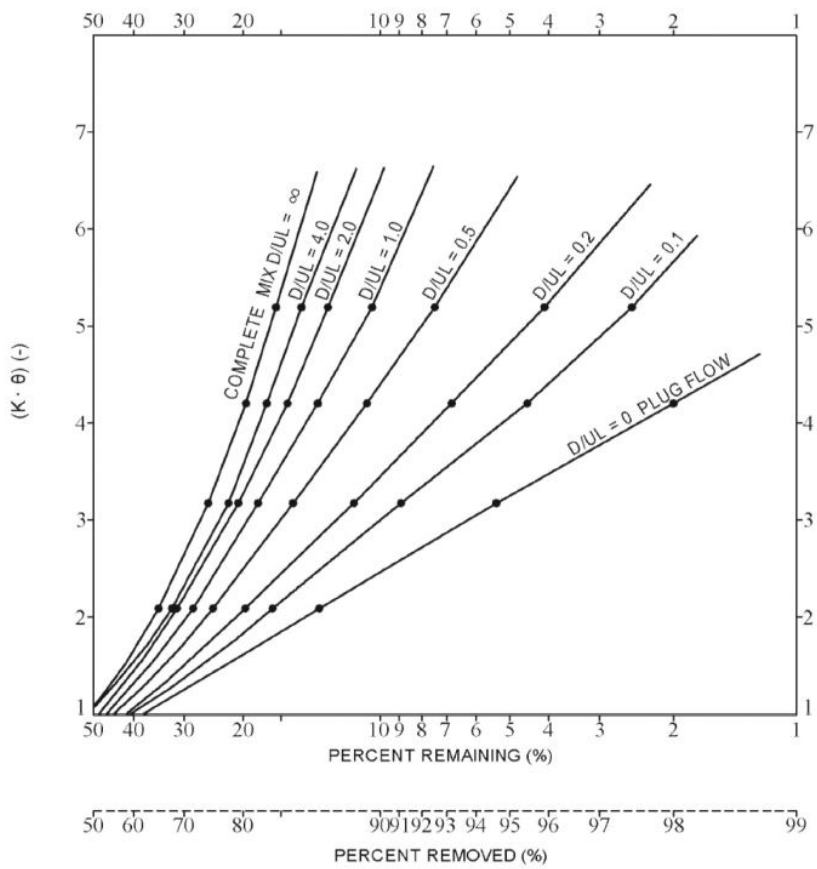
d: dispersion number (dimensions)

= D/UL = $D\Theta/L^2$

Where

D	:	Axial dispersion coefficient (length^2/time)
L	:	Length of axial travel path
Θ	:	Theoretical detention time (Volume/ Flow Rate)
U	:	Velocity of flow through lagoon (length/ time)
K	:	Substrate removal rate in lagoon (time^{-1})
S_0 & S	:	Initial and final substrate concentration (mass/volume)

Figure-57: Substrate removal efficiency using the dispersed flow model (Wehner - Wilhem equation) [4]



Mixing Conditions

The mixing conditions in a lagoon are reflected by the term'd' which is known as the "Dispersion Number" and equals (D/UL) or (D/L^2). It is affected by various factors. Observed results have shown the (D/UL) values to be in the approximate range as given below for different length-width ratios of lagoons. By suitable choice of a lagoon's geometry one can promote either more plug flow or more complete mixing type of conditions. In case of cells in series, each cell may be well mixed with value of D/UL approaching 3.0 or 4.0 but overall the arrangements would give a relatively plug-flow type arrangement.

Aerated Lagoon	Approximate range of D/UL values	Typical mixing condition
Length to width ratio 1:1 to 4:1	3.0 to 4.0 and over	Well mixed
Length to width ratio 8:1 or more	0.2 to 0.6	Approaching plug flow
Two or three cells in series	0.2 to 0.6 (overall)	Approaching plug flow

Effluent Characteristics

The effluent is generally made to flow over an outlet weir. As the concentration of solids passing out in the effluent may be nearly the same as that in the lagoon, the BOD corresponding to the volatile fraction of these solids (assumed as 0.77 mg per mg VSS in effluent) should be added to the value of the soluble BOD. Thus, the final effluent BOD is given by:

$$\text{Final BOD, mg/l} = \text{Soluble BOD, mg/l} + (0.77)\ (\text{VSS in effluent}), \text{mg/l}$$

It is because of the suspended solids (expected to range from 40 to 60 mg/l in case of sewage in the final effluent that the total effluent BOD is difficult to reduce below 30-40 mg/l in winter. At other times of the year BOD of less than 30 mg/l may be possible. This range of BOD is more than adequate for irrigation purposes.

In case of river discharge, the applicable standards should be ascertained and design made accordingly, Where necessary, further reduction of BOD can be achieved either by a small increase in detention time or by more efficient interception of solids flowing out (e.g. deeper baffle plate ahead of outlet weir) or by provision of an additional treatment unit. Nitrification is not likely to occur in aerated lagoons, Coliform removal shows considerable seasonal variation (60 - 90% removal).

Sludge Accumulation

Sludge accumulation occurs at the rate of 0.03 to 0.05 cum per person per year as in the case of oxidation ponds and is manually removed once in 5-10 years and used as good agricultural soil filler. The depth of the lagoon may be increased a little to allow for sludge accumulation, if desired.

8.9 Operational Trouble in Sewage Treatment Plant[5, 44, 46,47,48,49]

Redressal of trouble-shooting during operational stage of STP may be done as follows:

Operational Problem	Possible Causes	Suggested Action for Off-setting Trouble
A. Pre-treatment		
Unusual or excessive screening	Increase in domestic sewage or industrial effluent	Clean screen more often
Excessive grit	Excessive mixing of stormwater from roads	
Excessive organic matter in grit	Velocity is too low and detention period is too long	♦ Reduce the cross-sectional area of channels ♦ Install planks, bricks or reshape outlet weir to increase flow
Carryover of grit	Velocity is too high and detention is too low	Remove grit more frequently or increase number of channels or increase cross sectional area of channel
B. Sedimentation Tank		
Floating sludge in all tanks	Accumulated sludge decomposing in the tank and buoyed to the surface	Remove sludge more often and completely
Black liquor and strong odour	Septic sewage or strong digester supernatant	♦ Eliminate septicity by improving hydraulics of sewer system. ♦ Optimise digester operation to improve the quality of supernatant. ♦ Reduce flow into settling tank or bypass supernatants completely into lagoons till situation improves.

Operational Problem	Possible Causes	Suggested Action for Off-setting Trouble
Excessive settling in inlet channels	Velocity too low	♦ Reduce cross-sectional area of channel. ♦ Agitate adequately with air or water to prevent deposition
Excessive supernatant matter in effluent	♦ Accumulated sludge flow through tanks too fast (over loading) ♦ Humus sludge or under drainage return too fast	♦ Clean tanks more often and get the loading reduced. ♦ Reduce pumping rate.
Excessive floating matter in the effluent	Defective scum boards or none	Repair scum boards or install new ones.
Sludge pipes choke	♦ Sludge too thick ♦ Sludge contains grit	♦ Clean grit chamber more often ♦ Change sludge piping if necessary
Intermittent surging of flow	High intermittent pumping rates	♦ Adjust pumping rates to keep close to rates of flow or install. ♦ Adjust baffling to reduce inlet velocity and to have effective flow distribution across the width of tank.
Sludge hard to remove from hopper	♦ High content of grit or clay ♦ Low velocity in withdrawal line.	♦ Reduce grit content or reduce clay-content; or rod the clogged lines. ♦ Pump sludge more often; or change sludge piping.

Operational Problem	Possible Causes	Suggested Action for Off-setting Trouble
Highly objectionable odour	Anaerobic decomposition of sewage sludge or biological growth	♦ Maintain aerobic conditions in all units. ♦ Reduce accumulation of slime and biological growth.
C. Activated Sludge		
Change in Sludge Volume Index	High soluble organic loads in sewage	♦ Decrease aeration liquor suspended solids ♦ Control bulking of activated sludge.
Rising sludge (in settling tanks)	Due to excessive nitrification	♦ Increase rate of return activated sludge from the final settling tank. ♦ Decrease the rate of flow of aeration liquor into the tank ♦ Increase the speed of sludge collecting mechanism in the final settling tank to increase the rate of removal of sludge. ♦ Decrease nitrification by reducing aeration or lowering the detention period.
Frothing	♦ Synthetic detergents cause frothing ♦ The froth increases with decrease in aeration liquor suspended solids.	♦ Use water, effluent or clarified sewage sprays in the frothing areas. ♦ Apply defoamers in small quantities to tank surface. ♦ Increase aeration liquor suspended solids concentration.

Operational Problem	Possible Causes	Suggested Action for Off-setting Trouble
Sludge Digestion		
Fluctuation in sludge temperature		Pump large quantities of thin sludge at high rate for cooling
Temperature drops in units with hot water coils	Sludge solids adhering to coils forming a thick insulating layer preventing heat transfer to digester.	♦ Clean the surfaces of coils ♦ Replace this form of heating with external heat exchangers.
Temperature constant; gas production drops	♦ Increase in scum accumulation. ♦ Increase in grit accumulation. ♦ Excessive acid production due to – Organic overloading – Acid wastes – Toxic metals	♦ Control scum and grit. ♦ Prevent excessive acid condition by reducing organic overloads ♦ Reduce acid waste by pretreatment ♦ Over digested sludge to be withdrawn from digester.
Foaming	♦ Insufficient amount of well buffered sludge in the digester. ♦ Excessive additions of raw sludge & Poor mixing of digester contents ♦ Withdrawl of too much of digested sludge ♦ Excessive scum or grit accumulations.	♦ Temporarily reduce or stop raw sludge additions. ♦ Maintain pH between 6.8 to 7.2. ♦ Optimized mixing within the digester. ♦ Break-up or remove excessive .
Sludge dries more slowly than usual	♦ Sludge layer too thick ♦ Standing water ♦ Bed surface clogged ♦ Broken or clogged drains	♦ Put on less sludge ♦ Decant water ♦ Rake over; skim if necessary and redress the surface.

8.10 General Safety Aspects during Operation and Maintenance[5, 44, 46,47,48,49]

(a) Objective of "Safety Practices" during Operation

The overall aim of the "Safety Practices" for any operation is to have contingency planning to prevent accidents through good design, maintenance and inspection by which it is possible to reduce/ or eliminate the possible associated risk/ or hazard. Hence, major aim of Operational Safety is to achieve the following:

- Safeguard people
- Protection of equipments
- Safeguard of environment
- Initially containment and ultimately bringing the incident under control
- Secure the safe rehabilitation of the affected area
- Effectiveness of the rescue operation and medical treatment of affected person (s)

Safety Aspects during Operation

During operation and maintenance activities, it is essential to adhere to following "Safety Practices":

- Mitigation of Occupational Hazards
- Preventive maintenance of equipment
- Use of Personal Protective Equipment
- Minimization of Environmental Hazards

Preventive Maintenance

The overall aim of preventive maintenance is to ensure

- Up-keeping of the equipment
- Safeguard of equipment from damage due to operational risk.
- Protection of equipment from damage due to electrical hazard.
- Prevention of Fire Hazard

(b) Effective Management of Occupational Hazard

An important element of mitigation of risk is the Effective Management of Occupational Hazard i.e. recognizing that accidents are possible, assessing the consequences of such accidents and deciding on the emergency procedures, which are to be implemented in the event of an emergency. Emergency planning is just one aspect of safety and cannot be considered in isolation. In particular, it is not a substitute for maintaining good standards within the operations. Before starting to prepare the plan, it should be ensured that the necessary standards and safety precautions are in place. Hence, the overall aim of Emergency Preparedness and Response would be

- To localize the emergency and if possible, eliminate it.
- To minimize the effects of the accident on staff, equipment and property

Hazards Associated with Operation and Maintenance of STP & SPS

Personnel engaged in the operation and maintenance of Sewage Treatment Plants, Sludge Handling and Digestion and Sewage Pumping Stations are exposed to different type of occupational hazards like

- Physical injuries
- Infections due to pathogenic organisms in sewage,
- Danger inherent with exposure to noxious vapour and gases etc.
- Electrical Hazard
- Fire Hazard

The associated occupational hazards as stated above can be reduced or minimized by taking adequate safeguard measures and appropriate precautions

General Precautions for Occupational Safeguard

General precautionary measures required for occupational safeguard are:

- Narrow walks or steps over tanks, ladder and spiral staircases are potentially danger sport, particularly during darkness, rains and wind, where operator needs to remain alert to prevent accidents.
- All open tanks should be provided with guard rails to prevent accidental falls.
- Adequate lighting arrangements should be provided within and around the plant to give better visibility and to reduce chances of accidents during night.

- Honeycomb grating to be provided on open channel to avoid accidents on account of falling down or drowning.

- Adequate safety training shall be given to operating staff from time to time.

- All essential safety gadgets such as helmets, gumboots, hand gloves etc. to be provided to operating staff.

- Precautionary boards/ danger boards/ sign boards shall be displayed at all dangerous spots so that users shall remain attentive all the time.

- Gas poisoning, asphyxiation and gas explosion are potential hazards, where considerable attention is required. Smoking or carrying flames in and around digesters shall be strictly prohibited.
- Covered tanks, wet wells or pits must have the adequate provision of ventilation. Entry into the tanks must be restricted and permitted only after ensuring proper ventilation to have adequate preventive action against asphyxiation.

- Gas masks must be kept at the convenient and easily accessible locations where there is no possibility of contamination by gas.

- First aid facility/ kit shall be conveniently available round-the- clock.

- Appropriate fire extinguisher should be placed at strategic and approachable locations and shall be maintained in good condition at all times.

- All the staff shall be trained in rendering first-aid and operating fire extinguishing equipment.

Precautions to prevent infections

Personnel working at SPS and STP are prone to infections to varying magnitude and hence it is essential take adequate precautionary measures such as:

- Emergency first aid treatment kits shall be provided to take care of all minor injuries like cuts and burns.

- The workers shall be made aware about the hazards diseases such as typhoid and cholera, which are waterborne and tetanus, which is caused through cuts and wounds. Preventive periodic inoculations should be given to workers.

- The importance of personal hygiene should be emphasized and the workers should be instructed to keep finger nails well-trimmed and wash hands with soap before eating.

- Use of rubber gloves should be insisted so that sewage or sludge does not directly comes in contact with the hands.

Precautions to be taken at pumping stations

- Guards, shields, fencing, railings, enclosure etc. are to be appropriately designed to prevent slipping/ falling during operational work.

- While working on equipment

  - Always stop the machine before removing any guard.

  - Ensure that power supply to the equipment id cut off. Place a warning board on the switch so that nobody should accidentally put it on.

  - Temporary support should be given to machinery or equipment jacked or hoisted up before going under it.

Precautions against electrical shocks

- Only qualified and specially trained personnel should be allowed to operate and maintain equipment.

- All electrical control shall be kept dry and in good condition.

- No metal ladder or metal tapes should be used around electrical equipment.

- Insulated rubber mats should be provided before all electrical control panels and should be kept dry.

- Always test wires for current before working on any electrical item. use tools with insulated handles and rubber gloves.

Fire Hazard Management

- All personnel should be adequately trained regarding pertinent fire hazards associated with their work.

- Personnel should know rules of fire prevention and methods of combating fires.

- Fire extinguishers should be provided at convenient locations and personnel should be instructed in their use.

Precautions to prevent toxic effects

A noxious gas or vapour is any gas or vapour that is directly or indirectly injurious or destructive to the health or life of human beings. It can be simple asphyxiant, chemical asphyxiant, irritant volatile solvent or a combustible gas. Gases to be emanating from sewage pumping stations and sewage treatment plants contains varying quantities of carbon dioxide, methane, hydrogen, hydrogen sulphide etc. The potential hazard could be due to the presence of high

level of methane forming an explosive mixture and presence of hydrogen sulphide. There is a need to envisage strategic planning to reduce the effect of toxicity of gas or vapours on exposure both short term and long term. There are four types of exposures:

- Inhalation
- Skin Contact
- Eye Contact
- Ingestion

In case of exposure, following action needs to be taken immediately:

- Adequate flushing by means of water to minimize exposure.
- Providing general supportive measures (comfort, warmth, and rest).
- Consulting a doctor for all exposures except minor instances of inhalation or skin contact.

Provision of Personal Protective Equipment (PPE)/ Safety Equipment

The purpose of Personal Protective Equipment (PPE) or Safety Equipment is to have adequate protection from the associated operational hazards. Facility should have special protective equipment readily available for use during the operation and for protection of personnel working under hazardous situation. Hence, emphasis shall be given on preventing accidents during operation.. This means observing all recognized safe practices using necessary personal protective equipment and exercising proper control over toxic substances at the source of exposure. Equipment should be provided for adequate:

- Body protection
- Eye protection
- Respiratory protection
- Hands protection

Safety Equipment

The various safety equipment that are normally required at STP and SPS are gas masks, oxygen breathing apparatus, portable lighting equipment, non-sparking tools, portable air blowers, safety belts, inhalers and diver's suit.

(c) Training and Human Resources Development

In order to ensure effective functioning of Sewage Treatment Plants and Sewage Pumping Station, there is a need for continuous updation of skill and knowledge of staff through training and orientation. In this context, following guidelines to be followed:

- Operating staff to be engaged in technical and skilled work should be given adequate training.
- All supervisory staff must have professional training in Public Health Engineering or at least have orientation in Public Health Engineering.

- All junior operational staff shall receive on-the-job training
- It is desirable that operation and maintenance staff of STP shall have certificate of competency based on internal/ external training.
- There shall also be the provision of refresher training for operation and maintenance staff from time to time so as to keep them conversant and updated with latest procedures and guidelines.
- Operational and maintenance staff of one STP shall be sent to other STPs as a part of Knowledge Exchange Programme to share both the success stories and shortcomings. This would not only help in getting acquaintance with different system but also be useful in capacity and capability building.
- Staff shall be given comprehensive and refresher training of Safety Aspects.
- There shall be a procedure to assess effectiveness of training.

Operation and Maintenance (O&M) on regular basis helps the organization to envisage necessary preventive actions on continual basis to reduce the chances of "break-down" of plant. The O&M Procedures are to be updated on regular basis as a part of continual improvement. In addition, Occupational Health and Safety Procedures are to be followed stringently to protect human resources as well as physical and process resources. In these aspects, regular training and capacity building programmes are essentially required to update skill and knowledge of operational staff.

9. EU India Project: Training and Capacity Building

9.1 Inception of EU India Project Activities in Mumbai[2, 3,51,52,53]

The activities of EU India Project for Technical Cooperation for Environment, were started in Mumbai in May-2015. The EU Delegation of India and the Project Consortium participated in the "Sustainable Urbanization and World Cities" Conference on 25 May 2015. The Alternate Team Leader of EU-India Project delivered presentation on the progress of project with a particular focus on Sewage Treatment and Solid Waste Management in Mumbai. The participation in this event provided the opportunity to present the project's progress and objectives before the cross-section of stakeholders comprising of 150 participants. Further, TL and ATL of EU Project had Interactive Meetings with the Chief Engineer (SWM) and Chief Engineer (MSDP) in MCGM offices during Mumbai Mission in December-2015. Subsequently, team of project Short Term Experts visited Sewage Treatment as well as Solid Waste Management Facilities during the Mumbai Mission in January and April-2016. Various activities during this mission included site visits, interaction and data collection. Overall, a number of meetings have taken place overtime between the project and Mumbai representatives.

9.2 Interaction with Stakeholders and Training Need Analysis[51, 52, 53]

Officials of EU Delegation to India and Project Consortium visited Sewage Treatment and Solid Waste Management Facilities in Mumbai during April-2016. During this mission, EUD and Project Consortium interacted with the stakeholders in addition to site visits to facilitate the training areas for Study Tours to Europe.

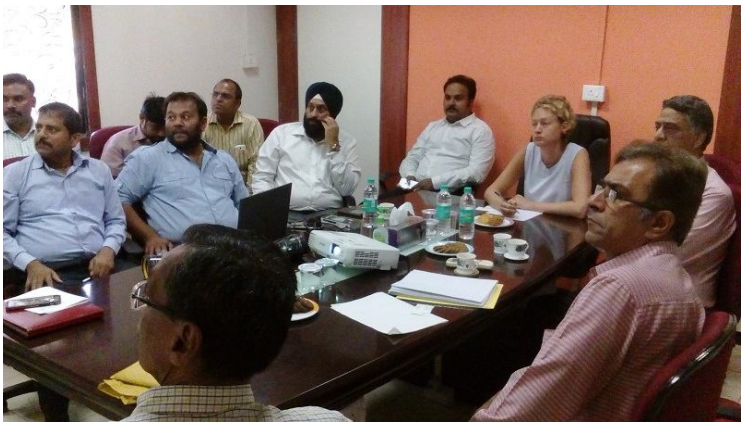


Figure-57: Interactive Meet (EUD, Project Consortium and MCGM Staff)

Figure-58: Interactive Meet (Project Consortium & MCGM Engineers)

Figure-59: Site Visit to Bhandup WWTF

Figure-60: Site Visit to Grit Chamber of WWTP

Figure-61: Visit to Sewage Pumping Station

9.3 Study Tours to Europe[3, 53]

As part of EU India Project of Technical Cooperation on Environment, Study Tours to Europe were organized by the Project Consortium. The objectives of these study tours was to have understanding of European Best Practices in following areas:

- Sewage Treatment and Sludge Management including Phosphorous Recovery
- Solid Waste Management including Waste-to-Energy, Composting, Landfill Management, Recycling, Biogas Upgradation etc.

The Study Tours were organized as per following schedule:

- Study Tour-I to Copenhagen, Denmark and Malmo, Sweden from June 4th -11th, 2016.
- Study Tour-II to Stockholm, Sweden from June 11th -18th, 2016.
- Study Tour-III to Stockholm, Sweden and Munich, Germany from June 17th -24th, 2017.

I. Participation in Study Tours from Mumbai

Study Tour	Name of Participant	Designation	Organization
ST-I June-2016	Mr.Satish R. Narkar	CE (MSDP)	Municipal Corporation of Greater Mumbai
	Mr.Mahesh M.Thakur	Dy.CE (M&E) SP	Municipal Corporation of Greater Mumbai
ST-II June-2016	Mr.Ratnakar N Anerao	AE, SWM Project	Municipal Corporation of Greater Mumbai
	Mr.Amol S Gundre	SE, SWM Project	Municipal Corporation of Greater Mumbai
	Dr.Y.B.Sontakke	Joint Director, WPC	Maharashtra Pollution Control Board
	Mrs.Jyoti Mhapsekar	President	Stree Mukti Sanghatana
	Ms.Ashwini Thakar	Manager, Projects	Mumbai First
ST-III June-2017	Dr.Sanjay Mukherjee	Additional Municipal Commissioner, Project	Municipal Corporation of Greater Mumbai
	Mr.Vijay Balamwar	Dy.MC, SWM	Municipal Corporation of Greater Mumbai
	Mr.P.S.Awate	CE, (SWM Project) I/C	Municipal Corporation of Greater Mumbai
	Mr.Satish R Narkar	CE, MSDP, I/C	Municipal Corporation of Greater Mumbai
	Mr.Mahesh M.Thakur	Dy.CE (M&E) SP	Municipal Corporation of Greater Mumbai
	Mr.Sudhakar Shinde	EE, MSDP	Municipal Corporation of Greater Mumbai
	Mr.Krishna Perekar	EE, (M&E)	Municipal Corporation of Greater Mumbai
	Dr.P.Anbalagan	Member Secretary	Maharashtra Pollution Control Board

II. Glimpses of Study Tours-2016[3]

Figure-62: Indian Stakeholders, Project Consortium and EUD Official

Figure-63 (a), (b), (c) & (d): Pilot Plant of World's Largest MBR

Figure-64: Indian Stakeholders at Malmö

III. Glimpses of Study Tour-2017[53]

Figure-65: Know-Why: European Best Practices

Figure-66: Know-How: European Best Practices

Figure-67: Hammerby Sjöstad "Smart City Solutions"

Figure-68: Biogas Up-gradation Plant

Figure-69 (a) & (b): Waste to Energy Plant at Borlänge

Figure-70 (a) & (b): Pilot Facility of MBR & SBR

Figure-71 (a) & (b): Sewage Treatment & Sludge Management Operations in City of Munich

IV. Learnings of Indian Stakeholders from visiting Pilot Facility of Wastewater Treatment Plant in Sweden[3, 18, 53, 54]

Visit to Hammarby Sjöstadsverk (HSSV) [18]

Stockholm Vatten AB (SVAB) is the largest water company in Sweden. SVAB treats wastewater from, and supplies drinking water to, more than one million people in the Stockholm area. In order to cope with an expanding city, SVAB is planning a major expansion of the largest wastewater treatment plant (WWTP) in Stockholm, Henriksdal WWTP, to be able to handle wastewater from approximately 1.6 million people in the future. To be able to handle these loads, membrane bioreactor (MBR) technology will be used in the process. The design of the plant is 864 MLD Peak Daily Flow (PDF) and 536 MLD Average Daily Flow (ADF).

Figure-72: Membrane Bio-reactor

The MBR is being installed by GE and its LEAPmbr technology will help Stockholm Vatten to expand the capacity of the facility and produce higher quality effluent to meet Sweden's environmental commitments under the Baltic Sea Action Plan (BSAP) and the European Union Water Directive. The Henriksdal facility will treats two-thirds of Stockholm's municipal wastewater. Located in the center of Stockholm, it incorporates over 18 kilometers of tunnels blasted into rock and that presents a challenge when it comes to expanding its capacity in the same relative footprint. LEAPmbr is based on GE's Zee Weed 500 membrane, an advanced ultrafiltration technology that separates solids, bacteria and viruses from water or wastewater. When the upgrade is completed, the plant will process up to 864 million liters of wastewater per day. "Considering the more stringent effluent requirements for nitrogen and phosphorus removal under the BSAP and E.U. Water Directive, GE's LEAPmbr technology is the right solution for the Henriksdal retrofit project"

Hammarby Sjöstadsverk (HSSV) is a research facility for water and wastewater treatment, owned and operated by a consortium led by IVL and the Royal Institute of Technology (KTH) in Stockholm. It is located close to Henriksdal WWTP, and there is close cooperation between IVL and SVAB. A pilot scale wastewater treatment line, built as a smaller copy of the future Henriksdal WWTP at Hammarby Sjöstadsverk, is in operation to study and confirm the selected process for expansion of Henriksdal WWTP. The process consists of an activated sludge treatment line in combination with a membrane bioreactor (MBR). The pilot scale MBR treatment line at Hammarby Sjöstadsverk has now been in operation since September 2013. Henriksdal WWTP will implement hollow fiber membranes, the pilot scale MBR is also using hollow fiber membranes.

The objective of pilot scale treatment line at Hammarby Sjöstadsverk, including activated sludge treatment and a MBR with hollow fiber membranes, is to fine-tune and optimize the process to meet the required target effluent limits. The general scope of the project is to follow and document the startup, fine-tuning and operation of the pilot scale treatment line, including all steps of startup, possible problems encountered, results and experiences. This would eventually be able to serve as a basis for starting up the full scale MBR process at the Henriksdal WWTP.

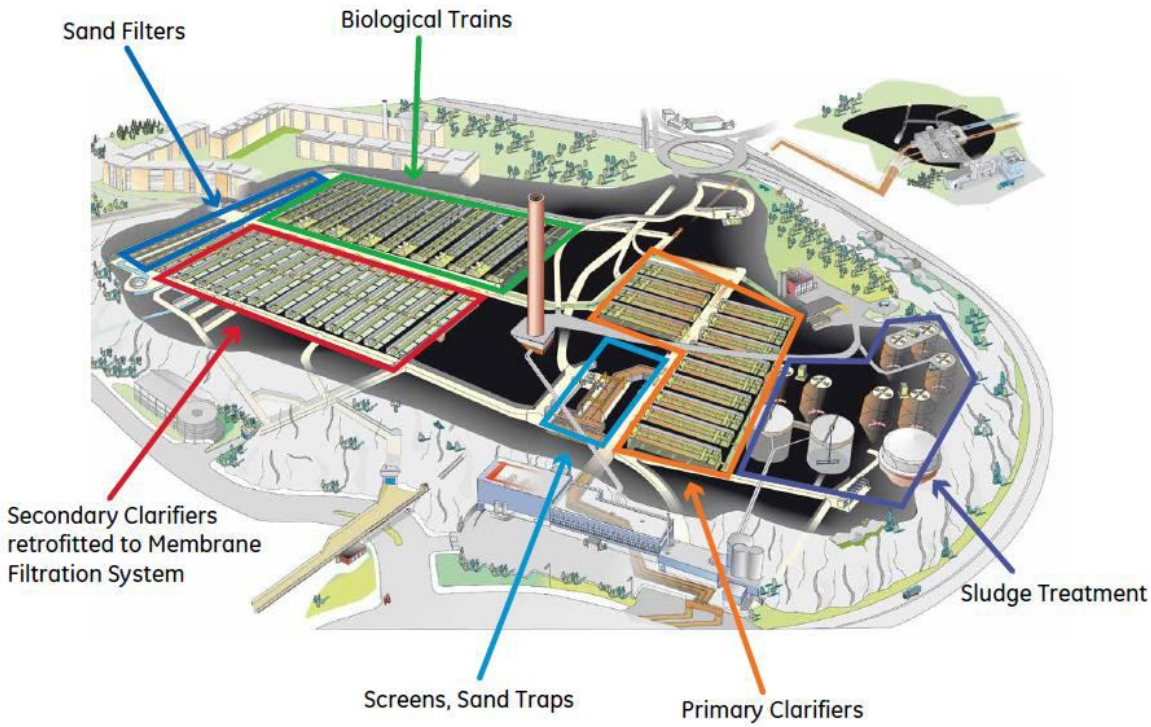
Figure-73: Indian Delegates at Facility[3]

About World Largest MBR Wastewater Treatment Plant at Stockholm[3, 54]

Wastewater has been treated in Stockholm since 1932. Since then, the city has set-up four treatment facilities to treat and manage its wastewater. Stockholm Vatten (SV), the City of Stockholm's water company, operates two large wastewater treatment plants (WWTP), the Bromma WWTP (320,000 population equivalents) and the Henriksdal WWTP shown in Figure 34 (780,000 population equivalents). The latest upgrade to the wastewater treatment facilities was done in the 1990s when the city was mandated to produce a combined effluent meeting 10 milligrams of Total Nitrogen, 0.3 milligrams of Total Phosphorous and 8

milligrams of BOD per liter of effluent produced. At this time a more significant upgrade was done at the Henriksdal facility for nutrient removal, increasing process volumes, adjusting the biological configuration, and adding sand filtration. While SV was able to meet the combined requirements, less work was done at the Bromma facility leaving it unable to meet the requirements on its own.

Figure-74: Schematic view of Henriksdal Underground WWTP[3, 54]



Looking ahead, Sweden has committed to the Baltic Sea Action Plan (BSAP) and EU Water Directive calling for more stringent discharge requirements into local receiving water bodies. As well, the city of Stockholm is currently one of the fastest growing cities in the Europe, growing at a rate of 1.5% per year, creating a need for increased capacity.

Way Forward

SV conducted several feasibility studies to determine the best path-forward for its infrastructure assets. These studies allowed SV and local officials to consider many factors in making a decision including: overall economics, potential new locations, a long-term sustainable solution, the city's development plan, use of existing infrastructure, potential for over-flow to Lake Mälaren, and impacts of different dis-charge points. The resulting decision was to close the Bromma WWTP, build a tunnel to convey wastewater to the Henriksdal facility and upgrade the Henriksdal WWTP with membrane bioreactor (MBR) technology.

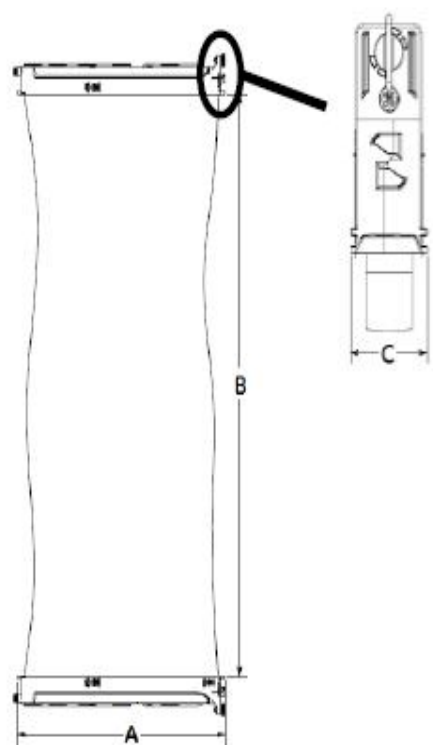
Design Consideration : The existing Henriksdal facility is built into a mountain with residential buildings built on top. The entire upgrade of the facility required to be done in the existing footprint and any additional tank volume required to be blasted from what is

available in the rock structure. The upgraded Henriksdal facility is designed to treat wastewater as per the design given below.

Parameter	Influent	Effluent Requirements
Average Daily Flow	535,680 m3/d	
Peak Daily Flow	864,000 m3/d	
Temperature	8 to 19°C	
Suspended Solids	60,000 kg/d	2 mg/l (daily average)
BOD	58,000 kg/d	6 mg/l (quarterly average)
Total N	17,500 kg/d	6 mg/l (annual average)
Ammonia-N	-	2 mg/l (monthly average May to Oct)
Total Phosphorous	1,500 kg/d	0.2 mg/l (quarterly average)

Technical Details : GE is supplying ZeeWeed 500d and LEAPmbr membrane configuration for the WWTP. The plant is split into seven hydraulically separated biological trains. The biological upgrade will involve phosphorous removal through pre-precipitation with provision for post-precipitation in the membrane tanks, and nitrogen removal through pre-de-nitrification followed by post de-nitrification using supplemental carbon. The fourteen existing secondary clarifiers will be retrofitted to become the membrane filtration system. Restrictions on the sizing of these tanks and a fixed ceiling height have created a challenge physically fitting the membranes cassettes in the tanks and having overhead access.

Figure-75: Design of ZeeWeed 500D[3, 54]



Technical Specification of ZeeWeed 500D Module

Product	Width (A) mm (in)	Height (B) mm (in)	Depth (C) mm (in)
370; 340	844 (33.2)	2198 (86.5)	49 (1.9)
440			52 (2.05)
300s		1835 (72.25)	49 (1.9)
350s			52 (2.05)

(i) Module properties

Application	Product	Nominal membrane surface area m² (ft²)	Maximum shipping weight kg (lb)	Material	Nominal pore size (µm)	Surface properties	Fiber diameter (mm)	Flow Path
MBR	370	34.4 (370)	28 (61)	PVDF	0.04	Non-ionic & Hydrophilic	OD : 1.9 ID : 0.8	Outside-In
	300s	27.9 (300)	24 (53)					
Non-MBR	440	40.9 (440)	32 (70)					
	350s	32.5 (350)	26 (57)					
All	340	31.6 (340)	28 (61)					

(ii) Operating and Cleaning Specification

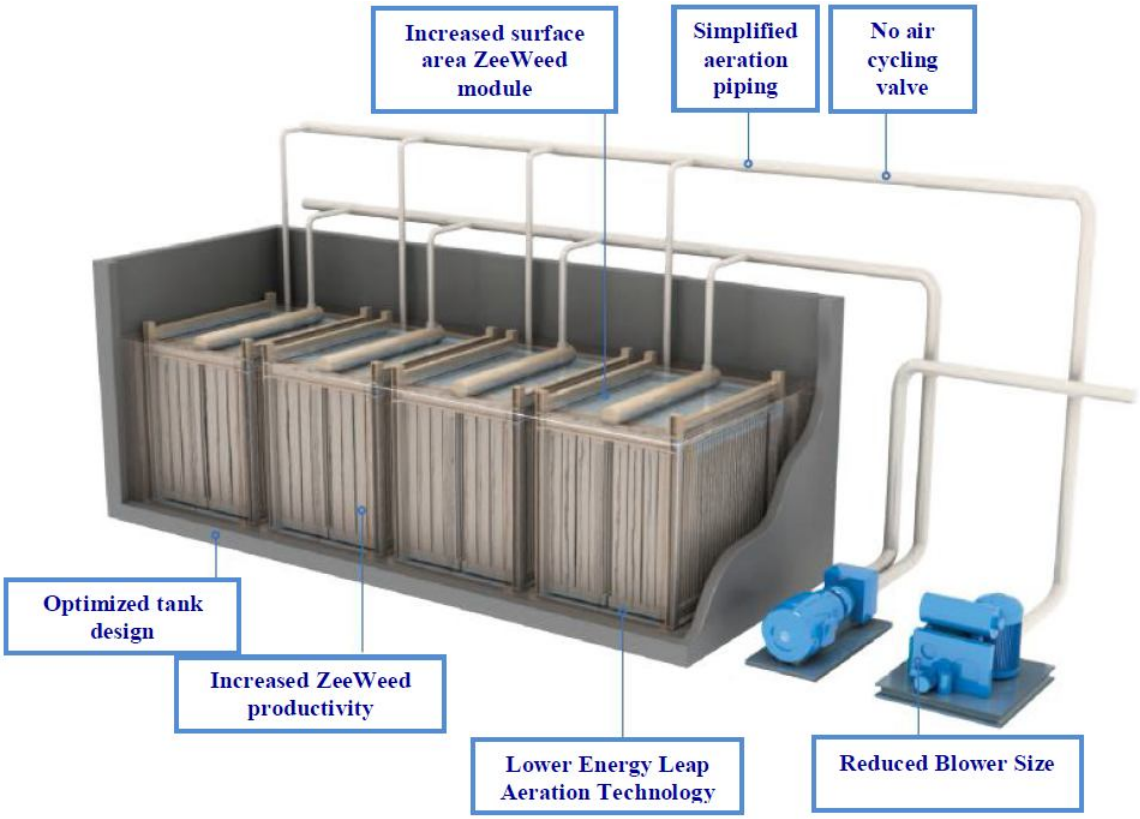
Application	Product	TMP Range kPa (psig)	Max. operating Temp °C (°F)	Operating pH range	Max. Cleaning Temp °C (°F)	Cleaning pH range	Max. Cl_2 concentration (ppm)
MBR	370, 340, 300s	-55 to 55 (-8 to 8)	40 (104)	5.0-9.5	40 (104)	2.0-10.0 (30-40°C)	1000
Non-MBR	440, 340, 350s	-90 to 90 (-13 to 13)					

Technical Specification of LEAPmbr

It has following salient features

- Increased Surface Area ZeeWeed Module
- Simplified Aeration Piping
- Optimized Tank Design
- Increased ZeeWeed Productivity
- Lower Energy LEAP Aeration Technology
- Reduced Blower Size

Figure-76: Design of LEAPmbr[3, 54]



Significant Aspects of Membrane Biological Reactor Technology

The concept of MBR system consists of utilizing a bioreactor and microfiltration as one unit process for wastewater treatment thereby replacing, and in some cases supplementing, the solids separation function of secondary clarifier and effluent filtration. Membrane processes are classified based on membrane pore size, mechanism, membrane material and configuration. The commercially successfully membrane separation processes are Micro-filtration (0.1 -0.2 µm) Ultra-filtration (0.002-0.1 µm) and Nano-filtration (0.0001- 0.001 µm). All the three processes rely on hydrostatic pressure differences for filtration[20, 26]. Membranes are usually made from ceramic and organic polymer materials but metallic membranes also exist. The most widely used commercially successful membranes are made from cellusloses, polyamides, polysulphone and polymeric substances such as polyvinylidene difluoride (PVDF) polyacrylonitrile (PAN), polyethylsulphone (PES), polyethylene (PE), and polypropylene (PP). These polymeric membranes have good chemical and physical resistance[20, 26,27].

The ability to eliminate secondary clarifier and operation at high MLSS concentration provide **advantages** such as (i) higher volumetric loading rates and thus shorter reactor hydraulic retention times (ii) longer SRTs resulting in less sludge production (iii) operation at low DO concentrations with potential for simultaneous nitrification-denitrification in long SRT design (iv) high quality effluent in terms of low suspended solids and BOD and (v) less space requirement. The **disadvantages** of MBR (i) high capital costs (ii) potential high cost for membrane replacement (iii) higher energy costs and (iv) the need to control membrane fouling[20].

Membrane fouling remains a major drawback of MBR as it significantly reduces membrane performances and membrane lifespan, leading to an increase in maintenance and operating costs. Membrane fouling in MBRs is attributable to suspended particulates (microorganisms and cell debris), colloids, solutes, and sludge flocs. These materials deposit onto the membrane surface and into the membrane pores, clogging the pores, and leading to a decline in the permeability of the membrane. The heterogeneous nature of suspended solids and active microorganisms in mixed liquor suspended solids (MLSS) makes membrane fouling an inevitable challenge that is difficult to control in long-term MBR applications.

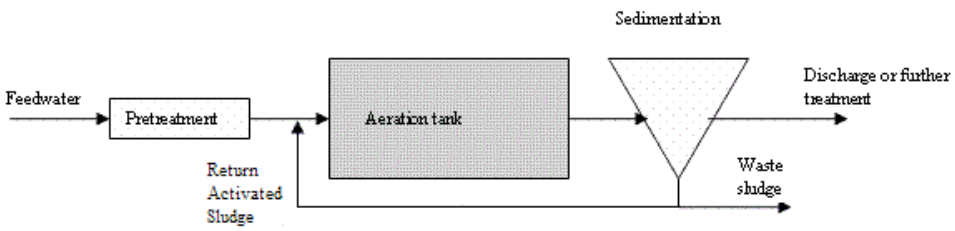
Membrane fouling mitigation in MBRs has been one of the key areas of extensive research in order to enhance the wider application of the MBR technology in wastewater engineering. Fouling in MBRs occurs in different forms, namely, pore narrowing, pore clogging and, cake formation. Pore clogging refers to the blocking of membrane micro pores by foulants. Pore clogging depends, to a large extent, on the size of the particle and the membrane pore size. The attachment of the materials in the pores is aided by sticky substances in the solution. Cake formation, on the other hand, results from the continuous accumulation of bacteria clusters, biopolymers and inorganic matter, which form a layer (biocake) on the membrane. The cake layer increases membrane filtration resistance. In operational terms, membrane fouling decreases the permeate flux when the MBR is operated at constant trans-membrane pressure (TMP), and results in the increase of TMP when the MBR is operated at constant permeate flux. At constant flux operation, a sharp increase in TMP indicates severe membrane fouling. This sudden TMP increase is called a “TMP jump”. TMP jump has been described as a three-stage process[4, 44, 47]

Stage 1 An initial “conditioning” fouling, which is caused by initial pore blocking and solutes adsorption;

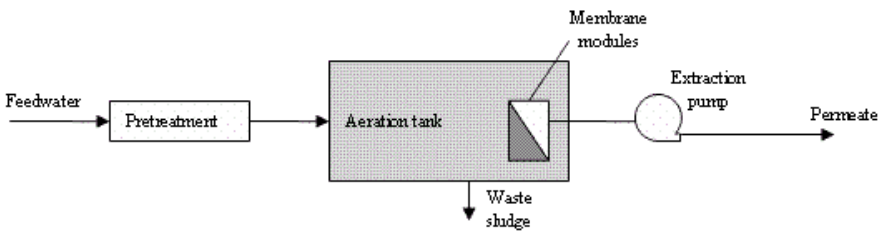
Stage 2 Linear or weakly exponential gradual rise in TMP due to biofilm formation and further membrane pore blocking; and

Stage 3 A sudden rapid increase in the rate of TMP rise (dTMP/dt). This stage is considered to be the consequence of severe membrane fouling, and is believed to be due to successive closure of pores and changes to the local flux resulting from fouling, which causes local fluxes to exceed the critical value, hence, acceleration of particle deposition and sudden changes of the cake layer structure. Bacteria in the inner biofilms tend to die due to oxygen limitations, thereby releasing more EPS. Once stage 3 occurs, membrane cleaning is required. The practical implication of this is that a delay in stage 3 will allow for a reduction in membrane cleaning frequency, which will ultimately result in MBR operational cost savings. Thus, one key objective of fouling control is to retard TMP jump through modification of sludge characteristics (MLSS, floc size, EPS content, and apparent viscosity) or lowering of operational flux.

Figure-77: Broad Flow Diagram: Conventional ASP and ASP/MBR Technology



Conventional Biological Treatment Process



Membrane Bioreactor (MBR) Process

Precautions to Control/ Minimize Membrane Fouling

In the activated-sludge reactor, biomass coats the outer layer of the membranes used in an integrated MBR during effluent withdrawal. Finer particles may penetrate the inner pores of the membrane, thereby causing an increase in pressure loss. Continuous membrane fouling control methods are used during the operation of the MBR, with periodic more aggressive cleaning to maintain the filtration capacity of the membrane[44].

Factors Affecting Membrane Fouling in MBR: Membrane Characteristics[44, 47]

Factor		Effect on membrane
♦ Membrane Material	:	Ceramic membranes are hydrophilic, hence they foul less. Polymeric membranes are mostly hydrophobic and exhibit more fouling
♦ Water affinity	:	Increasing hydrophilicity indicates less membrane fouling propensity while hydrophobicity correlates well with increase propensity for membrane fouling
♦ Membrane surface roughness	:	Membrane fouling tends to increase with increasing surface roughness as the rough surface provides a valley for the colloidal particles in the wastewater to accumulate on. However, higher projections on the membrane surface exhibits higher antifouling property and better permeability recovery after back-flushing than gentle roughness.
♦ Membrane surface charge	:	The colloidal particles depositing on the membrane makes them negatively charged, hence they can attract cations in the MLSS, such as Ca^{2+} and Al^{3+} leading to inorganic fouling
♦ Membrane pore size	:	Increasing membrane pore size increases the tendency for pore blocking mechanism

Factors Affecting Membrane Fouling in MBR: must optimize Operational Conditions[44, 47]

Factor		Effect on membrane
♦ Operating mode	:	Operating in cross-flow filtration mode reduces cake layer formation on the membrane surface
♦ Aeration	:	Increasing aeration rates results in a reduction in membrane fouling
♦ Solid Retention Time (SRT)	:	Operating at high SRTs reduces the production of EPS, hence reduced fouling. However, extremely high SRTs rather increase membrane fouling due to the accumulation of MLSS and increased sludge viscosity
♦ Hydraulic Retention Time (HRT)	:	Decreasing HRTs results in increasing rate of membrane fouling. However, extremely high HRTs leads to an accumulation of foulants
♦ Food-Microorganism (F/M) Ratio		The rate of membrane fouling in MBRs increases with increasing F/M ratio due high food utilisation by biomass resulting in increased EPS production
♦ OLR	:	Membranes foul more as OLR increases
♦ COD/ N Ratio	:	♦ Operating at higher COD/N ratio reduces rate of membrane fouling, improved membrane performance and a longer operation period before membrane cleaning ♦ On the contrary, other studies found that low COD/N ratio results in lower MLSS concentration, lower SMPs production, lower carbohydrates, proteins, and humic acids in loosely bound EPS and hence, low membrane fouling
♦ Temperature	:	Low temperatures increase the propensity for membrane fouling as more EPS are released by bacteria and the number of filamentous bacteria increases. Sudden temperature changes also increase fouling rate due to spontaneous release of Soluble Microbial Products (SMPs)

Factors Affecting Membrane Fouling in MBR: must optimize Feed Biomass Characteristics[44, 47]

Factor		Effect on membrane
♦ Mixed liquor suspended solids	:	♦ Increasing MLSS correlate with increased rate of membrane fouling ♦ Other studies report no (or little) effect of MLSS on membrane fouling
♦ Sludge apparent viscosity	:	Increasing the viscosity results in increased membrane fouling
♦ Extracellular polymeric substances	:	Increase in the concentration of EPS (bound EPS and SMPs) result in membrane fouling
♦ Flocs. size	:	Decrease in flocs. size increases membrane fouling
♦ pH	:	Decrease in pH results in increased rate of membrane fouling
♦ Salinity	:	Increasing salinity increases membrane fouling by altering biomass characteristic like more release of bound EPS and SMPs, floc size and zeta potential

Additional measures to Control Membrane Fouling in MBR

The addition of coagulants and adsorbents has also shown significant membrane fouling reduction as reported by some researchers but further research is needed to establish optimum dosages of the various coagulants and adsorbents in order to strike a balance between cost savings arising from fouling abatement and the cost of the additives and handling of the resulting sludge. Aerobic granulation is a promising biotechnology that targets biofouling and organic fouling. It is also reported that integrating aerobic granulation with MBRs show significant reduction in membrane fouling as well as enhanced organics and nutrients removal. However, Aerobic Granular MBR is still in the development phase. Further research is needed to establish the EPS-membrane fouling relationship in AGMBR and optimum operating conditions on real wastewater applications[44, 47].

A method developed by Zenon Environmental to control fouling on the outside surfaces of the membrane fibers involves a three step process[20]:

- **Mechanical Scouring :** The coarse bubble aeration is to be provided at the bottom of the membrane tank directly below the membrane fibers. The air bubble flow upward between the vertically oriented fibers, causing the fibers to agitate against one another to provide mechanical scouring.
- **Back-flushing :** The filtration has to be interrupted about every 15 to 30 minutes and the membrane finers are backwashed with permeate for 30 to 40 seconds. The system remains online during back-washing and the total time for back-flushing is to be about 45 minutes per day. Typically, a low concentration of chlorine (<5 mg/l) is to be maintained in the back-flush water to inactivate and remove microbes that colonize the outer membrane surface.
- **Maintenance Clean :** About three times per week, a strong solution of sodium hyprochlorite (100 mg/l) or citric acid is to be used in the back-flush mode for 45 minutes after that the system is to be flushed with permeate for 15 minutes. An additional permeate flush-to-drain operation is to be performed for 10 to 15 minutes to purge the system of free chlorine once the vacuum is initiated. The total system downtime during a maintenance clean is about 75 minutes.

The combination of air scour, back-flushing and maintenance cleaning may not be completely effective in controlling membrane fouling, and the pressure drop across the membrane increases with time. The pressure drop across the membrane is to be monitored to indicate fouling problems and cleaning needs. At the maximum operating pressure drop of ~60 kPa, the membranes are to be removed from the aeration basin for recovery cleaning during which, a membrane cassette is to be soaked in a tank containing 1500 to 2000 mg/l sodium hypochlorite solution for about 24 hrs. Spare membranes are typically installed in the aeration tank during recovery cleaning to continue uninterrupted treatment. A similar fouling control procedure has been reported for the Mitsubishi Membrane. In the KUBOTA MBR process, the flat-plate membranes are not removed for cleaning and an infrequent back-flush with a 0.5 percent solution of hypochlorite has been shown to be effective[20].

Typical Operation and Process Data for a Membrane Bioreactor[44]

Parameter	Unit	Range
Operational Data		
COD loading	kg/ m^3.d	1.2 - 3.2
MLSS	mg/l	5000 - 20000
MLVSS	mg/l	4000 - 16000
F/M	g COD/ g MLVSS.d	0.1 - 0.4
SRT	d	5 - 20
HRT (τ)	h	4 - 6
Flux	L/m^2.d	600 - 1100
Applied vacuum	kPa	4 - 35
DO	mg/l	0.5 - 1.0
Performance Data		
Effluent BOD	mg/l	<5
Effluent COD	mg/l	<30
Effluent NH_3	mg/l	<1
Effluent TN	mg/l	<10
Effluent Turbidity	NTU	<1

V. Visit of Indian Stakeholders to Wastewater Treatment Plants in Denmark[3, 52]

At Roskilde Utilities, five sewage treatment plants (total capacity 23,100 m^3 per day), work around the clock to clean wastewater in Roskilde Municipality. The wastewater is channeled to Roskilde five wastewater treatment plants through almost 1,000 km of sewer system and over 200 pumping stations spread throughout the municipality. The waste water is treated before it is discharged to the Roskilde Fjord, lakes or streams.

The Wastewater Treatment Plant in Roskilde Utilities includes the:

- Bjergmarken treatment plant
- Jyllinge treatment plant
- Ågerup treatment plant
- Gadstrup treatment plant
- Viby wastewater treatment plants

Figure-78: Rosklide Municipality Map[3]

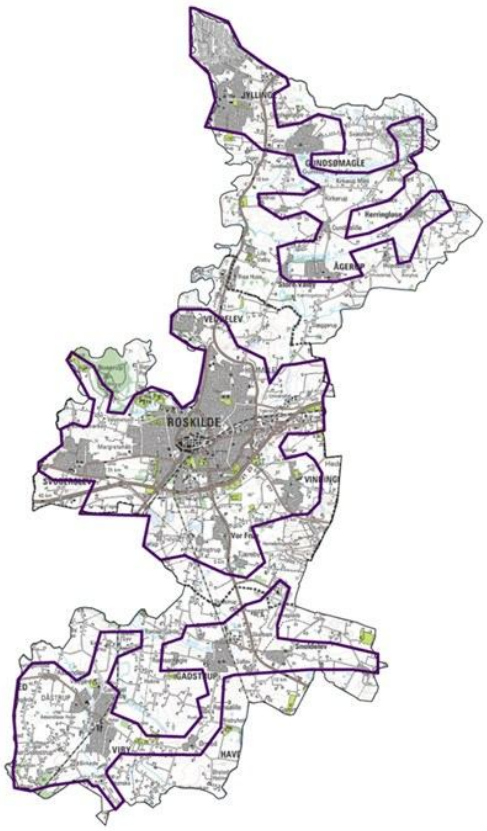


Figure-79: Understanding Process[3]

Figure-80 (a), (b) & (c): STP Process Survey[3]

VI. Participation of Indian Stakeholders in Holistic Sludge Management Conference at Malmö June 7-9, 2016[3, 52]

The purpose of this conference was to provide a forum for practitioners to exchange the latest developments regarding holistic sludge management. It gave possibilities to examine and discuss the different challenges connected to resource recovery through treatment and handling of wastewater.

The conference covered sludge management and resource recovery from wastewaters within a broad holistic system perspective. It included energy recovery and quality assurance of sludge as a prerequisite for enabling sludge to be recycled to farmland as well as different upstream or downstream processes and procedures for recycling of nutrients such as phosphorus and nitrogen in more refined ways.

The main goal has been to share knowledge, practices and ideas for the future directions of process development of wastewater handling and the sludge treatment as well as taking a major step forward by addressing various aspects of sludge management based on the experience of various countries in following areas:

- Energy Recovery by Anaerobic Digestion Process Design
- Pathogenic Aspects of sludge Re-use
- Anaerobic Digestion Pre-treatment
- Enhancement of Anaerobic Digestion Process
- Incineration of Sludge and Handling of Ashes
- Recycling of Material including Nutrients with particular focus on phosphorous recovery.
- Synthesis of PHA from phosphorous.
- Influence of Microbiology on Sludge Management
- Sludge Management in German and Swedish Perspectives
- Certification in Sludge Management
- Life Cycle Assessment Tools for Sludge Management
- Toxicity Aspects in Sludge Management

New research ideas significant to the context of India, emerged from HSM-2016 at Malmo

- Phosphorous recovery from sewage sludge
- Recovery of Polyhydroxyalkanoates (PHA) from sewage sludge

Why research on phosphorous recovery from sewage sludge is significant for India?

- India is the second largest consumer of phosphate based fertilizer after China and current consumption rate is 19% of the world. Current annual demand is 26.5 million tonnes[56].
- There imports rock phosphate or processed phosphate to meet the demand of fertilizer and phosphoric acid industry.
- The rock phosphorous reserves are limited in India and are mainly found in Rajasthan and Madhya Pradesh.

Sewage as a source of Phosphorous

Domestic sewage (as estimated 60 billion litres per day generation in urban areas only) is a rich source of phosphorous as it is available ranging from 0.8 to 4 gram per capita per day (P) [56] and 50% reduced in treatment. The current sewage treatment capacity of country is only 24 billion litres per day. The availability of phosphorous in sludge is 5-10 % by mass. Hence, current potential of phosphorous availability in sewage sludge is upto 1000 tonnes per day, which would increase substantially with the augmentation of sewage treatment capacity. **Hence, recovery of phosphorous from sewage sludge is a potential area of research to make India self-reliant with respect to production of fertilizers. Otherwise, the presence of phosphorous in sewage/ sludge is detrimental to wetlands due to pollution by means of "eutrophication".**

Why research on PHA recovery from sewage sludge is significant for India?

Polyhydroxyalkonates (PHA) are biodegradable plastics that are synthesized by microbial fermentation of glucose or sugar. PHA has been used in the fixation and orthopedic applications, tissue engineering, production of bio-plastic, food services, in packaging, pharmaceutical industries and agriculture. Innovative properties of PHA can bring additional value to the applications in which these are being used. It is expected that further research & process optimization in the synthesis of PHA from waste would help in making it an alternative to the conventional plastic[58].

Waste treatment by alternating aerobic and anaerobic conditions like enhanced biological phosphate removal (EBPR) can be an effective process in respect to concurrent implementation of PHA production using enriched activated sludge synthesis of PHA by Phosphorous Accumulating Organisms (PAO), with energy derived from polyphosphate breakdown (release of phosphorous) under anaerobic phase and later utilize the stored form of PHA to restore poly phosphate and sustain normal metabolic activities[57].

VII. Visit of Indian Stakeholders to Gut Großlappen WWTP in the City of Münich, Germany [59, 60, 61]

The Münchner Stadtentwässerung, a self-supporting wastewater management enterprise (Eigenbetrieb) since 1993, is responsible for the construction, operation and administration of Münich's sewer system and wastewater treatment plants. Since previous 100 years, these tasks were performed by a subdivision of the municipal construction department.

The Gut Großlappen Plant shares its workload with Münich's other large scale plant, Gut Marienhof. Both the plants together have treatment capacity of three million population equivalents (PE), which accounts for domestic, commercial and industrial wastewater from Münich and 22 neighbouring communities. The treatment processes in the plants remove 99 percent of the organic pollutants and a major part of the nutrients nitrogen and phosphorus. These would otherwise enhance eutrophication in receiving waters.

- The WWTP Münich I, Gut Großlappen has the capacity of 2 million PEs. The maximum flow is 10 m^3/s, the minimum flow is 1 m^3/s and average flow is 4 m^3/s.

- The WWTP Münich II, Gut Marienhof has the capacity of 1 million PEs. The maximum flow is 6 m^3/s, the minimum flow is 0.5 m^3/s and average flow is 3.33 m^3/s.

Figure-81: WWTP Münich I, Gut Großlappen [60]

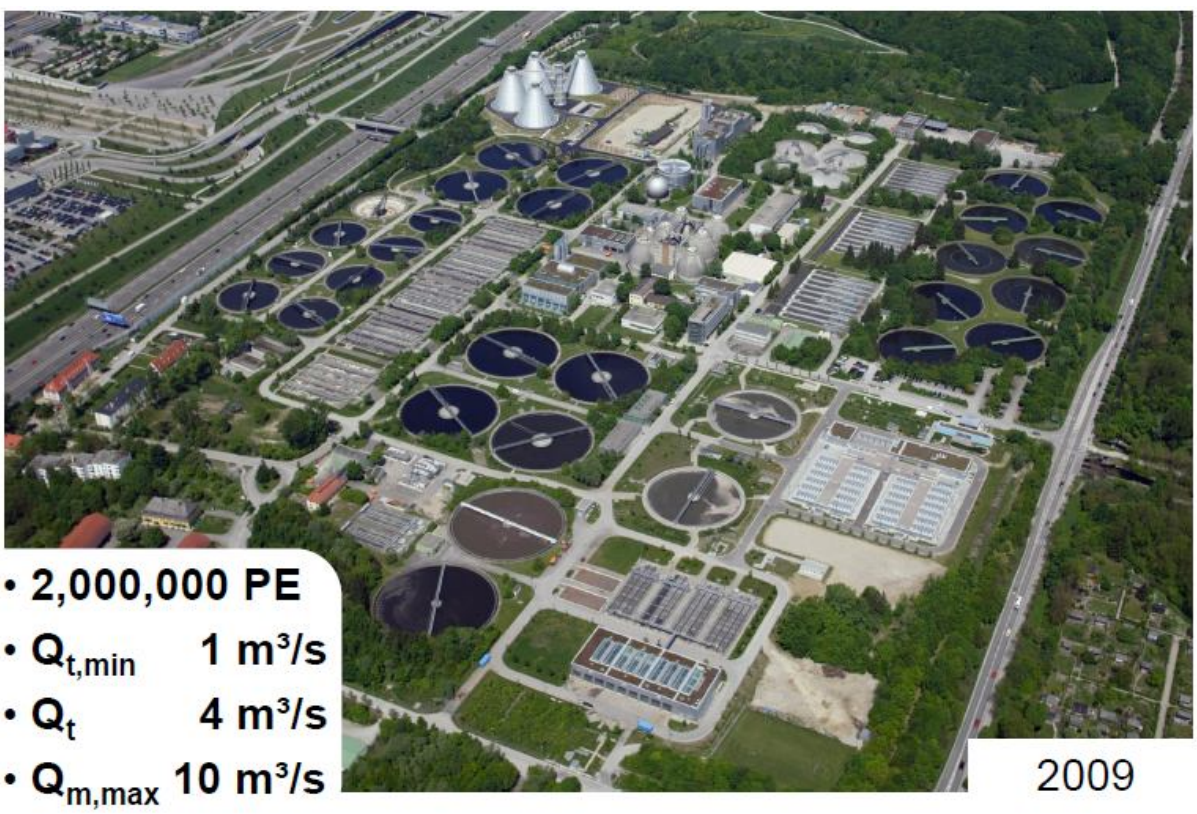


Figure-82: WWTP Münich II, Gut Marienhof [60]

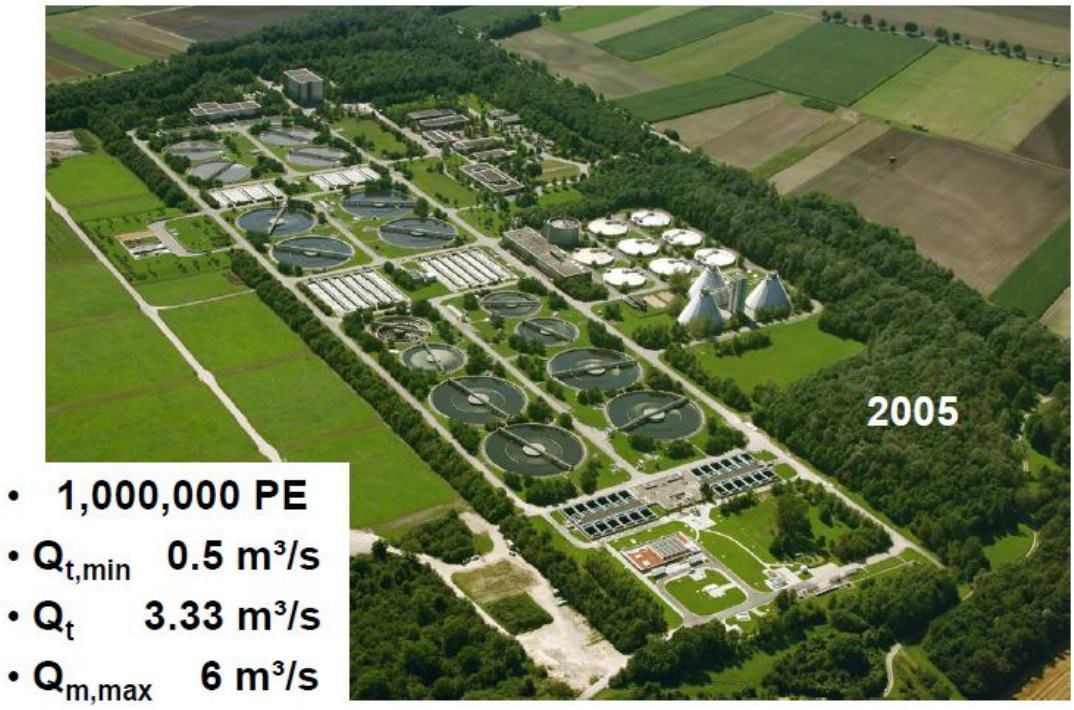


Figure-83: Layout of WWTP Münich I, Gut Großlappen [59]

Effluent Standards at WWTP Gut Großlappen

- Suspended Solids : 15 mg/l
- BOD_5 : 15 mg/l
- COD : 45 mg/l
- NH_4-N : 5 mg/l
- $N_{inorganic}$: 13 mg/l
- P_{tot} : 1 mg/l

Figure-84: Sludge Digestion Plant of WWTP Münich I, Gut Großlappen [60]

Figure-85: Cross-section of New Sludge Digester at WWTP Münich I, Gut Großlappen [60]

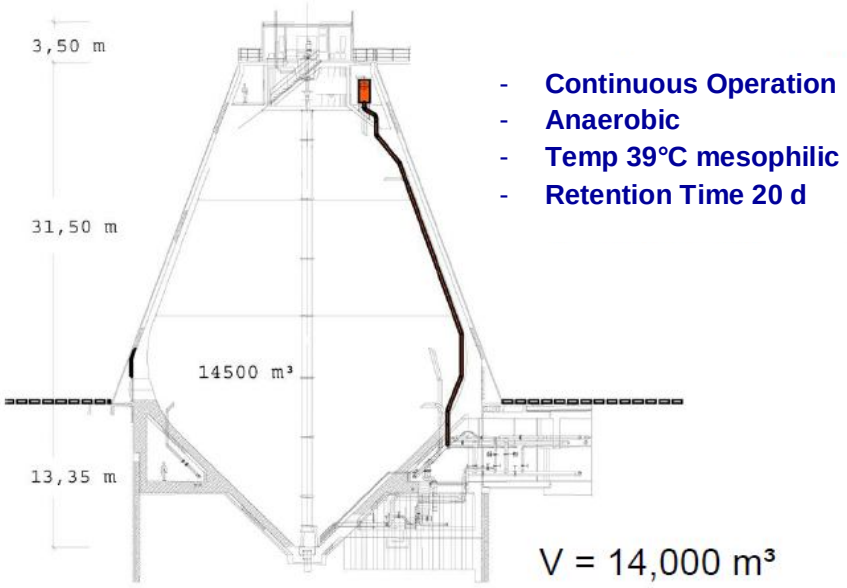


Figure-86: Biogas use in Block Heat Power Plant (WWTP Münich I, Gut Großlappen) [60]

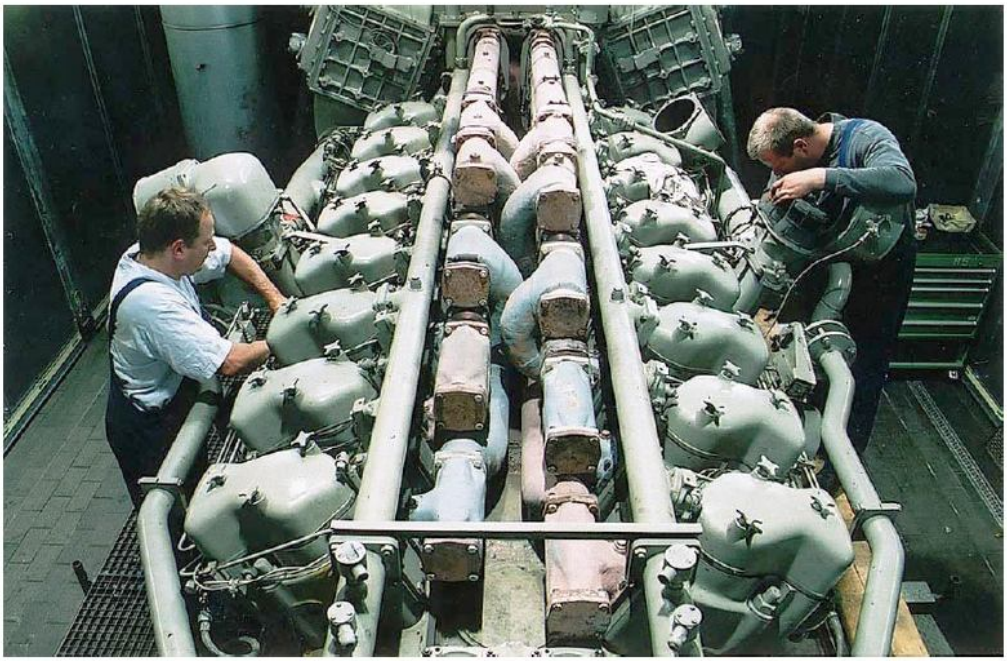


Figure-87: Approach towards Energy Optimization (WWTP Münich I, Gut Großlappen) [60]

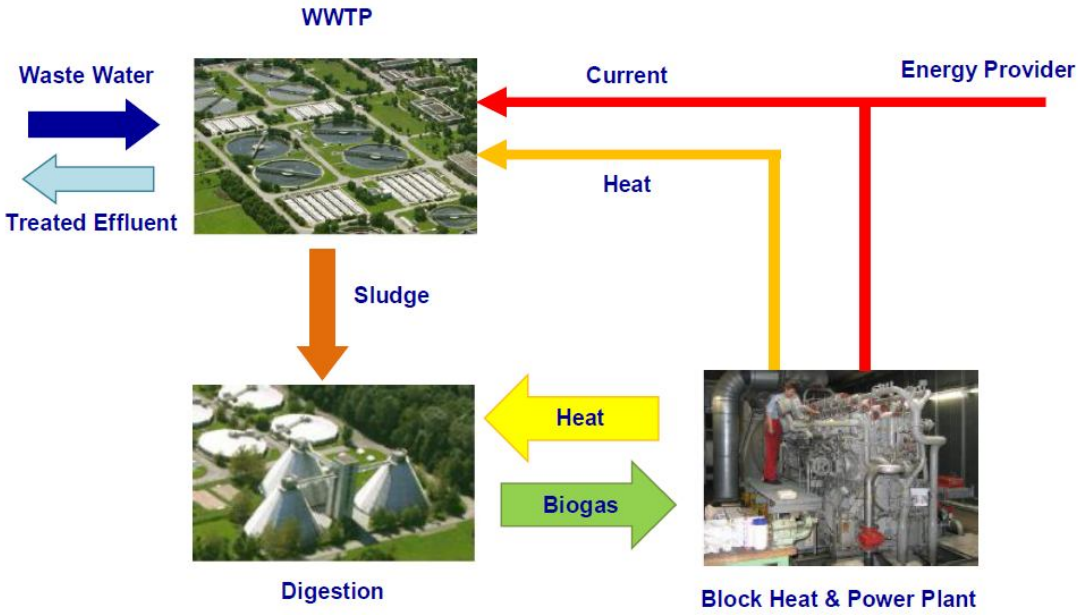
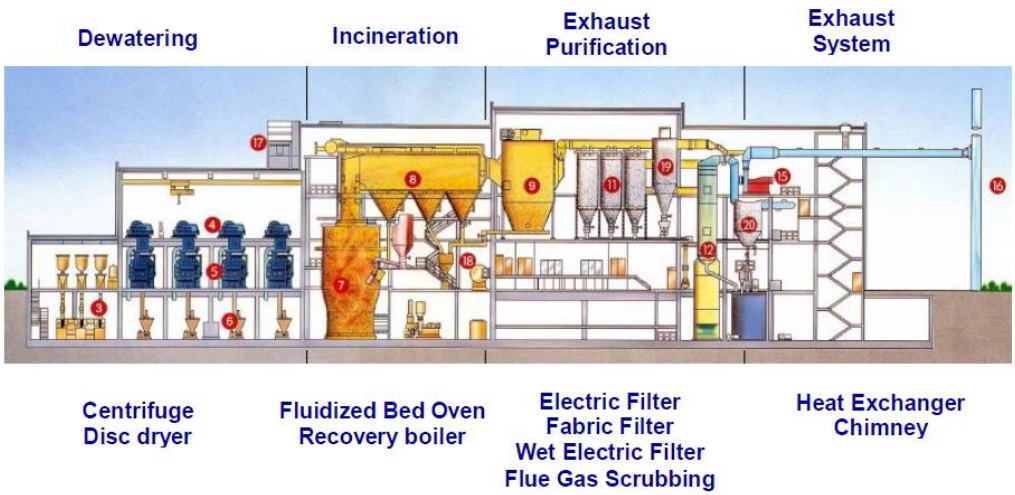


Figure-88: Mono Sludge Incineration Plant (WWTP Münich I, Gut Großlappen) [60]



Process Control of Gut Großlappen WWTP[59]

The treatment plant is controlled by a central process control system in connection with numerous subsystems, online instruments and measurement transmitters. Experienced employees supervise the processes in the central control room round the clock. Approximately 190 persons are employed at Gut Großlappen Wastewater Treatment Plant.

Figure-89 (a) & (b): Indian Stakeholders at WWTP Münich I, Gut Großlappen) [60]

The Study Tours were conceptualized with an aim to showcase Best Available Technologies in Europe to Indian Stakeholders, in the areas of Sewage Treatment, Sludge Management and Solid Waste Management.

9.4 Consultation Workshops in Mumbai

The objective of organising Consultation Workshops was to examine best practices (Experience of EU and India) as well as to understand perspectives, challenges, opportunities, and solutions in implementation of Sewage Treatment and Solid Waste Management Technologies. The Consultation Workshop (CW-II) on Sewage Treatment and Sludge Management Technologies, was organized on March 15, 2017 at Oberio, Mumbai.

The inaugural session of Consultation Workshop on Wastewater Management Technologies included the welcome address by the Team Leader, genesis of Consultation Workshop by the Alternate Team Leader and the keynote address by the Chief Guest, Additional Municipal Commissioner, Dr. Sanjay Mukherjee. This was followed by the Technical Sessions to deliberate on EU-India Best Practices on Wastewater Management alongwith Challenges and Opportunities.

Figure-90 (a) & (b): Address by the Municipal Commissioner during CW-I on SWM Processing Technologies

Figure-91 (a) & (b): Address by the Additional Municipal Commissioner (Projects)

Figure-92 (a) & (b): Inaugural Session

Figure-93 (a) & (b): Address by the TL and ATL of EU Project

Figure-94 (a) & (b): Swedish Consul General adorned the Occasion (During CW-I)

Technical session 1 Best Practices & Novelties on Sewage Treatment & Sludge Management: European Union

Figure-95 (a) & (b): Presentation on Best Practices in Sewage Treatment in Europe

Technical Session-2 Best Practices, Challenges & Opportunities in Sewage Treatment & Sludge Management: India

Technical Session-3 Policies on Sewage Treatment and Sludge Management

Figure-96: Presentation by Member Drainage Delhi Jal Board

Figure-97: MCGM Presentation (Chair: CE, MSDP I/C)

Figure-98: Presentation by ATL-EU Project on Recovery of Phosphorous

Figure-99: Presentation by Joint Director, MPCB on Policies

Figure-100 (a) & (b): Interactions during Workshop

Figure-101 (a): Panel Discussion and (b): Group Picture

9.5 Participation in IFAT, Mumbai at Bombay Exhibition Centre

IFAT is the India's Leading Trade Fair for Water, Sewage, Refuse and Recycling, in which Best Available Technologies in the areas of Sewage Treatment & Sludge Management and Solid Waste Management (the two thematic areas of EU India Project) are exhibited. The EU Project team has participated in IFAT to showcase the visibility of EU India Project as well as to have an overview of BAT in the project thematic areas. The technological demonstration at IFAT included:

- Water Treatment Technologies including Water distribution and sewers
- Industrial Effluent Treatment & Sludge Management
- Energy efficiency technologies, services and products in the areas of water, sewage, refuse and recycling
- Refuse disposal, recycling and generating energy from waste materials
- Decontamination of old sites and land remediation
- Environment management and services

Interactions

The EU-India Project team interacted various technology providers from India and Europe, apprised them about EU India Project Activities including distribution of project brochure, newsletters and reports. The prominent stakeholders included:

- KOMPTECH
- SFA Handels GmbH
- Effwa Infra & Research
- SS Techno Limited
- OZ-AIR
- Value-e-Products
- GUNTHER Envirotech
- GRUNDON
- BMH Technology
- Johnson Screens (Aqseptence Group)
- LANXESS
- Indus Media

Outcome

EU India Project team has not only showcased the visibility of EU India Project amongst stakeholders but also understood the Best Available Technologies (BAT), which would be further disseminated during upcoming Technical Interactions with Municipal Corporations in Delhi and Mumbai.

Figure-102 (a), (b), (c), (d), (e) & (f): Participation in IFAT Mumbai

Future Mumbai Missions within the Life Cycle of EU India Project on Technical Cooperation for Environment, would include Technical Training on sub-themes of Sewage Treatment and Sludge Management.

10. Wrap-Up and Way Forward

The EU-India Project on Technical Cooperation for Environment, the thematic areas of which have closer synergies with the *"Swachh Bharat Mission"* and National Action Plan on Climate Change, has major aim to create enabling environment for building the capacities of Indian Stakeholders so that the project can contribute towards the "Sustainable and Inclusive Development of India" through skill development.

After the completion of Inception Period of the project in April-2015, wide-spectrum of stakeholders were contacted and interactive sessions were organized from October-2015 to March-2016 and during interaction with wider cross-section of stakeholders, the areas of training needs were identified. Accordingly, two study tours to Europe were organized in June-2016 in the areas (i) Sewage Sludge Management and (ii) Solid Waste Management and third Study Tour on combined thematic areas has been organized during June-2017. In addition, Consultation Workshops on themes (i) Solid Waste Management Processing Technologies, (ii) Sewage Treatment and Sludge Management Technologies and (iii) Landfill Mining Aspects, were organized in Mumbai respectively on 2nd January 2017, 15th March 2017 and 28th September 2017. In these workshops, apart from sharing European Best Practices by the experts from Europe, the stakeholders from Delhi have also contributed by sharing their experience. The workshops were participated by diverse groups comprising of implementers in Mumbai and Delhi, Regulators, European Stakeholders and Project Consortium.

The Project Consortium after understanding the need of the stakeholders and careful review of available literature on Best Available Technologies on the subject matter together with collation and interpretation of data collected from various sources, compiled this Technical and Policy Reports on Sewage Treatment in Greater Mumbai.

The endeavor of Project Consortium is to present a pragmatic document to Municipal Corporation of Greater Mumbai, which shall not only provide interpretation of current status vis-à-vis prevailing rules but also the information about the advanced waste management technologies being practiced along with technical know-how and know-why. The overall aim is to provide a Decision Support System to the EU-India stakeholders so that necessary actions can be envisaged to facilitate Sustainable and Inclusive Development.

Way Forward

The knowledge and insight being acquired by the Indian Stakeholders as well as the Project Consortium through various missions and study tours, would be well documented and shall be widely circulated to enhance technical acquaintances from time to time. Not only this, the onsite technical training programmes would also be organized till the life cycle of the project, to provide a platform to stakeholders to interact on various emerging issues. This would create an enabling environment for learning and skill development.

11. Brief about Project Consortium Organisations

I. IVL Swedish Environmental Research Institute, Sweden

The IVL Swedish Environmental Research Institute is an independent, non-profit research institute, owned by a foundation jointly established by the Swedish Government and Swedish industry. IVL Swedish Environmental Research Institute was established in 1966 and has since then been involved in the development of solutions to environmental problems, at national and international level. IVL undertake research projects and contract assignments in the entire environmental field. The activities include for example climate issues, environmental technology, indoor environment, waste management, working environment, environmental measurements, and environmental quality evaluation. IVL also performs studies of the environmental effects in air, water, and soil, and the institute has its own accredited laboratories for analysis. All activities are linked to six major theme areas: Climate and energy, Sustainable building, Air and transport, Sustainable production, Resource-efficient products and waste, and Water. The broad scope of IVL's activities, combined with its multidisciplinary approach, enables IVL to offer its customers holistic solutions, as well as answers to highly specific problems.

II. Danish Technological Institute, Denmark

The Danish Technological Institute (DTI) is a self-owned and not-for-profit institution. DTI develop, apply and disseminate research and technologically-based knowledge for the Danish and International business sectors. DTI undertakes consultancy and standardization services, which contribute to a dynamic and harmonious development of society with the objectives to ensure that new knowledge and technology quickly converted into value for customers in the form of new or improved products, materials, processes, methods and organizational structures. The major focus of DTI is on:

- Innovation and competitiveness
- Management and training
- Sustainable exploitation of resources
- Cost-effectiveness in company and society

III. Shriram Institute for Industrial Research, Delhi, India

The Shriram Institute for Industrial Research (SRI) established in the year 1947. SRI is an independent, not-for-profit, self-sustaining, multi-locational contract research organization of international repute dedicated to support wide-spectrum of stakeholders through industrial research. The major Thrust Areas of SRI are Environment Protection Division (EPD) including Atmospheric Science, Micro-meteorology, Water Resources Management, Waste Management, EIA/EMP, Climate Change and Chemical Risk and Hazard Assessment; Biological Sciences; Material Sciences and Analytical Sciences. SRI is accredited by NABL, ISO-9001, ISO-14001, OHSAS 18001 and QCI/NABET in addition to its approval by the MoEF&CC. The EPD provides services in multi-disciplinary areas with the overall objectives, such as:

- Facilitation in devising Decision Support Systems for Sustainable Development.
- To support regulators by providing unbiased monitoring data.
- Natural Resource Accounting and Assessment of supportive capacity of ecosystem.
- Capacity Building of Stakeholders for making effective strategies.

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List of Abbreviations

ADWF	:	Average Dry Weather Flow
AE	:	Assistant Engineer
AF	:	Anaerobic Filter
AFB	:	Anaerobic Fluidized Bed
AL	:	Aerated lagoon
APHA	:	Americal Public Health Association
ASP	:	Activated Sludge Process
AVO	:	amps', 'volts' and 'ohms
AWWA	:	Americal Water Works Association
BIOFOR	:	Biological Filtration and Oxygenated Reactor
BIS	:	Bureau of Indian Standards
BOD	:	Biochemical Oxygen Demand
BSAP	:	Baltic Sea Action Plan
BSDP	:	Bombay Sewage Disposal Project
CE	:	Chief Engineer
CEPT	:	Chemically-enhanced primary treatment
CGWB	:	Central Ground Water Board
COD	:	Chemical Oxygen Demand
CPCB	:	Central Pollution Control Board
CPHEEO	:	Central Public Health and Environmental Engineering Organization
CRZ	:	Coastal Regulation Zone
CW	:	Consultation Workshop
DDP	:	Draft Development Plan
DI	:	Ductile Iron
DJB	:	Delhi Jal Board
DNA	:	Deoxyribonucleic acid
DO	:	Dissolved Oxygen
DPCC	:	Delhi Pollution Control Committee
DTI	:	Danish Technological Institute
EBB	:	Eco Bio Block
EBPR	:	Enhanced biological phosphate removal
EC	:	Electrical Conductivity
EE	:	Executive Engineer
EIA	:	Environmental Impact Assessment

ELU	:	Existing Land Use
EMP	:	Environmental Management Plan
EPS	:	Effluent Pumping Station
EPS	:	Extracellular polymeric substances
EUD	:	European Union Delegation to India
F/M	:	Food to Microorganisms
FAB	:	Fluidized Aerobic Bioreactor
FBAS	:	Fixed Bed Biofilm Activated Sludge Process
GOD	:	Ground Operated Dis-connectors
GOI	:	Government of India
HP	:	Horse Power
HRT	:	Hydraulic Residence Time
HSM	:	Holistic Sludge Management
HSSV	:	Hammarby Sjöstadsverk
HT	:	High Tension
HTL	:	High Tideline
HWL	:	High Water Level
IEC	:	Information, Education and Communication
IFAT	:	International Federation for Alternative Trade
IPS	:	Influent Pumping Station
ISO	:	International Organization for Standardization
IVL	:	IVL Swedish Environmental Research Institute
Kgy	:	kilogray
kWh	:	kilowatt hour
LWL	:	Low Water Level
M&E	:	Mechanical and Electrical
MBBR	:	Moving Bed Bio Reactor
MBR	:	Membrane Bio Reactor
MCGM	:	Municipal Corporation of Greater Mumbai
MCRT	:	Mean Cell Residence Time
MDG	:	Millennium Development Goals
mg/l	:	milligram per litre
MLD	:	Million Litres per Day
MLSS	:	Mixed liquor suspended solids
MMC	:	Mumbai Municipal Corporation
MoEF&CC	:	Ministry of Environment, Forests & Climate Change

MPCB	:	Maharashtra Pollution Control Board
MSDP	:	Mumbai Sewage Disposal Project
NABET	:	National Accreditation Board for Education and Training
NCT	:	National Capital Territory
NDZ	:	No Development Zone
NEERI	:	National Environmental Engineering Research Institute
NGO	:	Non-government Organisation
NH_4-N	:	Ammoniacal Nitrogen
NO_3-N	:	Nitrate Nitrogen
NPSHr	:	Net Positive Suction Head Required
O&M	:	Operation and Maintenance
OD	:	Oxidation Ditch
OHSAS	:	Occupational Health and Safety Management
PAN	:	Polyacrylonitrile
PDF	:	Peak Daily Flow
PE	:	Polyethylene
PE	:	population equivalents
PES	:	Polyethylsulphone
PHA	:	Polyhydroxyalkanoates
PHED	:	Public Health Engineering Department
PP	:	Polypropylene
PPE	:	Personal Protective Equipment
PPP	:	Public Private Partnership
PPP	:	Pollution Control Boards
PST	:	Primary Sedimentation Tank
PVC	:	Polyvinyl Chloride
PVDF	:	Polyvinylidene difluoride
QCI	:	Quality Council of India
RBC	:	Rotating Biological Contactor
RPM	:	Revolutions per Minutes
SAFF	:	Submerged Aeration Fixed Film
SAR	:	Sodium Absorption Ratio
SBR	:	Sequencing Batch Reactor
SE	:	Sub-Engineer
SMP	:	Soluble Microbial Products
SPA	:	Special Planning Authority

SPS	:	Sewage Pumping Stations
SRI	:	Shriram Institute for Industrial Research
SRT	:	Solids Retention Time
SSR	:	Sludge Settling Rate
ST	:	Study Tour
STP	:	Sewage Treatment Plant
SVAB	:	Stockholm Vatten AB
SVI	:	Sludge Volume Index
SWD	:	Side Water Depth
SWM	:	Solid Waste Management
TMP	:	Trans-membrane pressure
TSS	:	Total Suspended Solids
UASB	:	Up flow Anaerobic Sludge Blanket
ULB	:	Urban Local Bodies
UWWTD	:	Urban Waste Water Treatment Directive
VSS	:	Volatile Suspended Solids
WEF	:	Water Environment Federation
WP	:	Work Packages
WPC	:	Water Pollution Control
WSP	:	Waste Stabilization Pond
WSS	:	water supply and sanitation
WWTF	:	Wastewater Treatment Facilities