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Introduction

Urbanization and industrialization draw people from rural areas to migrate to cities in search of a better standard of living. In fast-developing countries like India, the large flow of migrants to major cities puts much pressure on city infrastructure especially on the water supply and sanitation system and particularly on sanitation infrastructure such as the wastewater collection network, treatment through sewage treatment plants (STPs), sewage disposal system, and the reuse distribution system. As a consequence, around 80% of the total drinking water supply ends up as wastewater. In several instances, the facilities provided have become either insufficient or improperly maintained. Kulkarni, Wanjule, and Shinde (2018) report that out of the total sewage produced in India only 10% is treated and the rest is discharged into water bodies or on the ground. In most cities, wastewater is often untreated, and thus contaminating the surface as well as groundwater resources. Therefore, proper sewage treatment is essential; and sometimes treated sewage can be used for other purposes as well (Kulkarni, Wanjule, and Shinde (2018).

Around 80% of the total drinking water supply ends up as wastewater.

Local, state, and central governments must develop and put in place sanitation policies to help improve hygiene and living conditions of a large sector of the population. India has established several such policies, the Jawaharlal Nehru National Urban Renewal Mission

(JNNURM) and Atal Mission for Rejuvenation and Urban Transformation (AMRUT) among them. These programs have facilitated the development of sanitation infrastructure in several cities, which have brought sanitation and hygiene benefits to city residents. In addition, such large infrastructure projects also offer economic and social spillovers, depending on the technical efficiency of the sewer network, sewage treatment methodology, operation and maintenance of the STP, and continuous monitoring of the effluent characteristics. It is thus necessary to study and evaluate the STP process from its inception; because a small error corrected in time saves a large amount of effort and money over time. This study examines the technical efficiency and socioeconomic spillovers of the STP at Navi Mumbai Municipal Corporation (NMMC) in Navi Mumbai, Maharashtra, India.

To assess the STP's technical efficiency, we study the quality of its influent (raw) sewage and effluent (treated) sewage. The Supervisory Control and Data Acquisition (SCADA) system collects and monitors relevant time series data on several sewage characteristics such as pH, temperature, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and dissolved oxygen (DO). By comparing the observed sewage quality before and after treatment, we are able to assess the treatment efficiency (technical) of the STP over a period of time.

We also assess the sanitary project's socioeconomic spillover effects over the area by studying other benefits such as increased property values; increased number of settlements; increase in tax revenue; environment health-related aspects like air quality, water quality, and public health life; decrease in waterborne diseases; and the monetary benefit in the sale of treated water for various purposes like industrial use, gardening, and road wash.

In India, the Manual on Sewerage and Sewage Treatment by the Central Public Health and Environmental Engineering Organisation (CPHEEO) (1993) provides the standard guidelines for designing an STP. The manual was revised in 2012. In addition, a few case studies have reported on the performance evaluation of STPs worldwide (UNEP 1991; Belhaj et al. 2014; Hegazy and Gawad 2016; Kulkarni, Wanjule, and Shinde 2018; Bhave and Rahate 2018; and Ahmed et al. 2018); some have reported on STP performance using soft-computing techniques (Hamed, Khalafallah, and Hassanein 2004; Hanbay, Turkoglu, and Demir 2008); but very few studies have studied and reported on the STP's spillover effects. The Central Pollution Control Board (CPCB) of the Government of India has issued evaluation guidelines (CPCB 2007) for assessing the operation and maintenance of STPs in India. But there are no standard guidelines for studying spillovers, especially socioeconomic spillovers, even though good reports are available to study the environmental assessment of STPs (UNEP 1991).

STPs bring about other ancillary benefits, such as improved hygiene, better water quality in tanks and ponds, larger numbers of migratory birds in coastal cities as a result of discontinued dumping of untreated sewage into creeks (flamingo migration in the NMMC area), and good health and overall economic growth. The lessons learned from employing these sanitation policies, the technical knowledge from their implementation, and the quantification of the spillover effects offer useful knowledge for decision makers to accelerate other sanitation projects not only statewide but also nationwide.

India's National Urban Sanitation Policy

In November 2008, the Government of India launched a national urban sanitation policy with the goal of eradicating open defecation and creating totally sanitized cities in which wastewater is safely collected and treated. JNNURM (2005–2014) played an important role in financing urban water supply and sanitation through central government grants. However, the grants were limited to the 35 largest cities in the country and 28 other selected cities. Many cities with less than 1 million inhabitants were not eligible. Hence, after 2014, the policy was extended to all cities through AMRUT, the government's new flagship urban development program. In addition, the government announced its high-profile Swachh Bharat Abhiyan (Clean India Mission) policy, which aimed to eradicate open defecation by 2019 in 4,041 cities and towns. The program has received funding and technical support from the World Bank, corporations, and state governments under the Sarva Shiksha Abhiyan and Rashtriya Madhyamik Shiksha Abhiyan schemes. These large sanitation policies are expected to provide sanitation facilities throughout India.

The government has taken on the following roles: at the national level it generates awareness and provides funding and assistance; at the state level, it ensures that standards are set and the tenure and space issues are resolved for providing sanitation to the urban poor; and at the city level, it conducts capacity building and training as well as monitoring and evaluation. The urban local bodies on the other hand are responsible for preparing city sanitation plans, planning for the financing of schemes, obtaining the required approvals, execution, and operation and maintenance.

To address urban sanitation issues—such as poor awareness, poor institutional arrangement, lack of an integrated citywide approach, reaching the urban poor, and lack of responsiveness to demand—India's government introduced the National Urban Sanitation Policy to (i) generate awareness about sanitation and its link to public and environmental health; (ii) promote access to safe sanitation facilities for households; (iii) establish proper planning and management of community toilets; and (iv) strengthen institutions at the national, state, and local levels to prioritize the provision of a properly planned, implemented, and managed sanitation scheme.

After the launch of the national urban sanitation policies, several urban local bodies approached the state and the central government to provide sanitation in their cities. Several cities have successfully implemented sanitation facilities in consequence, but some of these facilities are now more than 5 years old. This paper studies the sanitation facilities in a large city—in NMMC in particular—and evaluates the efficiency of the STPs and examines the spillover effects of providing such a large-scale facility.

Navi Mumbai, the Study Area

Navi Mumbai is a planned township off the west coast of the Indian state of Maharashtra in the Konkan Division. Since it is a planned city, its facilities are state of the art. Navi Mumbai has lived up to expectations of absorbing the population shock of migrants from the megacity of Mumbai, evident in the recorded population growth of more than 51% between 2001 and 2011.

Navi Mumbai was designed to decongest Mumbai and is one of the largest planned cities in India.

Conceived in 1972, Navi Mumbai was designed to decongest Mumbai and is one of the largest planned cities in India. In 1970, a public sector undertaking, the City and Industrial Development Corporation (CIDCO), was incorporated for the purpose of planning, developing, and maintaining the city of Navi Mumbai. Accordingly, CIDCO prepared a development plan for an estimated area of 343.70 square kilometers (km^2) covering 95 villages from the Thane District to Raigad District. CIDCO planned to develop 14 nodes in Navi Mumbai, of which 8 nodes (Airoli, Ghansoli, Kopar Khairane, Vashi, Sanpada, Nerul, CBD Belapur, and Digha) were developed first to form the NMMC in 1991. The development of the industrial belt in Navi Mumbai attracted a fairly large population as it brought forth employment opportunities. Given the ease of connectivity to Mumbai, the city quickly became urbanized.

NMMC jurisdiction is divided into eight zones from Digha in the north to Belapur in the south. Of the total 343.70 km^2 area demarcated for Navi Mumbai, 108.63 km^2 is under the purview of NMMC. According to Urban Health Post estimates for 2016–2017, the population of the NMMC area is around 1.5 million (1,469,302) with an average population density of about 13,525 persons per km^2, which is 37% of Mumbai's current average population density.

Navi Mumbai lies in the tropical climate zone and has three seasons: summer, monsoon, and winter. Normal temperature in Navi Mumbai varies from 22°C to 36°C, while the maximum summer temperature ranges from 36°C to 41°C and the minimum winter temperature between 17°C and 20°C. Average annual rainfall is 2,000–2,500 millimeters and humidity varies from 61% to 86%. Navi Mumbai's ideal environment and proximity to Mumbai attracts industry and many people.

Compared with other cities of similar population size, NMMC infrastructure gives its residents the assurance of 24/7 water supply, 100% sewerage connection and sewage treatment, a stormwater network, solid waste management system, and transport. Focusing our study on the technical efficiency and socioeconomic spillover effects of the sanitation program, we assess technical efficiency by measuring influent and effluent characteristics, and infer socioeconomic spillovers from other benefits. While we cannot attribute the spillover effects entirely to the sanitation program, the program has made major contributions to overall city improvement.

NMMC infrastructure gives its residents the assurance of 24/7 water supply and 100% sewerage connection and sewage treatment.

The Sanitation Program of the Navi Mumbai Municipal Corporation Area

While developing the planned city of Navi Mumbai, CIDCO had demarcated land for various types of infrastructure, especially for sewage treatment plants. Several nodes and sectors were developed in the NMMC area, and prospective locations were identified for the construction of sewage treatment plants.

In 1991, CIDCO constructed aerated lagoons in seven locations. Although they served the purpose albeit not to the full extent, residents over time observed bad odor emanating from the treatment plant, frequent breakdown of the aerators, and stormwater inlets causing lagoons to overflow during the monsoon.

First, these lagoons occupied a large area, giving rise to a potentially large carbon footprint. Second, the diameter of the installed 150-millimeter drain pipes was too small to serve the population (in 1991), causing the pipes to be blocked in several locations and making maintenance very difficult. Third, only 70% of the developed nodes had an underground drainage system; in effect, the drainage did not cover the remaining 30% which included the original villages (and those existing before the NMMC area was developed). Hence, sewage from the area occupied by the 30% flowed freely from individual household septic tanks to the open drains.

In 2000–2010, the central government launched a sanitation program for large cities under JNNURM. Following the introduction of the National Urban Sanitation Policy in 2005, JNNURM and NMMC prepared a detailed project report (DPR) with the following aims:

1. Provide a sewer network that would cover 100% of the total area, including the villages.
2. Treat collected sewage using the latest technique, thus reducing the carbon footprint of the STP area and meeting the national standards for treated effluent before letting the treated water out into the creek.

The NMMC appointed project management consultants, M/s Tandon Urban Solutions Pvt Ltd., to prepare the DPR and obtained approval from the local councils. The DPR was approved in principle by the central and state governments. Technical approval of the DPR was issued by the Ministry of Urban Development and CPHEEO.

Thereafter, the government sought technical advice from higher technical institutes such as the Indian Institute of Technology Bombay (IITB). IIT Bombay vetted the designs of the sewer network and the STP and gave the following suggestions:

1. Drainage pipes for the sewer network should have a minimum diameter of 250 mm.
2. Perform conditional assessment studies prior to replacing damaged and frequently blocked area networks (Sourabh and Timbadiya 2018).
3. Install in STPs a self-cleansing velocity of 0.8 meters per second (m/s) for the sewage quantity of the designed period (30 years from 2008).

4. Reduce NMMC's carbon footprint and automate control of the STP for easy operation and maintenance as well as for monitoring the influent and effluent sewage characteristics.

The revised DPR was again tabulated before the local, state, and central governments for financial approval. The government approved the grant and NMMC started the work in 2009 and completed it in 2012. All seven STPs under this program began functioning simultaneously during 2012–2013. Residents felt the impact of the sanitation policy right after commissioning: there was no more odor in the vicinity of the STP, and the STP construction area was reduced, leaving more space for future STPs.

Almost 100% of the sewage water generated by the NMMC area is treated before it is released in the creek.

NMMC operates seven active STPs, all of which have secondary treatment facilities with an aggregate capacity of about 454 million liters per day (MLD). Table 1 describes the location, capacity, and secondary treatment technology of the STPs in Navi Mumbai. Under the "open-defecation-free city" policy, the government installed several public toilets within NMMC limits, especially in the area occupied by the floating population. Special suction units were installed to clean the sewage from public toilets—there are around 10 suction units, 7 units with a capacity of 2,000 liters and 3 units of 6,000-liter capacity. These units collect sewage and dispose it to the treatment plants. The NMMC area currently generates an estimated 205 MLD of sewage, which are collected and treated. Almost 100% of sewage water is treated before it is released in the creek.

Table 1: Location and Capacity of Sewage Treatment Plants in the NMMC Area

<table>
<tr><th>Serial No.</th><th>Node and Sector</th><th>Design Capacity (MLD)</th><th>Secondary Treatment Technology</th></tr>
<tr><td>1</td><td>CBD Belapur located in sector 12</td><td>19</td><td rowspan="7">Cyclic activated sludge process (SBR technology)</td></tr>
<tr><td>2</td><td>Nerul located in sector 50</td><td>100</td></tr>
<tr><td>3</td><td>Sanpada located in sector 21</td><td>37.5</td></tr>
<tr><td>4</td><td>Vashi located in sector 18</td><td>100</td></tr>
<tr><td>5</td><td>Kopar Khairane located in sector 14</td><td>87.5</td></tr>
<tr><td>6</td><td>Ghansoli located in sector 15</td><td>30</td></tr>
<tr><td>7</td><td>Airoli located in sector 18</td><td>80</td></tr>
<tr><td>Total</td><td></td><td>454</td><td></td></tr>
</table>

CBD = central business district, MLD = million liters per day, NMMC = Navi Mumbai Municipal Corporation, SBR = sequencing batch reactor.

Source: NMMC (2017).

Each STP is equipped with primary and secondary treatment facilities, which operate on the cyclic activated sludge treatment technology using the advanced sequencing (sequential) batch reactor (SBR) process. The system operates on a batch reactor mode, which eliminates all the inefficiencies of the continuous process. The complete process takes place in a single reactor, which administers the steps of biological treatment in sequential order. Water quality tests are conducted daily during secondary treatment.

Technical Efficiency and Spillover Effects of the STPs

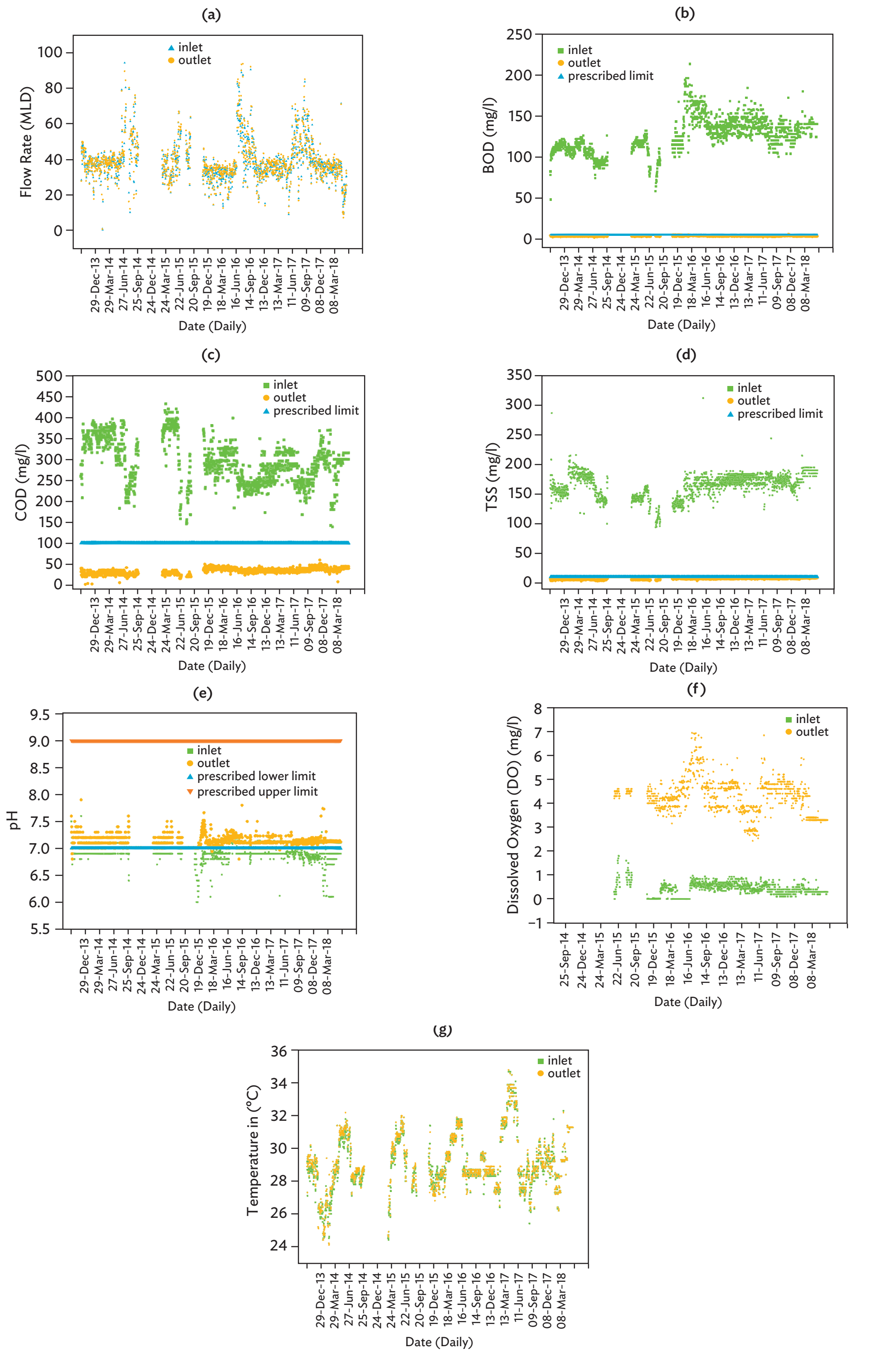
We analyzed the technical performance of STPs at Nerul (sector 50) in Navi Mumbai by first collecting daily observed characteristics of influent and effluent treated sewage such as the flow rate, BOD, COD, TSS, pH, DO, and temperature over a 5-year period from October 2013 to May 2018. The data were measured continuously using a detailed SCADA program and tested once daily at labs inside the STPs. Once weekly the sewage characteristics were tested in government-approved labs outside the STP. Figure 1 shows the observed raw and treated sewage characteristics and the prescribed sewage standards for the sewage at the Nerul STP. From the time series plots in Figure 1, we observe that the levels of effluent characteristics are well within the prescribed standard limits, confirming that the plant is working efficiently.

Initially, we also performed a statistical analysis of influent and effluent characteristics. Tables 2 and 3 show the results of this statistical analysis such as the mean and standard deviation of the influent and effluent sewage characteristics at the Nerul STP. Figure 1 is a pictorial analysis (or time series), and Figure 2 shows box plots of the data.

Based on the analysis, we found that the maximum flow rate of raw sewage reached 93.6 MLD during the monsoon period, and around 50% of the plant capacity during the non-monsoon period. The high inflow rate during the monsoon period could be a result of heavier groundwater infiltration or the mixing of stormwater through the manholes.

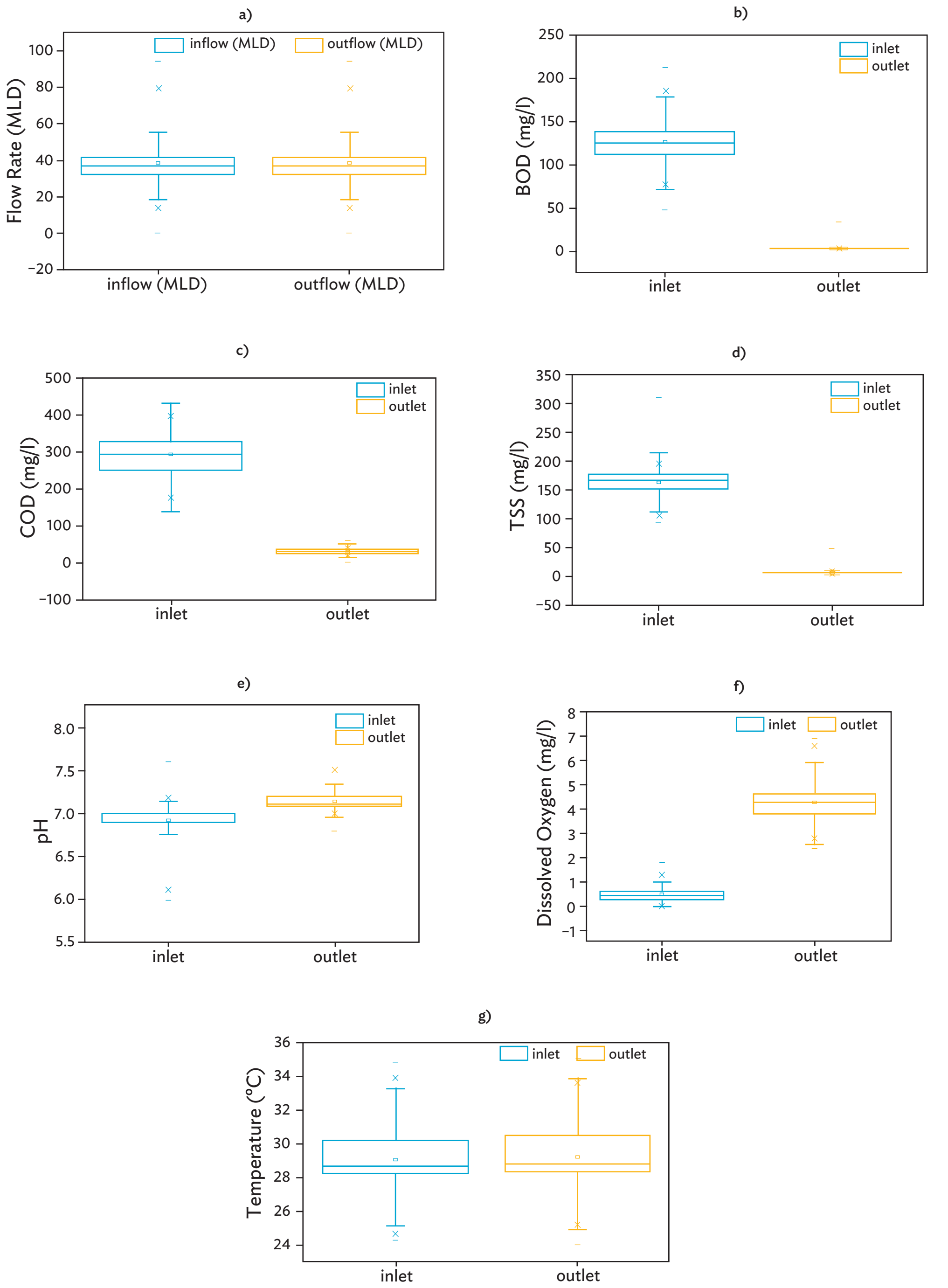
The biological oxygen demand (BOD) of raw sewage reached the highest levels during summer (March–May) and are lowest during the high-intensity monsoon periods (June–September), which may be attributed to the mixing of stormwater during monsoon periods and the consequent dilution of the BOD concentration. The minimum BOD level of observed raw sewage was 48 milligrams per liter (mg/l) and the maximum level was 213 mg/l. The maximum value of raw sewage BOD was observed during March 2016 and the minimum value in October 2016. After treatment, the minimum and maximum BOD levels of the treated sewage (effluent) were 2 mg/l and 5.8 mg/l, respectively, which are well within the standard limits. In fact, the CPHEEO manual (CPHEEO 1993) suggested that the BOD level of treated effluent could be 10 mg/l, but NMMC wanted it to be 5 mg/l. The maximum value of treated sewage BOD was 5.8mg/l, which was observed during November 2018. Since NMMC had planned on using the treated water for industrial purposes and also for non-human contact purposes such as gardening and road washing, the standard of 5 mg/l is a good choice.

Figure 1: Influent (Raw) and Effluent (Treated) Sewage Characteristics at Nerul STP



BOD = biological oxygen demand, COD = chemical oxygen demand, MLD = million liters per day, mg/l = milligrams per liter, STP = sewage treatment plant, TSS = total suspended solids.
Source: Data from NMMC and figures drawn by authors.

Figure 2: Box Plots of Raw Sewage (Influent) and Treated Sewage (Effluent) at Nerul STP



BOD = biological oxygen demand, COD = chemical oxygen demand, MLD = million liters per day, mg/l = milligrams per liter, STP = sewage treatment plant, TSS = total suspended solids.
Source: Data from NMMC and figures drawn by authors.

Table 2: Raw Sewage (Influent) Characteristics of the Nerul STP

Parameters	Mean	Standard Deviation	Skewness	Kurtosis	Minimum Value	Maximum Value	Prescribed Value
Flow rate (MLD)	38.26	11.23	1.19	6.37	0.03	94.15	100
BOD (mg/l)	125.89	21.34	0.28	3.52	48	213	250
COD (mg/l)	294.45	52.97	0.010	2.42	139	432	400
TSS (mg/l)	165.02	20.21	(0.19)	6.02	94	312	200
pH	6.909	0.21	(12.19)	286.37	6	7.60	5.5–9.0
DO (mg/l)	0.421	0.28	0.52	4.31	0	1.80	
Temperature (°C)	29.098	1.76	0.65	5.04	24.4	40.63	

( ) = negative value, BOD = biological oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen, MLD = million liters per day, mg/l = milligrams per liter, STP = sewage treatment plant, TSS = total suspended solids.

Source: Data from NMMC Sewerage Department.

Table 3: Treated Sewage (Effluent) Characteristics at Nerul Pond

Parameters	Mean	Standard Deviation	Skewness	Kurtosis	Minimum Value	Maximum Value	Prescribed Value
Flow rate (MLD)	38.75	11.57	1.23	6.19	0.49	93.67	100
BOD (mg/l)	3.73	0.47	0.56	3.59	2	5.8	< 5
COD (mg/l)	33.82	6.87	(0.32)	3.61	2	60	< 100
TSS (mg/l)	7.06	1.22	(0.28)	2.91	3.2	10.2	< 10
pH	7.13	0.17	(10.10)	181.72	6.8	7.9	7 to 9
DO (mg/l)	4.30	0.74	0.47	3.83	2.43	6.94	
Temperature (°C)	29.19	1.71	0.35	3.35	24.1	34.8	

BOD = biological oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen, MLD = million liters per day, mg/l = milligrams per liter, STP = sewage treatment plant, TSS = total suspended solids.

Source: Data from NMMC Sewerage Department.

The chemical oxygen demand (COD) of the influent sewage was in line with the BOD. The maximum COD (432 mg/l) was observed during summer months and minimum (139 mg/l) during monsoon periods. After treatment the COD of the effluent was within the range of 2 mg/l to 60 mg/l, depending on the COD of raw sewage values. The COD characteristics of the treated sewage was well within the prescribed standard limit of 100 mg/l considered during the design period.

The minimum and maximum values for the total suspended solids (TSS) of raw sewage were 94 mg/l and 312 mg/l, respectively. For the treated sewage, the minimum and maximum TSS values for the effluent at outlet were observed to be at 3.2 mg/l and 10.2 mg/l, respectively. The minimum and maximum values for pH at the inlet were 6 and 7.6, respectively; the values for pH at the outlet after treatment were 6.8 minimum and 7.9 maximum, respectively, which shows that the STP has

The STP is working well and is treating the sewage at 100% efficiency.

maintained the TSS and pH characteristics of the effluent within the design limit. For dissolved oxygen (DO), the maximum and minimum DO levels of raw sewage were 0 mg/l and 1.80 mg/l, respectively; and after treatment the levels were 2.43 mg/l and 6.94 mg/l, respectively. The mean value for temperature was 29.09°C. The minimum and maximum temperatures of the influent sewage were 24.4°C and 40.63°C, respectively, while the mean temperature of treated sewage was 29.19°C, while the minimum and maximum temperatures were 24.1°C and 34.8°C, respectively. Although there is no standard mentioned, the temperatures are well within the air temperature prevailing in NMMC. Based on the statistical analysis of the raw sewage (influent) and treated sewage (effluent) characteristics of the STP at Nerul in NMMC, we can conclude that the STP is working well and is treating the sewage at 100% efficiency according to the prescribed standards. We conducted the above analysis for one STP since all other STPs are using the same treatment process and are also monitored using the SCADA system.

After treatment, the treated sewage is discharged into the creek. Before discharging the water from STPs into the creek, NMMC monitors water quality regularly and sends reports to the Maharashtra Pollution Control Board (MPCB), a government organization responsible for the upkeep of the environmental condition of the entire Maharashtra. This type of monitoring helps to check the levels of various parameters, which affect water quality as well as the efficiency of treatment plants. Table 4 presents the average performance of the raw and treated sewage in all other STPs in Navi Mumbai, clearly indicating that all parameters are well within the standard limits until 2016–2017.

Table 4: Average Performance and Efficiency of STPs in the NMMC Area, 2013–2018

Serial No.	STP	pH 6.5–9		BOD (mg/l) <10		COD (mg/l) <50		TSS (mg/l) <20	
		Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated
1	CBD Belapur	7.1	7.5	105	4	255	49	162	8
2	Nerul	6.9	7.1	146	4	235	35	133	8
3	Sanpada	6.9	7.4	140	3	294	32	128	7
4	Vashi	6.8	7.0	140	4	256	48	174	9
5	Kopar Khairane	6.9	7.2	116	4	324	28	131	6
6	Ghansoli	6.8	7.2	124	4	252	44	112	6
7	Airoli	6.7	7	156	4	306	44	152	8

BOD = biological oxygen demand, CBD = central business district, COD = chemical oxygen demand, mg/l = milligrams per liter, STP = sewage treatment plant, TSS = total suspended solids.

Source: Data from NMMC Sewerage Department.

Additional Policy Decisions Made After the Success of STPs in NMMC

Realizing the need to conserve water, NMMC adopted a policy to reuse the treated sewage water, especially where human contact is absent such as in industries and gardening. This additional policy has fetched monetary benefits, which will be used for the maintenance of existing STPs.

After implementing the STPs and the sewer network, NMMC adopted the "open-defecation-free city" policy, which also applies to the floating populations.

Reuse of Treated Wastewater

As mentioned earlier, NMMC had required the mandatory reuse of treated wastewater and had given incentives for industries to comply. It also plans to meet the water demand for various secondary applications in the city.

As a pilot project for secondary treatment, 40 MLD of water was again treated using a tertiary process, for supply to large industries. NMMC proposed the commissioning of a direct pipeline to directly transfer treated sewage water from the Nerul STP to industries, thus reducing transportation cost. In addition to selling the treated sewage water to industries, NMMC uses the treated sewage water for the following purposes:

- Supplied to CIDCO for watering plantations along road medians;
- Supplied to the NRI Complex at Seawoods for gardening purposes;
- Supplied to construction sites for construction activity; and
- Used for watering the lawns of NMMC gardens (several new public parks have been created).

Improvement in Biodiversity of the NMMC Area

NMMC's biodiversity has improved considerably since the flow of untreated sewage into creeks and water bodies has been completely stopped. Navi Mumbai has an abundant green cover ranging from forest patches to mudflats and mangroves in the coastal region, making it an ideal spot for bird-watching. Different species of water birds, local migrants, and passage migrants can be spotted in several areas. During 2016–2017, more than 168 species of birds many of them migratory in nature were observed in key biodiversity hotspots in parts of the Thane Creek and the Uran Creek. Nerul's Talave, Airoli, and Ghansoli mudflats are also home to some exotic birds. Ornithologists have also

Ornithologists have observed a substantial rise in bird population.

observed a substantial rise in bird population and attribute the reason for this to the availability of sufficient food and conducive habitat as a consequence of cutting the flow of untreated sewage water into these areas.

Air Quality

There are four continuous ambient air quality monitoring stations currently installed, at Airoli, Kopar Khairane, Turbhe, and Nerul. Table 5 shows the monitored air quality in these stations. The air quality in Kopar Khairane, Airoli, and Vashi has improved considerably because the large-scale STP reduced the odor and emission of a large quantity of nitrogen dioxide (NO_2) from the aerated lagoons. But the rising number of settlements and consequent increase of vehicles have produced more than the permissible limits of nitrogen oxide (NO_x), carbon monoxide (CO), and $PM_{2.5}$ concentrations.

Socioeconomic Spillovers

To study socioeconomic spillovers, we first analyzed population growth in the area. NMMC's estimated population in 2016–2017 was about 1.469 million, which is 1.4% more than the 2015 survey data from Urban Health Post (UHP), NMMC's health department. The population increase coupled with the rise of industrial, educational hub, economic activities, and infrastructure are major driving forces of the city's growth. Figure 3 shows NMMC's steady growth during 2012–2016. NMMC reports that it has reached its saturated level in terms of human settlement, and that CIDCO has started developing the nearby area. But infrastructure and other facilities in the left-over areas (near the STPs) have been improved.

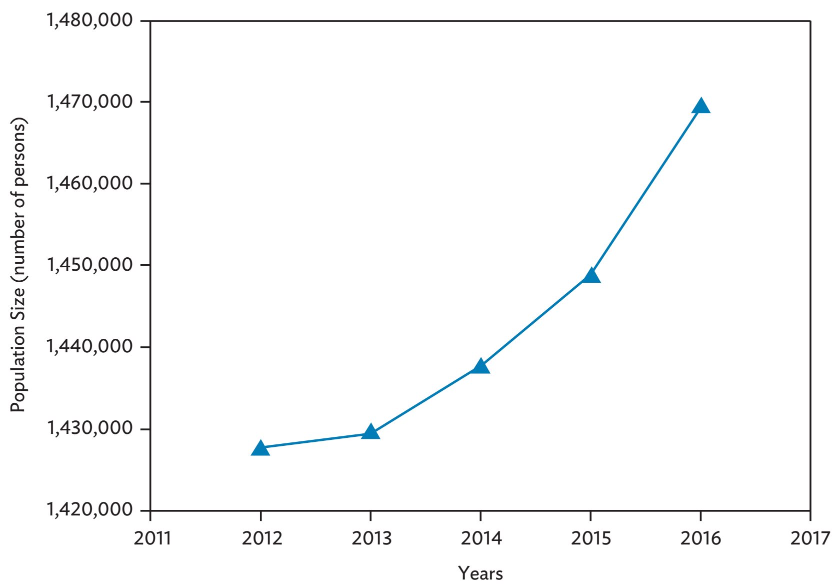
Table 5: Annual Trend in Concentration of NOx at CAAQMS in Navi Mumbai

Year	Kopar Khairane (μg/m³)	Airoli (μg/m³)	Vashi (μg/m³)	Turbhe (μg/m³)
Annual standard	40	40	40	40
2009–2010	NA	82.69	57	NA
2010–2011	NA	66.56	45	NA
2011–2012	79.34	59.13	43	NA
2012–2013	80.34	77.69	56	22
2013–2014	63.83	46.38	44	30
2014–2015	42.53	27.25		35
2015–2016	57.40	42.35	Site shifting under process	33.30
2016–2017	27.72	39.74		28.61

CAAQMS = continuous ambient air quality monitoring stations, NA = not available, NOx = nitrogen oxide.

Source: NMMC (2017).

Figure 3: Population Growth in Navi Mumbai, 2012–2016

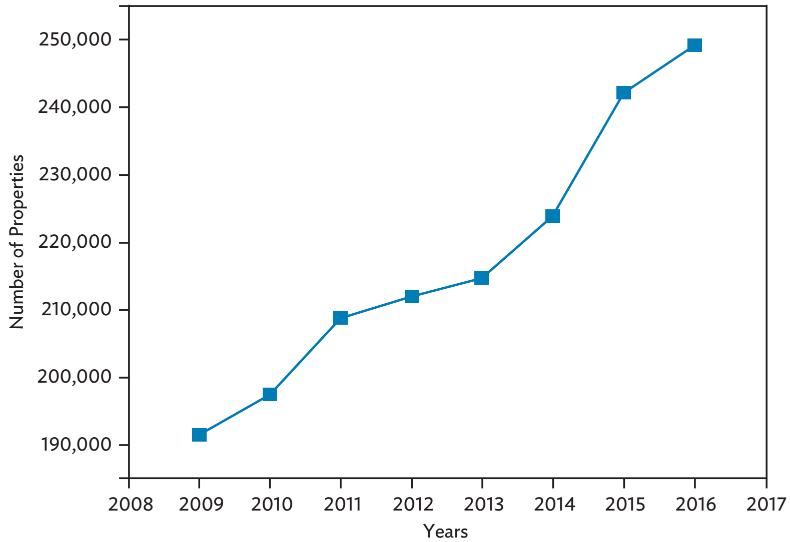


Source: Urban Health Post Survey, Navi Mumbai Municipal Corporation.

Figure 4 shows a distinct 25% increase in the number of properties in NMMC since 2009–2010. In 2016–2017, residential properties recorded the highest number at 82% or a total of 307,710 properties, followed by commercial buildings with a 17% share, and Maharashtra Industrial Development Corporation (MIDC) with the least share of all at 1%. A land-use map in 2003 and 2016 of the Nerul STP clearly indicated a substantial change in land use, because after constructing the STP in 2009–2012 the odor had reduced, the scenario had changed, people started developing the area, and now 8 years later, the area around the STP has become one of the well-sought areas in NMMC. Figure 5 shows the change in population and property growth in Navi Mumbai.

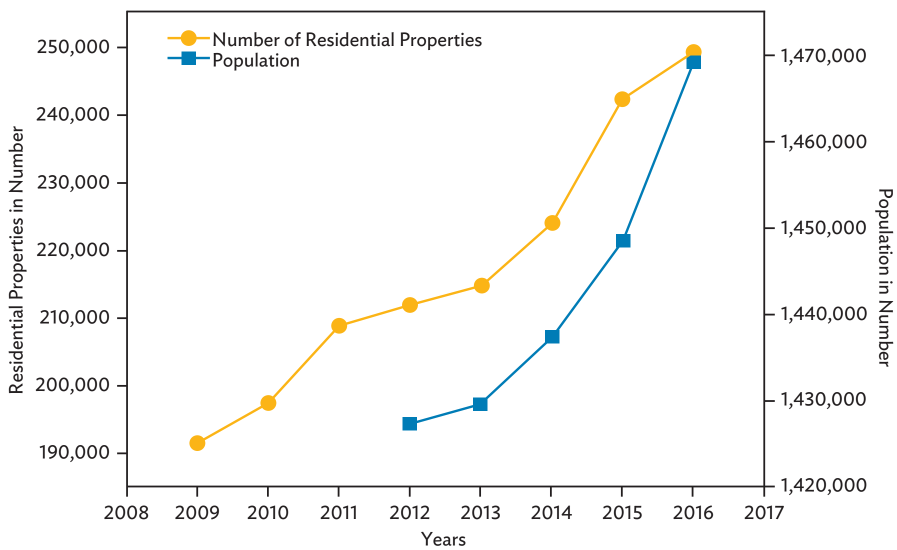
The area around the sewage treatment plant has become one of the well-sought areas in NMMC.

Figure 4: Property Development Trend in Navi Mumbai, Over the Last 8 Years



Source: Town Planning Department, Navi Mumbai Municipal Corporation.

Figure 5: Population and Property Growth in Navi Mumbai



Source: NMMC (2017).

Health and Hygiene Improvement in the NMMC Area

The second spillover parameter we studied after implementation of the sanitation program is the health condition of the residents in the area served by the STPs. From the Health Department of NMMC we collected data pertaining to water-related diseases.

Waterborne diseases are illnesses caused by intake of water contaminated with animal and human feces, which contains harmful or pathogenic microorganisms. These diseases are commonly found in tropical and subtropical regions where many people have no access to safe drinking water and live in unhygienic conditions. These diseases contribute to around 17% of the total global burden of infectious diseases. Malaria is the most common of these diseases, and dengue is one of the fastest growing vector-borne diseases in the world. Over the last decade (2000 to 2009), water-related health issues have become more and more complex, new water-related diseases have emerged, and existing ones have reemerged. Table 6 shows the total number of persons affected by waterborne diseases over the NMMC area, and Figure 6 shows the trend in the number of waterborne diseases. The number of affected persons has reduced drastically compared with the years 2008–2013.

Table 6 shows a drastic reduction in the number of cases for gastrointestinal diseases during 2014–2015 and 2015–2016. There is almost a 90% decrease (35 cases) in the number of cases when compared with the recorded cases during 2015 (351 cases). *Norovirus* is known to cause gastroenteritis which commonly occurs when consuming contaminated food and water. It is also contagious and may be contracted by direct contact with an infected person. Figure 6 records a drastic decrease of dysentery cases, by almost 98%, with the number of cases dropping from

Table 6: Persons Affected by Waterborne Diseases in NMMC, 2009–2017

	Patients per Node							
Area	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017
CBD Belapur	14	21	10	8	5	8	12	2
Karave	21	27	7	6	1	4	8	12
Nerul	23	20	4	8	6	5	12	1
Nerul II	21	32	15	5	7	4	16	0
Shiravane	23	29	17	5	51	42	33	2
Sanpada	8	24	15	7	6	10	21	1
Indranagar	48	37	35	26	29	32	36	5
Turbhe	81	40	63	6	25	30	55	8
Vashi	22	19	16	22	18	12	14	3

continued on next page

Table 6 *continued*

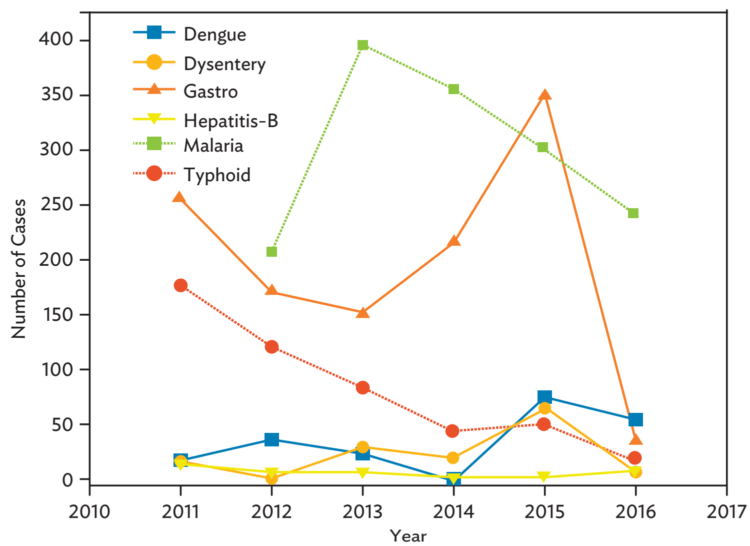
Area	Patients per Node							
	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017
Juhugaon	20	12	28	33	1	1	26	7
Khairne	81	38	23	28	52	48	41	11
Mahape	56	16	63	37	24	26	28	1
Pawane	8	15	7	28	18	12	18	4
Ghansoli	18	32	38	21	18	16	34	4
Rabade	3	4	6	8	13	11	12	1
Katkaripada	21	20	2	2	0	5	19	2
Airoli	29	22	86	40	25	25	34	1
Chichpada	50	11	8	3	3	2	12	0
Digha	11	14	13	9	10	8	21	1
Nagaon	0	–	–	–	2	0	0	0
Ilthanpada	0	16	16	5	4	1	16	1
Nocil Naka	0	0	0	0	4	0	8	0
Total	**558**	**449**	**472**	**307**	**318**	**302**	**476**	**67**

– = not available, CBD = central business district, NMMC = Navi Mumbai Municipal Corporation.

Source: NMMC (2017).

65 cases in 2015–2016 to only 1 case in 2016–2017. On the other hand, hepatitis-B cases doubly increased from 6 cases in 2015–2016 to 12 cases in 2016–2017, while cases of typhoid fever declined from 54 to 19, respectively, during the same period. A decreasing trend is also observed for reported malaria cases in 2014–2015 and 2015–2016. The number of cases decreased from 396 in 2013–2014 to 242 in 2016–2017. Dengue is spread throughout the tropics and the intensity of its occurrence is influenced by rainfall, lack of hygiene and sanitation, and unplanned urban growth. Good practices, such as covering and periodic cleaning of domestic water storage tanks and eliminating mosquito breeding sites through proper environmental management, could prevent the spread. The number of dengue fever cases has dropped (54) in 2016–2017, registering an almost 29% reduction from the number of recorded cases during 2015–2016.

Figure 6: Trend in Number of Waterborne Diseases in Navi Mumbai, 2011–2016



Source: NMMC (2017).

Environmental Indices

NMMC has calculated three indices annually from the year 2000—the Environmental Quality Index (EQI), the Urban Infrastructure Index, and the Quality of Life Index. NMMC also calculated the Environmental Performance Index, which the Maharashtra Pollution Control Board (MPCB) has endorsed. Overall improvement of EQI is attributed to enhanced air and water quality, sanitation facility, water supply, effective segregation and maximum recycling of solid waste, protection of mangroves, and continuous monitoring of water quality, among others.

Lessons Learned from the Implementation of a Large STP in a Large City such as NMMC

Initially, the sewage network and aerated lagoons used to treat sewage in 1991 to 2009 did not cover the entire NMMC area. The sewage area emitted bad odors especially during the non-monsoon periods. During the monsoon periods, heavy rains and consequently the stormwater inlet filled the lagoons to overflowing, with the non-sewer area dumping sewage into stormwater drains which were in turn connected to the creeks. Thus, aside from polluting water bodies and the creek environment, the old sanitation method had the following drawbacks:

1. The method of treating sewage used conventional aeration techniques, which did not meet treatment quality standards. Consequently, monitoring agencies such as MPCB and CPCB issued warning letters to NMMC.
2. A foul odor was emitted in and around the STP area.
3. The large area under the STP generated a large carbon footprint.
4. Many sewage pipes were blocked or damaged because of the small size of their diameter.

Motivated by the JNNURM policy, NMMC in 2006 adopted the policy of 100% sanitation and in 2008–2009 submitted the project report containing a detailed design of networks and STPs with advanced biological reactors. The central government approved the design in principle and agreed to fund it. And the central government, state government, and the NMMC Corporation (local government) all provided project funding.

During the evaluation, NMMC asked IIT Bombay, a technical institute, to give feedback on technical issues. The evaluation found that in several locations, the size of the sewage pipe measured a minimum of 150 millimeters (mm), and the design did not meet the standard self-cleansing velocity of 0.8 m/s. During the field visit, IIT Bombay and NMMC officials found that NMMC is a highly populated and dense area and the 150-millimeter pipes were too small and disproportionate to the population size of the settlement being served. The evaluation suggested therefore that sewage pipes should have a diameter of at least 250 millimeters. Local authorities obtained approval to apply the recommended diameter size, and as a result, maintenance of sewage blocking has reduced. The technical recommendation has helped decision makers in the urban development ministry to approve the use of pipes 200–250 mm in diameter as the minimum size depending on the population size. IIT Bombay proposed that effluent quality be measured manually to cross validate the SCADA-measured influent and effluent qualities.

NMMC has adopted the policy of using SCADA to measure water quality daily and perform manual measurement once weekly. Because of NMMC's success, several other corporations also followed the same procedure. This sanitation project was completed in 2012 and has been in service from 2013 to date.

In general, NMMC's experience offers the following lessons:

1. Adopt a sanitation policy in collaboration with the central, state, and local bodies in order for a sanitation program to succeed; this type of collaboration also helps to obtain the required funds.
2. The detailed project report (DPR) has to be prepared with sound technical knowledge and should contain minute details of the design (external consultants may be involved). The DPR can be vetted by a higher technical institute and can be verified by the technical advisory committee. This will help to identify appropriate technology for treatment, minimize cost, and reduce the carbon footprint.
3. Identify the appropriate team to implement (or execute) and monitor the project, which may entail the selection of motivated local engineers.

4. Be prepared to adopt additional policies such as the open-defecation-free city, reuse of treated sewage water, use of the continuous measurement policy, and new technology to reduce carbon footprint.
5. Train technical staff to keep them updated with the knowledge required for the future maintenance of sanitation programs.

The time series data analysis reveals that the efficiency of the STPs is at 100%.

Conclusions

This case study presents the socioeconomic spillover effects and technical evaluation of the sanitation program at the Navi Mumbai Municipal Corporation (NMMC) area in Navi Mumbai, Maharashtra, India. The NMMC area has seven STPs which treats around 454 MLD using the sequencing batch reactor technology. We collected data pertaining to sewage characteristics such as pH, temperature, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and dissolved oxygen (DO) through the SCADA program to analyze the STPs' technical efficiency. The time series data analysis reveals that the efficiency of the STPs is at 100%.

To study the STPs' spillover effects, we collected from various departments of the NMMC office data pertaining to population statistics, public health by studying the number of people affected by waterborne diseases, land values, number of settlements, air quality, and other parameters.

Our study revealed positive effects such as improvements in public health, hygiene condition, and air quality; monetary benefits in the sale of treated sewage; and increase in the number of settlements near the STP areas. Overall, the socioeconomic spillover effects of the NMMC's sanitation program are quantifiable and clearly visible in the area.

The NMMC experience offers useful lessons for policy makers to adopt in designing and implementing similar large-scale sanitation projects not only in other parts of the state but also in the country as a whole.

References

Ahmed, I., D. Ofori-Amanfo, E. Awuah, and F. Cobbold. 2018. Performance Assessment of the Rehabilitated Mudor Sewage Treatment Plant at James Town Accra-Ghana. *Journal of Water Resources and Protection.* 10: 725–739.

Belhaj, D., I. Jaabiri, N. Turki, C. Azri, M. Kallel, and H. Ayadi. 2014. Descriptive and Multivariable Analysis of the Water Parameters Quality of Sfax Sewage Treatment Plant after Rehabilitation. *IOSR Journal of Computer Engineering.* 16: 81–91.

Bhave, P., and S. Rahate. 2018. Impact of Redevelopment Projects on Waste Water Infrastructure. *Journal of Institution of Engineers India (Series A).* 99(3): 503–509.

Central Pollution Control Board (CPCB). 2007. Evaluation of Operation and Maintenance of Sewage Treatment Plants in India-2007. *Control of Urban Pollution Series.* CUPS/68/2007. New Delhi: Central Pollution Control Board, Ministry of Environment and Forests.

Central Public Health and Environmental Engineering Organisation (CPHEEO). 1993. *Manual on Sewerage and Sewage Treatment.* New Delhi: Ministry of Urban Development.

Hamed, M., M. G. Khalafallah, and E. A. Hassanein. 2004. Prediction of Wastewater Treatment Plant Performance Using Artificial Neural Network. *Environmental Modeling and Software.* 19: 919–928.

Hanbay, D., I. Turkoglu, and Y. Demir. 2008. Prediction of Wastewater Treatment Plant Performance on Wavelet Packet Decomposition and Neutral Networks. *Expert Systems with Applications.* 34: 1038–1043.

Hegazy, M. H., and M. A. Gawad. 2016. Measuring and Evaluating the Performance of a Wastewater Treatment Plant. Proceedings of the World Congress on Civil, Structural, and Environmental Engineering (CSEE'16), AWSPT 111-1 to AWSPT 111-5. Prague, Czech Republic. 30–31 March 2016.

Kulakarni, B., R. V. Wanjule, and H. H. Shinde. 2018. Study on Sewage Quality from Sewage Treatment Plant Based at Vashi, Navi Mumbai. *Science Direct, Materials Today: Proceedings.* 5: 1859–1863.

Navi Mumbai Municipal Corporation (NMMC). 2017. Environmental Status Report of Navi Mumbai Municipal Corporation. Internal Report. Navi Mumbai, India.

Sourabh, N., and P. V. Timbadiya. 2018. Hydraulic and Condition Assessment of Existing Sewerage Network: A Case Study of an Educational Institute. *Journal of Institution of Engineers India (Series A).* 99(3): 555–563.

United Nations Environment Programme (UNEP). 1991. Environmental Impact Assessment: Sewage Treatment Plant for Port Sais. *UNEP Regional Seas Reports and Studies.* No. 133.

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