Integrated Urban Infrastructure Planning for Sustainable Development: A Case Study of Navi Mumbai Airport Influenced Notified Area (NAINA), India

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Abstract - *The NAINA (Navi Mumbai Airport Influenced Notified Area) project is indeed ambitious, aiming to create a well-integrated urban environment that provides essential services like water supply, wastewater management, stormwater drainage, and solid waste management for a vast and developing area. The focus on designing and managing these utilities effectively is crucial for the success of the project and for ensuring that the environmental impact of rapid urbanization is minimized.*

NAINA is larger than Navi Mumbai and is being developed in phases over the next 20 years, the challenge is to design the infrastructure in a way that accommodates long-term growth while addressing immediate needs. It seems like a multi-phase; adaptive approach will be necessary to cater to both urban expansion and sustainability.

The detailed planning for water supply systems, wastewater, and stormwater drainage are all essential components that will need to be highly coordinated. Additionally, focusing on sustainability within the wet infrastructure design especially considering the potential impacts on groundwater and surface water resources is crucial for ensuring that the urbanization does not lead to resource depletion or environmental degradation.

Key Words*: NAINA, Urban environment, Water supply, Wastewater management, Stormwater drainage, Solid waste management, Rapid urbanization, Infrastructure design.*

1.INTRODUCTION

The NAINA project, as envisioned by CIDCO, is a significant and strategic development initiative, especially in the context of its proximity to the Navi Mumbai International Airport and its boundary with several key municipalities. The thoughtful planning in phases (Phase I and Phase II) helps address both the immediate need for infrastructure in high-demand areas while also considering long-term urbanization. By designating Phase I as the priority area for infrastructure development, CIDCO can address the most pressing issues of urbanization in those regions that are likely to experience rapid growth first. This will ensure that services like water supply, wastewater treatment, stormwater management, and solid waste management are prioritized where development pressure is most intense. It also allows for a more manageable approach to the overall urbanization process, especially NAINA covers a large area of 474 km^2, which would be overwhelming to develop uniformly in just 20 years.

The mix of flat and hilly terrain, with rivers like Kalundre, Kirki, and Gadhi passing through, adds a layer of complexity in planning for infrastructure particularly when considering water management, stormwater drainage, and environmental sustainability. The natural water bodies present in the area also require careful consideration to avoid disruption to ecosystems and to ensure the urban infrastructure integrates well with the natural landscape.

The development of the region's infrastructure will also have significant impacts on the surrounding areas, such as Panvel Municipal Corporation (PMC), Ambernath, and other neighboring towns. These impacts could include changes in real estate values, patterns of migration, and the demand for services, all of which will need to be managed effectively.

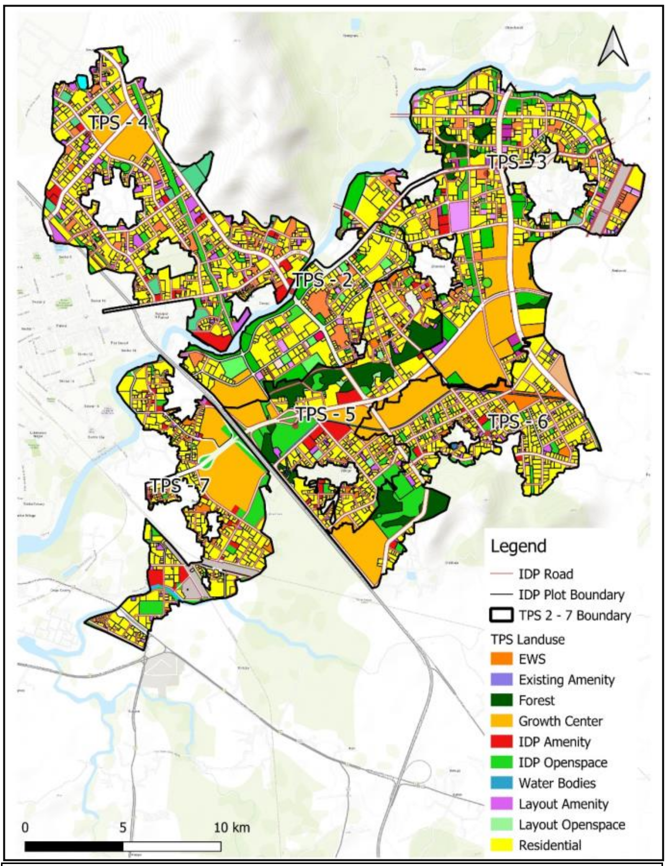
This paper addresses the design and implementation of three critical urban infrastructure systems for NAINA describe below:

Water Supply Systems: The objective is to plan and design various water utilities, including distribution and transmission networks, service reservoirs, pumping stations, and allied structures.

Wastewater Management and Sewage Treatment: The objective is to plan and design the sewerage system, which includes a sewerage network, intermediate pumping stations, and sewage treatment plants (STPs).

Stormwater Management: The objective is to plan and design various Stormwater network design using Bentley Sewer GEMS (Storm Module).


TMC
27 VILLAGE (MMRDA)
AKBSNA (MMRDA)
NMMC
GMMC
Thane Creek
Navi Mumbai (CIDCO)
Panvel Creek
NMIA
PAMC
NAINA
MESZ
JNPT
UMCL
KNTNA (CIDCO)
Patalganga Industrial Area
KMCL
KHMCL
PMCL
Dharamtar Creek
NAINA Boundary
ESZ
NTDA
SPA
ULB
MMR Boundary


TPS - 4
TPS - 3
TPS - 2
TPS - 5
TPS - 6
TPS - 7
Legend
IDP Road
IDP Plot Boundary
TPS 2 - 7 Boundary
TPS Landuse
EWS
Existing Amenity
Forest
Growth Center
IDP Amenity
IDP Openspace
Water Bodies
Layout Amenity
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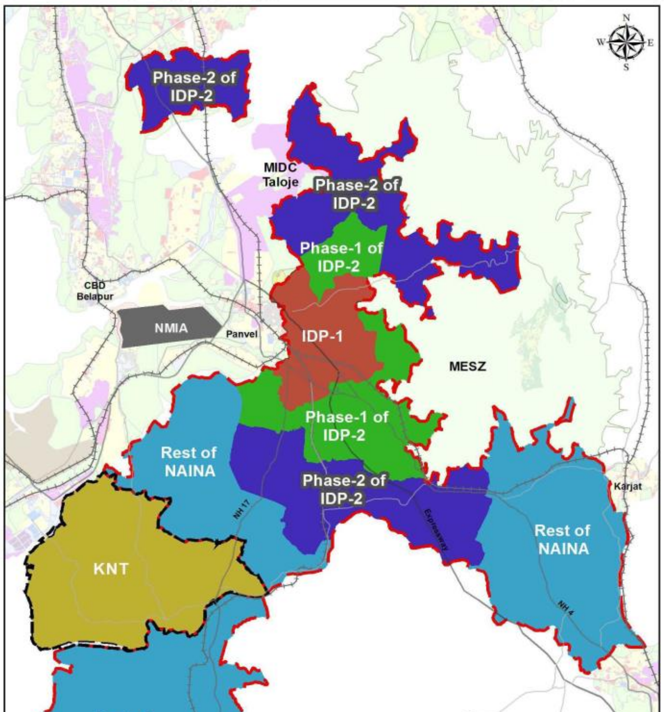
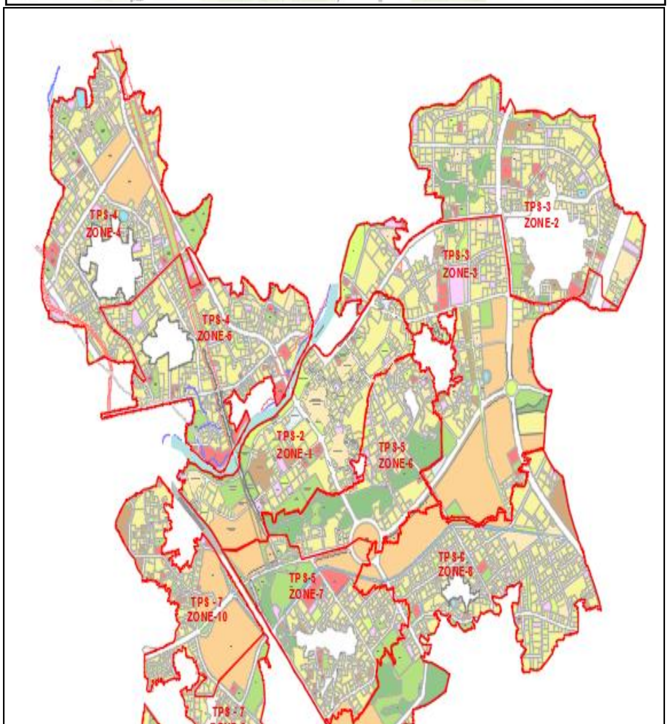
Residential
0
5
10 km


Phase-2 of IDP-2
MIDC Taloje
Phase-2 of IDP-2
Phase-1 of IDP-2
CBD Belapur
NMIA
Panvel
IDP-1
MESZ
Phase-1 of IDP-2
Rest of NAINA
Phase-2 of IDP-2
Karjat
Rest of NAINA
KNT
Rest of NAINA
Pen
0 1 2 4 6 8 10 km


TPS-4 ZONE-4
TPS-3 ZONE-2
TPS-3 ZONE-3
TPS-4 ZONE-5
TPS-2 ZONE-1
TPS-6 ZONE-6
TPS-5 ZONE-7
TPS-6 ZONE-8
TPS-7 ZONE-10
TPS-7 ZONE-9

2. CASE STUDIES

2.1: Indore Water + City

Indore's designation as India's first "Water Plus" city marks a significant milestone in the nation's pursuit of cleanliness and environmental sustainability. This accolade, awarded under the Swachh Survekshan 2021, recognizes Indore's exemplary efforts in managing its wastewater and ensuring the cleanliness of its rivers and drains. To achieve this distinction, Indore implemented rigorous measures, including treating all wastewater before releasing it into the environment, connecting public toilets to sewer lines, and recycling a substantial portion of sewer water. By adhering to these criteria, Indore has not only enhanced its sanitation infrastructure but also set a precedent for other cities to follow. The city's success underscores the importance of holistic approaches to urban sanitation, emphasizing the need to protect water bodies and promote the responsible use of resources. Indore's achievement demonstrates that effective governance, community participation, and technological innovation can pave the way for a cleaner, more sustainable future for urban environments across India.

2.2: Cape Town, South Africa

Cape Town, South Africa, achieved remarkable success in water conservation despite a 30% population increase over 15 years, reducing water usage by 30%. This accomplishment was attributed to a comprehensive water conservation program that targeted both behavioral change and technological advancements. The program included initiatives such as adjusting water pressure, repairing pipes, installing water meters, and implementing efficient water meter management systems. Furthermore, the city conducted training sessions in 60 schools to promote water conservation awareness among students and staff. Additionally, Cape Town persuaded 95 parks to adopt the practice of reusing treated wastewater for irrigation purposes, demonstrating a commitment to sustainable water management practices across various sectors. These efforts underscore the city's proactive approach to addressing water scarcity and its dedication to promoting a culture of water conservation and reuse.

2.3: Bangalore, Gwalior, Nagpur, Nashik – Best performing cities for wastewater reuse in India.

Some of the WWTPs of Bangalore, Gwalior, Nagpur, and Nashik cities have achieved 100% recycle and reuse of wastewater by discharging secondary treated wastewater into rivers and diverting it for irrigation purpose. Also, additionally Bangalore uses this treated WW for the horticulture & landscaping, public office gardening etc. The sale of treated water has reduced the consumption of fresh water. The amount spent on fresh water is saved and the sale of treated wastewater also generate income for the ULB. 95% of the treated WW from Delhi's Rithala STP is supplied to power plant and remaining is supplied for horticulture purposes. Also, by converting available pollutant to power as a non – conventional source of energy and generation of green power through bio-gas engines. Meanwhile, Chennai has its energy produced from biogas plant is utilized in the wastewater treatment plant, which has resulted in energy cost savings. Enables reuse of treated wastewater to reduce the burden on freshwater- relevant especially in a city like Chennai which depends on groundwater.

3. METHODOLOGY

3.1 Water Supply Systems

The water supply system for NAINA is designed for a 24x7 operation, ensuring equitable distribution with minimal losses.
Storage and Distribution: Central Water Reservoirs (CWR) and Elevated Service Reservoirs (ESR) are strategically placed based on population density and terrain.
Population Forecasting: Based on FSI, occupancy rates, and master plans for design years 2027, 2057, and 2077.
Demand Projections: Water demand calculated for ultimate design year 2057, accounting for residential, commercial, and institutional needs.
Hydraulic Design: Designed 24x7 Distribution system with uses of DI K-9 Pipe and MS pipes with peak factors of 1.5 and residual pressures of 7–10m to ensure reliability.

3.2 Wastewater Management and Sewage Treatment

The wastewater management system includes a decentralized sewerage network and advanced treatment technologies.
Sewerage Collection Network: Designed sewer network for a minimum self-cleansing velocity of 0.6 m/s and infiltration allowance of 10%.
Materials: RCC pipes with a minimum diameter of 250 mm were selected for durability.
Peak Factors: Adjusted based on population size for design year 2057.
STP Design: Sequencing Batch Reactor (SBR) technology is recommended for its modular scalability, automation, and cost efficiency.
Reuse of Treated Water: Treated effluent is reused for irrigation, toilet flushing, and construction, reducing freshwater dependency.

3.3 Stormwater Management

The stormwater management system integrates hydraulic modelling, flood mitigation, and eco-friendly infrastructure.
Drainage Network: Designed to handle peak flows with optimized pipe sizes and outfall locations.

Flood Mitigation: High Flood Level (HFL) assessments guide the placement of detention basins and embankments.
Sponge City Practices: Green roofs, permeable pavements, and bio-swales enhance infiltration and reduce runoff.
Rainwater Harvesting: Modular systems at strategic locations reduce reliance on freshwater resources.

4. DETAILED DESIGN

4.1 Population Projection and Demand

The water and wastewater infrastructure requirements are based on detailed population projections. By 2057, the NAINA area is expected to host a population of approximately 3.3 million, including residents, growth canters, and gaothans. The freshwater demand is projected to increase from 21.29 MLD in 2027 to 275.20 MLD by 2057. Similarly, treated water demand for purposes such as flushing and irrigation is estimated at 60.06 MLD, while sewerage generation will reach 162.94 MLD. These figures underline the need for a strategic and phased infrastructure development approach to cater to both immediate and future needs.

4.2 Water Supply System

The water supply system has been meticulously planned to ensure uninterrupted access to potable water across the NAINA area. The transmission main, designed for the year 2057, will utilize DI K9 pipes for diameters up to 800 mm and MS pipes for larger diameters. The system will leverage gravity-fed hydraulics from the Kondhane Dam to zonal reservoirs, minimizing energy consumption.

Central to the supply chain is the Central Water Reservoir (CWR) near Kondhane Dam, located at an elevation of 50 meters. This reservoir will act as the primary storage structure, facilitating the distribution of water to Elevated Service Reservoirs (ESRs) and Ground Service Reservoirs (GSRs) within various zones. Each reservoir is designed with a retention capacity of eight hours, ensuring an adequate buffer during peak demand periods. The distribution system is planned as a 24/7 operation, maintaining residual pressures between 7 and 10 meters, with a minimum pipe diameter of 150 mm to ensure efficient flow.

4.3 Treated Water Supply System

A dedicated treated water supply system has been proposed to address the demand for non-potable uses such as flushing and irrigation. This system will rely on tertiary-treated water sourced from strategically located Sewage Treatment Plants (STPs). Storage structures, primarily RCC GSRs, will be built at STP sites with a retention capacity of 10 hours.

The treated water distribution system is designed to maintain residual pressures between 7 and 10 meters, with a minimum pipe diameter of 100 mm. This ensures consistent and reliable water delivery for its intended purposes. By 2057, the treated water supply is projected to meet a total demand of 60.06 MLD for flushing and 21.5 MLD for irrigation, aligning with the project's sustainability goals.

4.4 Sewerage System

The sewerage system is designed to manage the projected generation of 162.94 MLD of sewage by 2057. The collection network, constructed with RCC pipes of a minimum diameter of 250 mm, will operate on a gravity-based system to transport sewage efficiently. The system is engineered to maintain velocities between 0.6 to 3 m/s, ensuring optimal flow and preventing blockages.

Intermediate Pumping Stations (IPS) will be strategically located at low points within sewerage zones to facilitate the transfer of sewage to STPs. Each IPS is designed with a retention period of 30 minutes to handle peak inflows effectively. Sewage Treatment Plants will be modularly designed to accommodate incremental capacities, with a total capacity of 162.94 MLD by 2057.

To ensure high-quality effluent suitable for reuse, the Sequencing Batch Reactor (SBR) technology is recommended. This technology offers a compact design, adaptability to flow variations, and cost-effectiveness. The treated effluent will meet stringent standards, with BOD levels below 6 mg/L and TSS levels below 10 mg/L, making it suitable for non-potable applications.

4.5 Stormwater Drainage System

The stormwater drainage system for the NAINA project is meticulously designed to manage peak runoff, minimize flooding, and integrate sustainable drainage practices. It follows the guidelines set by the CPHEEO Manual and CIDCO norms, ensuring a robust, efficient, and environmentally sensitive infrastructure.

4.5.1 Hydrological Design Principles: The design of the drainage system is based on the Rational Method, which calculates peak runoff using the formula.

$Q = C \cdot I \cdot A$

Here, Q represents the peak discharge in cubic meters per second, C is the runoff coefficient reflecting the imperviousness of the surface, I is the rainfall intensity, and Ais the catchment area. The runoff coefficient varies depending on the type of surface, with values ranging from 0.15 for lawns and parks to 0.92 for urbanized areas. This ensures accurate representation of different land uses within the catchment. Rainfall intensity is calculated based on historical data and intensity-duration-frequency (IDF) curves, while the catchment area is determined through detailed site analysis.

4.5.2 Time of Concentration: Time of concentration is a critical parameter representing the duration required for rainwater to travel from the farthest point of the catchment to the outlet. Calculated using Kirpich's formula, it considers catchment slope and flow length. CIDCO has standardized the time of concentration for Navi Mumbai at 30 minutes, ensuring consistency across designs.

4.5.3 Return Period: The system is designed to handle a 10-year return period for urban drainage, aligning with CPHEEO norms for residential and commercial areas. This ensures adequate capacity for storm events while balancing economic feasibility.

4.5.4 Hydraulic Design Parameters: The stormwater drainage network operates on gravity flow principles, with Manning's equation governing the design of velocity and discharge. The formula is expressed as $V = 1/n \cdot R^2/^3 \cdot S^1/^2$

Where V is velocity, R is the hydraulic radius, S is the slope of the hydraulic gradient, and n is Manning's coefficient of roughness. The minimum velocity of 0.6 m/s ensures self-cleansing to prevent sediment deposition, while the maximum velocity of 3 m/s avoids channel erosion. Freeboard, the additional height above the design flow, is incorporated to account for uncertainties and debris accumulation.

4.5.5 Design Software: Advanced tools, including Bentley Storm CAD and Civil 3D, are utilized for precise modelling and analysis. These enable accurate topographic assessments, hydraulic simulations, and detailed cross-sectional designs.

4.6 Sustainable Practices

Sustainability is at the core of the NAINA project. Treated water will be reused extensively for flushing and irrigation, reducing the dependency on freshwater resources. The tertiary treatment process will include ultrafiltration and chlorination to ensure water quality meets required standards. Sludge management is another critical aspect. Excess sludge generated from STPs will be dewatered using centrifuge or filter press systems, achieving a solid concentration of 18-20%. The dewatered sludge will undergo pathogen reduction treatments, enabling safe disposal or potential reuse as a soil conditioner.

4.7 Implementation Phases

The project will be implemented in three distinct phases to align with the region's development trajectory:

Phase 1 (2027): The initial infrastructure will cater to 20% of the projected population, with modular STPs installed to manage 12.68 MLD of sewage.

Phase 2 (2042): Infrastructure will be expanded to serve 40% of the population, increasing STP capacity to 54.49 MLD.

Phase 3 (2057): The final phase will achieve full-scale infrastructure development, accommodating a population of 3.3 million with an STP capacity of 162.94 MLD.

5. CONCLUSION

The NAINA Township Development Project is a strategic initiative aimed at establishing a sustainable and efficient water management system for the rapidly urbanizing region influenced by the Navi Mumbai International Airport. The project focuses on three key areas: water supply, wastewater management, and stormwater drainage. A well-structured water distribution network ensures continuous (24x7) supply, while sewage treatment plants (STPs) utilizing advanced technologies like SBR, MBBR, and MBR enable efficient wastewater treatment and reuse. The stormwater management system incorporates sustainable urban drainage solutions, rainwater harvesting, and flood mitigation measures to prevent waterlogging and optimize water conservation. Integrating innovative infrastructure and smart planning, the project ensures water security, environmental sustainability, and resilience against climate challenges, setting a benchmark for future urban development in India.

This study provides a replicable framework for urban planners to address infrastructure challenges in rapidly growing urban areas. By integrating advanced technologies and sustainability principles, NAINA serves as a model for future urban developments.

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