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INTEGRATION OF GIS AND HYDRAULIC MODELING TOOLS FOR SIMPLIFIED DECENTRALIZED SEPARATED SEWERAGE SYSTEM PLANNING IN DENSE URBAN CATCHMENTS: A CASE STUDY OF KAMLAPUR, DHAKA

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ABSTRACT

Dhaka, a densely populated megacity, faces a severe wastewater management crisis due to an old and insufficient sewerage system, built in the early 20th century. Rapid urbanization has outpaced this system, forcing most residents to rely on on-site and poor sanitation systems. This results in extensive release of untreated wastewater, polluting groundwater and severely damaging key rivers and the environment, like the Buriganga, creating a huge burden on treatment facilities. To address this problem, this study assessed the possibility of adopting a simplified decentralized separate (SDS) sewerage system in the highly populated Kamlapur locality within the Dhaka Metropolitan area.

A detailed field survey was conducted to gather essential spatial and structural data, including residential information, population density, existing sanitation facilities, and details on utility and road networks. These data were processed using ArcGIS 10.8.2 and AutoCAD 2025 to create an accurate geometric modeling layout. Hydraulic simulation was then performed in SewerGEMS using local regulatory parameters such as per capita sewage of 115 lpcd (liters per capita per day) of residential and commercial integrated buildings and the self-cleansing velocity thresholds of ≥ 0.6 m/s for the main conveyance conduit and ≥ 0.45 m/s for household collection according to BNBC 2020, Dhaka Sewerage Master Plan 2019, BBS (Bangladesh Bureau of Statistics) 2015, etc. The design horizon was set for 2050, with a projected population of 59,023 in the 0.429 km² of the study area.

The SDS system proposed incorporates the conventional gravity sewers of wide roads (>3m) and the non-conventional PVC lines of small lanes and household connections covering the entire network. The hydraulic modeling, the entire sub catchment system was divided into two sub-networks to deliver peak flow (167.53 L/s) to two strategic outfalls (O-4 and O-5) without surcharging or pumping stations and reduces the hydraulic stress by 17% and provides 41% excavation and materials saving with 32% construction cost minimization proving the best sanitation solution for dense urban areas like Dhaka.

This combined GIS, CAD, and Bentley SewerGEMS-based hydraulic modeling approach is a data-driven method and compatible with urbanizing sanitation systems. Besides providing economic benefits, such an SDS sewerage system reduces untreated sewage discharge from high-density areas and also lessens the load on the treatment plant. The results strongly support it as a viable and scalable solution for Dhaka's sanitation problems. This model offers valuable insights for engineers, planners, and policymakers striving to improve public health, environmental sustainability, and resilience of the world's fast-growing megacities, also for low-income and dense urban settings.

Keywords: *Decentralized sewerage, hydraulic modeling, GIS, Dhaka, SewerGEMS.*

1. INTRODUCTION

The rapid growth of megacities, particularly in developing nations like Bangladesh, has been completely overwhelmed by the poorly engineered existing sanitation systems. These systems struggle to cope with large populations and pose a significant challenge to public health (Adugna, 2023). In many low and middle-income cities like Dhaka, household wastewater is often dumped untreated into informal drains, posing serious threats to human health and environmental stability (Amoah et al., 2020). The case of Dhaka is typical due to the excessive growth of the population, the large areas of informal and unplanned settlements, the low and poorly planned coverage of the sewer networks, and the direct discharge of sewage into the water bodies and the groundwater. These problems have resulted in the extensive use of on-site sanitation systems, a typical collection system, a lack of proper sewerage treatment, and untreated effluents dumped into the water bodies and groundwater (Mills et al., 2024). Also, existing traditional sewerage systems of Dhaka can hardly keep up with such active urban development. They often experience over-infiltration or inflow, high conveyance cost, and extended lead-time expansion, and low adjustability to informal low-planned settlement patterns (Obeidat et al., 2024). Besides, economies of scale, which the large wastewater treatment plants are based on, might not apply to situations where settlement patterns are fragmented, lanes are narrow, land-use is mixed, and housing is informal. These difficulties urge the thought of a modern solution (Garrido-Baserba et al., 2024)

Several methods have been introduced in modern solutions to combat such difficulties, such as centralized (wastewater treated at a central plant), small bored and settled (solids are removed and only liquids are conveyed), combined (domestic and storm convey together), partially separate (domestic and a limited portion of storm water convey together), etc (Ouattara et al., 2023). On the other hand some of the possible benefits of simplified decentralized (low cost, small diameter, and convey wastewater to nearby treatment plant), separate (domestic and stormwater are collected separately) sewerage networks are conveyance and treatment systems structured at the local level, including shorter pipe lengths, smaller excavations, simpler retrofitting in narrow lanes, the possibility of energy savings, high maintenance efficiency, and enhanced system resiliency to disruptions (Garrido-Baserba et al., 2024). In most circumstances (SDS) system is competitive with or better than other systems on a life-cycle basis, especially in areas where conventional systems are high-density, terrain, or settlement structure makes them costly (Machado et al., 2007). Consequently, there has been an increased enthusiasm for this system using special and hydraulic modeling tools, such as GIS, SewerGEMS, SWMM, HECRAS, HES-HMS, etc., in high-density urban fabrics (Yan et al., 2021). These concepts are compatible for growing megacities like Dhaka and low-income countries as Bangladesh, such as Jakarta (Putri, 2017), Manila, and Honai (Vietnam) (Jalilov et al., 2017).

Several studies have examined sanitation challenges in Dhaka. Hassan et al. (2017) analyzed the influent characteristics and operational constraints of the Pagla Sewage Treatment Plant, highlighting the excessive inflow of untreated sewage. Haque (2025) studied the environmental impact of wastewater, and Yin et al. (2021) demonstrated that mismanaged urban wastewater significantly contributes to Buriganga River pollution using GIS. Recently, Mills et al. (2024) documented the public health risks associated with septic tank discharge into open drains across Dhaka, emphasizing the systemic failure of on-site sanitation in dense neighbourhoods. While these studies provide critical insights into environmental and public health, they do not address neighbourhood-scale sewer network planning or the hydraulic feasibility of SDS systems. This lack of localized hydraulic evidence limits the practical adoption of SDS strategies proposed in policy documents and master plans of WASA.

Nevertheless, this network system and the concept cannot be considered a panacea: issues of hydraulic design during peak flows, coverage of service, integration with the existing infrastructure, institutional governance, and cost sharing are some retard to this system (Zhang et al., 2023). Against this backdrop and the lack of literature on Dhaka city, the present study investigates the feasibility of implementing an SDS sewerage network in a high-density settlement within the Dhaka metropolitan area. By combining GIS mapping, AutoCAD layout modeling, and SewerGEMS-based hydraulic simulation, the research aims to assess whether a neighbourhood-scale sewer network can satisfy regulatory self-cleansing velocity thresholds, manage projected design flows, and deliver improved service coverage in populated planned/unplanned development contexts. In doing so, it fills a gap in the literature and practical conveyance of design in dense urban fabrics of rapidly growing megacities like Dhaka.

2. STUDY AREA AND DATA COLLECTION

2.1 Study Area

Dhaka is one of the most densely populated capital cities in the world, with an estimated population density exceeding 23,000 persons per square kilometer (Hossain, 2022). The study area, Sub-Division A (Named according to the DWASA plan) of the Kamlapur catchment, is located within Motijheel Thana (Figure 1) in the western part of the Pagla sewerage catchment area.

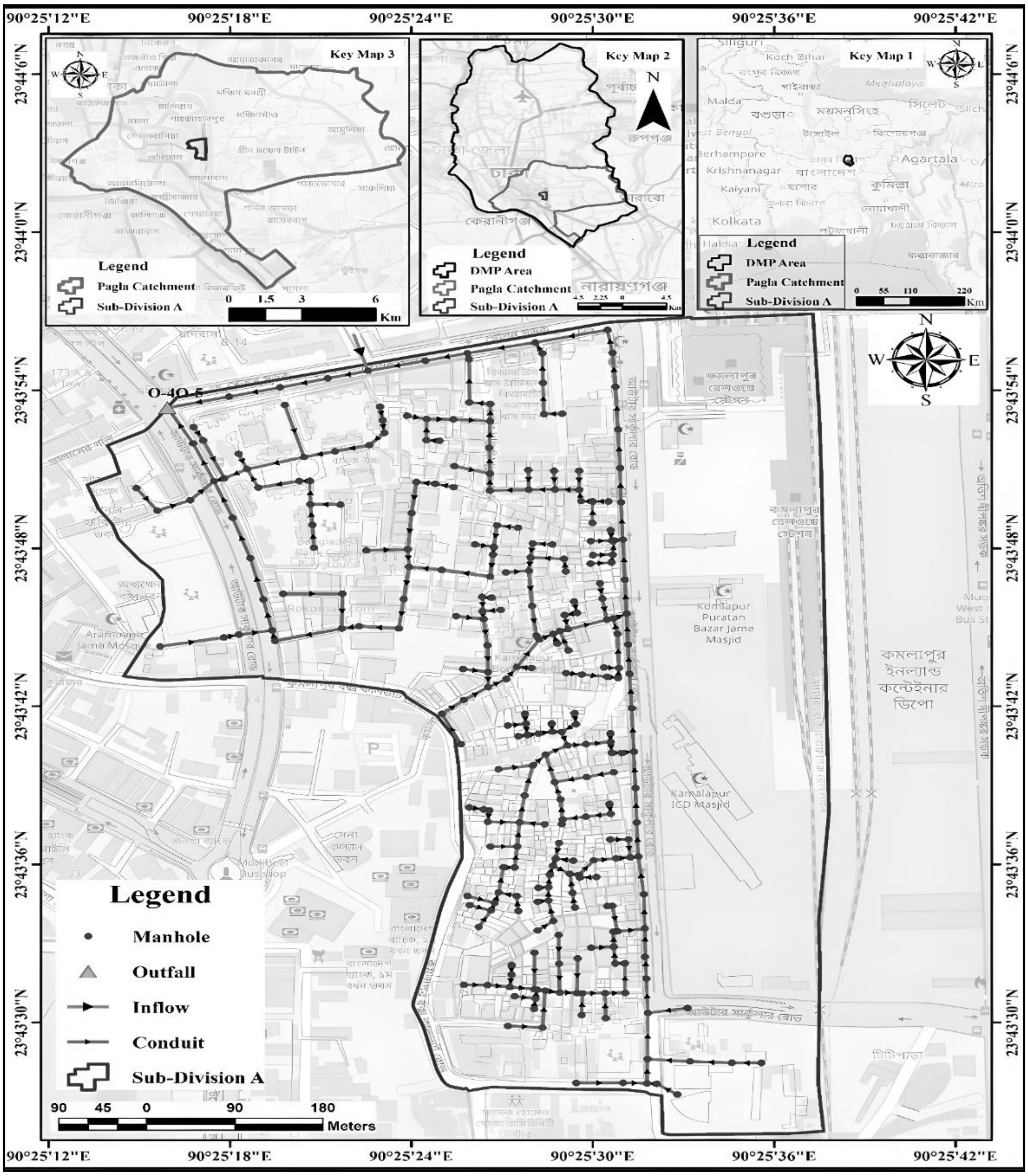


Figure 1: Selected study area (Sub-Division A) for the hydraulic modeling.

It falls under the jurisdiction of the Dhaka Water Supply and Sewerage Authority (DWASA). Geographically, it lies between latitudes 23°40′ N and 23°54′ N and longitudes 90°25′ E and 90°30′ E, bounded by the Buriganga River to the south and the Balu and Shitalakhya Rivers to the east. The total study area covers approximately 0.429 km^2 and consists of high-density, mixed-use developments, including residential, commercial, institutional, educational, and transportation facilities.

The region has key facilities, including the Kamlapur Railway Station, schools, government offices, and small industries, which cause tremendous wastewater production and hydraulic strain to available infrastructure. The ground level of the study area is between 5 to 7 m PWD (Public Works Datum) on average, and the absence of good natural drainage worsens urban floods during the monsoon season. The area was selected due to its inadequate sewer coverage, narrow roads, and limited space for network expansion, which make it a suitable pilot site for SDS system planning. It is also under the Pagla Wastewater Treatment Plant coverage, which offers a viable integration into the network in the future.

2.2 Data Collection

A large amount of field survey data was gathered between 2023 and 2024 to create a robust input database to support hydraulic network design and modeling, including the structural, demographic, and spatial elements. The surveyed buildings amounted to 875, with 741 of them residential, 85 mixed-use (residential and commercial), and the rest being institutional, commercial, and industrial buildings. In each building captured in terms of the number of floors, dwelling units, type of occupancy, and the approximate population of the residents are captured to come up with the domestic and non-domestic sewage contribution. The population statistics were taken based on the information in the Bangladesh Bureau of Statistics 2015 and projected according to the Dhaka Structure Plan of RAJUK, 2017, and the Sewerage Master Plan in Dhaka of 2019. In order to verify land use and occupancy data, field verification was utilized with the use of household enumeration and photographic documentation. The entire data was tabulated in a GIS-readable format so as to aid in hydraulic evaluation at a later stage.

Topography, utilities, and road networks were measured through ground survey using a differential GPS (DGPS) system and an auto-level tool to ensure that the elevation is accurate with reference to the PWD datum. The lanes greater than 3 m wide were in conventional types of connection (on the basis of the road width) and less than 3 m non-conventional shallow PVC sewers. The existing infrastructure was digitized with high-resolution images of Google Earth Pro and DWASA maps, which captured digitized manholes, pipe alignments, and outfalls.

3. METHODOLOGY

3.1 Population Estimation and Hydraulic Design Parameters

One of the most important factors that determines the sewerage system size is population estimation. The design horizon was determined to be 2050, as per DWASA Sewerage Master Plan 2019. The Water Supply Master Plan, 2019, the Population Projection of BBS, 2015, and the Dhaka Structure Plan were used as sources to verify population projections. Three mathematical progressions, arithmetic, geometric, and graphical methods, were used; also, the RAJUK model was chosen as an approach to the long-term growth trends. According to these examinations, the estimated population density of Motijheel Thana was 84,474 persons per km^2, and the design population of Sub-division A (0.429km^2) was 36,239. The overall population for design horizon 2050 used in the model was 59,023, keeping the high-rise and mixed-use nature of the area compared to the whole area of the Motijheel Thana, which is equivalent to 6 occupants per dwelling unit, as suggested by BNBC 2020.

The sewage flow rate was determined based on generation and infiltration allowances per capita. In a building where the floors were comprised of commercial and residential, per-capita water consumption of 130 lpcd was taken, 70% of which was taken to be wastewater, which left 91 lpcd of domestic sewage. With a commercial and institutional flow of 13.2 lpcd and infiltration loss of 10.42 lpcd, the total sewage load of 115 lpcd was found, which was in line with the recommendations in BNBC 2020 and DWASA 2019, and the rest of the other occupancy is in Table 1. The infiltration allowance was based on leakage through the pipes, and ingress water through the ground, as well as seepage through the joints, especially in the old concrete conduits. The Babbitt peak factor (PF) was used to measure the variability of flows empirically with respect to population size to allow short-term movement in the daily flow. The given factor, which is commonly employed in the development of sewer systems (Vieira and Ghisi, 2016), ensured that there was adequate conveyance capacity at the peak periods without overcharging.

Household connection design was based on accessibility and road width. For roads ≥3 m wide, a conventional connection system was used, with laterals from two adjacent houses connected directly to the nearest manhole (Figure 2). For narrow lanes (less than 3 m), a non-conventional shallow sewer was used where PVC pipes (150-200 mm diameter) were installed with a minimum cover depth of 0.45 m and inspection pits spaced at 5 m (Figure 2). This combination method guaranteed complete coverage, reduced excavation, and self-cleaning velocities throughout the lateral network.

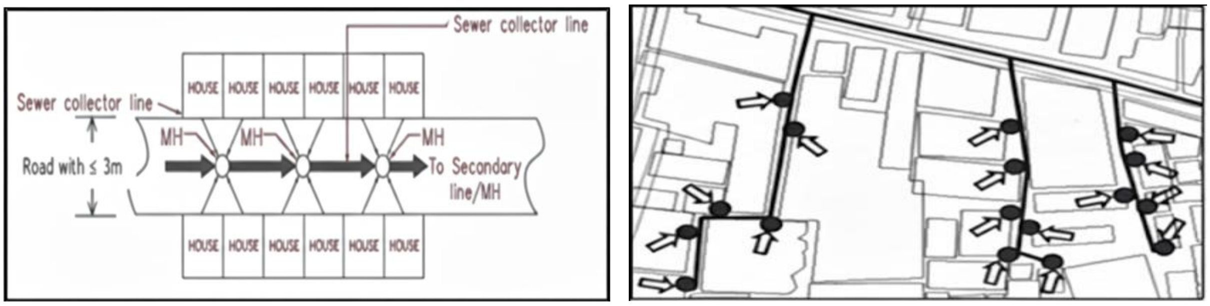


Figure 2: Conventional (Left) and Non-conventional (Right) Sewerage Connection

Table 1: Sewerage flow rate consideration (BNBC 2020)

Type of Building (Single Occupancy)	**Water Consumption (lpcd)**	**Wastewater Production (70% of water consumption) (lpcd)**	**Infiltration (10% of wastewater production) (lpcd)**	**Total Sewage Load (lpcd)**
Domestic/Residential	130	91	9.1	101
Educational Institute (School/ College, etc.)	100	70	7	77
Praying Spaces (Mosques, Churches, Temples, etc.)	75	52.5	5.25	58
Hotels	300	210	21	231
Industrial Buildings	40	28	2.8	31
Business / Office	45	31.5	3.15	35
Mercantile	45	31.5	3.15	35
Hospital	450	315	31.5	347
Convention Halls	90	63	6.3	70
Garage / Workshop	15	10.5	1.05	12

Design criteria were defined in accordance with DWASA 2019 standards. The minimum velocity for gravity sewers was maintained at 0.6 m/s, while the maximum velocity was limited to 3.0 m/s to prevent scouring, and the minimum velocity of house collection (150mm) was 0.45 m/s. The minimum pipe diameter was 200 mm and 150 mm for house connections, and the maximum manhole spacing ranged from 75 to 200 m, depending on pipe size. The design depth ratio (d/D) was maintained below 0.75 for smaller pipes (≤300 mm) and 0.82 for larger ones (>300 mm). PVC was used for diameters ≤450 mm and GRP for diameters >450 mm, both having a Manning's roughness coefficient (n) of 0.011. The minimum safe cover depth was 1.0 m, reduced to 0.5 m along narrow service roads shown in Table 2.

Table 2: Design Criteria and guidelines of the sewerage network

Design Parameter	**Values**
Design Horizon	The year 2050
Maximum Velocity	V_{max} = 3.0 m/s
Minimum Velocity for Gravity Sewers	V_{min} =0.6 m/s in general, V_{min} =0.45 m/s ensured for initial pipes (150mm) flowing partially full (less than 40%)
Minimum Pipe Diameter	200 mm
Design Depth of Flow (d/D)	For diameter ≤ 300 mm; d/D should be ≤75%, for diameter > 300 mm; d/D should be <82%
Pipe Material	PVC (diameter ≤ 450 mm), GRP (diameter > 450 mm)
Roughness Coefficient	0.011 for PVC, 0.011 for GRP
Minimum Safe depth / Cover from GL to the top of the pipe	1.0m in general, 0.5m for the narrow service road where the width≤ 3m
Maximum Manhole Spacing	75m up to 600 mm diameter, 100m to 1000 mm diameter, 150m to 1500 mm diameter, 200m up to 1650 mm diameter
Minimum manhole spacing	As per the site condition
Pipe Matching	Crown to crown in general

3.2 Sewer Layout Development and Hydraulic Model Simulation

A comprehensive GIS-assisted hydraulic modeling framework was developed to design the gravity-driven sewer network for Kamlapur Subdivision-A by integrating spatial, hydraulic, and engineering datasets. The modeling approach combined ArcGIS 10.8.2, AutoCAD 2025, and SewerGEMS (Bentley Systems) platforms, adhering to the Planning Users Group Code of Practice (Zhang et al., 2018) and DWASA (2019) design standards. Topographic and infrastructural data collected through detailed field surveys and digitized in AutoCAD to generate existing manhole locations, pipe alignments, ground elevations, house locations, roads, and other services. This information was utilized in the laying of the new sewerage system, manholes, outfalls, and house connections.

These data were then exported to ArcGIS to be referenced geospatially; conduits and manholes were overlaid on the digital elevation model (DEM) to ensure the terrain-based flow directionality. All centroid building points were defined as a property connection point, and usage made of lateral connections to the closest manhole or service pit with the nearest-neighbour spatial algorithm. Where direct connection was not possible through physical factors, non-standard shallow PVC laterals (150-200 mm) were used, with 5 m separation of inspection pits, such that the full range of services was covered by narrow lanes. The complete GIS-based network with all the nodes, conduits, and elevation was exported in SewerGEMS for hydraulic modeling (Figure 3). Figure 4 indicates the network layout.

The process of developing and validating was done sequentially in the hydraulic modeling in SewerGEMS. All the spatial and structural layers were imported through the tool Model Builder, and then the errors were checked through the tool Navigator to rectify any misaligned data. A unit sanitary load table was developed, and a conduit catalogue was prepared, which contained all the information on conduit as outlined in Table 2, all property connections, sanitary load, and population. The design constraint was implemented on the flex table conduit property, as it was discussed in the prior section. The peak factor was adjusted to the Babbitt equation of extreme flow, and the simulated result was repeated until all the design requirements were met. Hydraulic stability validation was employed to detect performance bottlenecks using diagnostic tools like flex tables, flow graphs, and color-coded thematic layers. The optimized final model established the conditions of stable flow in the network, meeting design constraints and achieving operational efficiency. After the hydraulic stability was checked and found to be non-surcharging, the results were corrected and made practical.

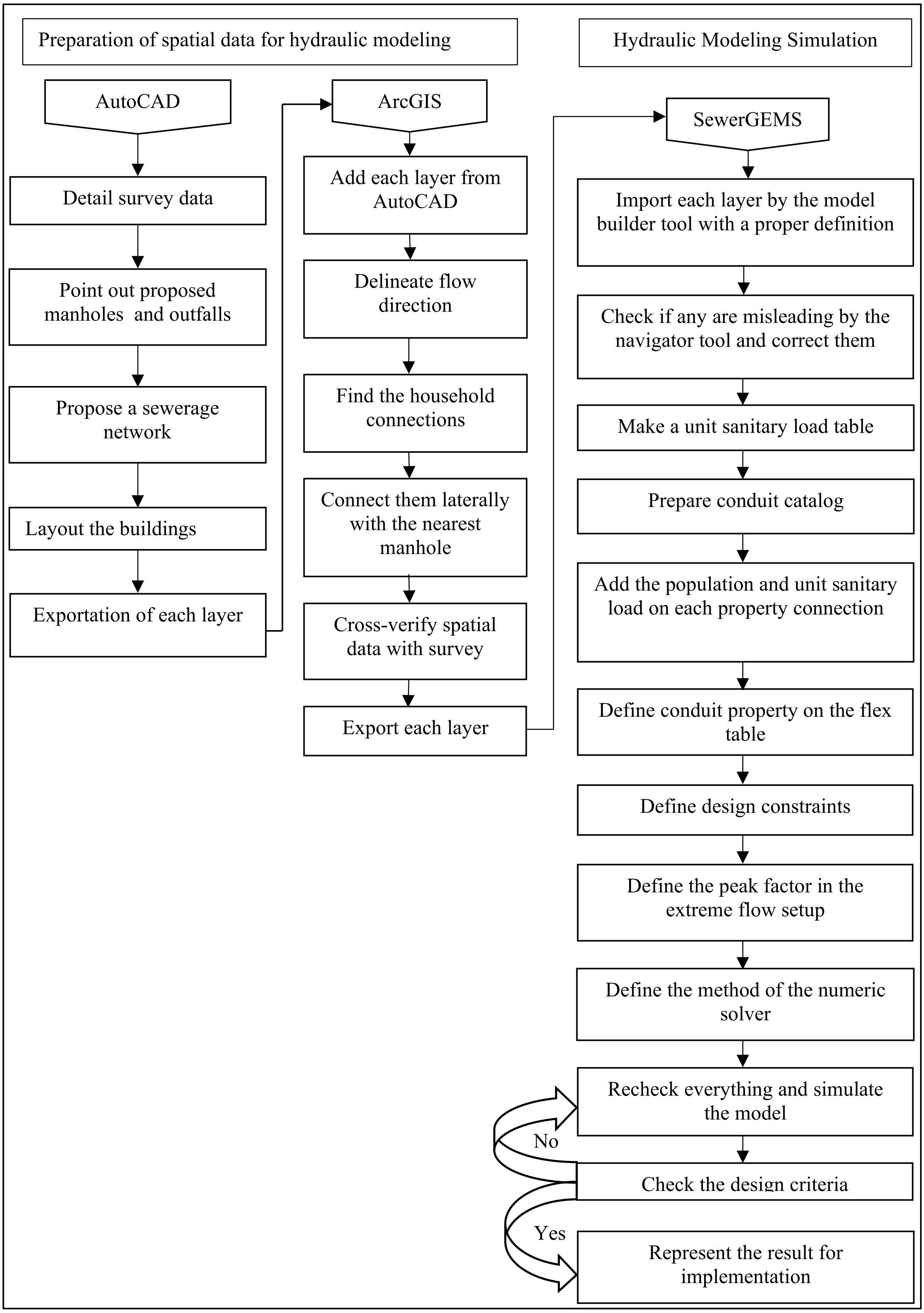


Figure 3: Hydraulic modeling and spatial data process flowchart

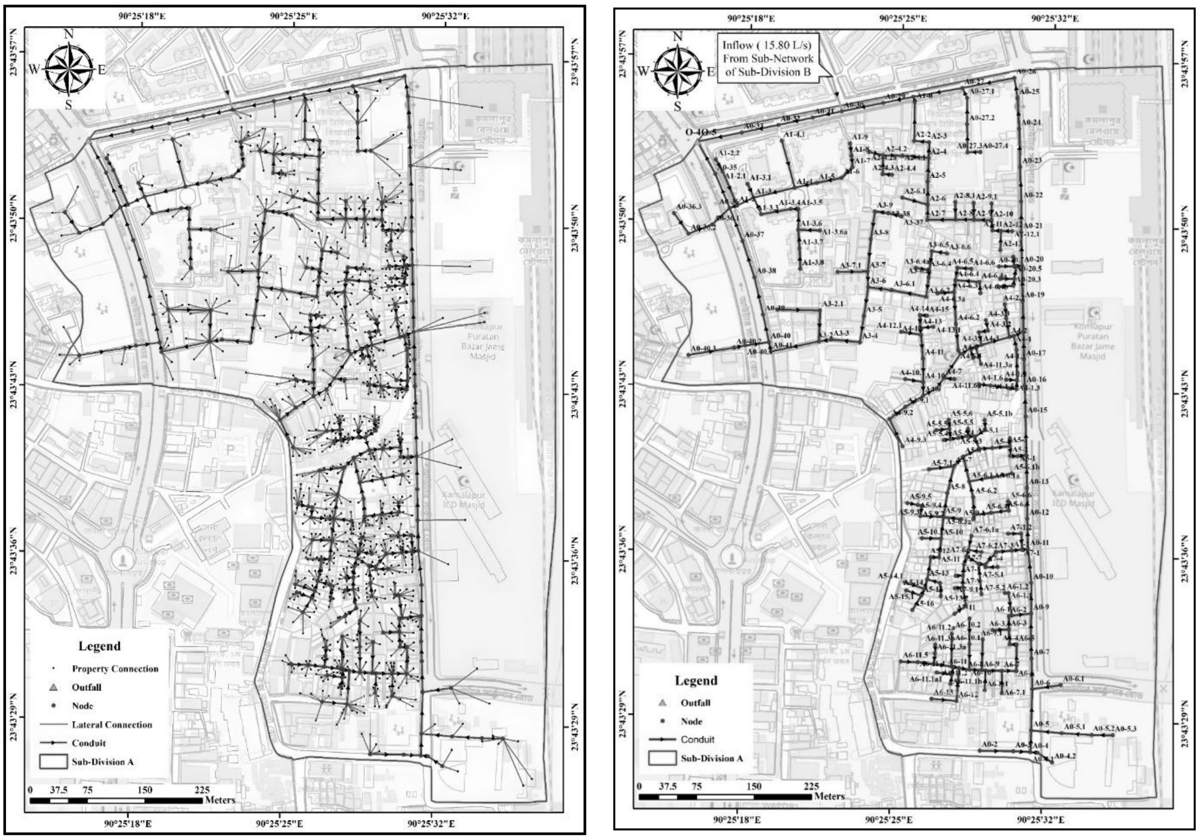
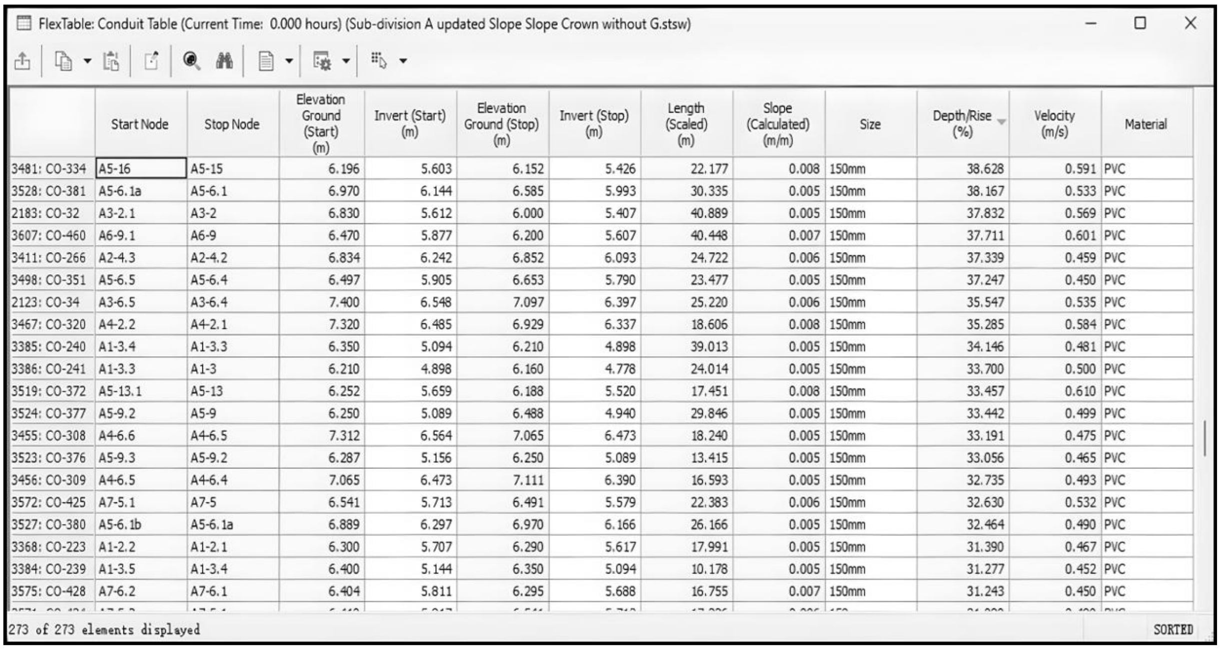


Figure 4: Proposed sewerage network with property connection (Left) and with node ID (Right)

4. RESULTS

The hydraulic modeling of the proposed SDS sewerage network for the Kamlapur sub-division A was simulated using Bentley SewerGEMS OpenFlow Sewer 2024 version with the GVF-Convex solver to represent gradually varied flow conditions. The optimized network consists of 272 conduits, 272 manholes, and two terminal outfalls (O-4 and O-5), extending over 6.76 km within a 0.429 km² catchment (Figure 4). Pipe diameters range from 150–500 mm, primarily PVC (6.27 km, 262 nos.) for lateral and secondary lines and more than 500 mm GRP (0.489 km, 10 nos..) for larger trunks, in accordance with the design parameters listed in Table 2. The system was designed for a projected 2050 population of 59,023, generating an average discharge of 15.81 L/s and a peak of 129.45 L/s. Simulation outputs confirm that all conduits maintained self-cleaning velocities ≥ 0.6 m/s in the main conduits and ≥ 0.45 m/s in the house connections, with a peak velocity of 1.19 m/s (A1-0 to A0-28). The depth-to-diameter ratio (d/D) was between 0.17 (17.39%) and 0.78 (77.76%), which made the flow partly full and capable of good ventilation and less sedimentation. The highest discharge on the flex table (Figure 5) was 129.45 L/s, from manhole A0-30 to outfall O-5 (Figure 4). Under both dry and peak flow conditions, the Hydraulic Grade Line (HGL) remained below the crown level in all conduits (Figure 6), confirming non-surcharging behaviour. The average hydraulic gradient was 0.0052 m/m, where the max and min were 0.009 and 0.002, signifying uniform energy distribution (Figure 7).

Velocity and slope mapping (Figure 7) illustrate that 94% of conduits achieved the design self-cleansing threshold, while the remaining 6% mainly short, shallow laterals in narrow lanes, operated slightly below at 0.45-0.55 m/s, which remains hydraulically acceptable due to low sedimentation potential for house connection and acceptable as design criteria. Calibration using field data from pre-monsoon 2024 produced a coefficient of determination (R^2 = 0.91), demonstrating excellent agreement between simulated and observed values. Sensitivity analysis with ±10% variation in infiltration showed minimal performance deviation, maintaining velocities above 0.6 m/s in the main conduits and 0.45 m/s at the house connection, and d/D satisfied the criteria (Figure 7). The dual-outfall configuration effectively distributed the total flow (167.53 L/s) via O-4 (38.08 L/s) and via O-5 (129.45 L/s), reducing downstream hydraulic stress by 17% compared to preliminary single-outfall simulations. The SDS sewerage model also minimized excavation and material requirements, reducing average excavation depth by 41% and estimated construction cost by 32% relative to a conventional centralized layout.



FlexTable: Conduit Table (Current Time: 0.000 hours) (Sub-division A updated Slope Slope Crown without G.stsw)

	Start Node	Stop Node	Elevation Ground (Start) (m)	Invert (Start) (m)	Elevation Ground (Stop) (m)	Invert (Stop) (m)	Length (Scaled) (m)	Slope (Calculated) (m/m)	Size	Depth/Rise (%)	Velocity (m/s)	Material
3481: CO-334	A5-16	A5-15	6.196	5.603	6.152	5.426	22.177	0.008	150mm	38.628	0.591	PVC
3528: CO-381	A5-6.1a	A5-6.1	6.970	6.144	6.585	5.993	30.335	0.005	150mm	38.167	0.533	PVC
2183: CO-32	A3-2.1	A3-2	6.830	5.612	6.000	5.407	40.889	0.005	150mm	37.832	0.569	PVC
3607: CO-460	A6-9.1	A6-9	6.470	5.877	6.200	5.607	40.448	0.007	150mm	37.711	0.601	PVC
3411: CO-266	A2-4.3	A2-4.2	6.834	6.242	6.852	6.093	24.722	0.006	150mm	37.339	0.459	PVC
3498: CO-351	A5-6.5	A5-6.4	6.497	5.905	6.653	5.790	23.477	0.005	150mm	37.247	0.450	PVC
2123: CO-34	A3-6.5	A3-6.4	7.400	6.548	7.097	6.397	25.220	0.006	150mm	35.547	0.535	PVC
3467: CO-320	A4-2.2	A4-2.1	7.320	6.485	6.929	6.337	18.606	0.008	150mm	35.285	0.584	PVC
3385: CO-240	A1-3.4	A1-3.3	6.350	5.094	6.210	4.898	39.013	0.005	150mm	34.146	0.481	PVC
3386: CO-241	A1-3.3	A1-3	6.210	4.898	6.160	4.778	24.014	0.005	150mm	33.700	0.500	PVC
3519: CO-372	A5-13.1	A5-13	6.252	5.659	6.188	5.520	17.451	0.008	150mm	33.457	0.610	PVC
3524: CO-377	A5-9.2	A5-9	6.250	5.089	6.488	4.940	29.846	0.005	150mm	33.442	0.499	PVC
3455: CO-308	A4-6.6	A4-6.5	7.312	6.564	7.065	6.473	18.240	0.005	150mm	33.191	0.475	PVC
3523: CO-376	A5-9.3	A5-9.2	6.287	5.156	6.250	5.089	13.415	0.005	150mm	33.056	0.465	PVC
3456: CO-309	A4-6.5	A4-6.4	7.065	6.473	7.111	6.390	16.593	0.005	150mm	32.735	0.493	PVC
3572: CO-425	A7-5.1	A7-5	6.541	5.713	6.491	5.579	22.383	0.006	150mm	32.630	0.532	PVC
3527: CO-380	A5-6.1b	A5-6.1a	6.889	6.297	6.970	6.166	26.166	0.005	150mm	32.464	0.490	PVC
3368: CO-223	A1-2.2	A1-2.1	6.300	5.707	6.290	5.617	17.991	0.005	150mm	31.390	0.467	PVC
3384: CO-239	A1-3.5	A1-3.4	6.400	5.144	6.350	5.094	10.178	0.005	150mm	31.277	0.452	PVC
3575: CO-428	A7-6.2	A7-6.1	6.404	5.811	6.295	5.688	16.755	0.007	150mm	31.243	0.450	PVC

273 of 273 elements displayed

SORTED

Figure 5: Hydraulic modeling results Flex Table of conduits

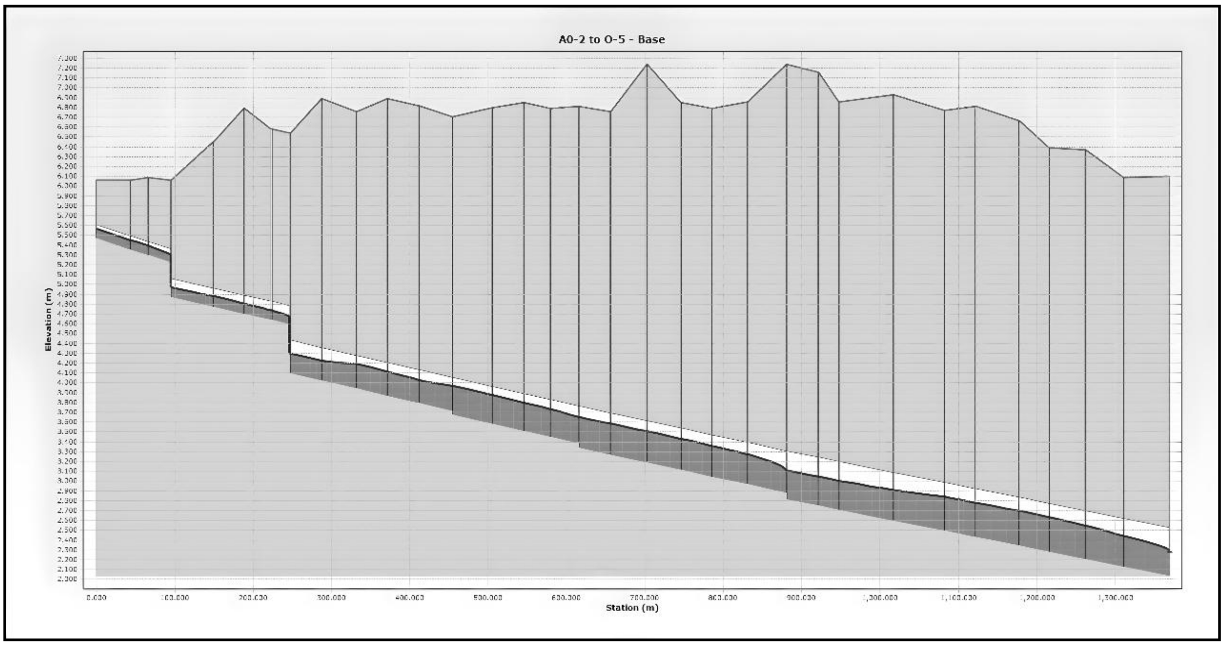


Figure 6: Hydraulic modeling profile for conduits from manhole A0-2 to outfall O-5

Overall, the integrated GIS AutoCAD SewerGEMS approach confirmed that an SDS network combining conventional gravity mains along wider roads and shallow PVC sewers in narrow lanes can efficiently convey projected wastewater loads under Dhaka's high-density conditions, while maintaining hydraulic stability, cost efficiency, and compliance with DWASA (2019) design standards.

Figure 7: Hydraulic modeling result of conduits (Diameter, Velocity, d/D, and Slope)

5. DISCUSSION

The modeling outcomes demonstrate that integrating GIS, AutoCAD, and hydraulic modeling can offer a technically viable and resource-efficient SDS sewerage system. This system offers a practical alternative to expanding trunk networks in high-density Dhaka city. A hybrid layout, using gravity-driven GRP conduits along wider roads and shallow PVC pipelines in narrow lanes, can effectively convey the design peak flow of 129.45 L/s by O-5 without surcharging. The system also maintained self-cleaning velocities of 0.6 m/s in the main conduits and 0.45 m/s in house connections, while keeping d/D ratios below 0.82. These outcomes meet DWASA (2019) design standards and reinforce the viability of SDS sanitation solutions for compact, high-rise neighbourhoods where land and right-of-way limitations restrict traditional centralized expansion. The dual-outfall arrangement was especially efficient in the process of distributing hydraulic loads (77.27% through O-4 and 22.73% through O-5) and, as such, increased redundancy and reduced stress in the downstream. This design was also discovered to have 17% less hydraulic head losses compared to the preliminary single-outfall simulation, implying that the design was more resistant to flow and more energy efficient. Such outcomes can be explained by international experience, whereby the SDS layout has become of great priority whenever fragmented or dense settlements are concerned (Garrido-Baserba et al., 2024).

Integration of topography and population layers in GIS, the methodology ensures that the flow direction, gradient, and network alignment are connected to the topography and pattern of operation within an urban environment. The design reduces construction cost and environmental disturbance compared to traditional systems; the resultant design reduces the excavation depths (41%) and material requirements (26%). The findings confirm that modular, data-driven sanitation systems have the potential to enhance operational efficiency, flexibility, and long-term sustainability in the rapidly urbanizing areas (Yan et al., 2021). Model calibration ($R^2 = 0.91$) and a sensitivity analysis further establish the hydraulic reliability and robustness of the proposed network under conditions of uncertain infiltration or flow variability. The ability to maintain non-surcharging, self-cleansing flow under ±10% infiltration change and +15% inflow stress underscores the design's adaptability to Dhaka’s monsoon-driven hydrology. This study offers a reproducible decision-support that can guide sub-catchment-level planning within the Pagla treatment catchment and other megacities confronting similar infrastructural limitations.

6. CONCLUSIONS

Integration of GIS, AutoCAD, and SewerGEMS provides good evidence in the design of SDS sewerage systems in high-density cities. The designed Kamlapur network was demonstrated to perform stable hydraulics under design and stress conditions with maximum flow (129.45 L/s) safely transported under non-surcharging conditions and under self-cleaning velocities over 0.6 m/s in the centre conduit and over 0.45 m/s in the house connection. The calibration accuracy ($R^2 = 0.91$) confirms its predictive reliability and suitability for practical implementation. By incorporating both conventional gravity sewers and non-conventional shallow PVC laterals, the hybrid design achieved 100% service coverage, a 41% reduction in excavation depth, and a 32% lower construction cost compared to others.

Except for some minor limitations avoided by several calibrations, such as quality of input data, uncertainties in pipe conditions, inflow, and infiltration, and simplifying the real world in a software environment, these findings point to the likelihood that SDS sewerage systems offer hydraulically efficient, cost-bearing, and ecologically sound sanitation systems in urban environments with limited space. This study also presents a scaled analytical model of the combination of spatial demographics and hydraulic simulation, which can be used to develop adaptive planning in the presence of population growth and uncertainty in infiltration. The approach aligns with SDG-6 and national policies, promoting climate-resilient urban infrastructure. SDS sewerage networks optimized through GIS-based hydraulic modeling represent a practical and replicable solution for modernizing urban wastewater systems in megacities like Dhaka. The findings provide actionable guidance for engineers, planners, and policymakers seeking to enhance urban resilience, environmental protection, and public health.

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DECLARATION OF AI USE

The authors declare that this work has been prepared independently and that no artificial intelligence (AI) tools or automated systems were used to assist in preparing the manuscript. All resources have been properly cited, and all the work is original to the author’s best knowledge.

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