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Design and Optimization of Sewerage Networks using Sewergems Software

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***Abstract*— The lack of a centralized sewerage infrastructure in Dhapewada village, a semi-urban village in Nagpur district's Kalmeshwar taluka, poses substantial sanitation and wastewater management difficulties. The current open drain–based greywater disposal system is under strain because of the growing population and the seasonal inflow of devotees. Both gravity and hybrid sewer systems must be explored as viable solutions due to the differential topography. The aim of this project is to use SewerGEMS software, which is based on CPHEEO (2013) recommendations, to design and optimize a sustainable and economical sewage network. The system planning for Dhapewada village was designed and analyzed using SewerGEMS software connected with GIS data, such that important factors like velocity, profiles, manhole excavation depth, and cost for both systems were assessed. The gravity system ensured a reliable self-cleansing flow, but the depth of excavation for such areas was 6.00 m–8.00 m, making excavation difficult and resulting in the collapse of existing infrastructure within the small road width, significantly increasing capital cost and maintenance problems during operation. The hybrid system reduced the depth to 3.00 m–4.00 m, directly affecting excavation costs; however, operation and maintenance of pumps, energy demand, and long-term operational dependency were identified as drawbacks of the hybrid system. Hybrid systems may be more cost-effective in differential terrains, although gravity systems remain preferable for long-term sustainability where slopes allow. This approach encourages sewer system selection for growing rural–urban areas such as Dhapewada.**

***Index Terms*— SewerGEMS, GIS-based hydraulic modelling, CPHEEO guidelines, CPHEEO guidelines.**

I. INTRODUCTION

Rapid urbanization in semi-urban and rural villages of India, the existing sanitation infrastructure has been severely challenged. Due to the increase in population and the transition of villages, because of the lack of sewerage infrastructure, villages majorly rely on open drains for wastewater disposal [2], [3], [6]. Dhapewada village, situated in Kalmeshwar taluka of Nagpur district, represents such a case where inadequate wastewater management has resulted in total sewage from households flowing into open drains, resulting in pollution of the Chandrabhaga River, majorly during the seasonal inflow of devotees in the village [2], [6].

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The provision of a sewerage system is very important to safeguard public health, protect surface and groundwater resources, and support a sustainable future. Based on this, the planning and selection of the sewerage system depend on various constraints such as terrain, road width, financial implications, future growth, and design constraints as per the CPHEEO manual [1]. Gravity-based sewer systems are preferred due to their low operational cost and future reliability, but they involve high excavation costs in differential terrain. Alternatively, hybrid sewer systems combined with gravity and intermediate pumping stations can reduce excavation costs but increase operational costs [5], [6], [7]. Hence, this research focuses on the planning, design, and optimization of a sewerage system for Dhapewada village using SewerGEMS and GIS software to determine its technical, economic, and long-term sustainability.

II. LITERATURE REVIEW

Various publications have been given in the form of technical papers up to this point on designing and optimization of sewerage network using Sewergems software. Some of the papers are discussed below: -

Avaduth Kulkarni, Sweety Wankhede, Shivani Takale, Rajashree Choudhary, Priyanka Thakur (2021) developed a sewerage system for Holkarwadi village using SewerGEMS. The study primarily focuses on sewer network design through the combined use of SewerGEMS and GIS, as conducting real-time or physical field surveys was not practical.

Digital Elevation Model (DEM) data were utilized to obtain terrain information, enabling the development of an optimized sewer network while minimizing dependence on physical surveys, thereby reducing time, resource use, and overall project costs. [2]

Abhishek Pawar, Yogesh Patil, Prof. Sachin Mane, Satyajeet Patil, Nikhil Toche, and Prof. Yugandhara Ingale (2021) focused on the design of a sewer system for the village of Vake, Taluka Malegaon, District Nashik, Maharashtra, which has no existing sewerage system. Contours were generated using ArcGIS and Google Earth Pro software. The sanitary load was taken as 240 litres per day based on information obtained from the Gram Panchayat. The result obtained was used for designing the sewerage network and developing the longitudinal profiles. [3]

Babagana Musa, Hassan Bukar, Abdulhakeem Yusuf Ngulde, and Babagana Sheriff (2020) studied the design of a hydraulic sewer network in Maiduguri, Borno State, Nigeria. Depending on the flow rate, PVC pipes with diameters ranging from 150 mm to 600 mm were utilized. For population projections over a ten-year design period, the Geometric Progression approach was used. 150 liters of water were consumed each day. The study found that the highest and lowest flow rates varied according to the distance of the pipes from the wastewater source. [4]

Murugesh Katti, Dr. B. M. Krishna, Dr. B. Manoj Kumar, and Jitesh C. studied the comparative analysis of Sewer Version 3.0 and SewerGEMS V8i software for sanitary sewer design. They observed variations in velocities and d/D ratios in both software packages.

The study concluded that the lowest pipe diameters were obtained using SewerGEMS V8i, and that pipe details, velocity, elevation, and flow are directly obtained, making it a simple and efficient sanitary sewer design program. In contrast, Sewer Version 3.0 resulted in very low slopes in some pipes and significantly higher d/D ratios. [5]

Ravikiran K, Arjun S. Virupakshi (2016) studied about the design of a sewer network for Janwad village using SewerCad V8i. The data regarding contours, land use, population, source of water, existing sewage network, and existing open drain network was collected from the local authority of the village. After the collection of data population projection was done using arithmetic method and after that planning and modelling was done in software leading to the conclusion after designing and analysis work as most of the manholes falls under depth of structure of 1m-3m, 92.8% of pipes falls under 150mm minimum diameter due to less load generated in each manhole causing velocity less than 0.6 m/s hence flushing manholes can be adopted for such cases. Finally, the results obtained are consistent with the design criteria, and they are acceptable for easy and smooth on the field without much difficulty. [6]

Ms.Harsha S.Bhavimani, Dr.Anand V.Shivapur (2017) studied about the design of a sewer network for zone 10, Belagavi city, using Sewergems V8i software. Based on the data collection done from local authority, modelling and planning have been done using SewerGems V8i software and it was found that 52.24 % of the manhole depth provided is less than 1.00 m, 29.85 % of manhole have depths between 0.3 to 0.6 m/s and 19.4 % have velocity greater than 0.6 m/s. Hence based it is concluded that for the design of sewerage network process is found to be easy and uncomplicated by using the software. [7]

III. Study Area

Dhapewada village is located along the Kalmeshwar–Saoner State Highway, approximately 25 km from Nagpur city, having coordinates of 21°18′10.68″ N latitude and 78°54′77.04″ E longitude. The total area of the village is about 92.20 ha, estimated using GIS software from Topography survey and DEM files. The village settlement pattern is predominantly distributed on both banks of the Chandrabhaga River, which runs adjacent to the village. Currently, the village lacks an underground sewerage network. As a result, domestic wastewater comprising blackwater and greywater is mainly managed through on-site septic tank systems, while a portion of untreated sewage ultimately finds its way into the Chandrabhaga River.

The village exhibits a maximum elevation of 326.62 m and minimum elevation of 311.80m difference of approximately 15.00 m.

Figure 1 Map Showing Study area of Dhapewada (Source: Generated by authors using ArcGis 10.8)

IV. Methodology and Analysis

A. Data Collection

The data regarding the village boundary information, population growth details, and records of the existing water supply and sewerage systems were obtained from census documents and local government offices. Preliminary data related to land use, road networks, and settlement patterns were collected using satellite images and GIS-based data. It is to note that the open spatial data was used only for preliminary base mapping and layout preparation work. A detailed field survey was conducted using instruments such as auto levels and DGPS equipment for TBM marking, elevation surveys, feasibility checks, high flood level identification, and bridge level measurements. The data obtained from the field survey were combined with contour maps and GIS information to analyze ground slopes, surface profiles, and natural drainage conditions of the study area. In addition, surveys were carried out to identify existing water supply pipelines, septic tank levels, underground utility services, and sewer outfalls discharging into the river. This assessment was undertaken with the objective of controlling and reducing pollution in the Chandrabhaga River. The compiled dataset served as the basis for the planning and design of the proposed sewerage system. The population data obtained from the 1971–2011 census will be used for future population projection [1]:

Table I: Population for Dhapewada from 1971-2011

Sr. No	Village Name	1971	1981	1991	2001	2011
1	Dhapewada	4189	4728	5293	5710	6098

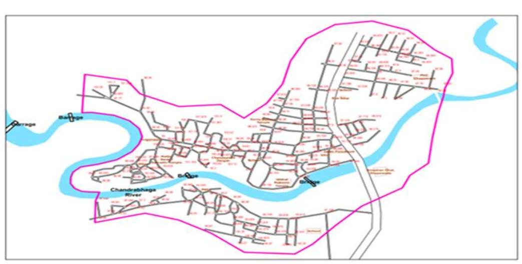


Figure 2 Base map for Dhapewada (Source: Generated by authors using ArcGis 10.8)

B. Waste Water Generation Estimation

Population data from census records between 1971 and 2011 were used as the base for estimating future population, which is necessary for designing the sewerage system over its intended service life. The design period was taken as 30 years for the sewer network and sewage treatment plant, while a service life of 15 years was considered for pumping machinery. To estimate the future population, standard projection methods such as arithmetic, geometric, and incremental increase methods were applied. The existing water supply in the village is about 55 litres per capita per day; however, for design purposes, a higher demand of 135 lpcd was adopted as recommended by CPHEEO [1]. Wastewater generation was assumed to be 80 percent of the total water demand, resulting in 108 lpcd. In the research, the infiltration loss has been assumed to be 5% of the total sewage flow. This satisfies the requirements of the CPHEEO [1] guidelines for the Nagpur region. Based on this, the total wastewater flow has been calculated and tabulated below.

TABLE II: UNIT SEWAGE GENERATION FLOW RATE

Unit Sewage Generation Flow Rate		
Sr. No.	Description	Value
1	Total per capita water supply	135Lpcd
2	Sewage generation at 80% of the total water supply	108Lpcd
3	Add for infiltration (about 5% of sewage rate)	6Lpcd
4	Total unit sewage rate being admitted to system	114Lpcd

TABLE III: WASTE WATER GENERATION CALCULATIONS

Sr. No	Year	Population	Sewage generation
1	2011	6098	0.69
2	2023	6692	0.76
3	2038	7439	0.84
4	2053	8197	0.93

C. Sewer Network Planning

In the village of Dhapewada, presently, an underground sewerage system is not developed, and untreated wastewater is directly diverted into the Chandrabhaga River, leading to environmental pollution. Although septic tanks are available in a few homes, a major share of wastewater is untreated and left unattended. To overcome the issue, the sewerage system has been designed in alignment with road development and land slopes. Manholes are provided at regular intervals as per design protocols for ease of maintenance. An interceptor sewer has also been suggested to collect all existing outfalls and redirect the water to a 1.00 MLD Centralized Sewage Treatment Plant, thus stopping water from going into the Chandrabhaga River.

Figure 3 Existing sewer condition of Dhapewada (Source: site visit image captured by author)

D. Modelling Tool Sewergems

Sewer GEMS, a hydraulic model development software created by Bentley Systems, has been employed for designing the sewage system of Dhapewada Village. This software provides for the detailed analysis of the working of the sewer system by taking into account the actual survey data of the sewage system layout and the ground levels and actual sewage load parameter such as peak flow rates. Design analysis has also been performed for the sewage system based on the necessary parameters such as the velocity of flow of sewage, slope of the pipe, or depth to pipe size ratio with consideration for the need for self-cleaning. This software also takes into account the varying sewage flow parameters that depend on ground topography. By accurately simulating these non-uniform flow conditions, SewerGEMS predicts water surface profiles, backwater effects, and surcharge scenarios, enabling the selection of appropriate pipe sizes and alignments. This approach ensures the design of a safe, efficient, and cost-effective sewerage system suitable for real operating conditions.

E. Standard Guidelines by CPHEEO (2013) [1] based Design Constraint

TABLE IV: DESIGN CONSTRAINTS AS PER CPHEEO (2013)

Sr. No.	Design Parameter	CPHEEO Requirement	Clause No.	Table No.	Usage in SewerGEMS
1	Minimum Self-Cleansing Velocity	0.6 m/s	Clause 4.3.3	Table 4.13	Ensures pipes do not settle solids
2	Maximum Velocity	≤ 3.0 m/s	Clause 4.3.4	Table 4.12	Prevents erosion/scouring of pipes
3	Manning's Roughness (n)	RCC: 0.013, PVC/DWC: 0.011	Clause 4.3.1 (Hydraulics)	Table 4.7	Input into conduit roughness field
4	Minimum Pipe Diameter	150 mm	Clause 4.3.2	—	Smallest permissible sewer size
5	Depth of Flow (d/D ratio)	≤ 0.8 (80%)	Clause 4.3.5	Table 4.9	Used during design checks to avoid full flow
6	Minimum Cover Depth	0.9 m (non-traffic), 1.2 m (traffic)	Clause 4.4.2	Table 4.15	Governs trench depth & protection
7	Recommended Minimum Slopes	As per the diameter, slope to maintain in design	Clause 4.3 series	Table 4.6	Sets minimum slopes for conduits
8	Peak Flow Factor (PFF)	2.0–3.0 based on population	Clause 3.4.3	Table 3.7 (Peak Factors)	Used in Extreme flow pattern
9	Sewage Generation	80% of water supply	Clause 3.3	Table 3.2	Used for manhole loading (population × LPCD)
10	Manhole Spacing	30–50 m (small diameter), 75–90 m (large diameter)	Clause 4.6.2	Table 4.16	Used for manhole placement along network

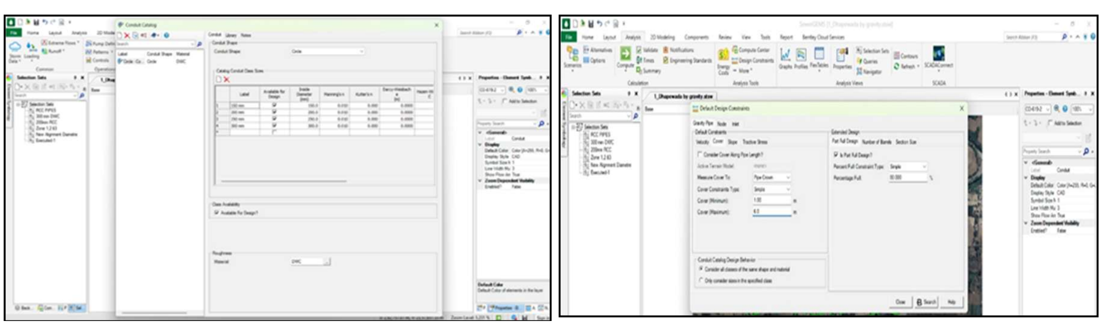
F. Design and Analysis

Modelling (Layout)

SewerGEMS modelling begins with creating a new model and importing the base map, road shapes and contours data to assign the accurate elevation for the planning of the sewer network towards the STP for further treatment. Manholes are developed using nodes and pipes are connected using conduit in the direction of flow towards the slope. Dhapewada village network was modelled using the survey data collected.

Design Constraint

Based on the planned and modelled sewer network of Dhapewada village, design constraints and wastewater loading derived from the projected population were applied in SewerGEMS, which operates on a heuristic design approach. It is essential to define design constraints such as pipe properties, minimum cover, permissible velocity limits, roughness coefficient, and D/d ratio in accordance with the CPHEEO manual [1], as discussed earlier. Sanitary loading was then assigned to the manholes using appropriate methods such as Thiessen polygon distribution or dead-end loading, depending on actual site conditions and defined peak factors. Finally, hydraulic simulations were carried out to estimate flow behaviour, velocities in the pipes, and hydraulic gradient lines. Based on these analyses, software flags out the conduit and manhole that are violating the design constraint that do not meet velocity, depth, slope constraints in the notification tab with yellow colour and red colour in case of steady state and extended period simulation respectively. Hence, based on this, further optimisation of the network to meet design standards and ensure reliable, efficient network performance is done.



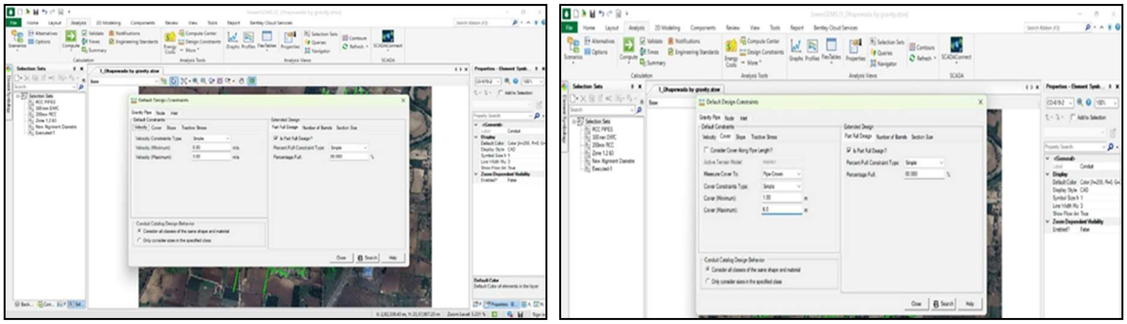
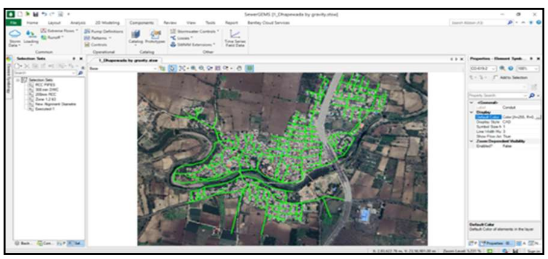


Figure 4 Design constraint in SewerGEMS modelling (Source: generated by authors using SewerGEMS software)

Scenarious Planning (Gravity+Hybrid)

The sewerage design for the Dhapewada village has been investigated for two sewerage design schemes. The first scheme includes a completely gravity sewer network that relies on the natural slope of the land for the flow of sewage. The second scheme includes a combination of gravity sewer network and the use of the Intermediate Pumping Station (IPS) at locations with irregular land. Both schemes have been analyzed with the SewerGEMS software in order to determine the performance and viability of the sewerage design for the selected village.



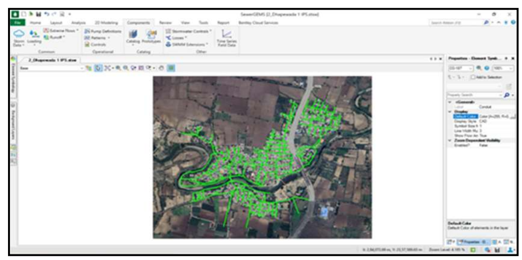


Figure 5 Scenario 1: - Gravity network (Source: SewerGEMS software) Figure 6 Scenario2: - (Gravity +IPS) (Source: SewerGEMS software)

V. Result and Discussion

Based on the comparative results of the analysis of the Gravity and Hybrid (Gravity + IPS) system obtained from SewerGEMS, and as per the CPHEEO Manual (2013) [1], the results obtained are as follows:

- Summary of Length: - Based on the hydraulic results obtained from SewerGEMS, the summary of length for both the scenarios (Gravity and Hybrid) was determined, and the results are summarized as follows:

TABLE V. SUMMARY OF LENGTH STATEMENT

Length Statement				
Sr. No	Material	Diameter	Scenario-1 Gravity (m)	Scenario-2 Gravity + IPS (m)
1	DWC	150mm	12392	12577
2	DWC	200mm	2308	2308
3	RCC	250mm	2992	2943
4	RCC	300mm	487	187
	Total Length		18179	18016

The size comparison of the gravity and Hybrid sewer system, designed as per the CPHEEO (2013) [1], highlights that the 150 mm DWC pipes are prominent in both gravity and Hybrid sewer networks and are based on the minimum size requirements of the branch sewers. The presence of the Intermediate Pumping Station in the Hybrid sewer network reduces the requirement of larger RCC trunk mains, in the case of 300 mm sizes, and favored the usage of smaller DWC pipes. This has improved the hydraulic regulation and decreased the loading effect downstream. The overall length of the sewer network is reduced by 163 m (≈0.9%) from 18,179 m to 18,016 m.

- Depth of Manhole: - Based on the hydraulic results obtained from SewerGEMS, the summary for depth of manhole statement for both the Gravity and Hybrid (Gravity + IPS) scenarios was evaluated, and the findings are summarized as follows: -

TABLE VI: DEPTH WISE MANHOLE DETAILS

Depth wise Manhole Details			
Sl. No	Depth of Manhole	Nos. of Manhole Scenario-1 Gravity	Nos. of Manhole Scenario-2 Gravity + IPS
1	1.00m-2.00m	561	573
2	2.01m-3.00m	168	182
3	3.01m-4.00m	60	65
4	4.01m-5.00m	24	11
5	>5.00m	22	0
Total Number		835	831

Based on the Depth-wise analysis of manholes, assessed as per the CPHEEO Manual (2013) [1], shows major improvements when shifting from a gravity system to a hybrid (gravity + IPS) system. In the gravity design, 22 manholes (>5.0 m) represented about 2.6% of the total, and 24 manholes (4.01–5.00 m) accounted for 2.9%. With the introduction of an IPS, manholes deeper than 5.0 m were eliminated (100% reduction), while the 4.01–5.00 m category reduced by more than 50% (from 2.9% to 1.4%). The desirable 1.0–3.0 m depth range increased from 71% to nearly 80%. Although total manholes decreased only slightly (835 to 831 = 0.5%), the redistribution significantly improves constructability, safety, and CPHEEO compliance [1].

- Velocity Details: - Based on the hydraulic results obtained from SewerGEMS, the velocity distribution for both the Gravity and Hybrid (Gravity + IPS) scenarios was evaluated, and the findings are summarized as follows:

TABLE VII: VELOCITY DISTRIBUTION

Velocity Distribution			
Sl. No	Velocity	Length of Scenario-1 Gravity (m)	Length of Scenario-2 Gravity + IPS (m)
1	<0.6m/s	16767	17024
2	0.6 m/s-2.0 m/s	1412	992
3	>2.0m/s	0	0
Total Number		18179	18016

Design and Analysis of the sewer network under two design scenarios—Gravity and Gravity + IPS—showed that the majority of pipes operate below the CPHEEO [1]-recommended self-cleansing velocity of 0.6 m/s, covering 92–94% of the total network length, while only 5–8% lie within the optimal velocity range of 0.6–2.0 m/s. Since the minimum diameter of 150 mm is maintained, velocities cannot be increased by reducing the diameter; instead, flushing tools are provided at the upstream manhole to enhance self-cleansing and reduce sediment deposition in low-velocity pipes. To address this limitation of conduit operating below self-cleansing velocity, flushing tools were evaluated in sewergems by using short-duration inflows at upstream manholes using an extended period simulation. It was observed that velocity increased by 0.35 m/s to 0.5 m/s, exceeding the self-cleansing velocity. Periodic flushing should be performed at upstream manholes at every 15-30 days.

- Profile Section: - Based on the hydraulic results obtained from SewerGEMS, the profile for trunk line in case of Gravity and Hybrid (Gravity +IPS) has been shown: -

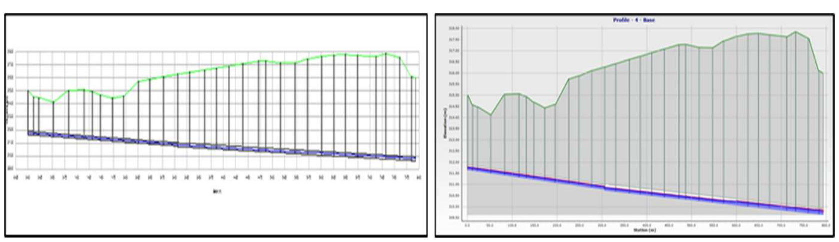


Figure 7 Profile for Trunk in Gravity based system (Source: generated by authors using SewerGems software)

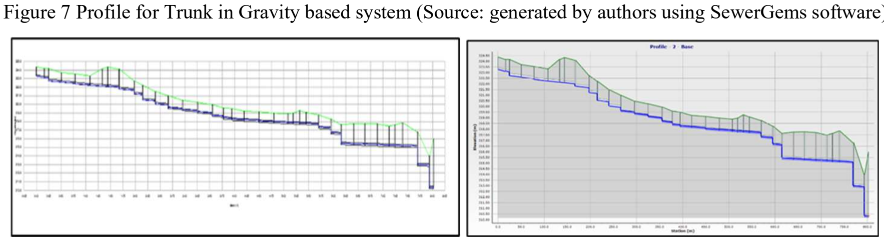


Figure 8 Profile for Trunk in Gravity + IPS based system (Source: generated by authors using SewerGems software)

It has been observed that the depth of excavation in the Gravity system reaches up to 8.08 m, whereas in the Hybrid system the maximum depth is reduced to approximately _4.09_m, primarily due to the incorporation of an Intermediate Pumping Station, which limits deep-cut sections and improves constructability.

- Cost Comparison: - The cost evaluation has been done using the output generated from hydraulic models for both scenarios using the MJP CSR 2023-2024 rates. A comparative summary of the resulting costs is summarised below:

TABLE VIII: COST COMPARISON OF SEWERAGE STATEMENT

Cost comparison of Sewerage System			
Sr. No	Description	Amount for gravity scenario in (Cr.)	Amount for Hybrid scenario in (Cr.)
1	Estimate for Pipeline	6.08	5.21
2	Estimate for Manhole	4.06	3.81
3	Estimate for House service Connection -(1800 Nos)	4.38	4.38
4	Estimate for Road Reinstating	5.24	5.2
5	Dhapewada National Highway Crossing for 300 mm RCC pipe Crossing	0.5	0.5
6	Estimate for IPS	0	0.77
7	Estimate for STP 1 MLD SBR technology	3.9	3.9
	Total Amount Rs.	24.16	23.77

VI. CONCLUSION

- Based on summary of sewer length statement in Table 4, it has been observed that the hybrid (gravity+IPS) shows a reduction in sewer length (0.9%) and an increase in 150mm DWC pipes, making on-site execution work more practical and feasible.
- Based on the manhole details in Table 5, it has been observed that the deep manholes with depth greater than 5.00m are eliminated, and the depth between 4.01-5.00m has been reduced by half in the case of Hybrid system (gravity+IPS), leading to more economical excavation.
- Based on the velocity details in Table 6, it has been observed that more than 92% of the pipe length is having velocity less than 0.6m/s which is operating below the self-cleansing velocity. As the diameter is already at the minimum of 150mm as per CPHEEO (2013) [1].
- It was observed that velocity increased by 0.35 m/s to 0.5 m/s, exceeding the self-cleansing velocity by using periodic flushing tools.
  It should be noted that flushing should be performed at an interval of 15-30 days at selected upstream manholes.
- It has been observed from the sewergems results that the maximum excavation depth drops from 8.08m in the gravity system to 4.09m in the case of Hybrid system with an additional Intermediate pumping station, causing restriction in deep excavation, leading to more economical excavation.
- Based on cost comparison in Table 7, it has been observed that total estimated cost has been reduced from ₹24.16 Cr. in the Gravity system to ₹23.77 Cr. in the Hybrid system, mainly due to reduction in pipe diameter, manhole depth, despite additional cost of Intermediate pumping station.

FUTURE SCOPE

- The use of smart flushing systems, CCTV inspections, and GIS-based asset management can improve maintenance of low-velocity sewer sections and help prevent sediment buildup.
- Installing automated sensors to detect blockages, overflows conditions can support early warning and timely maintenance in critical sewer stretches.

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