

EVALUATION OF HIGH-DENSITY POLYETHYLENE VERSUS POLYVINYL CHLORIDE PIPES IN DRINKING WATER CONVEYANCE IN RURAL AREAS

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Improving water supply infrastructure in rural areas is crucial to achieving Sustainable Development Goal 6 (SDG6), which aims for universal access to safe drinking water and sanitation. Water supply systems in rural communities in Honduras face unique challenges, including geographic isolation, limited infrastructure, and financial constraints, which have hindered their progress. Currently, in Honduras, Polyvinyl Chloride (PVC) pipes are used to design and construct drinking water supply systems; however, new materials and construction techniques must be employed in water supply projects to enhance the coverage and quality of water services in rural areas and meet SDG6. Thus, the primary focus of this study was to determine whether implementation of High-Density Polyethylene (HDPE) pipes in drinking water conveyance systems is feasible and viable. Velocities, pressures, optimal diameters, and losses were determined using EPANET for both PVC and HDPE pipes, with no significant differences observed. Regarding costs, HDPE pipes are 8.92% cheaper in CAPEX and 6% in OPEX compared to PVC pipes. Additionally, execution times are shorter for HDPE pipes due to their more straightforward installation process compared to PVC. The results indicate that incorporating HDPE pipes into drinking water conveyance systems in rural areas of Honduras is both viable and feasible. This finding is significant as it has potential to improve water supply situation in Honduras, particularly in rural areas, and contribute to achieving the SDGs.

Keywords: HDPE, PVC, Costs, Hydraulics, Water supply, Execution time.

1 INTRODUCTION

Pipelines are one of the primary components of drinking water supply systems. Common materials used in their construction include iron, concrete, copper, high-density polyethylene (HDPE), and polyvinyl chloride (PVC). The latter two are the most widely used due to their durability and low acquisition and installation costs (Haas 2012, Essaidi and Triki 2021).

PVC pipes have been the most commonly used material in water supply systems worldwide due to their durability, ease of handling, and availability. However, worldwide, HDPE pipes have increasingly replaced PVC due to their ability to mitigate pressure fluctuations, lower costs, easier processing, recyclability, and durability (López Rodríguez 2012, Alsabri and Al-Ghamdi 2020). In Honduras, PVC pipes remain the predominant choice for water supply systems due to their low cost, national market availability, and compliance with technical standards for design and construction (SANAA 2014). HDPE pipes have recently been introduced in Honduras and are primarily used in irrigation systems.

In Honduras, approximately 92% of households have access to a piped water supply system. However, only 60% have continuous access to water. Despite an increase in national service coverage from 84% in 2015 to 92% in 2020, rural areas have remained stagnant at 84% over the same period (WHO 2021). Immediate action is required to expand water service coverage in rural areas, thereby improving residents' quality of life and contributing to the Sustainable Development Goals (SDGs), which aim to ensure the availability and sustainable management of water and sanitation by 2030. This research offers a potential solution to these challenges. Achieving these goals requires overcoming challenges such as population growth, migration, investment and maintenance costs, technical difficulties, and climate change (Fagerli *et al.* 2018). Alternative water supply methods must be evaluated to meet the national demand for potable water, particularly in rural areas.

Material choice is one of the most challenging parts of designing and making structural elements in construction. However, it is also essential for success, cost reduction, and better results. In addition, when the water distribution system reaches its lifespan, its pipes and infrastructure must be replaced or improved to ensure the continuity and quality of the water supply service. Proper operation and maintenance are also important to prevent pipe leaks that result in water loss, infrastructure damage, and degraded water quality. Water systems occasionally must be rehabilitated or replaced to meet quality, distribution, safety, and sustainability standards (Abdulah Shrrat Omar 2023).

HDPE has emerged as the preferred plastic material for manufacturing pipes in modern water supply networks. These pipes and fittings are known for their extended lifespan, minimal maintenance requirements, high mechanical strength, and lightweight nature. Compared to conventional piping materials, HDPE offers superior advantages, including greater flexibility, resistance to corrosion, and the ability to withstand fluctuating pressure conditions efficiently (Vlase *et al.* 2020). HDPE has served as a solution for addressing water scarcity in developing countries like Morocco in Africa (Sven *et al.* 2021).

This study aims to compare the technical and economic feasibility of implementing PVC versus HDPE pipes in a drinking water conveyance line in a rural area of Honduras and determine whether HDPE pipes are a viable alternative for such projects.

2 MATERIALS AND METHODS

This research employs a case study approach, utilizing a quantitative methodology with a non-experimental, cross-sectional descriptive design. The study focuses on the technical and economic analysis of a drinking water conveyance system designed to supply potable water to a group of households in the rural village of El Horno, Honduras.

The study focuses on El Horno, a rural village in the municipality of San Buenaventura, Francisco Morazán, Honduras. The village has an elevation of 1,600 meters above sea level, with coordinates 481643.48 m E and 1540577.09 m N. The region has an irregular topography with slopes of up to 40%. The climate is classified as savannah, characterized by low rainfall and temperatures ranging from 10°C to 26°C. Currently, some households in El Horno lack access to potable water and rely on water purchased from tanker trucks. A natural spring located approximately 3.2 kilometers from the village has been identified as a potential water source (Municipalidad de San Buenaventura 2019).

Hydraulic modeling data is presented in Table 1, included the current population, number of households, and topographic surveys. Since some lots and homes were unoccupied, the design population was determined based on maximum occupancy. Water demand calculations are based on the national rural water supply system design standards (SANAA 2014).

Table 1. Population and flow rate.

Description	Quantity	Units
Houses	165	Units
People/house	6	-
Design population	900	Habitants
Provision of water	120	Liters per person per day (Lppd)
Average flow rate	1.37	Liters per second (L/s)
Daily Maximum flow rate	2.06	L/s

The study aimed to evaluate flow velocities, losses, pressures, and Water Hammer (WH) for hydraulic simulations with PVC and HDPE pipes. The hydraulic model consisted of 20 nodes and 19 pipes. The key input parameters for the simulations included topographic survey data, design flow rate (maximum daily demand), and a pressure-breaking tank to regulate pressures along the line. The Hazen-Williams formula was used for head loss calculations, with a roughness coefficient of 150 for both PVC and HDPE.

Simulations were conducted using nominal pipe diameters of 2 inches for PVC and 63 mm for HDPE. Due to pressures exceeding 140 meters of water column (WC), a pressure-breaking tank was necessary, as PVC SDR-26 pipes and HDPE100 PN10 pipes can only withstand 112 WC and 102 WC pressures, respectively. The pipeline stands at a total length of 3182.16 m from the source to the tank.

The performance of the materials was determined based on the technical specifications provided by the suppliers. The Amanco Tubosistemas Technical Manual (Amanco Wavin® 2006) was used for PVC pipes, while the Technical Manual for Polyethylene Pipes, published by the Spanish Association of Manufacturers of Plastic Pipes and Fittings (Balairón Pérez 2008), was consulted for HDPE pipes. The performance of materials and labor for complementary civil works was determined using the Performance Manual published by the Honduran Social Investment Fund.

Additionally, two quotations for materials were obtained from local manufacturers and nearby hardware stores. Labor costs were determined based on the minimum wage established by the Honduran Council of Private Enterprise.

Construction timelines for PVC and HDPE pipelines were determined based on labor productivity and material handling requirements.

3 RESULTS

The hydraulic modeling results for both pipe materials showed similar behavior as shown in Table 2:

Table 2. Hydraulic simulation results.

Parameter	PVC	HDPE
Velocity (m/s)	0.85	0.85
Minimum pressure (WC)	18	18
Maximum pressure (MP) (WC)	87	86
Total head loss (WC)	43.10	44.31
Water Hammer (WC)	28.53	20.87
Wave speed (a) (m/s)	329.26	240.82
MP+WH (WC)	114.86	107.20

The estimated cost of constructing the pipeline with PVC pipes is \$21,716.94, whereas the cost of using HDPE pipes is \$19,778.85, representing a significant cost reduction of \$1,938.08 (8.92% lower CAPEX) (Table 3).

Table 3. CAPEX.

Description	PVC (\$)	HDPE (\$)
Topographic survey	2,467.91	2,467.91
Excavation	5,770.79	5,055.33
Grounding and compaction	5,363.66	4,657.24
Pipes	6,109.39	5,358.95
Valves	176.60	145.02
Pressure-breaking tank	1,800.00	1,800.00
Accessories	28.59	294.40
Total	21,716.94	19,778.45

Additionally, maintenance and operation costs for HDPE pipes were lower, providing a reassuring financial outlook for implementing HDPE pipes (Table 4).

Table 4. OPEX.

Description	PVC (\$)	HDPE
Wages	160	160
Transportation	40	40
Travel expenses	60	60
Venue rental	120	120
Tools	8	8
Repairs	22.33	0.36
Valves and accessories	3.15	0.13
Civil works	7.61	7.61
Total	421.09	396.10

Project execution time is estimated at 28 working days for PVC and 26 days for HDPE. The difference is primarily. HDPE's easier installation, requiring fewer pipe joints, is a key advantage. This shorter execution time underscores the efficiency of HDPE pipes in water conveyance systems.

4 DISCUSSIONS

The results obtained in hydraulic modeling meet the requirements of the Honduran national standard for rural aqueduct design; velocities are in the range of 0.60 to 2.00 m/s, minimum pressure is about 10 WC, and diameters above 1 inch.

The flow velocity remains consistent for both PVC and HDPE pipes at 0.85 m/s, as they share the same Hazen-Williams friction coefficient ($C = 150$) and have nearly identical internal diameters—55.7 mm for PVC and 55.4 mm for HDPE. Both materials exhibited the same minimum pressure, and the maximum pressures were nearly identical: 86 WC for HDPE and 87 WC for PVC. However, PVC pipes exhibit a higher wave celerity and, consequently, higher overpressures than HDPE pipes. HDPE offers greater resilience to water hammer; still, in both cases, operational control actions are required to mitigate the effects of sudden pressure variations because MP plus WH exceed the maximum pressure of the pipes. It is recommended to use slow valve closures, approximately 18 seconds for HDPE and 13 seconds for PVC.

Regarding initial investment costs, using HDPE pipes would result in a total savings of \$1,948.37. The difference in supply and installation costs is \$0.17 per linear meter, making HDPE cheaper than PVC. Similar results are found when comparing CAPEX with PVC and HDPE pipes (Estacio Natividad and Meléndez Rodríguez 2017, Gabriel Ramos 2018), with the latter showing

lower prices. In addition to being cheaper to acquire, HDPE pipes also have lower labor costs due to fewer joints per section compared to PVC. Despite the limited awareness of HDPE pipes and their scarcity in the local market, the cost of HDPE is lower than that of PVC. This is not common in markets since the price is generally higher when a material is scarce (Garcia *et al.* 2023).

According to OPEX calculations, HDPE pipes also have better costs. The main difference lies in repair, replacement, and/or expansion costs, as the acquisition cost of HDPE pipes is lower than that of PVC, and the lifespan of HDPE pipes is 50 years compared to PVC's 20 years (Ambrose *et al.* 2008). On the other hand, construction project execution times for water transmission lines are shorter using HDPE pipes due to their easier installation, requiring fewer joints between pipe sections.

These findings apply to regions with similar relation of labor and acquisition costs, where HDPE's ductility, fewer joints, and faster installs can lower life-cycle costs.

HDPE Pipes show better CAPEX, OPEX, and execution times in this case study; however, several notable limitations must be carefully considered during the implementation. Limitations such as slow crack growth, UV-induced aging, poor installation practices, and limited technical capacity increase failure risks (Wang *et al.* 2024, Najarchi *et al.* 2025).

5 CONCLUSIONS

The hydraulic simulation results demonstrate no significant differences in the hydraulic performance of PVC and HDPE pipes. However, HDPE pipes have shown superior cost-effectiveness in investment and maintenance over their service life. Additionally, their shorter installation times compared to PVC further enhance their feasibility. Considering these advantages, HDPE pipes represent a viable and practical alternative for the design and construction of potable water transmission lines in rural areas of Honduras.

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