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Assessment of the Current State of Water Distribution Infrastructure in Enugu Metropolis Using a QGIS-EPANET Framework

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Abstract - The condition of water distribution infrastructure in Enugu Metropolis has remained a critical determinant of water supply reliability, service coverage, and system performance. This study evaluates the existing water distribution components—including pipelines, valves, tanks, network layout, and hydraulic behavior—using an integrated QGIS–EPANET framework. Spatial datasets, institutional records, and field measurements were collected and analyzed to examine the physical condition, structural arrangement, and operational efficiency of the network. The geospatial analysis revealed issues such as uneven pipe distribution, aging mains, nonfunctional valves, and irregular network connectivity. Hydraulic simulations highlighted pressure deficiencies, flow inconsistencies, and high head-loss zones that limit service reliability across specific neighborhoods. The study concludes that modernization, network rehabilitation, and systematic hydraulic balancing are urgently required to improve water infrastructure in Enugu Metropolis.

Keywords: Assesment, Distribution, GIS, water supply.

1. INTRODUCTION

Water distribution infrastructure plays a vital role in ensuring equitable access to potable water in urban environments. In rapidly expanding cities such as Enugu Metropolis, persistent challenges—ranging from aging pipelines to spatially unbalanced distribution networks—have contributed to inadequate service delivery. Understanding the condition of these infrastructure components is therefore essential for diagnostic evaluation and strategic planning.

Infrastructure assessment requires a combination of spatial intelligence and hydraulic modeling to accurately characterize system performance. Geographic Information Systems (GIS) provide a robust platform for capturing, visualizing, and analyzing spatial attributes of the water network, while EPANET enables simulation of pressure, flow, and hydraulic grade throughout the system. The integration of these tools enhances the quality of analysis and supports evidence-based decision-making.

This paper focuses exclusively on Objective One: reviewing and critically assessing the current state of the water distribution infrastructure in Enugu Metropolis. It presents a rigorous breakdown of the physical and hydraulic conditions, identifies structural weaknesses, and establishes the baseline upon which subsequent modeling and optimization studies can be developed.

2. LITERATURE REVIEW

A comprehensive assessment of urban water distribution infrastructure requires an integrated understanding of spatial network characteristics, system aging, and hydraulic performance. Prior studies emphasize the need for modern diagnostic tools—particularly GIS and hydraulic simulation models—to evaluate system condition, detect operational deficiencies, and support informed decision-making.

Several scholars highlight the growing relevance of GIS in water distribution studies. According to Adeyemi and Ojo (2019), "GIS provides the foundational capability for digitizing, visualizing, and analyzing spatial characteristics of pipeline networks, enabling utilities to understand the geometrical and geographical disposition of their assets" (p. 114). GIS facilitates topology checks, mapping of pipe materials, and identification of high-risk areas where infrastructure deterioration may occur. In regions with rapid population growth, spatial mapping serves as a crucial first step toward understanding infrastructure capacity gaps (Kumar & Prasad, 2020).

Hydraulic modeling, particularly through EPANET, has become a widely adopted tool for quantifying system performance and predicting flow behavior. Rossman (2020) notes that "EPANET enables the simulation of extended-period hydraulic responses of water distribution systems, including pressure variation, flow allocation, and head losses under dynamic conditions" (p. 57). Several

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researchers argue that combining GIS and EPANET creates a more robust diagnostic platform, as spatial data enhances the accuracy of hydraulic simulations (Yazdon & Al-Weshah, 2018; Abdullah & Ahmed, 2021).

In the African context, water distribution challenges are often linked to aging pipelines, poor maintenance regimes, and intermittent water supply. Studies conducted in Ibadan (Adeyemo & Aladejana, 2020) and Nairobi (Mwangi et al., 2019) revealed that older neighborhoods commonly experience high leakage frequencies, friction losses due to corrosion, and pressure drops arising from undersized or deteriorated pipes. These findings resonate with research by Okeya and Nwankwo (2021), who emphasized that spatially uneven network development—typical of cities experiencing unregulated urban expansion—creates systemic imbalances in distribution efficiency.

Furthermore, literature consistently identifies valve dysfunction, absence of district metered areas (DMAs), and inadequate looped configurations as contributors to operational inefficiencies. According to Goyetche (2019), “Poorly maintained valves and linear, non-looped distribution pipe arrangements reduce system resilience and complicate pressure management” (p. 2081). These issues often result in water losses, low-pressure zones, and unreliable supply for end-users.

Recent investigations into Nigerian water utilities also underscore the importance of integrating field measurement data with digital modeling tools. Akintorinwa et al. (2022) demonstrated that combining GPS-based field verification with GIS-EPANET modeling improves accuracy in identifying structural weaknesses. The authors conclude that digitally enhanced infrastructure auditing provides a cost-efficient strategy for utilities dealing with aging systems.

Taken together, existing literature supports the need for detailed spatial–hydraulic assessment, particularly in cities with historic isupply, and limited maintenance investment. The gaps identified in previous studies—aging pipelines, spatial imbalance, poor hydraulic performance, and operational bottlenecks—justify the application of the QGIS–EPANET framework in assessing Enugu Metropolis’s water distribution infrastructure.

3. MATERIALS AND METHODOLOGY

3.1 Materials

The following data and tools were utilized:

Datasets

- **Existing Network Maps**: Obtained from ENSWC/ENRUWASA, showing pipeline alignments and service zones.
- **Satellite Imagery**: Used for spatial referencing and validation of visible water infrastructure.
- **GPS Field Data**: Coordinates and elevations of key system components.
- **Pipe Attribute Records**: Information on pipe diameter, age, material type, and installation year.
- **Field Measurement Logs**: Pressure and flow readings for comparison with baseline system conditions.

Software Tools

- **QGIS 3.x** for spatial analysis and network mapping.
- **EPANET 2.2** for hydraulic evaluation.
- **QEPANET Plugin** for data exchange between GIS and EPANET.

3.2 Methodology

3.2.1 Spatial Digitization in QGIS

The water distribution network was digitized from high-resolution basemaps. Pipe segments, junctions, tanks, and control features were extracted and stored in geospatial layers.
A topology check was carried out to detect and correct issues such as open nodes, intersecting lines, and missing attributes.

2.2.2 Physical Condition Assessment

Each pipeline segment was categorized based on:

- Age of installation
- Material composition (PVC, ductile iron, galvanized steel)

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- Structural integrity
- Observed leakage points
- Accessibility and environmental exposure

Attributes were validated through field verification and consultation with ENSWC technical staff.

2.2.3 Hydraulic Profiling in EPANET

The geospatial data were exported into EPANET for hydraulic simulation.
Baseline conditions were assessed through:

- Pressure distribution analysis
- Flow adequacy
- Identification of low-pressure zones
- Pipe roughness and head-loss estimation

3.2.4 Data Validation

Field measurements of pressure and velocity were compared with EPANET-simulated values to confirm accuracy.

4. RESULTS AND DISCUSSION

4.1 Spatial Condition of Existing Infrastructure

The spatial analysis revealed a highly uneven network structure. Older neighborhoods such as Achara Layout, Uwani, and parts of Ogui exhibit aging and undersized pipelines incapable of meeting present-day demand. Newer areas, particularly Independence Layout and GRA, have relatively improved network components.

Table 1: Summary of Physical Infrastructure Condition

Zone	Pipe Material	Average Age of Pipes	Condition	Remarks
Achara Layout	Galvanized Iron	35 years	Poor	Frequent leakage and corrosion
Uwani	Cast Iron	30 years	Fair	Pressure drops, brittle joints
GRA	PVC/uPVC	12 years	Good	Stable distribution
Independence Layout	PVC/uPVC	10 years	Good	Adequate capacity
New Haven	Mixed Materials	20+ years	Fair	High head loss in old mains

4.2 Hydraulic Assessment Results

Hydraulic simulation highlighted significant deficiencies in system performance:

4.2.1 Pressure Distribution

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Low-pressure zones (<10 m) were identified in:

- Achara Layout
- Uwani
- Abakpa low-lying areas

Conversely, adequate pressures (>20 m) were recorded in:

- GRA
- Independence Layout
- TransEkulu

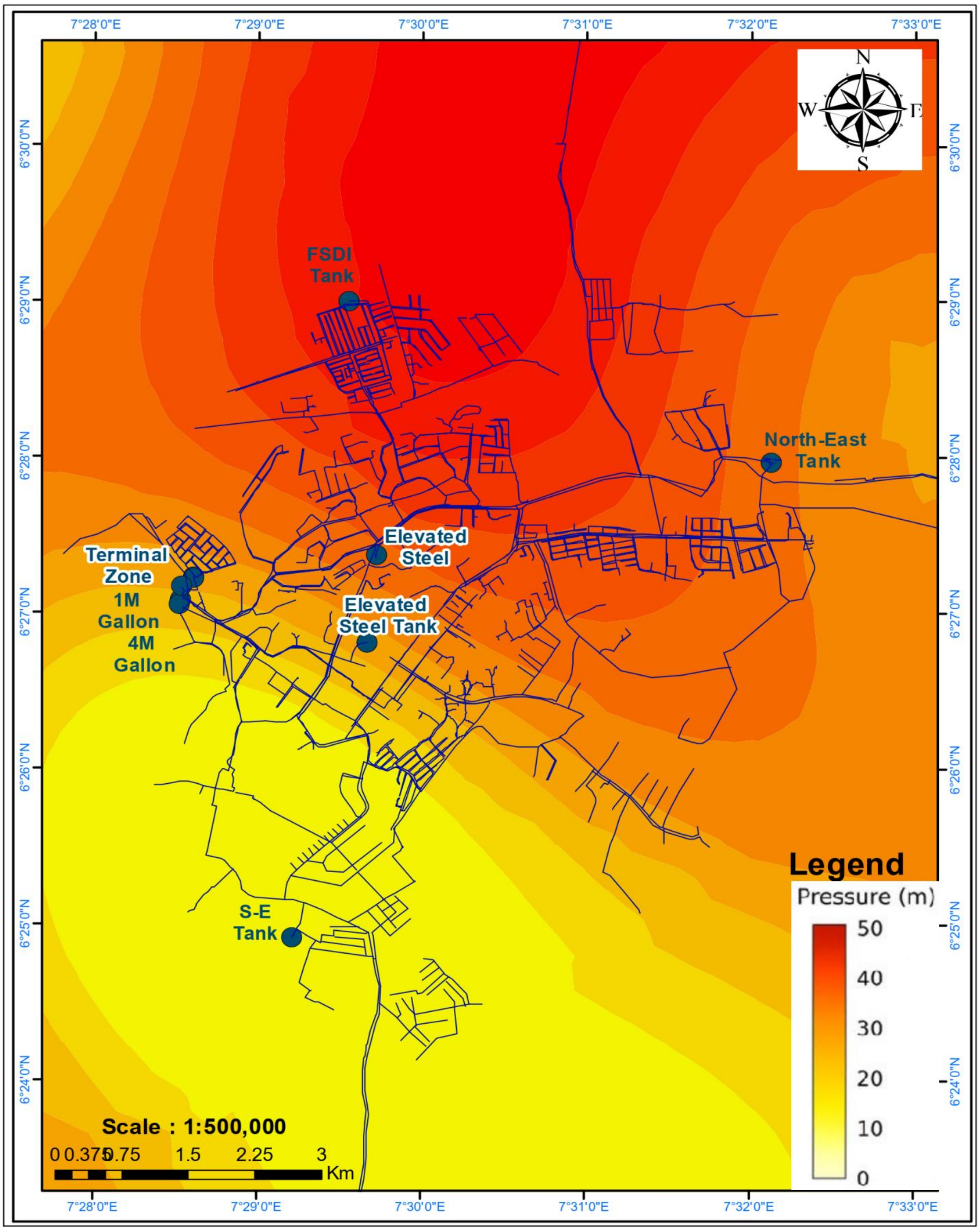

Figure 1: Spatial Pressure Distribution in the Existing Network

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4.3 Flow and Head Loss Assessment

Pipelines along major transmission corridors showed high head losses due to:

- Long distances
- Aging pipe materials
- Reduced effective diameter from internal roughness

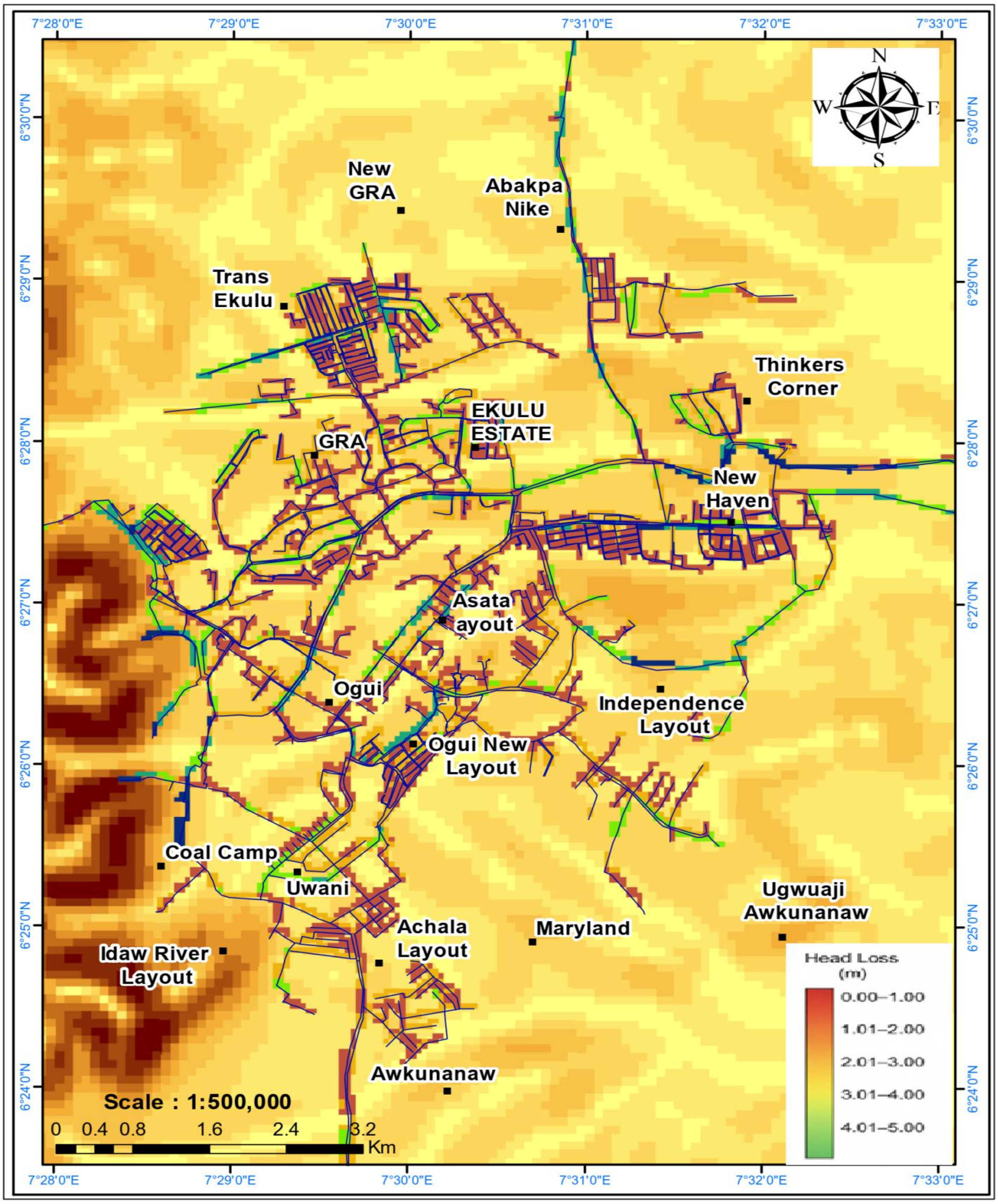

Figure 2: Head Loss Patterns Along Major Distribution Mains

Pipes with excessive head loss (>15 m/km) were predominantly located in older districts.

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4.4 Structural and Operational Deficiencies

Key issues identified include:

4.4.1 Leakage and Burst Frequency

Historical data revealed higher leakage frequencies in older ductile iron and galvanized pipelines.

4.4.2 Lack of Sectorization

The network lacks functional district metered areas (DMAs), resulting in:

- Poor pressure control
- Inability to track losses
- Unbalanced flows

4.4.3 Incomplete Network Connectivity

Several areas rely on linear pipe arrangements rather than looped systems, reducing network resilience.

4.4.4 Valve Dysfunction

Many control valves are either non-functional or buried, limiting operational control during emergencies.

5. CONCLUSION

The assessment of the water distribution infrastructure in Enugu Metropolis demonstrated substantial disparities in physical and hydraulic performance across the network. While modern developments such as GRA and Independence Layout present satisfactory conditions, older districts face deteriorating pipelines, poor pressure levels, and high head losses. The combined QGIS–EPANET approach effectively identified critical zones, quantified deficiencies, and highlighted infrastructural bottlenecks. System-wide rehabilitation, replacement of aging mains, introduction of DMAs, and reinforcement of trunk lines are essential to enhance water supply reliability and efficiency.

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