Environmental Industry Letters
https://ijitis.org/index.php/EIL
ISSN:2806-2965
Volume1, Issue2
DOI: https://doi.org/10.15157/eil.2023.1.2.101-110
Received: 15.11.2023; Accepted: 26.12.2023

Water Distribution System Design using QGIS and EPANET

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Abstract
These days, water management has become an extremely important aspect of urban planning, and as a result of rising population and a lack of available water, water is becoming increasingly limited on a daily basis. A number of issues, including leakage, excessive use, and others, had led to the depletion of all of our groundwater supplies. The waste of water that occurred as a result of poorly constructed water distribution systems was especially significant. In this article, the design of two different water distribution systems—one in a rural area and one in an urban area—was explored with the goal of optimizing water distribution and monitoring patterns of water usage. With the use of QGIS, the region is initially mapped, and then EPANET is utilized for the purpose of constructing the water distribution network and conducting an analysis of the various aspects that influence the pipe and network design.

Keywords*:* Water distribution network (WDN), QGIS, EPANET, Hydraulic analysis, Spatial data, Optimization, Network performance.

INTRODUCTION

Water distribution networks are vital infrastructure systems that ensure the reliable supply of clean water to communities. The efficient management and optimization of these networks are critical for maintaining a sustainable water supply. In this paper, the application of QGIS (Quantum Geographic Information System) and EPANET (Environmental Protection Agency's Network) software for the analysis and optimization of a water distribution network was observed. In the 75 years since India's independence, the annual per capita availability of water has declined by 75%, from 6,042 cubic meters in 1947 to 1,486 cubic meters in 2021. 65% of all reservoirs in India reported below-normal water levels, and 12% were completely dry. A proper water distribution system is required to deliver water to all customers of the system in sufficient quantity and to track water usage without oversupplying water. A case in point is the water supply system of Kampala City, whereby, after augmenting production to 160,000 m3/day in 2006, this being higher than the daily water demand at the time, there was still a massive outcry from consumers about water scarcity [1]. One of the primary causes of water loss is leaking pipes and equipment due to bursts or breaks. It is not an easy task to locate a leak in a huge distribution network. Other reasons for real losses in networks include service connections and overflows at storage tanks, while apparent losses result from unauthorized consumption, metering inaccuracies, and data handling errors. They can be visible, which appear on the surface, or non-visible, which do not appear on the surface and whose location depends on the use of equipment to scan the pipes.

QGIS is a powerful open-source geospatial platform that provides tools for data management, analysis, and visualization. It enables users to handle spatial data, perform geospatial analysis, and create detailed maps. EPANET, on the other hand, is a widely used software tool specifically designed for the hydraulic analysis and simulation of water distribution systems. It allows engineers and planners to model the flow of water, analyze network performance, and identify areas for improvement.

Some literature reviews in the field are as follows: Gareth et al. [2] discussed in their research new approaches for integrating and visualizing information to support water management. They are specifically developing a web-based EPANET simulation and visualization for large water networks. Prajapati et al. [3] investigated the planning of a water distribution network using GIS techniques and made a study of Baspa Village, Sami Taluka, Patan District, Gujarat. This study explains the paucity of the water supply system in Baspa village and the planning of a sufficient water supply and distribution network using the GIS technique. Stephen et al. [4] explored the significance of water distribution networks in water supply. It was concluded in this paper that higher pressures can be obtained when bigger-diameter pipes are used, which reduces frictional loss, thereby reducing the pumping cost. In another study by Muller et al. [5], a methodological approach for the compilation of a water distribution network model using QGIS and EPANET has been discussed. This paper presents the development of a methodological approach based on the integration of free-of-charge open-source software, e.g., QGIS and EPANET, and engineering practices applicable to water distribution network design.

The main objective of this study was to evaluate the performance of an existing water distribution network and propose strategies to enhance its efficiency and reliability for the case study. By integrating QGIS and EPANET [6-10], it was aimed at harnessing the combined power of spatial data analysis and hydraulic simulation to gain valuable insights into the network's behavior and make informed decisions for system improvement.

The research involved several key steps. First, comprehensive spatial data, including pipe networks, nodes, demand points, and geographical features, which were imported into QGIS for data management and visualization. This spatial analysis allowed to identify the network layout, understand the distribution of demand, and pinpoint potential problem areas.

Subsequently, the imported data was seamlessly integrated with EPANET, enabling hydraulic analysis of the water distribution network. By simulating the flow of water, analyzing pressure variations, and evaluating network performance indicators, the ability to assess the efficiency, reliability, and resilience of the system was observed. This analysis facilitated the identification of bottlenecks, areas of low pressure, and potential leakages.

Based on the findings from the hydraulic analysis, optimization techniques were employed to propose interventions for enhancing the network's performance. These interventions included pipe replacements, network extensions, pump station adjustments, and operational modifications. By modeling various scenarios and evaluating their impacts, it was aimed at identifying the most effective strategies for improving water distribution efficiency and reducing system vulnerabilities.

OBJECTIVE AND SCOPE

- To map two areas, one in Salt Lake and the other in Belda, and check if designing a water distribution system for that area is possible.
- to design the WDN for both areas and to check with the existing model if any optimization is required.
- to analyze the water requirement for the desired areas and run various simulations to get the desired output.

CASE STUDY AREA

The study area taken in this research is a particular area in the Salt Lake of Kolkata in West Bengal, India. The area lies between the center coordinates of 644981.52 E and 2498075.04 N in Salt Lake, Kolkata, and the center coordinates of 535192.7 E and 2441251.27 N in Belda, Midnapore. Both of these areas are in West Bengal. The area used for designing the Salt Lake area has a length of 1130.56 m and a breadth of 551.03 m, and the area used for designing the Belda area consists of 1743.13 m and a breadth of 850.16 m.

METHODOLOGY

First The mapping of the West Bengal area was done with the help of QGIS, and then two places were extracted from the West Bengal map, which are the Salt Lake area and the Belda area. Then, with the help of elevation data obtained through the extraction of satellite mapping, the elevation levels in both areas were checked. After that, a map of both areas was extracted from Google Earth Pro, and it was converted to a bmp file for exact mapping in EPANET. Then the water distribution network was designed for both areas, and simulations of hydraulic analysis were run to check the water distribution.

Data Collection: Obtain geospatial data for the study area, including digital maps, satellite imagery, elevation data, land use data, and road network data. QGIS can be used to import and manage these geospatial datasets.

Data Preparation and Integration: Perform necessary geospatial data processing tasks such as Google satellite imaging, web plugins, etc.

Network Modelling with EPANET: Create a hydraulic model of the water distribution network using EPANET. doing the following steps:

a. Network creation: Build the network model by defining pipes, nodes (reservoirs, tanks, demand nodes), and their attributes in EPANET.
b. Hydraulic analysis: Perform hydraulic simulations in EPANET to evaluate the flow patterns, pressure levels, and water distribution within the network under different operating conditions.
c. Model calibration: Adjust model parameters and compare simulation results with field measurements to ensure the model accurately represents the real-world behavior of the network.
The methodology can be adapted and expanded based on the specific requirements and complexity of the water distribution network design project.

Work in QGIS:

- Shapefiles are first sourced from Diva-gis.
- Then the water lines and inland water layer are sourced.
- Overlap the water line layer.
- overlap with the inland water layer.
- Then the desired area in West Bengal is extracted by layer.

Place Marking:

- Using Rastar to save a Google Earth image
- Again, use Rastar to extract the desired area by overlaying the map on the Google Earth image. (Figure 1)

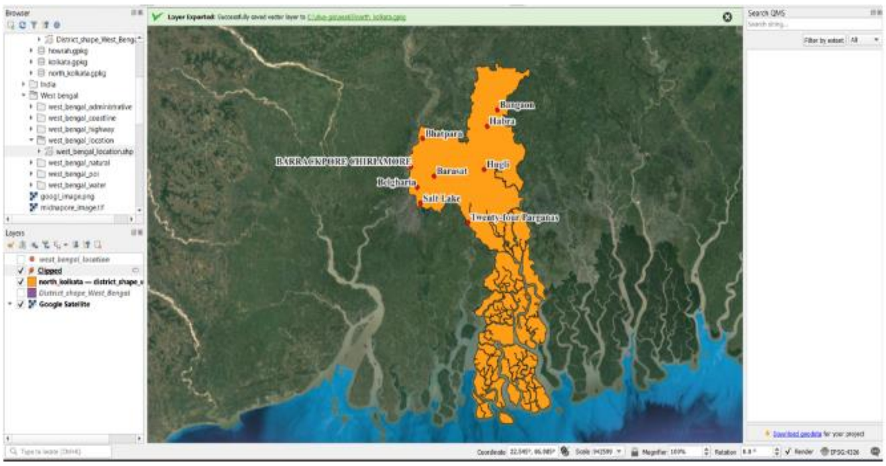


Figure 1. Overlapping North 24 Parganas on Google Satellite Image

Satellite Imaging:

- Geo-processing tools are combined to obtain web services through QGIS
- Web plugins are used to extract spatial data from web services such as Google Earth Pro. (Figure 2)

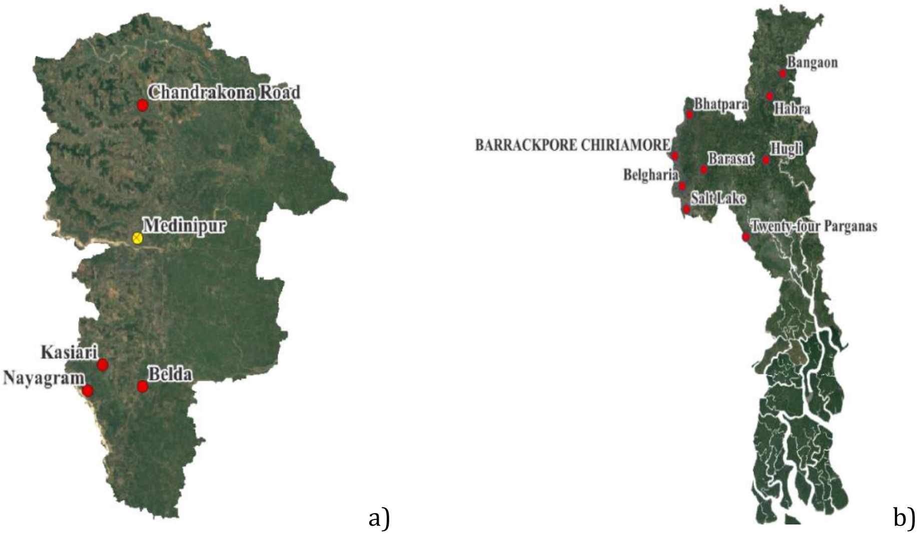
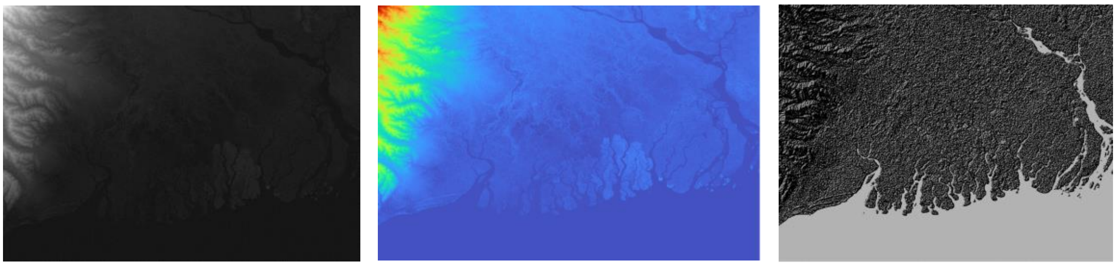


Figure 2. Satellite Image of a) Midnapore; b) North 24 Pargana

Elevation Imaging

- Single-band gray and pseudo-color band data is obtained after merging all the DEM square files.
- Meta-data on elevation is obtained similarly (Figure 3).



a) Single Band Grey b) Pseudo-colour Band c) Meta Data

Figure 3. Elevation Imaging

Work in MS Excel using Google Earth Pro

Select the desired area in Google Earth Pro, then note down the center coordinates of E and N. Take the length and height of the map. Then add the E coordinate with half of the length to get the upper right coordinate for E, and add the N coordinate with half of the height to get the upper right coordinate for N in the EPANET map.
Now subtract the E coordinate with half of the length to get the lower left coordinate for E, and subtract the N coordinate with half of the height to get the upper right coordinate for N in the EPANET map. The detailed coordinates of the case studies are in Table 1.

Table 1. Coordinates of case studies

Centre Coordinate	Salt Lake	Belda
East	6448981.52	535192.7
North	2498075.04	2441251.27
Length(m)	1130.56	1743.13
Height(m)	551.03	850.16
Upper Right (E)	645546.8	536064.265
Upper Right (N)	2498350.555	2441676.35
Lower Right (E)	644416.24	534321.135
Lower Right (N)	2497799.525	2440826.19

Work in EPANET:

Designing a water distribution network in EPANET involves several steps. Here is a general outline of the process:

Define Hydraulic Properties: Set the hydraulic properties for the network components. This includes specifying the pipe roughness coefficients, valve characteristics, and pump parameters. These properties determine the flow behavior and hydraulic performance of the system (Figure 4).

Creating the Network Model: Using EPANET's network editor, create the network model by adding pipes, nodes, and other components. Input the pipe lengths, diameters, roughness coefficients, elevation data, and demand patterns. Define the source nodes, reservoirs, tanks, and boundary conditions. Ensure that the model accurately represents the physical layout of the water distribution system (Figure 5).

Run Hydraulic Analysis: running the hydraulic analysis in EPANET to simulate the water flow and pressure within the network. EPANET calculates various hydraulic parameters, such as pressure, flow rates, velocities, and head loss, based on the defined properties and demand patterns (Figure 6 and 7).

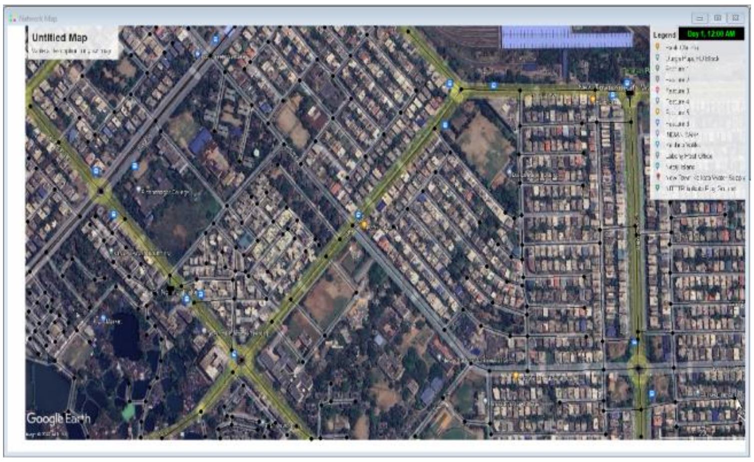


Figure 4. BMP Image of a portion of Salt Lake

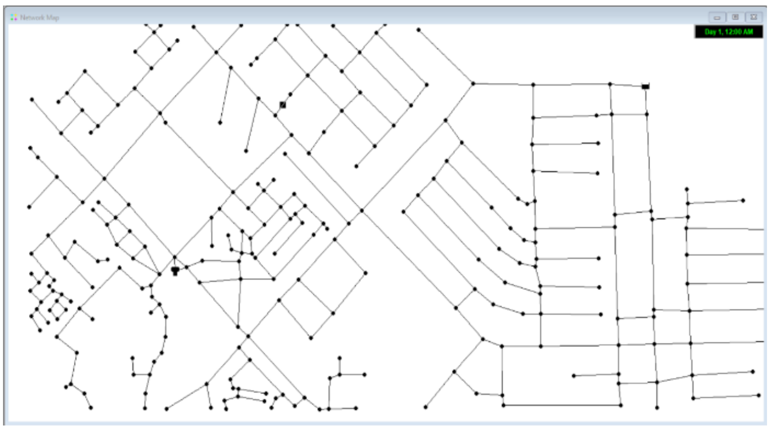


Figure 5. WDN Design of Belda

Figure. BMP Image of a portion of Belda

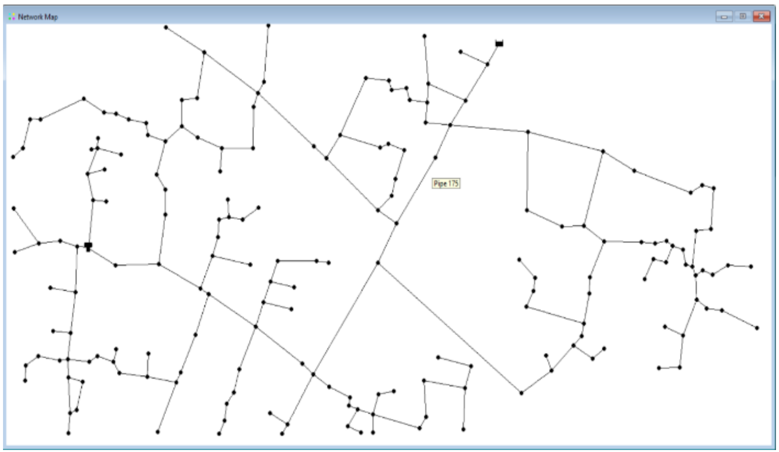


Figure 7. WDN Design of Belda

QGIS ANALYSIS

Elevation Data

This QGIS elevation data allows for detailed topographic analysis of the study area. By visualizing the elevation and terrain features, such as hills, valleys, and ridges, it becomes possible to understand the local topography and its influence on the water distribution network. And it can be seen from our data that the desired area for both Salt Lake location and Belda location has a smooth terrain without the need to adjust height in the water distribution network.

• Single band Grey & Pseudo-color band data is obtained after merging all the DEM square files.

• Meta-data on Elevation is obtained similarly.

EPANET ANALYSIS

The results obtained from EPANET for water distribution network design for our desired areas (Figs. 8–11) have provided us with valuable insights into the performance and efficiency of the network. Here are some key results that can be derived from the EPANET for water distribution network design:

- Pressure Analysis: Detailed information on water pressure within the network
- Flow Analysis: EPANET allows for the analysis of water flow rates within the network.
- Velocity Analysis: The evaluation of water velocities within the network

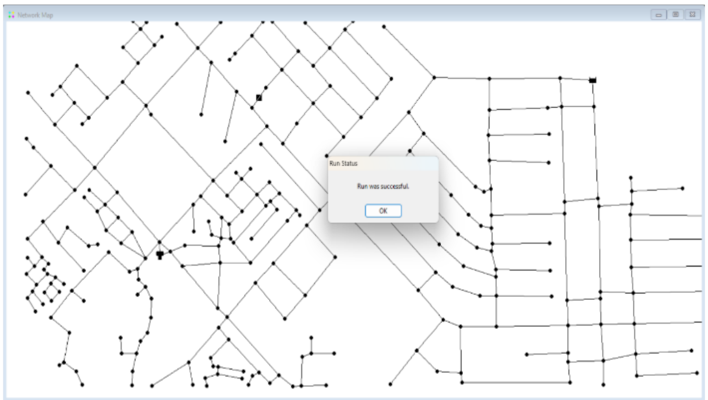


Figure 8. WDN Design of Salt Lake (Run)

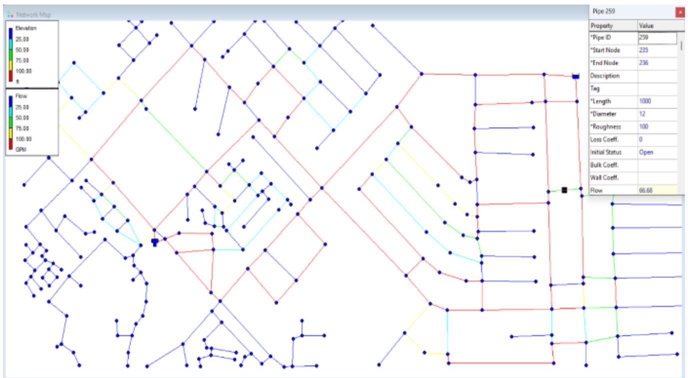


Figure 9. Output of WDN Design of Salt Lake

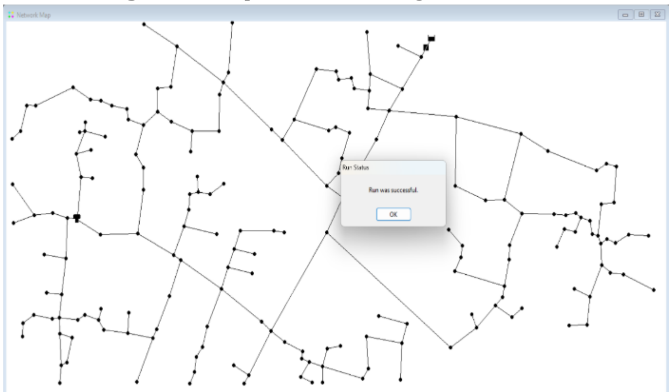


Figure 10. WDN Design of Belda (Run)

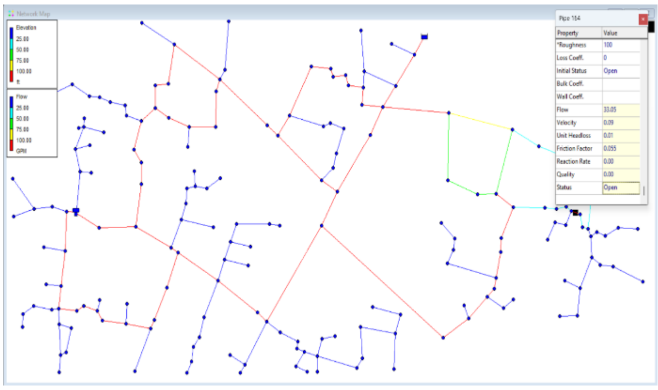


Figure 11. Output of WDN Design of Belda

analyzing the results obtained from the hydraulic analysis to evaluate the performance of the network. Identify areas with low pressure, high velocity, or excessive head loss. adjustments to the network design based on the analysis results. Run real-life data to analyze if the design is living up to its expectations. Modify the pipe sizes, valve placements, or pump settings to improve system performance, ensure sufficient water pressure, and minimize head loss. Keep on rerunning the hydraulic analysis until the desired performance is achieved.

CONCLUSION

From the results obtained, it can be concluded that the study area has been mapped into a bitmap file, therefore giving an accurate mapping length of pipes and nodes in the EPANET design and hence can be used for designing purposes and modeling. The study area from both areas shows that even though the rural area is larger as compared to the urban area, the density of population and the concentration of water networks required to supply water are much higher in the urban area. It also shows how much it differs in the density of the pipes laid out. With a large number of satellites from almost all major countries revolving around the earth and collecting data, it has become easier to get data from satellites in various applications like QGIS and EPANET. Therefore, it can be concluded that:

- The results obtained from elevation data and meta data analysis can be interpreted that the selected area of both Salt Lake and Belda area have consistent elevation output.
- The hydraulic analysis done for both the water distribution network design has been successful. The data obtained has given various outputs on pipes, ranging from roughness, flow data, velocities, unit head loss, and friction factor.
- The output obtained in this design needs to be validated with real-life data. Further studies are possible to the current data.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interest associated with this publication.

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