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Assessing Source Sustainability and Economic Efficiency Using WaterGEMS and CPHEEO Guidelines in the Yadgir Rural Water Supply Project, Karnataka, India

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Abstract **The Paper delves into the challenges and solutions of water supply in rural areas, particularly focusing on the Yadgir RWS project in Karnataka, India. It highlights the importance of sustainable water resources for various aspects of human development. The study analyzes the source sustainability of the Narayanpur Reservoir, finding it reliable in meeting the project's water demands. Additionally, the research uses WaterGEMS software to optimize the water distribution network, ensuring efficient delivery. An economic diameter analysis is conducted to select cost-effective pipe sizes. The author's internship at MEIL provides practical insights into large-scale project execution. Overall, the dissertation integrates technical and economic considerations, contributing valuable knowledge to water resource management and offering recommendations for improving rural water supply systems.**

Keywords — Water Supply, Source Sustainability, WaterGEMS, Economic Diameter Analysis, Rural Water Infrastructure, Hydraulic Modeling

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I. INTRODUCTION

This study presents a comprehensive evaluation of the Yadgir Rural Water Supply project in Karnataka, India, addressing critical challenges in rural water infrastructure. The research employs a multifaceted approach, combining source sustainability assessment, hydraulic modeling, and economic analysis to optimize water distribution systems Utilizing historical data and GIS analysis, the study confirms the reliability of the Narayanpur Reservoir as a sustainable water source. WaterGEMS software is employed to model and optimize the water distribution network, ensuring efficient design parameters and adherence to velocity and headloss standards. An economic diameter analysis, following CPHEEO guidelines, balances cost-effectiveness with hydraulic performance in pipe sizing.

The research is enriched by practical insights gained during a two-month applied work experience at Megha Engineering and Infrastructure Limited, providing valuable field experience in project execution. This integrated approach offers significant contributions to water resource management, presenting practical recommendations for enhancing rural water supply systems and ensuring long-term sustainability.

II. PROBLEM DEFINITION AND OBJECTIVES

A. *Problem Statement*

- Source Sustainability Evaluation
- Water Distribution Network Modeling
- Economic Pipe Diameter Analysis

B. *Objectives of the study*

- To Evaluate Source Assessment for Yadgir-Rural Water Supply (RWS) project for Reliability
- To Evaluate the Water Distribution Network (WDN) Design Using Water-Gems by Designing a Small Stretch of total network from Yadgir-RWS project
- To evaluate the economic diameter of a pipe, analyze the results based on the guidelines outlined in the CPHEEO manual
- Acquire practical knowledge and insights related to water supply through hands on experience in the field

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- Collect relevant data essential for the project through extensive involvement and data gathering during the internship period

III. Study Area

Yadgir district in Karnataka, India, which encompasses six taluks and 696 habitations, faces significant challenges regarding drinking water availability, particularly in rural areas. To address these issues, the Multi Village Drinking Water Supply Scheme, known as Jaladhare, has been initiated to provide treated drinking water to three urban local bodies—Kakkera, Kembhavi, and Hunasagi—under the Design, Build, Operate, and Transfer (DBOT) model of the Jal Jeevan Mission (JJM).

Launched by the Government of India, JJM aims to ensure safe and sufficient drinking water through tap connections for households by 2024. The Yadgir project seeks to enhance the quality of life for both rural and urban residents while promoting long-term sustainability through effective water management practices.

The district, with a population of approximately 1.8 million and a density of 160 people per square kilometer, struggles with frequent droughts, erratic rainfall, groundwater depletion, and inadequate water infrastructure. These challenges are compounded by seasonal variability and water quality issues, necessitating ongoing efforts for water conservation and substantial investment to meet the needs of rural communities effectively.

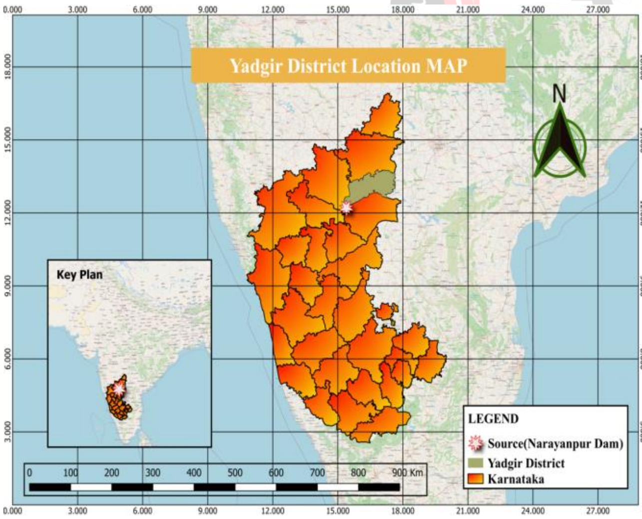

Figure 1: Yadgir District Location Map

IV. Methodology

This section details the methodology for achieving the study's objectives: evaluating source sustainability using historical and GIS data, analyzing the water distribution network with WaterGEMS software, and determining the economic diameter of pipes using CPHEEO manual guidelines.

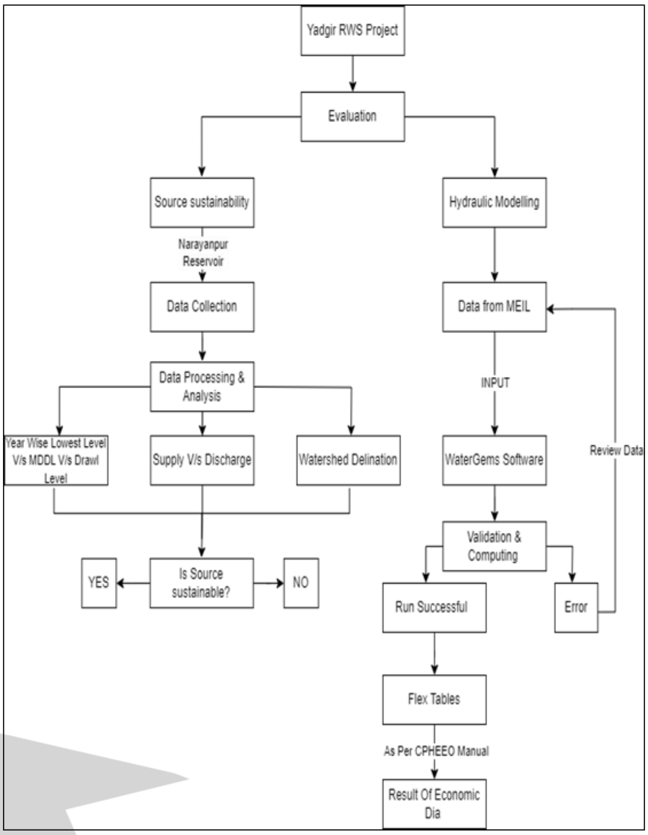

Figure 2: Process flow chart detailing the project's workflow

Evaluation of the sustainability source for yadgir RWS project

This study focuses on the Krishna Basin watershed, specifically the Narayanpur Reservoir outlet, where ArcSWAT was used to delineate the watershed and assess its sustainability by analyzing supply versus discharge patterns. This analysis is crucial for ensuring that water supply meets demand for drinking, irrigation, and industrial use. Additionally, a comparative study of year-wise lowest water levels against intake levels for the Yadgir RWS project provided insights into long-term water availability and informed conservation strategies. WaterGEMS software further optimized the Yadgir RWS network by integrating genetic algorithms and SCADA for real-time efficiency and pressure management, alongside an economic diameter analysis based on the Hazen-Williams equation to ensure optimal pipe sizing for hydraulic performance, in line with CPHEEO guidelines.

The study on source sustainability employs a comprehensive methodology that includes data collection through historical analysis and GIS evaluation. It focuses on deriving the watershed of the Krishna Basin for the Narayanpur Reservoir Outlet using ARC-Swat, enabling a detailed assessment of hydrological dynamics. Additionally, a supply versus discharge analysis is conducted to evaluate water availability and usage. The study also compares year-wise lowest water levels with the intake levels of the Yadgir Rural Water Supply (RWS) Project, providing insights into fluctuations and trends that impact sustainability. This multifaceted approach aims to ensure effective management and conservation of water resources in the region.

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Evaluation of WDN design for a starting stretch of Yadgir-RWS Network using WaterGems

WaterGEMS is a powerful tool designed to optimize water distribution networks and address water scarcity issues. Its key features include the use of genetic algorithms for automatic model calibration, leak detection, and efficient management of pipelines and pumps. The software integrates with SCADA systems for real-time data management, enhancing proactive network oversight. Additionally, it effectively establishes and manages pressure zones, ensuring consistent pressure throughout the system. Overall, WaterGEMS significantly improves the efficiency, reliability, and sustainability of water

distribution systems. (Source: Overview of WaterGems 'Le Huynh Tuyet Trinh'., et al)

Input Data to Watergems Software

Label	Elevation (m)
Jackwell (Suction Level)	477.0
WTP (Tip of Cascade Aerator)	515.65
HUN_ZBT_1	524.5
HUN_ZBT_2	544.5

After inputting essential data like demand, junction levels, and pipe specifications, a sample trial run should be conducted to obtain headloss values. These values are then used to calculate the total pump head, which should be assigned as the total elevation or adjusted by adding a pump. After making these adjustments, the system must undergo an actual run following proper validation.

Economic Diameter Analysis for initial stretch of Yadgir RWS Network

Selecting the appropriate pipe diameter is critical for optimizing pipeline design by balancing headloss and flow velocity. Hydraulic modeling software like WaterGEMS calculates headloss for various diameters, following the Central Public Health and Environmental Engineering Organisation (CPHEEO) guidelines that limit headloss to a maximum of 5 meters per kilometer. It's essential to maintain flow velocity between 0.7 and 1.3 meters per second to prevent sediment buildup and pipe wear.

The Hazen-Williams equations facilitate these calculations: for velocity, the formula is $V = k C R^{0.63} S^{0.54}$, where k is the conversion factor, C is the friction coefficient, R is the hydraulic radius, and S is the slope of the energy line.

The headloss due to friction is determined by $h_f = 10.67 \frac{Q^{1.852} L}{C^{1.852} d^{4.8704}}$, where h_f is head loss, Q is the flow rate, C is the Hazen-Williams coefficient, L is the pipe length, and d is the internal diameter. Analyzing these parameters ensures the efficient selection of pipe diameter for optimal performance.

V. Results

5.1 Source Sustainability Results

Delineation Results

By delineating the Krishna Basin at the Narayanpur Reservoir outlet, we gained a detailed understanding of the contributing area that feeds into the reservoir. This delineation helped us establish the perimeter of the topographic divide, which separates different water basins. The basin's area and perimeter provide crucial preliminary data for assessing the sustainability of the Narayanpur Reservoir as a reliable water source for the Yadgir Rural Water Supply Project. The delineation results, shown in **Figure 6**, outline the Krishna Basin, while **Figure 7** details the area (10,279.42 sq. km) and perimeter (625.07 km) of the basin.

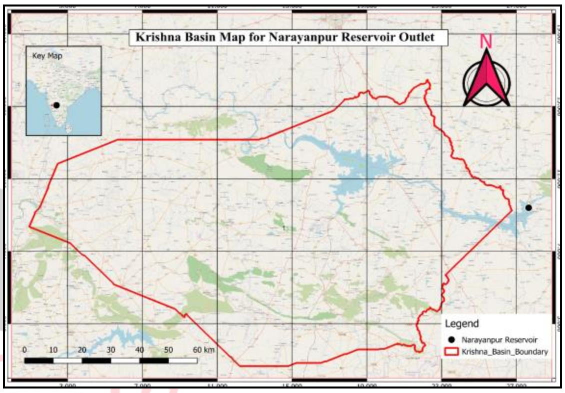

Figure 3: Map of Delineated Krishna Basin

The basin's vast area indicates a substantial inflow capacity, suggesting the reservoir's potential to support large-scale water supply projects. This large catchment area ensures that the reservoir is a robust and reliable source for water supply, capable of meeting the project's future water demands.

Supply vs Discharge

The substantial size of the Krishna Basin suggests that the Narayanpur Reservoir could meet the water demands of the Yadgir Rural Water Supply Project. However, upstream dams can influence water availability by delaying the inflow, increasing the time of concentration. To address this, we analyzed monthly inflow and demand data. Our calculations, based on historical demand (1.5 TMC/day), align with previous performance metrics of the reservoir.

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The inflow vs. discharge results are plotted in **Figure 4**, which demonstrates that supply consistently exceeds demand.

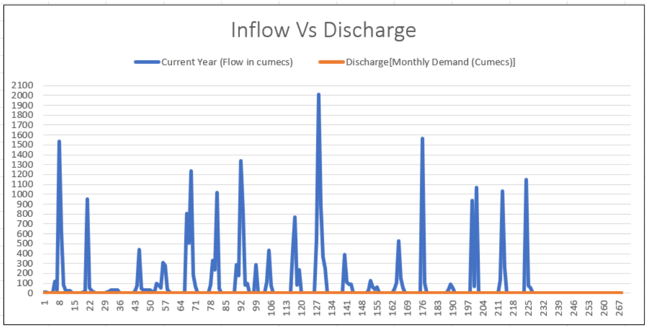

Figure 4: Inflow (Supply) Vs Discharge (Demand) Graph

This is further confirmed by comparing the reservoir's lowest water levels with the intake well levels. The graphical analysis strongly indicates that the reservoir is capable of supporting the current and future water supply needs of the project.

Reservoir and Intake Levels Analysis

To assess the sustainability of the Narayanpur Reservoir, we compared its lowest annual water levels with the intake well level and maximum drawdown level (MDDL). The analysis, depicted in **Figure 9**, shows that the reservoir's lowest recorded water levels over the past 23 years have consistently remained above the intake level required for the Yadgir Rural Water Supply Project. This suggests that the reservoir has sufficient capacity to support the project without risking depletion of resources.

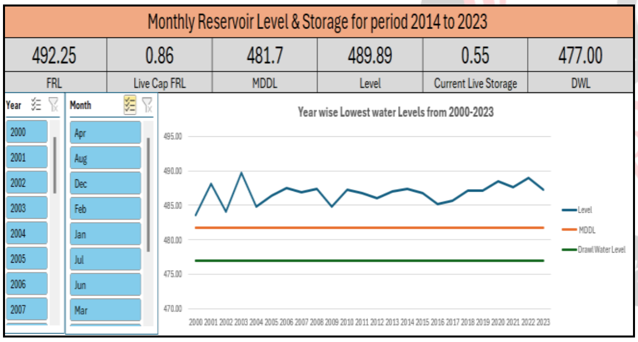

Figure 5: Annual lowest level of reservoir Vs Intake level for Project Vs MDDL

VI. Water Distribution Network Modelling Using WaterGems

The hydraulic model for the Yadgir Rural Water Supply (RWS) project was developed using WaterGems software. **Figure 10** and **Figure 11** illustrate the hydraulic model of the starting stretch of the Yadgir-RWS project, both with and without a Bing aerial map overlay.

To evaluate the water distribution network, we calculated the pump head requirements for different stretches of the system, as shown in **Table 4**. The total pump head was calculated by summing the differences in elevation, residual head requirements, head losses, and frictional head.

After inputting the calculated total pump head into the model, it ran successfully without errors. The velocity and head loss values for all nodes and pipe segments were within acceptable limits, ensuring that the system was designed efficiently and performed optimally.

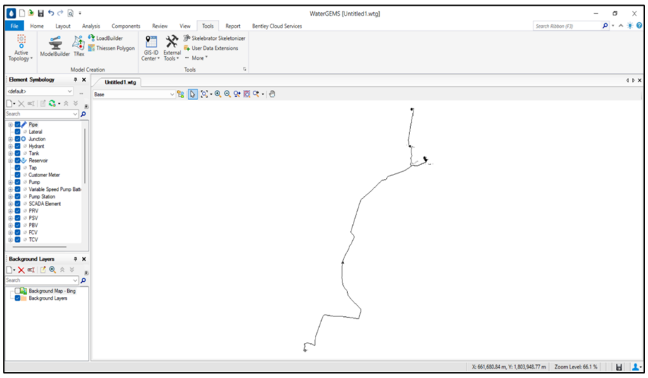

Figure 6: Hydraulic model of starting stretch of Yadgir-RWS Project in WaterGems interface

VII. Economic Diameter Analysis

The CPHEEO manual specifies that the head loss should not exceed 5 m/km, and velocities should fall within the range of 0.7 m/s to 1.3 m/s. The hydraulic model results, shown in **Figure 12** (flex table for junctions) and **Figure 13** (flex table for pipes), confirm that the design adheres to these guidelines.

The analysis reveals that residual pressures meet the minimum requirement of 3 meters of water column, while pipe velocities and head losses are within acceptable limits. Though velocities near the upper range were observed due to the low-resolution elevation data, the system remains reliable. With a velocity of 1.3 m/s, the current pipe diameters provide a cost-effective solution for the project while ensuring operational efficiency.

In conclusion, the pipe diameters and pump heads used in the Yadgir Rural Water Supply Project are economically viable and technically sound, as confirmed by the WaterGems hydraulic model.

FlexTable: Pipe Table

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)	Length (User Defined) (m)
68	CWR_to_HUN_ZBT_2	CWR	ZBT_2	213.9	Mild Steel	132.0	26	0.72	2.66	6,269
66	CWR_to_HUN_ZBT_1	CWR	ZBT_1	315.9	Mild Steel	132.0	73	0.93	2.69	100
67	JW_to_WTP	Jackwell	WTP_Aerator_Tip	1,150.0	Mild Steel	132.0	1,355	1.30	1.12	23,450

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Page 1 of 1

Figure 7: Flex Table (Pipe)

FlexTable: Junction Table

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (kPa)
63	WTP_Aerator_Tip	515.65	1,355	518.73	30
62	ZBT_2	544.50	26	548.03	35
61	ZBT_1	524.50	73	564.43	391

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Figure 8: Flex Table (Junction)

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Conclusion

The evaluation of the Yadgir-Rural Water Supply (RWS) project underscores its reliability and efficiency in delivering a sustainable water supply. Analysis confirmed the Narayanpur Reservoir's stability as a dependable source, complemented by a well-designed water distribution network. Using WaterGEMS, the network was validated for optimal velocity and headloss values, indicating effective hydraulic performance. To ensure cost-effectiveness, an economic diameter analysis was conducted in accordance with CPHEEO guidelines, successfully balancing pipe sizing with hydraulic needs. Practical fieldwork provided valuable insights into the operational aspects of the project, enhancing understanding of its implementation.

Data collection throughout the project period was crucial for a thorough evaluation and successful outcomes. It included essential information such as water levels in the Narayanpur Reservoir, water quality parameters, and flow rates in the distribution network. Analyzing this data allowed researchers to assess project performance and identify improvement areas. In conclusion, the Yadgir-RWS project exemplifies the integration of technical precision with economic considerations to achieve sustainable infrastructure solutions. Its success stems from the stable water source, optimized distribution design, cost-effective pipe sizing, and the insights gained from hands-on experience and comprehensive data collection.

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References

[1] Ame, M. A., & Shouhua, C. (2021). Economic pipe diameter of laterals in small tube irrigation system. Alexandria Engineering Journal, 61, 5361–5370.

[2] Central Public Health and Environmental Engineering Organisation. (1999). Manual on water supply and treatment (3rd ed.). New Delhi: Ministry of Urban Development, Government of India.

[3] Davis, P., & Marlow, D. (2008). Quantifying economic lifetime for asset management of large-diameter pipelines. Journal AWWA, 100(7), 1-17.

[4] Gama, C. H. de A., Souza, V. C. B. de, & Callado, N. H. (2019). Analysis of methodologies for determination of the economic pipe diameter. Revista Brasileira de Recursos Hídricos, 24, e35.

[5] Gokyay, O. (2020). An easy MS Excel software to use for water distribution system design: A real case distribution network design solution. Journal of Applied Water Engineering and Research, 8(4), 290-297.

[6] India Water Resources Information System. (n.d.). Retrieved [07/16, 2024], from https://indiawris.gov.in/.

[7] Kalyoncu, E. (2019). A sampling about for economic pipe diameter calculation. International Journal of Engineering Technologies-IJET, 5(1), 31-37.

[8] Karnataka Water Resources. (n.d.). https://waterresources.karnataka.gov.in/.

[9] KBJNL Karnataka. (n.d.). Retrieved [07/15, 2024], from https://kbjnl.karnataka.gov.in/.

[10] Khan, N. S., Alam, M. S., & Anees, F. (2021). Design of Haraulipur group of villages water supply scheme at Hamirpur District of Uttar Pradesh. International Journal of Advances in Engineering and Management (IJAEM), 3(8), 1643-1647.

[11] Lischer, V. C. (1948). Determination of economical pipe diameters in distribution systems. Journal (American Water Works Association), 40(8), 849-867.

[12] L. Zhang, C.Y. Li. "An Inexact Two-Stage Water Resources Allocation Model." Environmental Earth Sciences, vol. 77, no. 13, 2018, pp. 1-20.9.

[13] Megha Engineering and Infrastructures Limited. (n.d.). Drawing of intake levels for Jackwell and intake wells [Structural Design of Intake well Document]. Retrieved during internship.

[14] Mehta, D., Yadav, V., Waikhom, S. I., & Prajapati, K. (2017). Design of optimal water distribution systems using WATERGEMS: A case study of Surat City. In E-proceedings of the 37th IAHR World Congress (pp. 1-7). Kuala Lumpur, Malaysia.

[15] Ministry of Jal Shakti. (n.d.). Jal Jeevan Mission. Government of India. https://ejalshakti.gov.in/JJM.

[16] Pope, J., Annandale, D., & Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. Environmental Impact Assessment Review, 24(6), 595-616.

[17] US Geological Survey. (n.d.). EarthExplorer. Retrieved [07/13, 2024], from https://earthexplorer.usgs.gov/.

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