

Per-Capita Demand Forecasting for a Community Pilot Water Scheme in Bayelsa State, Nigeria

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ABSTRACT

Community pilot water schemes are often evaluated on whether they are working at the present time, with much less attention paid to whether their design capacity can meet the population they are intended to serve. The study evaluated a pilot water scheme (60 connections: 50 households and 10 public facilities) in Opolo, Yenagoa, Bayelsa State and used a geometric population-growth and per-capita demand forecasting model to test its adequacy over a ten-year period. Data were collected using a structured survey of 120 residents and scheme output records from the institutions. The forecasting model was based on the standard procedure in water-supply engineering of combining a geometric population projection with a per-capita design demand benchmark. Found to provide about 11.8 litres per capita per day to its served households, below the WHO 20 L/capita/day minimum threshold for basic water access. Applying the geometric growth model at 3, 5 and 7% per annum – rates consistent with population growth commonly reported by surveyed residents – it was shown that the volume required to sustain even the WHO basic-access minimum already exceeds the scheme's fixed 100 m³/month supply capacity in the base year, with the deficit projected to increase to 89 and 178 m³/month by 2034. The Opolo pilot scheme is too small for the current population prior to any growth adjustments, with capacity expansion and not incremental extension of the existing system underpinning its transition from pilot to permanent infrastructure, results indicate.

KEYWORDS

water demand forecasting; per-capita supply; population projection; pilot water scheme; Niger Delta; environmental engineering

I. INTRODUCTION

A pilot water scheme is, by definition, a small-scale, time-bound test of a water management approach, and its evidentiary purpose is only served if the pilot's data are analysed against a recognised design standard, rather than reported as a bare production figure. Population-projection techniques such as arithmetic, geometric and incremental-increase methods have long been employed in water-supply engineering to translate current service levels into a design-horizon capacity requirement (Twort, Ratnayaka & Brandt, 2000). The World Health Organization has set quantitative service-level benchmarks that convert consumption figures into an assessment of whether a water source or scheme is meeting basic human needs (Howard & Bartram, 2003). (House-Peters & Chang, 2011; Donkor et al., 2014; Sebi, 2016)

The two tools – population projection and a per-capita service level benchmark – are rarely used together in pilot schemes in Nigerian communities, most of which rely on household perception surveys alone for evaluation. This leaves an open question for schemes like the one piloted in Opolo, Yenagoa, whether the scheme's current output is adequate for its present population and if so, for how long will that remain true. This is a substantially different question from whether residents are satisfied with the scheme and one that only a quantitative demand-forecasting exercise can answer. (Donkor et al., 2014; Sebri, 2016)

This is a significant response in this particular context, as water infrastructure decisions in the Niger Delta are directly interacting with water quality outcomes already observed in the region: treatment plants serving the neighbouring Otuoke–Yenagoa corridor have been found to still show elevated metal concentrations at various treatment stages (Ogunlowo & Sakwe, 2023) and nearby surface water bodies already carry contaminant loads of concern for domestic use (Ogunlowo, 2024). The smaller the system is compared to the population; the more likely people are to be pushed into these compromised alternatives. The study therefore aimed at estimating the current per capita output of the Opolo pilot scheme in relation to WHO benchmarks and projecting the volume of output the scheme would be required to supply over a ten-year time horizon using a standard geometric population-growth model.

II. MATERIALS AND METHODS

A. Study Area

The research took place in the Opolo area of Yenagoa, which is the capital of Bayelsa State in Nigeria and is situated at a latitude of approximately 4°55'29"N and a longitude of 6°15'51"E in the Niger Delta. Because of continuous in-migration and residential expansion, the region is now placing greater pressure on its current water supply facilities.

B. Data Collection

The study used a mixed-methods approach which combined quantitative data on scheme output with a structured questionnaire survey involving 120 residents, selected from among traditional rulers, local government officials, community leaders and members of the community. Before the questionnaire was administered, it was checked and validated by the project supervisor. The scheme output data—namely the total amount of water produced each month and the number of households and facilities that were served—were obtained from the records kept by the pilot scheme.

C. The Engineering Model: Forecasting Geometric Population Growth and Per-Capita

Demand The forecasting model used in this instance adheres to the conventional two-step approach recommended in water-supply engineering (Twort et al., 2000). (Donkor et al., 2014; Xenochristou et al., 2020). The first step involves projecting the population served by the scheme using the geometric increase method:

$$P_t = P_0 (1 + r)^t$$

The projected population for year t is denoted by P_t , the currently served population by P_0 , the assumed annual growth rate by r , and t represents the number of years into the future. Secondly, the projected population is transformed into a required supply volume by means of a per-capita design standard:

$$V_t = P_t \times q \times 30$$

The monthly required supply volume, denoted by V_t , is calculated by multiplying the design per-capita consumption rate, q (measured in litres per capita per day), by 30, since this factor converts a daily consumption rate into a monthly volume. In this study, q was taken as 20 L/capita/day, which is the minimum threshold for basic access as established by the World Health Organization, since below this level there is a substantial increase in health risks associated with insufficient water for hygiene (Howard & Bartram, 2003), and this value of q was used as the benchmark against which the fixed supply capacity of the scheme was assessed. As the operating records of the scheme gave only a one-year baseline rather than a multi-year series of population data, P_0 was estimated from the 50 households that were served by using the urban average household size of 4.7 persons reported for Nigeria (National Population Commission [NPC] & ORC Macro, 2004), resulting in a value of P_0 equal to 235 persons, and the growth-rate sensitivity analysis was carried out at rates of 3%, 5% and 7% per annum, a figure that is in line with the population growth trend itself as reported by the survey respondents (60% of the respondents indicated that there had been significant population growth in Opolo over the previous five years). A summary of the model parameters is given in Table 1 (Williamson et al., 2002; Makki et al., 2015)

Parameter	Value	Basis
Present served population (P_0)	235 persons (50 households $\times$ 4.7 persons/household)	NDHS urban household-size average (NPC & ORC Macro, 2004)
WHO basic-access design standard	20 L/capita/day	Howard & Bartram (2003)
WHO intermediate-access standard	50 L/capita/day	Howard & Bartram (2003)
Measured pilot-scheme per-capita supply	≈ 11.8 L/capita/day	Derived from Table 1 (this study)
Current fixed supply capacity	100,000 L/month (100 m ³ /month)	Reported total monthly output (this study)

Recent water-demand forecasting research confirms that model selection should reflect the forecasting horizon, temporal resolution, spatial aggregation and available explanatory variables. Reviews show that long-term planning commonly uses econometric, scenario-based or population-linked approaches, while short-term operational forecasting increasingly uses time-series and machine-learning methods. At household and small spatial scales, historical consumption and household characteristics can be particularly important predictors (Donkor et al., 2014; Sebri, 2016; Xenochristou et al., 2020). These findings support the present study's use of a transparent population-growth/per-capita model for a ten-year pilot-scheme capacity assessment, while also identifying more data-intensive forecasting methods as suitable for future operational refinement.

III. RESULTS AND DISCUSSION

A. Present Per-Capita Supply against WHO Service-Level Benchmarks

The pilot scheme's operational records deliver the total number of liters produced per month, namely, 100 000 litres for 60 connections, 50 residential and 10 public institutions. On average, each connection produces 1666.67 litres per month. By multiplying the percentage of the household connections by this number and dividing it by the estimated number of people who benefit from the scheme, 235, one can obtain 11.8 litres per person per day, which is approximately 0.65 litres per hour. Figure 1 below demonstrates the comparison between the per capita supply rate and the WHO benchmark for basic and intermediate access levels.

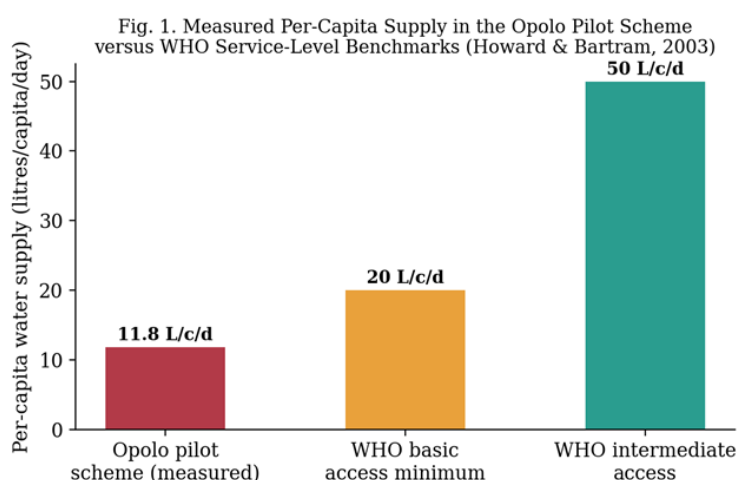


Figure 1. Measured per-capita supply in the Opolo pilot scheme versus WHO service-level benchmarks (Howard & Bartram, 2003).

At an estimated 11.8 L/capita/day, the Opolo pilot scheme is unable to meet even the most basic of the WHO's criteria for essential water access, which stands at 20 L/capita/day, providing only 59% of that life-sustaining threshold. The scheme compares even less favourably to the organisation's secondary criterion of 50 L/capita/day for intermediate access, as it only manages to deliver under a quarter of that amount. With these findings, the survey result, which in its turn corroborates the initial assessment, gains new credibility, as expressed by the 75% of the respondents that indicated experiencing water scarcity and the 36.7% reporting having access to a safe water source at their household. Essentially, the finding processes the basic water access level of the scheme to be inadequate according to a reputable international standard, which in turn can motivate the prioritisation of its improvement over other matters, including the consideration of population growth. (Bennett et al., 2013; Makki et al., 2015)

B. Population Projections of Geometric Growth

Table 2 and Figure 2 below reflect the 10-year projection of the population growth of the 50 households served by the water supply scheme under review, which will influence the water demand in the area for the foreseeable future. (Donkor et al., 2014; Sebri, 2016)

Year	3%/yr (persons)	5%/yr (persons)	7%/yr (persons)
2024	235	235	235
2027	257	272	288
2030	281	314	350
2034	316	383	462

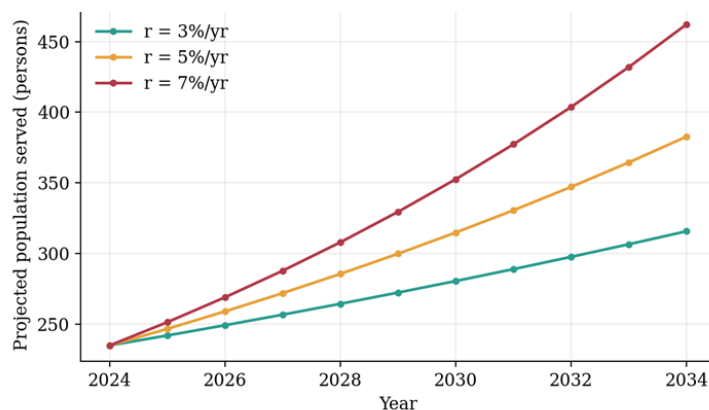


Figure 2. Geometric population-growth projection for the Opolo pilot scheme's 50 served households (after Twort et al., 2000).

C. Projected Supply Requirement versus Fixed Scheme Capacity

Using the population data found in Table 2 and the WHO's basic-access design standard 20L/capita/day, we obtain the curve of the volumetric water demand and the scheme's constant supply capacity equal to 100 m³/month (Figure 3). (Donkor et al., 2014; Xenochristou et al., 2020)

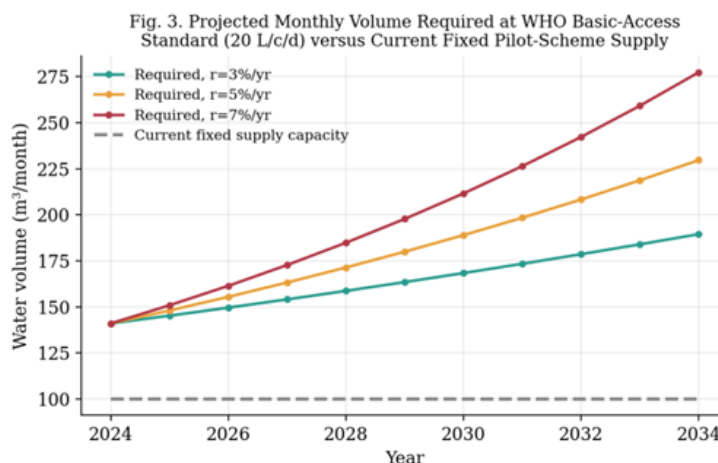


Figure 3. Projected monthly volume required at the WHO basic-access standard (20 L/capita/day) versus the current fixed pilot-scheme supply capacity.

The most telling finding from the model is that the volume needed to meet even the most basic needs (according to the WHO) for the scheme's current population - roughly 141 m³ per month - already exceeds the 100 m³ /month in the scheme's fixed capacity for the 2024 base year, regardless of growth considerations. This finding confirms, from the perspective of the scheme's capacity, the shortfall identified from the demand-side analysis in Section 3.1: the scheme is currently undersized for the population it serves, not just

potentially at risk of being undersized in the future. Under the growth scenarios described, this shortfall would widen from roughly 41 m³/month in 2024 to between 89 m³/month (3%/year) and 178 m³/month (7%/year) in 2034. (Mu et al., 2020; Bata et al., 2020)

The fixed-capacity finding also has an important forecasting implication. Forecast accuracy and usefulness depend on the spatial and temporal scale of the decision being supported; advanced short-term models can outperform simpler approaches when high-frequency demand data are available, but their applicability requires substantially richer datasets than the one-year scheme record available in this study (Bennett et al., 2013; Mu et al., 2020; Bata et al., 2020). Thus, the geometric population-growth model is appropriate here as a transparent strategic screening tool rather than as a substitute for future high-resolution operational forecasting.

This, then, is where the analysis has implications for the pilot and its intended role within the local community. A pilot scheme, by definition, is designed to inform the specifications of a larger permanent scheme (Kar & Chowdhury, 2015); as such, the findings suggest that the Opolo pilot should not be scaled up, at least not in its current configuration, since doing so would fail to address the community's water needs for the foreseeable future. The implied recommendation is that any transition from the current pilot setup to a permanent scheme should consider expanding capacity in accordance with the demand envelope identified in Figure 3 rather than relying on the 100 m³/month as a proxy for the service the permanent scheme should provide. Left unaddressed, the identified capacity-shortfall trajectory could also see an impact on environmental quality, specifically in the case of Opolo: if residents are unable to obtain the water they need from the pilot scheme, there may be a secondary effect of them seeking alternative sources of water, which for the Opolo region would likely entail surface water or groundwater, both of which have been identified as being at risk of contamination (Ogunlowo & Sakwe, 2023; Ogunlowo, 2024). (Donkor et al., 2014; Sebri, 2016)

IV. CONCLUSION

An application of a geometric population-growth-based and per-capita demand forecasting model to the Opolo pilot water scheme indicated that the scheme currently provided for the needs of its served households at a rate of just under 12 LPCD, far below the 20 LPCD recommended by the WHO for basic access, and that the volume needed to meet even that minimal standard for the population already exceeded the scheme's 100 m³/month capacity for 2024, before factoring in population growth. Under the 3–7% annual growth scenarios also identified as relevant for the population, the volume shortfall would increase significantly over a 10-year outlook. The analysis recommended that consideration for scaling the pilot into a permanent community water supply scheme be informed by the forecasted demand-envelope trajectory rather than the current capacity of the pilot scheme, with specific consideration given to the population growth the community was already projected to experience.

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