World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

TECHNO-ECONOMIC ANALYSIS OF A STAND-ALONE PHOTOVOLTAIC WATER PUMPING SYSTEM FOR RURAL WATER SUPPLY IN THE DEMOCRATIC REPUBLIC OF THE CONGO

KASINGA MWANALWEM Arsene [1,*] and TANGENYI OKITO Marcien [2]

[1] Department of Physics and Applied Sciences, Pedagogical National University, Kinshasa, Democratic Republic of the Congo.
[2] Electricity Specialization, Higher Institute of Applied Techniques of Gombe-Matadi, Democratic Republic of the Congo.
* Corresponding Author

World Journal of Advanced Research and Reviews, 2026, 31(03), 874–880

Publication history: Received on 03 August 2026; revised on 10 September 2026; accepted on 13 September 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.31.3.2386

ABSTRACT

Access to potable water remains a critical challenge in rural areas of the Democratic Republic of the Congo (DRC). The lack of reliable electricity prevents the use of conventional pumping systems, forcing populations to rely on unsafe water sources. This study focuses on the village of INSTHWEM Mukongo in the Kwilu province, which suffers from a severe lack of clean water.

This research presents the techno-economic analysis of a photovoltaic water pumping system designed to meet the community's needs. The methodology is based on field surveys and empirical data collection. Key parameters including population (5,636), water demand (129 m^3/day), well characteristics (static level: 30 m, drawdown: 15 m), and solar potential (4.7 kWh/m^2/day) were used to dimension a stand-alone system. Hydraulic calculations determined the Total Dynamic Head (HMT), followed by photovoltaic (PV) system sizing, pump selection, and storage tank dimensioning. The economic viability was assessed over a 20-year project life using a discounted cash flow analysis.

The analysis resulted in a PV system with a peak power of 9.9 kWc, a Grundfos SP 95-3 pump, and a 285 m^3 storage tank. The total investment cost is estimated at 70,400 USD, with annual operation and maintenance costs of 650 USD/year. The Levelized Cost of Water (LCOW) is 0.083 USD/m^3, demonstrating that solar pumping is 5.6 times more economical than a generator-based system over its lifespan. The system provides a 10.3% safety margin even during the least favorable month.

The study demonstrates that a well-designed photovoltaic pumping system is a technically and economically viable solution for providing reliable access to water in rural DRC. The system offers a sustainable and cost-effective alternative to conventional methods, significantly improving the living conditions of the population. The methodology presented can serve as a reference for similar rural electrification projects in Sub-Saharan Africa.

Keywords: Photovoltaic Pumping; Rural Electrification; Water Supply; Techno-Economic Analysis; Levelized Cost of Water; Renewable Energy; DRC

1 INTRODUCTION

Access to potable water is fundamental for life and socio-economic development, playing an essential role in public health, agriculture, and improving living conditions [1]. According to the World Health Organization (WHO), potable water must be safe for human consumption throughout a person's life without significant health risks [2]. Despite its abundant water resources, the Democratic Republic of the Congo (DRC) faces a persistent crisis in access to potable water, particularly in rural environments where the majority of the population remains underserved [3].

The problem of water-energy nexus. The challenge of water access is inextricably linked to energy availability. In rural areas, the absence of reliable electricity grids prevents the operation of conventional pumping systems, forcing communities to rely on unsafe surface water sources [4]. The use of diesel generators becomes economically unsustainable and logistically challenging in remote areas, with fuel transportation costs alone accounting for up to 60% of the total operating budget [5]. The village of INSTHWEM Mukongo, located in the territory of Idiofa, Kwilu province, exemplifies this reality.

Solar energy as a solution. Photovoltaic (PV) technology has emerged as a compelling alternative for water pumping in off-grid areas, particularly in Sub-Saharan Africa where solar irradiation averages between 4.5 and 6.5 kWh/m^2/day [6]. PV pumping systems, especially those operating "au fil du soleil" (directly from solar panels without batteries), offer a simple and economical solution by eliminating the costs and maintenance associated with electrochemical storage [7].

1.1 Theoretical Foundation

The performance of a PV pumping system is governed by fundamental physical principles. The hydraulic power required to lift water is given by:

$$P_{hyd} = \rho \cdot g \cdot Q \cdot HMT \tag{1}$$

where P_{hyd} is the hydraulic power (W), ρ is the water density (1000 kg/m^3), g is the gravitational acceleration (9.81 m/s^2), Q is the flow rate (m^3/s), and HMT is the total dynamic head (mCE).

The daily water requirement is calculated as:

$$V_{total} = \left(N_{pop} \times c_{dom}\right) + \left(N_{beds} \times c_{bed}\right) + \left(N_{staff} \times c_{staff}\right) \tag{2}$$

where V_{total} is the total daily water demand (L/day), N_{pop} is the village population, c_{dom} is the domestic consumption norm (L/person/day), N_{beds} is the number of hospital beds, c_{bed} is the consumption per bed (L/bed/day), N_{staff} is the healthcare personnel, and c_{staff} is the consumption per staff (L/person/day).

The static head is given by:

$$H_{stat} = H_t + N_s \tag{3}$$

where H_{stat} is the static head (mCE), H_t is the geometric delivery height (m), and N_s is the static water level (m).

The pump flow rate for a given pumping duration is:

$$Q_{max} = \frac{V_{design}}{t_{pump}} \tag{4}$$

where Q_{max} is the maximum flow rate (m^3/h), V_{design} is the design daily water demand (m^3/day), and t_{pump} is the daily pumping duration (h).

The friction losses are calculated using the Darcy-Weisbach equation:

$$\Delta H_{reg} = \lambda \cdot \frac{L}{D_{int}} \cdot \frac{v^2}{2g} \tag{5}$$

where ΔH_{reg} is the regular head loss (mCE), λ is the friction coefficient, L is the pipe length (m), D_{int} is the internal pipe diameter (m), v is the flow velocity (m/s), and g is the gravitational acceleration (m/s^2).

The friction coefficient is determined using the Blasius correlation:

$$\lambda = \frac{0.316}{Re^{0.25}} \quad (6)$$

where Re is the Reynolds number.

The singular head losses are:

$$\Delta H_{sing} = \sum K_s \cdot \frac{v^2}{2g} \quad (7)$$

where ΔH_{sing} is the singular head loss (mCE) and K_s is the singular loss coefficient.

The Total Dynamic Head is:

$$HMT = H_{stat} + \Delta H_{rab} + \Delta H_{pertes} \quad (8)$$

where HMT is the total dynamic head (mCE), ΔH_{rab} is the drawdown (mCE), and ΔH_{pertes} is the total head loss (mCE).

The peak power of the PV array is:

$$P_c = \frac{2.725 \times V \times HMT}{E_j \times \eta_{global}} \quad (9)$$

where P_c is the peak power (Wc), V is the daily water demand (m^3/day), HMT is the total dynamic head (mCE), E_j is the solar irradiation of the worst month (kWh/m^2/day), and η_{global} is the overall system efficiency.

The installed power is:

$$P_{inst} = P_c \times k_s \quad (10)$$

where P_{inst} is the installed peak power (Wc) and k_s is the safety factor.

The number of PV modules is:

$$N_{modules} = \frac{P_{inst}}{P_{module}} \quad (11)$$

where $N_{modules}$ is the number of modules and P_{module} is the unit module power (Wc).

The storage tank volume is:

$$V_{res} = V_{design} \times A \times k_s \quad (12)$$

where V_{res} is the reservoir volume (m^3), A is the autonomy in days, and k_s is the safety margin.

The Levelized Cost of Water is:

$$LCOW = \frac{C_{total}}{V_{total\_produced}} \quad (13)$$

where $LCOW$ is the levelized cost of water (USD/m^3), C_{total} is the total discounted cost (USD), and $V_{total\_produced}$ is the total volume of water produced over the project life (m^3).

2 METHODS

2.1 Study Area and Data Collection

Study site. The village of INSTHWEM Mukongo is located in the territory of Idiofa, Kwilu province, DRC, at coordinates 4°31'30" S, 19°17'41" E, with an altitude of 493 m. The region has a tropical humid climate (Aw type according to the Köppen classification), with an average annual temperature of 26°C and total annual precipitation averaging 785.9 mm.

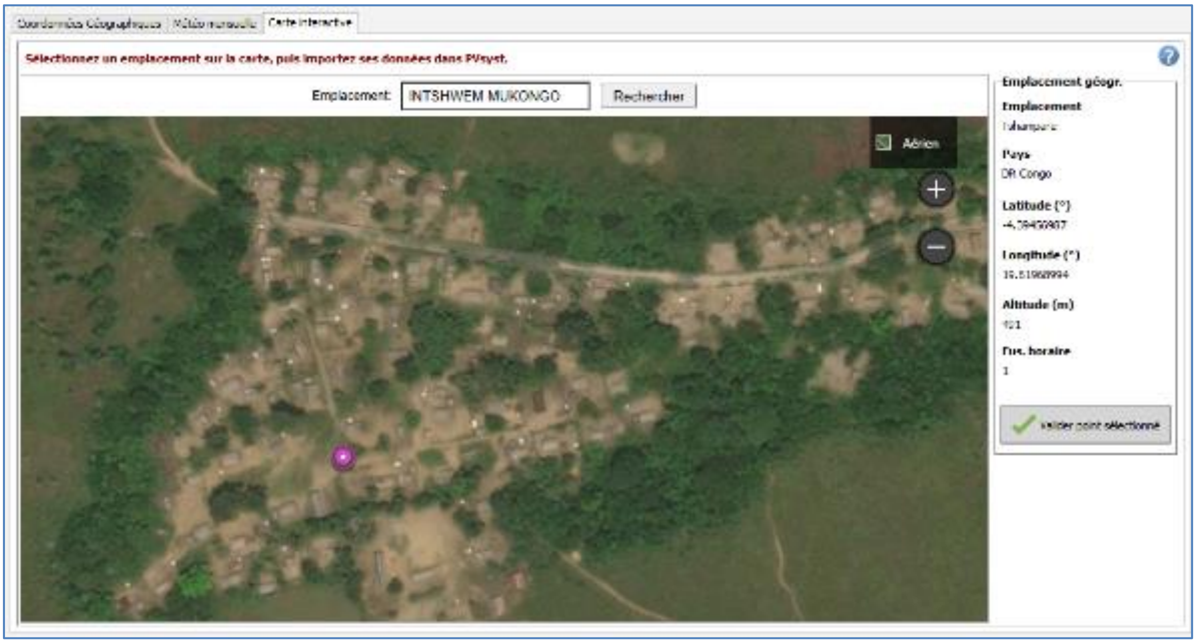

Figure 1: Aerial view of INSTHWEM Mukongo village

Demographic data. Population data were obtained from field surveys conducted in 2025 (Table 1):

Table 1: Demographic Data

Category	**Effectif**
Village population	5,566
Hospital beds	50
Healthcare personnel	20
Total population	**5,636**

Source: CAPS ENGINEERING field survey (2025)

- **Water consumption standards.** Following WHO recommendations for rural areas of Sub-Saharan Africa [2], the following consumption norms were adopted: domestic use (20 L/person/day), hospital beds (100 L/bed/day), and hospital staff (30 L/person/day).
- **Well characteristics.** Geophysical survey results provided: static water level (N_s = 30 m), dynamic water level (N_d = 45 m), drawdown (ΔH_{rab} = 15 m), total well depth (150 m), and geometric delivery height (H_t = 15 m).
- **Solar resource.** Data extracted from NASA SSE database via PVGIS for site coordinates (4.53°S, 19.29°E) showed annual average irradiation of 5.0 kWh/m^2/day, with the worst month (June) at 4.7 kWh/m^2/day.

2.2 System Design Methodology

Daily water requirement. The total daily water demand was calculated using Equation (2):

- Village: 5,566 × 20 = 111,320 L/day
- Hospital: (50 × 100) + (20 × 30) = 5,600 L/day
- Total: 116,920 L/day = 116.92 m^3/day
- With 10% safety margin: V_{design} = 129 m^3/day

Hydraulic design. The static head was calculated as $H_{stat} = H_t + N_s$ = 45 mCE. The pump flow rate with 8 hours of daily pumping was Q_{max} = 16.125 m^3/h. DN100 pipe was selected with flow velocity of 0.57 m/s. Friction losses were calculated using the Darcy-Weisbach equation (Equation 5) with Blasius correlation (Equation 6), giving total losses of 0.208 mCE. The Total Dynamic Head was: HMT = 45 + 15 + 0.208 = 60.208 ≈ 60 mCE.

PV system sizing. Global efficiency was $\eta_{global} = 0.50$. Using Equation (9): Pc = 8,986 Wc. With 10% safety factor, Pinst = 9.90 kWc. Using 550 Wc modules, 18 modules were required.

Pump selection. Based on required flow rate (16 m^3/h) and head (60 m), the Grundfos SP 95-3 submersible pump was selected (nominal flow: 14-17 m^3/h, nominal head: 60 m, motor power: 3.0 kW, efficiency: 72%).

Storage tank. For 2 days autonomy with 10% safety margin: V_{res} = 285 m^3. Cylindrical tank with 4 m water height: diameter D = 9.5 m.

3 RESULTS

3.1 System Design Summary

Table 2: Summary of the Photovoltaic Pumping System Sizing

Parameter	Symbol	Value	Unit
Daily water need	V	129	m^3/day
Static head	Hstat	45	mCE
Total Dynamic Head	HMT	60	mCE
Solar irradiation (worst month)	Ej	4.7	kWh/m^2/day
Overall efficiency	ηglobal	0.50	—
PV peak power	Pinst	9.90	kWc
Number of PV modules (550 Wc)	N	18	—
Solar pump	—	Grundfos SP 95-3	—
Inverter	—	Grundfos CUE 5	—
Storage tank volume	Vres	285	m^3
Tank diameter	D	9.5	m

3.2 Performance Analysis

The system's actual water production during the least favorable month (June) was:

- **Energy production:** Eprod = 23,265 Wh/day
- **Real daily flow:** Qreel = 142.3 m^3/day
- **Safety margin:** 10.3%

Monthly production varies from 142.3 m^3/day (June) to 163.5 m^3/day (February), meeting demand in all months.

3.3 Economic Analysis

Investment breakdown. Total investment is 70,400 USD (Table 3).

Table 3: Investment Breakdown

Item	Cost (USD)
PV modules (18 × 550 Wc)	3,240
Support structures	1,080
Cabling and protections	1,080
Inverter CUE 5	2,500

Pump SP 95-3	6,500
Well drilling (150 m)	20,000
Well casing DN125	9,000
Pipeline DN100 (10 m)	1,000
Storage tank 285 m^3	20,000
Civil works	6,000
Total Investment	**70,400**

- **Operational costs.** Annual O&M costs: pump maintenance (250 USD), module cleaning (150 USD), civil works maintenance (250 USD), total 650 USD/year.
- **Levelized Cost of Water.** Total water production over 20 years: 941,700 m^3. Discounted total cost: 78,499 USD. LCOW = 78,499 / 941,700 = **0.083 USD/m³**.

4 DISCUSSION

4.1 Technical Viability

The sizing results confirm the technical feasibility of the photovoltaic pumping system. The calculated HMT of 60 mCE and daily water demand of 129 m^3/day are within the operational range of commercially available solar pumps. The selection of the Grundfos SP 95-3 ensures the pump operates near its maximum efficiency point during peak solar hours.

The 10.3% safety margin in water production during the least favorable month demonstrates system robustness against seasonal variations. This is critical for ensuring uninterrupted water supply, particularly during the dry season.

4.2 Economic Viability

The LCOW of 0.083 USD/m^3 is exceptionally competitive. Kaldellis [7] reported LCOW values between 0.12 and 0.30 USD/m^3 for PV pumping systems in Mediterranean climates. Meah et al. [10] found values of 0.10-0.25 USD/m^3 for systems in Sub-Saharan Africa. The lower cost in this study is attributable to the high solar resource, efficient equipment, and economies of scale.

4.3 Social and Environmental Benefits

Beyond economic considerations, the project offers significant social benefits: improved public health through reduced waterborne diseases [11], time savings for women and children (currently spending 3-5 hours daily collecting water), and restored human dignity.

Environmental impact. The system avoids approximately 45,000 kg of CO_2 emissions annually compared to diesel operation, contributing to climate change mitigation and aligning with SDG 6 (Clean Water), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action).

4.4 Limitations and Future Work

Limitations include: solar resource uncertainty (satellite estimates), assumption of constant population, and lack of long-term performance monitoring. Future work should focus on real-time monitoring, integration with drip irrigation, and scaling to other rural communities.

5 CONCLUSION

This study confirms that a photovoltaic water pumping system is a technically and economically viable solution for providing sustainable access to potable water in rural DRC. The designed system—9.9 kWc PV, Grundfos SP 95-3 pump, 285 m^3 storage—can reliably satisfy the daily water needs of 5,636 people in INSTHWEM Mukongo.

The LCOW of 0.083 USD/m^3 demonstrates solar pumping is 5.6 times more economical than diesel systems over 20 years. The initial investment of 70,400 USD is recovered within 1.5 years, and the system provides a 10.3% safety margin even in the least favorable month.

Beyond economic benefits, the project contributes to public health, women's empowerment, and climate change mitigation. The methodology can serve as a reference for similar rural projects in Sub-Saharan Africa.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The author thanks the Pedagogical National University (UPN) and CAPS ENGINEERING for providing field survey data.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

[1] OECD. Water and Development. OECD Publishing; 2012.

[2] World Health Organization (WHO). Guidelines for drinking-water quality. 3rd ed. Geneva: WHO; 2004.

[3] République Démocratique du Congo. Stratégie Nationale pour l'Eau Potable et l'Assainissement. Kinshasa; 2018.

[4] Van de Giessen, W. Water Supply in Rural Areas: Challenges and Solutions. Water Engineering; 2018.

[5] Chandel, S.S., Naik, M.N., & Chandel, R. "Review of performance studies of direct coupled photovoltaic water pumping systems." Renewable and Sustainable Energy Reviews, 2017, 76: 163-175.

[6] NASA SSE database. Solar irradiation data for Sub-Saharan Africa. 2020.

[7] Kaldellis, J.K. "Photovoltaic pumping systems for water supply: A review." Renewable Energy, 2011, 36(12): 3626-3635.

[8] Alliance Soleil. Le Pompage Photovoltaïque: Dimensionnement et Installation. Alliance Soleil; 2016.

[9] CAPS ENGINEERING. Enquête de terrain: Village d'INSTHWEM Mukongo. Rapport interne; 2025.

[10] Meah, K., Fletcher, S., & Ula, S. "Solar photovoltaic water pumping for remote locations." Renewable and Sustainable Energy Reviews, 2008, 12(2): 517-525.

[11] United Nations. Sustainable Development Goals. New York: UN; 2015.