

Energy Efficiency Analysis and Performance Improvement under Real Operating Conditions in Ilorin Kwara State, Nigeria

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Abstract –The performance of Asa and Agba dam waterworks in Kwara State, Nigeria was carried out using flow rate (m^3/hr), power consumption (kW) and efficiency of the pumps (%). Daily flow rate of low and high lift pumps were obtained from log book of the Asa dam pump operators from 2011 to 2015 while the monthly electrical power consumption was retrieved from the archive of the Power Holdings Company of Nigeria (PHCN) in Ilorin, Nigeria. The data were analyzed using statistical parameters in the Microsoft Excel to determine measures of central tendency such as monthly minimum, maximum, mean and standard deviation. Analysis of Variance (ANOVA) was used to test for statistically significant in the interaction between the flow rate, power consumption and the efficiency of the pumps. Results revealed that maximum efficiency of the pump varies between 35.5 % in 2011 to 20.4% in 2015. Comparison between pump efficiencies and design specification of 75-90 %, implies that the pump is performing below its design specification. The ANOVA results indicate that there is statistically significant interaction between the flow rate, power input and the efficiency of the pumps. It can be concluded that there is need to upgrade and replace the damage pump parts for its optimum performance.

Keywords: Energy, Asa, Efficiency, Pump, Waterworks.

Received: 05/10/2025 – Revised: 26/11/2025 – Accepted: 14/12/2025

I. Introduction

Pumps are widely used in transporting fluids from one location to another, especially from lower elevation to higher one. Pumping systems account for about 25% of the world's electrical energy demand, which varies between 30 to 55% of the electrical energy requirement in some industrial areas [1, 2]. In waterworks, pumps require electrical energy which is very significant in water distribution systems [3, 4]. Electrical energy applied in water distribution systems plays a vital role in global water consumption. The energy consumption as a result of water pumping represents a very high percentage of the total energy costs in water supply scheme [5-8]. Approximately less than 4% of the global electrical energy consumption is utilized in pumping

water, while about 85% of it, is applied to motor-pump [9-12].

Studies have been conducted on optimum pumping schedule, taking into considerations the fact that cost of electrical energy can be minimized through its consumption during off-peak periods. Therefore, a fraction of the electrical energy that is utilized by pump is related to ineffective operation of pump. Performance of pump also reduces after its prolonged usage [13-16]. In many water pumps, wear takes place immediately after the commencement of operation; its performance reduces after the first ten years. The gross reduction in the efficiency of an inappropriately maintained pump can be less than 10% in the initial 5 years of operation



and up to 20% in next 5 years [17,18]. UK Department of Environment highlighted that fractions of the reduction in efficiency is as a result of wearing of the impeller/casing rings. Ormsbee and Reddy [19] applied an optimization algorithm to reduce the operational costs of drinking water in Washington D.C. the results revealed a significant difference in the management implementation provided by the model. A reduction of 6.9% was observed in electric energy cost. The degradation rate is much higher in pumps that are operating below the best-efficiency level due to increased shaft deflection. Reduction in efficiency is usually resulted from accumulation of corrosion materials in cast iron casings. This takes place in most pumps that are applied in pumping clean water. Regular maintenance of pumps will improve its efficiency. Inefficiencies of pumps have a serious economic impact on water utilities operating cost due to surge electric energy consumption [20-22].

In this context, the present study aims to evaluate the energy efficiency and operational performance of pumping systems at the Asa and Agba dam waterworks in Ilorin, Kwara State, Nigeria, under real operating conditions. The analysis is based on long-term operational data collected over a five-year period (2011–2015), including pump flow rates, electrical power consumption, and efficiency. Unlike conventional studies that rely on design parameters or short-term measurements, the novelty of this work lies in the use of actual historical field data combined with statistical analysis to quantify performance degradation and efficiency losses over time. Furthermore, the study employs Analysis of Variance (ANOVA) to statistically assess the interaction between flow rate, power input, and pump efficiency, providing a deeper understanding of the factors influencing energy performance.

II. Methodology

The study area is Ilorin which is the capital of Kwara State, north central region, Nigeria. It is situated on Latitude 8°30' N and Longitude 4°35' E. The population of Ilorin as at 2006 census is 781,934 [23]. Ilorin has a tropical dry-wet climate; days are very hot in dry season from April to November with temperatures normally varies between 32°C to 38°C. Vegetation comprises of southern guinea savanna and the derived savanna [24]. Ilorin presently occupies an area of about 89 km² while the three main rivers that drain the city are: Asa, Moro and Oyun rivers, which serve as a predominant source of water to the city [25-28]. The drainage pattern of Ilorin is

dendritic. It occupies fairly large valley which divide the city into two: western and eastern part. Map of the study area is shown in Figure 1.

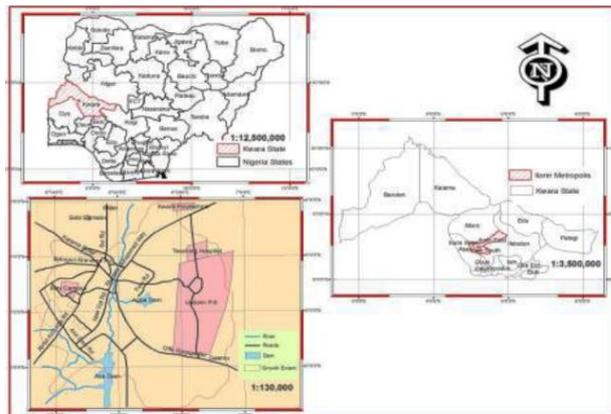


Figure 1. Nigeria map showing Kwara State and Ilorin City inset

Pumps details, specification and daily flow rate (m³/hr) for low and high lift pumps were obtained from the log book of the Asa and Agba dams pump operators from 2011 to 2015 while the monthly electrical power consumption were obtained from the Power Holding Company of Nigeria (PHCN).

The monthly variations of flow rate power consumption and pump efficiency were established for low and lift pumps respectively. Correlation coefficient and coefficient of determination were used to establish relationship between flow rate, power consumption and pump efficiency for low and high lift pumps respectively. Analysis of Variance (ANOVA) was used to test for statistically significant interaction between the flow rate, power input and the efficiency of the pumps. Characteristics of the pumps used at Asa and Agba dams are presented in Tables 1 and 2.

Table 1. Asa Dam Pump Characteristics

Low lift pump		High lift pump	
Pump type	Vertical turbine pump	Pump type	Horizontal turbine pump
No of pump	5	No available	6
Pump Head	37.03 m	Pump Head	142 m
Power input	200 kW	Power input	776 kW
Flow rate	1350 m ³ /hr	Flow rate	1650 m ³ /hr

Table 2: Agba Dam Pump Characteristics

Low lift Pump		High Lift Pump	
Pump type	Single impeller WEIR pump	Pump type	Double impellers ALSTOM pump
No of pump	1	No available	1
Pump Head	58 m	Pump Head	95 m
Power input	45 kW	Power input	110 kW
Flow rate	180 m ³ /hr	Flow rate	180 m ³ /hr

III. Results and discussion

3.1. Monthly flow variation

Figures 2 and 3 present the monthly variation of flow rate from 2011 to 2015. The monthly flow rate for the low and high lift pumps respectively revealed that there was decrease in flow rate across the year which varies between 0.11m³/h in November and December in 2015 to 0.19 m³/h in January in 2011 for the low lift pump. Also the flow rate for the high lift pump reduces from 0.336 to 0.271m³/h, this implies that pumps performance was reducing over the year.

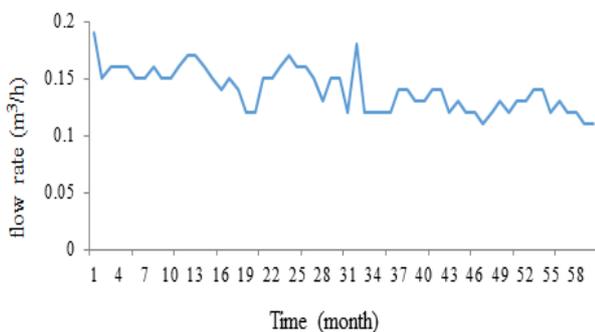


Figure2. Monthly Flow Rate for Low Lift Pump

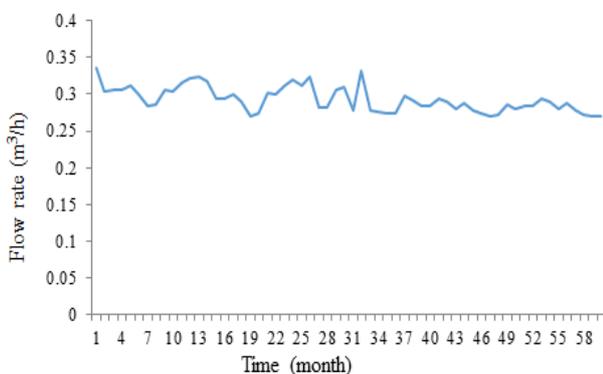


Figure 3. Monthly Flow Rate for High Lift Pump

3.2. Monthly power consumption variation

The power consumption for low and high lift pumps shown in Figures 4 and 5 reveal that the power consumption varies in relation to the quantity of water lifted by the low and high lift pump respectively. The power consumption ranges between 44.0 to 67.0 kW for low lift pump while high lift pump reduced from 468 to 376.5 kW. It was deduced that the performance operation of the pumps is reducing over the years.

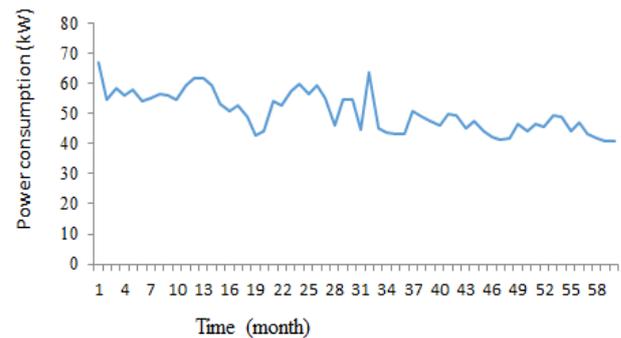


Figure 4. Monthly Power Consumption (kW) for Low Lift Pump

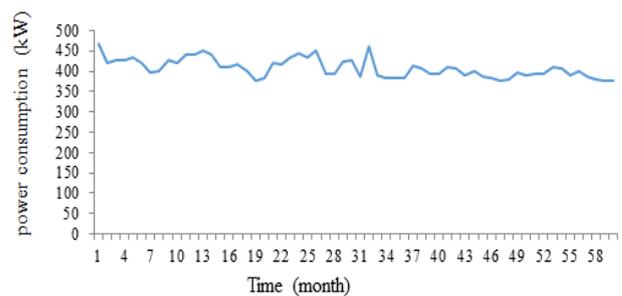


Figure 5. Monthly Power Consumption (kW) for High Lift Pump

3.3. Monthly pump efficiency variation

Monthly pump efficiency (%) for low and high lift pumps presented in Figure 6 indicates that the maximum efficiency is 35.5 % in 2011 while minimum is 20.4% in 2015 and the mean values ranging from 23.2 % to 28.3 %. Comparison between the results of low lift pump efficiencies and that of the design specification of 75 to 90%, this simply means that low lift pump is performing below the design specification. Figure 7 also shows monthly pump efficiency (%) for high lift pump from 2011 to 2015, the maximum value obtained are 60.32 % in 2011 while minimum value is 49.02 % in 2015 and the mean values ranging from 55.74 % to 50.02 % which is less than the design efficiency specification of 82%, for the high lift pump. This implies that the high lift pump is also performing below the specification. This may cause the erratic and low pressure water available to the final consumers in Ilorin metropolis [29].

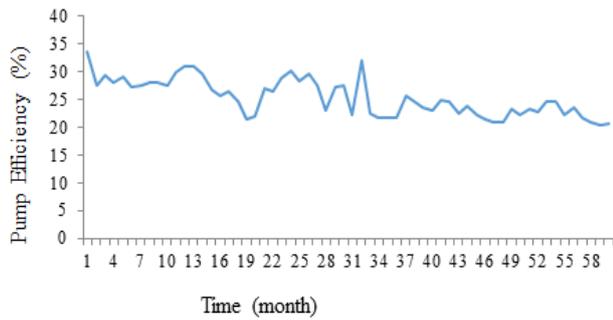


Figure 6. Monthly Pump Efficiency (%) for Low Lift Pump

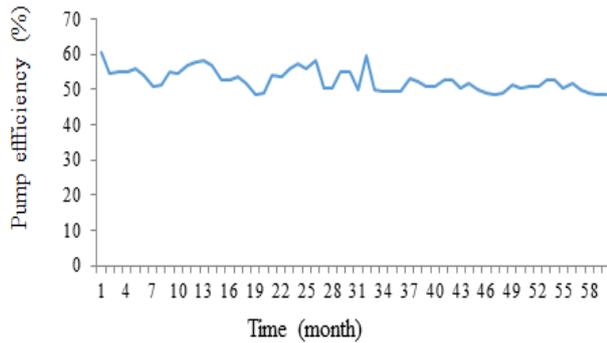


Figure 7. Monthly Pump Efficiency (%) for High Lift Pump

3.4. Relationship between efficiency and flow rate for low lift pump

Relationship between pump efficiency and flow rate for the low lift pump shown in Figure 8 reveals that the flow rate is linearly proportional to the efficiency with very strong determination coefficient (R^2) of 0.974. Therefore, as the flow rate of the pump increases the efficiency will also increase and vice versa. This implies that there is direct relationship between the pump efficiency and the flow rate.

Relationship between power output and flow rate for the low lift pump in Figure 9 shows that as the operational power of the pump also increases as flow rate increases with very strong R^2 of 0.972. This reveals a direct and very strong relationship between the pump efficiency and the flow rate.

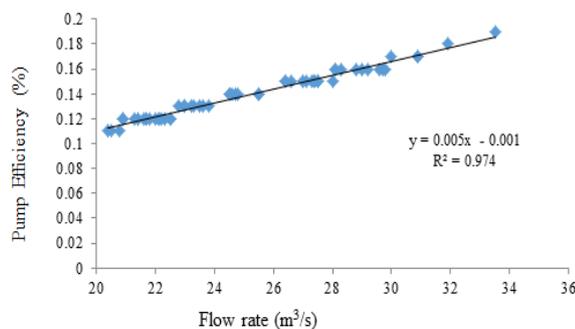


Figure 8. Relationship between Pump Efficiency and Flow Rate for Low Lift Pump

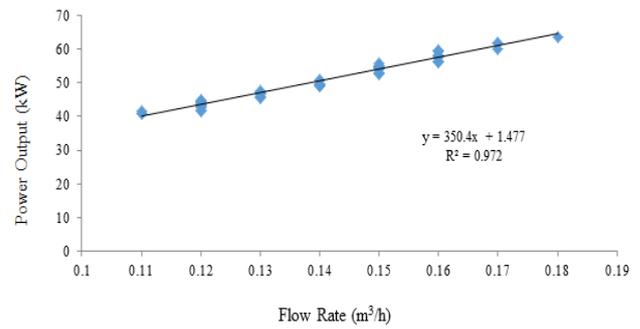


Figure 9. Relationship between Power Consumption and Flow Rate for Low Lift Pump

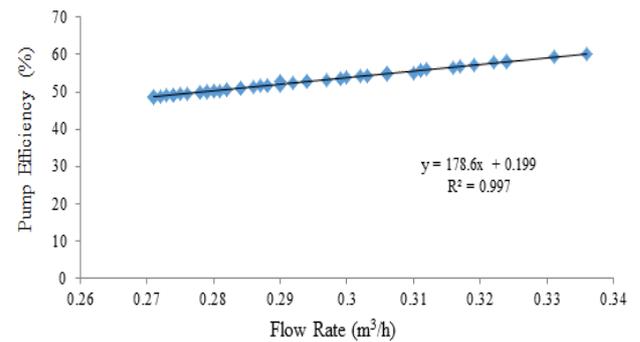


Figure 10. Relationship between Pump Efficiency and Flow Rate

3.5. Relationship between efficiency and flow rate for high lift pump

Similarly, Figure 11 shows relationship between the pump efficiency and flow rate for the high lift pump which shows the R^2 of 0.995. It implies that the high lift pump efficiency is strongly related to flow rate with R^2 of 0.995. That is, the flow rate is directly proportional to the efficiency of the pump. This was further corroborated with the correlation coefficient of 0.987.

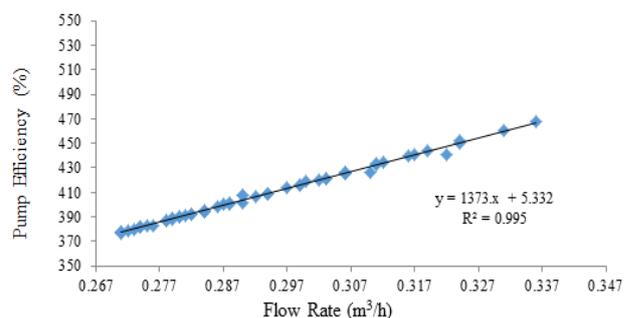


Figure 11. Relationship between Power Output and Flow Rate for High Lift Pump

3.6. Analysis of Variance

The Analysis of Variance (ANOVA) results for low and high lift pumps presented in Tables 3 and 4 respectively indicates F, p-value and F-critical values of 0.010, 1.00 and 2.216 for low lift pump while that of high lift pump

are also 0.0012, 1.00 and 2.216 respectively. Since the F-value is less than F-critical for both low and high lift pumps, it implies that there is statistically significant interaction between the flow rate, power consumption and the efficiency of the pumps.

Table 3. ANOVA Results for Low Lift Pump

Variation Source	Sum of Square	Degree Freedom	Mean of Square	F	P-value
Between Groups	71.21	11	6.474	0.010	1
Within Groups	15309.59	24	637.9		
Total	15380.81	35			

Table 4. ANOVA Results for High Lift Pump

Variation Source	Sum of Square	Degree Freedom	Mean of Square	F	P-value	F-crit
Between Groups	6717468	11	61.07	0.0012	1	2.216
Within Groups	1181788	24	49241			
Total	1182459	35				

IV. Conclusions

The assessment of the performance of the water pumps at the Asa and Agba dam waterworks was carried out by assessing the flow rate, power consumption and efficiency of the pumps. Daily data of the flow rate (m³/hr) of the low and high lift pumps were obtained from the log book of the Asa dam pump operators from 2011 to 2015 while the monthly electrical power consumption were obtained from the Power Holdings Company of Nigeria. The data were analyzed using statistical parameters available in the Microsoft Excel to determine measures of central tendency such as monthly minimum, maximum, mean and standard deviation. Analysis of Variance (ANOVA) was used to test for statistically significant interaction between the flow rate, power input and the efficiency of the pumps. The results revealed that the efficiencies of the pumps are far below 70%. Considering the age of the distribution pipes and the leakages along the pipeline network this can contribute to the reduction in the pump efficiency. The results for the one-way ANOVA indicate that there is statistically significant interaction between the flow rate, power input and the efficiency of the pumps. This was corroborated with the correlation and determination coefficient of over 0.9. It can be concluded that the pumps are performing below their minimum specifications. There is need to upgrade and replace the damage pump parts for its optimum performance.

The perspective is to extend this work by continuing the performance and energy efficiency assessment of the Asa and Agba dam waterworks over a more recent and extended period from 2016 to 2025. This future study will enable the evaluation of long-term trends in pump efficiency, energy consumption, and system degradation, as well as the impact of maintenance actions, equipment upgrades, and changes in operating conditions. Expanding the dataset will also allow for more robust statistical analysis and comparative assessment between different operational phases, thereby strengthening decision-making strategies for pump rehabilitation, replacement planning, and sustainable energy management in water supply systems.

Acknowledgement

We are grateful to all those who participated in the survey and to the students who helped with the data entry. The authors acknowledge the Tertiary Education Trust Fund (TETFUND) National Research Fund (NRF) for sponsoring this study through the TETF/DR & D – CE/NRF/2020/SETI Grant and University of Ilorin, Ilorin for providing enabling environment.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism

References

- [1] I. Yusuf, M. Musa, and A. Sanusi, "Performance Modelling and Enhancement of Solar Water Pumping System using Gumbel-Hougaard Family Copula," *International Journal of Mathematics in Operational Research*, vol. 26, no. 2, 2023, pp. 200–230.
- [2] A. D. Rego, A. C. P. A. Santos, and J. A. R. Pereira, "Assessment of Water Pumping System and Improvement in Hydro-Energetic Performance," *Journal of Urban and Environmental Engineering*, vol. 11, no. 1, 2017, pp. 42–50.
- [3] A. Carravetta, G. Del Giudice, O. Fecarotta, and H. M. Ramos, "Energy Production in Water Distribution Networks: A PAT Design Strategy," *Water Resources Management*, vol. 26, 2012, pp. 3947–3959.

- [4] R. Pandey and R. P. Saini, "Performance Analysis of Pump as Turbine using Artificial Neural Network Techniques," in Proc. National Conference on Emerging Trends and Advances in Electrical Energy and Renewable Energy, 2008.
- [5] U. J. Efetobor and T. N. Esabunor, "Design and Fabrication of a Pumping Machine for Water Supply: Meeting the Challenges of Modern Water Infrastructure," *International Journal of Trend in Scientific Research and Development (IJTSRD)*, vol. 7, no. 5, 2023, pp. 859–867.
- [6] M. Mustapha, M. Sridhar, and A. O. Coker, "Assessment of Water Supply System from Catchment to Consumers as Framed in WHO Water Safety Plans: A Study from Maiduguri Water Treatment Plant, North East Nigeria," *Sustainable Environment*, vol. 7, no. 1, 2021, pp. 1–14.
- [7] I Sarbu, "A Study of Energy Optimization of Urban Water Distribution System Using Potential Elements". *Water*, vol. 8, no 12, 2016. <https://doi.org/10.3390/w8120593>
- [8] J. Viholainen, J. Tamminen, T. Ahonen, J. Ahola, E. Vakkilainen, and R. Soukka, "Energy-Efficient Control Strategy for Variable Speed-Driven Parallel Pumping Systems," 2013.
- [9] L. T. Wong, C. S. Chan, K. W. Mui, and D. Zhang, "Optimizing the Pump Storage System for Hot Water Showering at Swimming Pools," *Water*, vol. 15, 2023, pp. 1–11.
- [10] E. S. Edward, A. J. H., and F. J. L., "The Estimated Impact of California's Urban Water Conservation Mandate on Electricity Consumption and Greenhouse Gas Emissions," *Environmental Research Letters*, vol. 13, no. 1, 2018, pp. 1–11.
- [11] S. Takahashi, S. Adachi, T. Takemoto, and M. Umek, "Water Distribution Solution for More Efficient Operation of Water Supply," *Hitachi Review*, vol. 64, no. 9, 2015, pp. 564–569.
- [12] J. G. Bene, I. Selek, and C. Hos, "Neutral Search Technique for Short-Term Pump Schedule Optimization," *Journal of Water Resources Planning and Management*, vol. 136, 2010, pp. 133–137.
- [13] N. S. H. Abdelhakeem, M. I. S. Abodie, and M. I. Elsayed, "Optimize Energy Management Techniques to Decrease Operational Costs in Water Treatment Plants at No Investment Based on Improved Pumps Operation Schedules," in Proc. 16th Al-Azhar Engineering International Conference, July 2024, pp. 270–283.
- [14] J. David, O. M. Abubakar, and H. Ismail, "Performance Evaluation of a Modified Axial Flow Water Lifting Pump for Small to Medium Irrigation in Nigeria," *Global Journal of Engineering and Technology Advances*, vol. 19, no. 3, 2024, pp. 56–70.
- [15] T. M. Müller, P. Leise, I. S. Lorenz, L. C. Altherr, and P. F. Pelz, "Optimization and Validation of Pumping System Design and Operation for Water Supply in High-Rise Buildings," *Optimization and Engineering*, vol. 22, 2021, pp. 643–686.
- [16] P. Cardoso, A. Santos, R. Rato, and M. Estrela, "Assessment of Pump's Performance in Water Supply Systems – Data Collected from Multiple Case Studies," *European Journal of Sustainable Development*, vol. 6, no. 2, 2017, pp. 217–226.
- [17] H. Karimi, M. A. Adibhesami, H. Bazazzadeh, and S. Movafagh, "Green Buildings: Human Centered and Energy Efficiency Optimization Strategies," *Energies*, vol. 16, 2023, pp. 36–81.
- [18] E. S. A. Badr and A. A. Al-Naem, "Assessment of Drinking Water Purification Plant Efficiency in Al-Hassa, Eastern Region of Saudi Arabia," *Sustainability*, vol. 13, 2021, pp. 22–61.
- [19] L. E. Ormsbee and S. L. Reddy, "Nonlinear Heuristic for Pump Operations," *Journal of Water Resources Planning and Management*, vol. 115, no. 2, 1995, pp. 302–309.
- [20] B. Coelho and A. Andrade-Campos, "Efficiency Achievement in Water Supply Systems," *Renewable and Sustainable Energy Reviews*, vol. 30, 2014, pp. 58–59.
- [21] A. M. F. Diniz, C. H. Fontes, C. A. Da Costa, and G. M. N. Costa, "Dynamic Modeling and Simulation of Water Supply System with Applications for Improving Energy Efficiency," *Energy Efficiency*, vol. 8, 2014, pp. 417–432.
- [22] A. R. Fishbein, "Public Water Energy Efficiency," *Journal of Science Policy and Governance*, vol. 5, no. 1, 2014, pp. 1–13.
- [23] T. Brinkhoff, "National Population Commission of Nigeria," online database, 2011. Accessed: Sept. 19, 2017.
- [24] O. R. Yusuf and I. I. Abbas, "Variation in Productivity of Urban Vegetable Cultivators in Ilorin, Nigeria," *International Journal of Development and Sustainability*, vol. 1, no. 3, 2012, pp. 1158–1169.
- [25] A. M. Ayanshola, A. A. Alao, A. W. Salami, S. O. Bilewu, A. A. Mohammed, O. O. Adeleke, and O. O. Olofintoye, "Modeling of Turbidity Variation in a Water Treatment Plant," *Acta Technica Corviniensis – Bulletin of Engineering*, vol. 14, no. 4, 2021, pp. 41–44.
- [26] A. A. Alao, "Assessment of Performance of Asa Dam Water Treatment Plant and Modeling of Turbidity Variation," M.Sc. thesis, University of Ilorin, Ilorin, Nigeria, 2017.
- [27] E. D. Ashaolu and O. Omotosho, "Assessment of Static Water Level and Overburden Pattern for Sustainable Groundwater Development and Management in Ilorin City, Nigeria," *Malaysian Journal of Society and Space*, vol. 1, no. 9, 2015, pp. 1–11.
- [28] A. M. Ayanshola, B. F. Sule, and K. Mandal, "Evaluation of Supply Variability of Household Water Use in Ilorin Metropolis North Central Nigeria," *Science, Technology and Arts Research Journal*, vol. 4, no. 2, 2015, pp. 252–258.
- [29] I. P. Ifabiyi, "Willingness to Pay for Water at Household Level in Ilorin, Kwara State, Nigeria," *Global Journal of Human Social Science*, vol. 11, 2011, pp. 15–24.