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Assessing the efficiencies of domestic water pumps and distribution systems for household water supply in Enugu State, Nigeria

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ABSTRACT

Water scarcity and supply fluctuation are experienced in high-rise buildings in the study area. This study becomes a necessity to find out the challenges of water supply to high-rise buildings in Nsukka Local Government Area, Enugu State. Factors extensively accessed are the pumping and distribution systems that convey fresh water from the source to the high-rise buildings. Twenty (20) high-rise buildings with fifty-eight (58) blocks of flats were considered. The buildings that were assessed use centrifugal pumps to convey water from the source. The hydraulic efficiencies of the 20 centrifugal pumps of three manufacturers and piping systems were analyzed. The study revealed a significant disparity between the high-water demand and the insufficient supply in the studied area. Additionally, a significant decrease in the water supply to households is observed in most of the high-rise buildings in the research region that use water pumps. The hydraulic efficiencies of the pump were seen to vary between 4.787 and 58.996 percent. However, among the 20 pumps assessed, only one pump was within the typical efficiency of 55% for most centrifugal pumps. Additionally, data obtained on pump operating parameters such as power, voltage, head, and so on showed a slight variation in these parameters compared to what is available on the pump nameplate. On the piping system, improper connections and leakage were observed. It was concluded that the operating parameters of the pumps and the irregular piping system, among others, were the influencing factors in the hydraulic efficiency of the pumps.

Keywords: Centrifugal pump; pump efficiency; water supply; water distribution network; water scarcity

1. INTRODUCTION

Water resources are essential for all economic and social activities, and because of population and economic growth in developing countries, total global water demand is increasing (Alcamo et al., 2007). The worldwide availability of water and its impact has been raised in recent decades (Fragkou and McEvoy, 2016). According to reports, over 4 billion people, or almost two-thirds of the global population, experience acute water shortages for at least one month each year. By 2050, projections indicate that this number will rise to nearly 6 billion people, with 73% residing in developing countries (Emile et al., 2022). Economic and population expansion are the main factors contributing to the excessive extraction of conventional freshwater resources in different parts of the world, resulting in a water shortage (Villacorte et al., 2015). The scarcity of water is a typical incident of natural resource scarcity. In a water shortage situation, the total annual runoff accessible for human use is usually less than 1000 m3/capita/year (Dhakal et al., 2022).

Water scarcity has affected 28 countries, most of which are developing, as of 2015 (Afangideh and Udokpoh, 2021; Afangideh and Udokpoh, 2022; Dhakal et al., 2022). The global water scarcity situation is anticipated to worsen further by 2050, as the global population is projected to reach 9 billion. About 44 countries with a combined population of approximately 2 billion people are projected to experience water scarcity by 2050 Dhakal et al., (2014), with developing countries accounting for 95% (1.9 billion) of those affected (Udokpoh et al., 2021). A substantial number of these countries are situated in Asia and Africa; notably, they are as follows: Afghanistan, Malawi, Ethiopia, Sudan, Somalia, Nigeria, Uganda, Tanzania, Niger, Zimbabwe, Burundi, Eritrea, and Haiti (Dhakal et al., 2022). The increasing population growth and growing rural-urban migration will worsen the situation of water scarcity in these countries, mainly owing to the withdrawal of freshwater to meet the needs of urban areas and agriculture (Afangideh and Udokpoh, 2022). But compared to half of the world's population now, 70% is expected to live in urban areas by 2050 (Srinivasan et al., 2013). The situation will be exacerbated even more.

The depletion of groundwater sources and freshwater bodies, excessive domestic water consumption, increasing contamination, and wastage of suitable water all contribute to the diminishing supply of water for human consumption, which in turn affects human survival and quality of life (Koop et al., 2019; Carrard et al., 2019; Hasan et al., 2019; Tzanakakis et al., 2020; Afangideh and Udokpoh, 2020). Changing precipitation patterns triggered by climate change and local interventions like massive deforestation aggravate these problems (Udokpoh and Garba, 2023; Garba and Udokpoh, 2023). Inefficient water use (loss during transit) and habits (such as leaving pumps running unnecessarily) contribute to the problem as well. As water supply variability is anticipated to alter due to global climate change, scarcity issues may be aggravated (Lenzen et al., 2013).

To mitigate the water scarcity caused by climate change, stricter demand management policies are necessary to maximize water efficiency (Lenzen et al., 2013). The magnitude and pattern of the changes in precipitation and average global temperatures are predicted to differ between regions due to climate change. However, they are projected to range from 1.4oC to 5.8oC by 2100. (DeNicola et al., 2015). Water availability and quality will be profoundly impacted by these changes because of the close relationship between the hydrological cycle and climate change, particularly the increase in greenhouse gases in the atmosphere that causes global warming (Garba and Udokpoh, 2023). Climate change's potential impacts on the hydrological cycle include changes in precipitation volume and distribution throughout the year, increased intensity of rainfall, more frequent and severe weather events, changes in the position of rain and snow, the influence of rising sea levels on coastal communities, an increase in evapotranspiration, and a decrease in soil moisture (DeNicola and Subramaniam, 2014; DeNicola et al., 2015).

Developing and low-income countries have far more complicated problems and challenges regarding access to safe drinking water (Oki and Quiocho, 2020). Due to rising demands on already-scarce freshwater resources and a lack of funds to finance necessary infrastructure upgrades, these countries are in danger of experiencing catastrophic water shortages (Emile et al., 2022). According to Oki and Quiocho, (2020), two major causes of water shortages are urbanization and internal migration. Economic development in developing countries typically concentrates on developed cities, leaving less developed regions behind, as pointed out by (Oki and Quiocho, 2020). This is also true for urbanization in these countries. Because of this, urban water supplies have become insufficient to meet the needs of the population. Furthermore, extraction, privatization, and overuse of water resources are further reasons for concern in developing nations (Bartels et al., 2018).

Despite the increasing depletion of groundwater, several international corporations continue to exploit water resources and pollute the water table excessively. Approximately 90% of untreated sewage is released into the water in developing countries (Boretti and Rosa, 2019). Privatization of water is common in situations where governments lack the financial means to support water purification and distribution networks. Privatization might seem like a good idea at first. Still, it usually ends up causing problems like "corruption, lack of corporate accountability, loss of local agency, weakened water quality standards", and it prevents people experiencing poverty from having access to water. Furthermore, the shortage of adequate wastewater treatment could aggravate the problem when combined with inadequate water quality standards (Emile et al., 2022). This implies that water with the potential for reuse may not be accessible and serves no use other than adding to the groundwater pollution.

Existing sanitation and water infrastructures in Nigeria, which have ample natural and human resources and an estimated population of 198 to 210 million people, are under intense pressure, with some on the verge of collapse (Onyenechere et al., 2012). It is noteworthy that more than 65 percent of the Nigerian populace resides in urban and rural areas, where they are severely neglected and deprived of modern infrastructure necessities essential to the promotion and conservation of health (Popogbe et al., 2021). In many states, including Abuja, Borno, Yobe, Niger, Adamawa, Kano, Bauchi, Sokoto, Gombe, Zanfara, Enugu, etc., women and children are observed spending time and energy traveling long distances in search of water (Udokpoh et al., 2022). Water scarcity has emerged as a national concern in Nigeria, according to Emenike et al., (2017), due to the insufficient supply of safe drinking water in many towns.

According to Ishaku et al., (2011), water crises are the leading cause of governance issues in most Nigerian states. The impoverished in rural and urban areas are particularly affected by water crises, scarcity, and deficiencies caused by the government's weak and unpredictable policies and interventions on infrastructure vital for sanitation and water facilities. Water delivery companies in some areas, such as Abuja, only provide water at specific hours of the day, and the pressure is sometimes inadequate (Raimi et al., 2019). Trucks hauling water from a central source can to reach high-pressure points, where it is pumped to storage tanks placed above ground for use by residents. In addition to the main water supply, individual homes or housing developments often have separate groundwater wells that residents use for drinking water. Therefore, pumping water to outside tanks is necessary in residential areas when the groundwater supply or the combined use of groundwater and the central water supply is exhausted.

Present-day urban homes in most of Nigeria have water pumps powered by electric motors linked to the utility network. Pump systems have widespread use in many places, including water pumping in homes, businesses, and agriculture; wastewater transport in municipal utilities; and fluid transportation in several specialized industrial sectors. In addition to the main water supply, individual homes or housing developments often have separate groundwater wells that residents use for drinking water. Therefore, pumping water to outside tanks is necessary in residential areas when the groundwater supply or the combined use of groundwater and the central water supply is exhausted. Present-day urban homes in most of Nigeria have water pumps powered by electric motors linked to the utility network. Pump systems have widespread use in many places, including water pumping in homes, businesses, and agriculture; wastewater transport in municipal utilities; and fluid transportation in several specialized industrial sectors.

Pumps are mechanical devices fixed in place and used to transform mechanical energy from a rotating shaft into hydraulic pressure. The pumping system consists of the liquid to be conveyed, a pump unit, a suction reservoir, and a delivery reservoir, in addition to pipe arrangements. Pump units comprised of motors, variable frequency drives (VFDs), transformers, and AC supplies. To regulate the pump's output (flow), the variable frequency drive (VFD) typically changes the supply frequency that the induction motor generates. Based on their primary principle of operation, pumps are broadly categorized into two main groups: Rotodynamic pumps and positive displacement pumps. Rotodynamic pumps account for 73% of all pumps installed globally, whereas positive displacement pumps account for 27% (Shankar et al., 2016). Being the most common type of rotodynamic pump, centrifugal pumps are often simply called rotodynamic pumps.

Among the various types available, centrifugal pumps are widely used for their versatility in pumping liquids. Centrifugal pumps consist of an impeller, casing, and volute, which work together to pump fluid from a suction reservoir to a discharge reservoir. Centrifugal pumps are generally preferred for applications with high flow rates and medium heads. The centrifugal pumps require less maintenance compared to the positive displacement pumps because the piston slides through the cylinder to pump fluid. The centrifugal pump has mainly two components: Rotating components and stationary components. The shaft and impeller (open, semi-enclosed, and fully enclosed) come under the category of rotating components, and the casing (volute, vortex, and circular) comes under stationary components (Li et al., 2020). Though positive displacement pumps are comparatively more efficient than centrifugal pumps, they have limitations like a minimal flow rate and need regular maintenance (Shankar et al., 2016).

The most common type or preferred kind of pump used by most houses in Nigeria is the centrifugal pump because of its availability and affordability. A significant drawback of the centrifugal pump is its limited pumping capacity, which hampers its long-term effectiveness and sometimes results in excessive energy consumption for optimal performance. This issue is prevalent in Nigeria, where instances of expensive and erratic power supply have been recorded Udokpoh and Nnaji, (2023), making it nearly impossible for households to use these pumps to their maximum efficiency. Centrifugal pumps are not capable of functioning effectively in high-head conditions at heights above 60 meters in high-rise buildings. This issue is more problematic since the building industry in Nigeria is significantly expanding its involvement in the construction of high-rise buildings. Efficiently managing and minimizing losses in domestic water supply is critical to ensuring the conservation of water resources.

Pump efficiency, service intervals, control strategies, process requirements, maintenance schedules, and system design are just a few of the variables that affect the pump's performance. Flow rate, system head, and pump efficiency are among the most essential parameters of pump performance (Kini et al., 2008). The efficiency and prevention of cavitation in a process fluid are assessed by determining various parameters such as liquid viscosity, temperature, specific gravity, vapor pressure, concentration, shear sensitivity, abrasiveness, pump environment, pressure, and flow rate (Chitale et al., 2021). The main parameters contributing to system inefficiency are the setup design, operation, and maintenance of the pipe network connected to the motor-pump system. An extensive bending network in the piping system significantly hampers operational efficiency and lengthens the duration of operation.

Conversely, a piping system that is inadequately maintained may facilitate the development of air pockets or vortices, which can impede the unrestricted flow of liquids. When a pump system is placed in the process layout, the available installation selections are sometimes limited owing to the constraints of the workplace. Common factors that intensify the condition include forcefully aligning pipe connections, including additional bends, and installing pipe components and control valves that often result in slight misalignments. This leads to inefficient and dangerous pumping operations over time due to the accumulation of considerable energy loss. A significant number of complaints have been received from users regarding pumps, including insufficient capacity, inefficient operation, and excessive power consumption. However, this study will seek to assess in-use water pumps and their respective efficiencies for water supply systems in high-rise buildings in the Nsukka local government area, Enugu State. It also focuses on pump capacity, pump efficiency, and piping and pumping systems for households.

2. METHODOLOGY

Study area

The research was conducted in the Nsukka Local Government Area, located in Enugu State. Igbo-Eze South, Igbo-Eze North, Enugu-Ezike and Uzo-Uwani are the local government areas that border Nsukka. The average temperature of the area is around 27°C (80°F) and it is characterized by typical rainforest vegetation. The location is situated between the coordinates of 6°51′24″N and 7°23′45″E, and it has an altitude of 550 meters above sea level (Figure 1). The population of Nsukka was recorded at 309,633 according to the 2006 census, and it covers an area of 5,545.38 square kilometers. The vast majority of the population consists of public servants, traders, and farmers (Nnaji et al., 2021; Nnaji and Udokpoh, 2023). The main campus of the University of Nigeria is situated in the area.

The area has a rainy season from May to October, with an average rainfall of more than 1,500 mm. In rural areas, nearly all houses collect rainwater for domestic use, while some villages also rely on streams and springs for additional water sources. From November to April, the magnitude of rainfall in this region is very low (Nnaji and Udokpoh, 2022). In the dry season, surface water sources are scarce; however, the depth of groundwater is often significant, sometimes exceeding 200 meters. Due to the lack of surface water in the famous town of Nsukka Urban in Enugu State, Nigeria, groundwater is primarily relied upon as the primary source of potable water supply, with boreholes serving as the conventional source. Recently, there has been an increased focus on the use of groundwater. Water tankers are the only viable alternative for most households to such time-consuming water collection means.

The vendors of tanker trucks deliver water across rural and urban areas, with an increased rate of operations during the dry season. To meet the water demands, Nigerian federal and state government agencies have drilled several boreholes within the last twenty years. Some households were provided with pumps and generators, while others had small piped distribution systems that supplied public and private taps. Currently, a significant number of these boreholes are non-functional as a result of inadequate or no maintenance. The residents now depend on privately owned boreholes, necessitating powered pumps to distribute water in high-rise buildings.

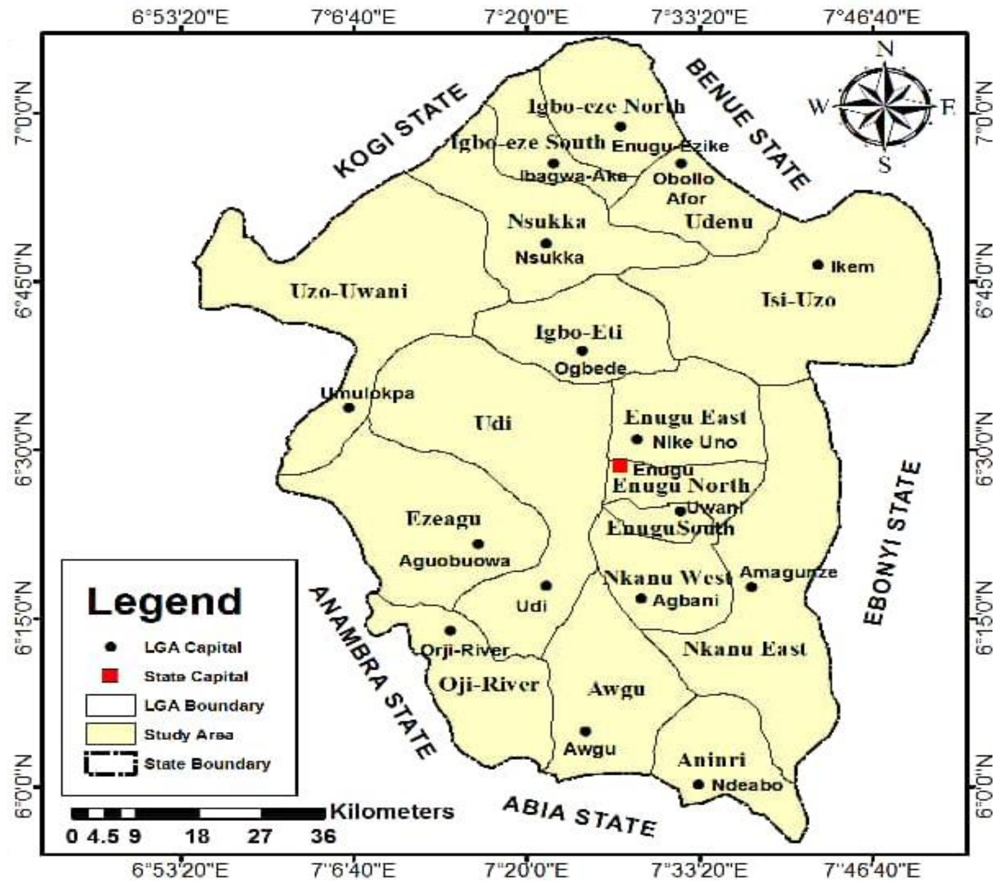

Figure 1 Map of Enugu State showing Nsukka Local Government Area

Data collection

Field surveys and the administration of questionnaires provided the data used in the present study. A sample of 58 respondents was selected from the flat blocks of 20 high-rise buildings in diverse locations within the Nsukka Local Government Area, Enugu State, Nigeria. The respondents were administered structured questionnaires that had already been developed. A total of 58 units were evaluated, and one participant was selected from each unit. The units examined in this study vary from four-bedroom to two-bedroom apartments. The survey specifically focused on high-rise structures with pumps. Several parameters must be taken into account to ascertain the efficiency of the pump.

Pump operating parameters

The following parameters were either obtained from the nameplate of the pump or evaluated by analysis to determine the pump efficiency effectively:

Pump shaft power Ps: When the load is constant, the pump shaft power Ps is determined by multiplying the input power of the motor by the motor's efficiency. The power input to the pump shaft, Ps, may be determined using a portable power analyzer. The manufacturer is currently writing the pump's body, which contains this specific function.

Flow rate measurement Q: The volume of water passing through a fixed point in a given time interval is called the flow rate. One way to measure flow is to track the speed of a fluid across a predetermined area. The tank filling method was used to measure the flow rate Q in this research.

Tank filing method: The flow rate may be determined by observing the change in tank levels during a specific time interval when the outflow from the tank is halted. Before commencing this process, it is crucial to know the tank volume, V.

Total Head H: This refers to the overall dynamic discharge head, measured from the lowest point of the supply tank to the highest point of the receiving tank. The validation of the individual pump head was achieved by measuring the operating pump head and adding the static head.

Density ρ: The following determines the fluid's density:

$$\varrho = \frac{mass}{volume} \quad (1)$$

Acceleration due to gravity g: The acceleration value due to gravity serves as g = 9.81.

Hydraulic power Ph: Once the parameters mentioned above are obtained, they may be used to calculate the hydraulic power. All the elements in the equation below are related:

$$\text{Hydraulic power} = \text{Ph (KW)} = \frac{QH\rho g}{1000} \quad (2)$$

Pump efficiency η: The efficiency of a pump, denoted as η, is the ratio of the power that the pump transfers to the fluid to the power used to operate the pump. The efficiency of a pump depends on the discharge and operating head; hence, its value is not constant. The efficiency of centrifugal pumps usually increases with flow rate up to a certain point around the center of their working range, beyond which it starts to decrease. This study's most crucial component is calculating the pump shaft power PS, which determines the pump efficiency. Only by considering the present surroundings and process requirements can the right equipment be chosen to improve system efficiency. The calculation is done by dividing the hydraulic power by the power of the pump shaft.

$$\eta = \frac{P_h}{P_s} \quad (3)$$

Power, current, and voltage: All of the pumps in the research area were tested and measured for power consumption, current, and voltage using a portable handheld power meter (PCE-PA 8000). This power meter is an automated system that records data in an Excel file format and measures various electrical qualities in real-time. The data is then moved to a computer so that it can be analyzed with Microsoft Excel.

Maximum flow rate: The maximum flow rate (Q) of each pump in the study area was measured using the equation below.

$$\text{Maximum flow rate } Q = \frac{\pi D^2 nH}{4g} \quad (4)$$

Where D is the impeller diameter (m), n is the pump speed (RPM), H is the pump head (m), and g is the acceleration due to gravity.

Weight: The individual weight of the pump was measured using an electronic weighing balance.

Sampling Site and Size

A section of the sampling site was divided and spread across the whole city. The residences accurately represented each section of the local government area. A stratified random sampling technique was employed at each section to ensure that the entire class was adequately represented in the population. Following the selection of the initial household in each residential area, the remaining households were visited alternatingly until all of the households were visited. Table 1 displays the total number of units for each building. Additionally, these numbers indicate the number of participants who expressed their willingness to engage in the survey. For data analysis, relevant statistical tools in Microsoft Excel were used. We used tables, pie charts, and bar charts for the data analysis and presentation. In analyzing the data, both descriptive and inferential techniques were adopted.

Table 1 Number of units in a building

HRB	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Total
NF	3	4	2	3	2	4	3	2	2	4	2	3	4	2	3	4	3	2	3	3	58

HR= High rise building; NF= No. of flats

3. RESULTS AND DISCUSSION

High-rise buildings in the study area suffer greatly from inadequate water supply since most of them are not designed and built with a functional water supply system. Also, due to the relatively low supply of water provided by Enugu State Water Cooperation, these buildings have resorted to other sources of water, such as ground wells, water tanker trucks, and boreholes, as shown in (Figure 2).

Figure 2 Prevalent means of water supply in the study area

Preliminary assessment of water distribution systems

Table 2 presents the results of the preliminary survey to identify high-rise buildings with pumps, the type of building, the number of occupants in each building, the volume of their water storage tanks, the height of the storage tank, and the rate of water supply to that household. This survey reveals that only high-rise houses in the study area use energy-powered pumps to distribute potable water from the above means to their storage tanks.

Table 2 Household water pumps and Water demand data

HRB	NF	NO	VST (Litres)	HWS (m)	FS (Monthly)	NS	Monthly supply (Liters)	Per capita monthly demand (Liters)
A	3	1	750	12.60	2	4 Story	1500	1500
		6	1500	9.45	4		6000	1000
		5	1500	6.30	5		7500	1500
B	4	10	3000	15.75	6	5 Story	18000	1800
		3	3000	12.60	4		12000	4000
		4	3000	9.47	6		18000	4500
		7	3000	6.32	4		12000	1714
C	2	1	1500	12.44	2	5 Story	3000	3000
		4	1000	12.44	8		8000	2000
D	3	5	1500	9.15	5	3 Story	7500	1500
		9	3000	9.15	7		21000	2333
		3	2000	6.25	4		8000	2667
E	2	5	1500	6.15	7	3 Story	10500	2100
		6	2000	6.15	6		12000	2000
F	4	4	3000	12.45	3	3 Story	9000	2250
		8	2000	12.45	4		8000	1000
		4	4000	8.35	5		20000	5000
		11	3000	8.35	8		24000	2182
G	3	3	1500	9.45	6	4 Story	9000	3000
		7	3000	9.45	4		12000	1714
		4	2500	6.30	3		7500	1875
H	2	7	3000	12.45	3	4 Story	9000	1286
		4	3000	12.45	6		18000	4500

I	2	1	1500	9.31	2	5 Story	3000	3000
		5	1500	9.31	3		4500	900
J	4	1	750	8.42	4	3 Story	3000	3000
		5	1500	8.42	4		6000	1200
		2	2000	4.15	3		6000	3000
		3	1000	54.14	6		6000	2000
K	2	1	750	7.45	3	3 Story	2250	2250
		7	3000	7.45	6		18000	2571
L	3	5	1500	9.45	8	4 Story	12000	2400
		4	3000	4.15	5		15000	3750
		8	2000	4.15	6		12000	1500
M	4	9	3000	15.60	6	5 Story	18000	2000
		7	1500	15.60	8		12000	1714
		4	3000	12.45	5		15000	3750
		6	2500	12.45	3		7500	1250
N	2	2	750	6.45	5	4 Story	3750	1875
		9	2500	6.45	5		12500	1389
O	3	7	1500	12.46	8	4 Story	12000	1714
		5	3000	6.30	6		18000	3600
		6	6000	6.30	6		36000	6000
P	4	11	3000	12.40	7	4 Story	21000	1909
		3	3000	12.40	6		18000	6000
		2	3000	9.15	3		9000	4500
		8	3000	9.15	6		18000	2250
Q	3	1	750	8.75	3	3 Story	2250	2250
		3	2000	8.75	6		12000	4000
		5	1000	4.35	7		7000	1400
R	2	4	1500	5.12	5	2 Story	7500	1875
		6	2000	5.12	4		8000	1333
S	3	6	3000	8.41	4	3 Story	12000	2000
		3	2500	8.41	5		12500	4167
		6	2000	8.41	5		10000	1667
T	3	8	4000	6.30	4	4 Story	16000	2000
		7	4000	6.30	4		16000	2286
		5	4000	6.30	4		16000	3200
Total	58	296	134250					

HRB=high rise building; NF=number of flats; NO=number of occupants; VST=volume of storage tank; HWS=height of water supply; FS=frequency of storage; NS=number of story.

The data in Figure 3 above shows the number of times people living in a household with a pump require a tank supply of water. This result shows that houses with just one occupant and a large storage tank do not need regular water supplies. The water demand of these various houses also depends on the individual's water usage rate. Comparing the data, using house A and house G, as illustrative examples, it is observed that the water demand for house 1 is 250 liters per person per month. In comparison, that of house 7 is approximately 500 liters per person per month. This analysis shows that the water demand can differ among household individuals. Considering houses M and P from the above chart, both have the highest water demand per capita per month. This is because of the number of individuals living in those houses. However, the value of water demand per person per capital in a month is higher in-house P than in house M, with an average value of 546 liters per person per month, and is so because of the rate of usage of water.

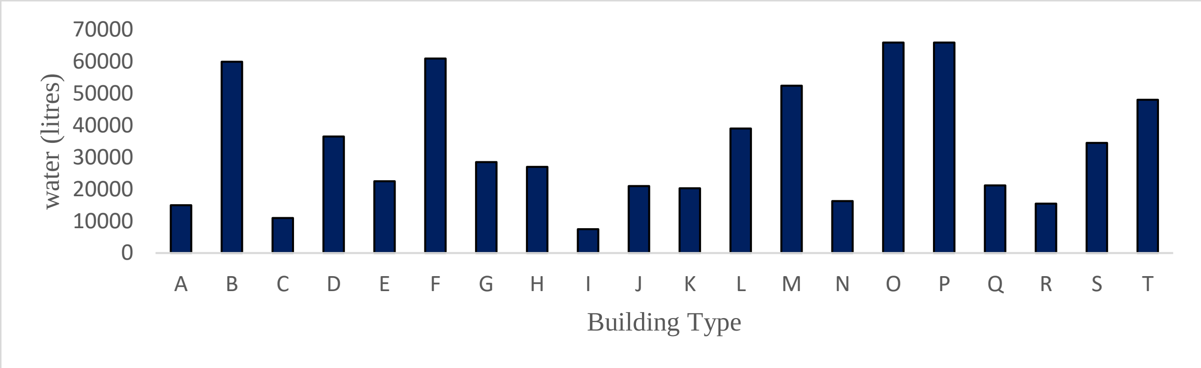

Figure 3 Water supply in each building per month

Description of prevalence type of pump in the study area

The survey of twenty high-rise buildings in the Nsukka local government area yielded the following data, which Table 3 shows: The type of pumps used by the buildings and the details obtained from the pump's nameplate.

Table 3 Pump operating parameters from nameplate

Parameters	DAB JET 132 M	DAB JET 102 M	ATLAS 125	GRANAC JET 100 M (1HP)	GRANAC JET 100 M (1.5HP)
Power (W)	1000	750	750	750	1100
Voltage (V)	240	240	220	220	220
Horsepower (hp)	1.36	1.0	1.0	1.0	1.5
Current (A)	5.1	5.1	4.8	4.8	4.8
Head (m)	48	54	54	50	50
MFR (l/m)	80	60	60	60	400
Weight (kg)	25	25	10	20	20
LE (years)	5-10	5-10	5-10	5-10	5-10
NPA	2	9	4	3	2

MFR=Maximum Flow Rate; l/m=Litres per minute; LE=Life Expectancy; NA= Number of Pump available

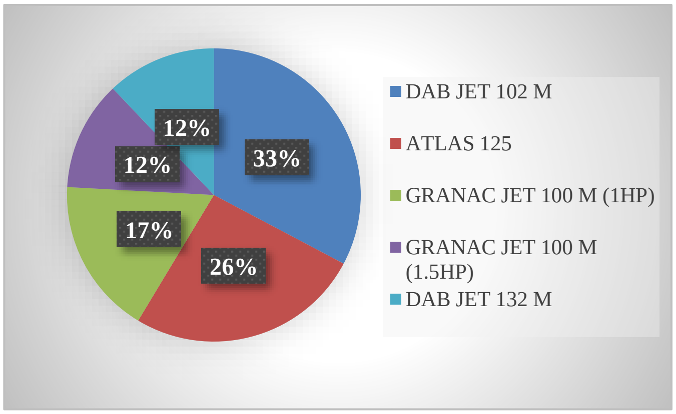

Figure 4 Prevalence of types of pumps

Figure 5 Typical ATLAS 125 pump

Figure 6 Typical DAB JET 102 M pump

Figure 7 Typical GRANAC JET 100M pump

From the survey conducted in high-rise buildings in the Nsukka local government area, the results showed that the most common type of water pump used is the DAB JET 102 M water pump (Figure 4), which has a motor power (MAX) of 1.13 KW, a pump capacity of 0.6–3.6 m3/h, and a maximum supply height of 53.8m. Next are the ATLAS 125 water pumps, which have a motor power of 0.75 KW, a pump capacity of 60 l/min (3.6 m3/h), and a maximum height of 60m. Other types of water pumps seen are the GRANAC JET 100M (1HP), GRANAC JET 100M (1.5HP), and DAB JET 132 M. From the survey carried out among the household pump owners, it was noted that the DAB JET 102 M pump was widely used among household pump owners (Figure 5, 6, 7).

The life span of these water pumps ranges from 10 to 15 years. This depends on the type of pump, the maintenance, and the manner of usage. From the survey, the maximum life span of the pumps evaluated in Nsukka is seven years. The reasons why most households go for the DAB JET 102 M pump are that it is readily available in the market and also because they believe that the cost of repair or maintenance is more affordable. Some households also assumed that since the ATLAS 125 was cheaper than the DAB JET 102M, it would be of higher quality and efficiency.

DAB Jet 102 M and Jet 132 M

This is a centrifugal jet pump made of self-priming stainless steel and cast iron. The exceptional deep suction capabilities and distinctive self-priming features of DAB jet pumps have earned them a widespread reputation. These devices are specifically engineered to effectively manage water that is both abrasive and corrosive, particularly for spear tip applications. This system is appropriate for providing water in residential settings, small-scale farming, and gardening.

ATLAS 125

This surface centrifugal water pump is perfect for water delivery from wells and reservoirs in domestic, public, industrial, garden, and irrigation applications. For optimal performance, it should be used with either a foot valve or a non-return valve, and it is intended for transfer purposes.

Granac Jet 100 M (1HP) and Jet 100 M (1.5HP)

The Jet 100 M is an extremely effective and self-priming series of jet pumps with exceptional suction power. Pump components include a nozzle-equipped jet pipe and a single-spoke impeller. These pumps can benefit domestic and small-scale industrial water delivery systems.

Table 4 Observed pump operating parameters from the field survey

HRB	Pump type	Power (W)	Voltage (V)	Current (A)	Head (m)	MFR (l/m)	Weight (kg)	Age (years)	Cost ($)
A	DAB JET 102 M	750	240	5.08	54	58	25	3	105
B	DAB JET 102 M	740	238	4.79	49	49	24	5	105
F	DAB JET 102 M	722	235	4.89	48	52	23	6	83
J	DAB JET 102 M	745	238	4.81	51	51	24	4	85
L	DAB JET 102 M	731	230	4.56	47	47	24	7	101
K	DAB JET 102 M	744	238	5.08	51	59	24	2	85
P	DAB JET 102 M	750	240	5.05	52	58	23	3	88
O	DAB JET 102 M	720	233	5.01	49	55	24	4	84
S	DAB JET 102 M	748	240	5.10	53	58	22	5	95
M	GRANAC JET 100 M (1.5HP)	1083	219	4.71	48	350	18	4	75
T	GRANAC JET 100 M (1.5HP)	1055	215	4.68	47	345	17	5	80
D	ATLAS 125	746	220	4.80	51	59	9	4	50
G	ATLAS 125	729	218	4.76	52	57	8	4	65
Q	ATLAS 125	750	220	4.81	49	58	9	5	53
C	ATLAS 125	748	219	4.80	52	58	8	4	55
E	GRANAC JET 100 M (1HP)	750	220	4.80	50	55	19	3	60
H	GRANAC JET 100 M (1HP)	746	218	4.78	49	54	18	5	70
I	GRANAC JET 100 M (1HP)	750	220	4.80	49	60	17	2	75
N	DAB JET 132 M	980	236	5.12	45	76	23	3	120
R	DAB JET 132 M	997	240	5.10	47	78	24	1	105

MFR=Maximum Flow Rate; l/m=Litres per minute

Table 4 also presents the cost of each pump assessed in the area. The DAB JET 102 M pump has a price range of $83 to $105 (₦74000 to ₦94000), the ATLAS 125 price ranged from $50 to $65 (₦45000 – ₦580000), the GRANAC JET 100M (1HP) price also ranged from $70 to $75 (₦62000 – ₦67000), while the GRANAC JET 100M (1.5HP) price ranged from $75 to $80 (₦67000 – ₦71000), and the DAB JET 132 M price ranged from $105 to $120 (₦34000 – ₦40000). The official exchange rate of the naira to the dollar was pegged at ₦892 per dollar. The variation in the cost of pumps in the study area, according to dealers, is attributed to the make of the pump, the capacity of the pump in terms of horsepower, and logistics expenses incurred during the importation of the pump. However, these factors could independently or collectively affect the cost of this pump. The most minor age of the pump in the area was one year in building R, while the highest age of seven years was observed in building L.

Other parameters, such as pump head and power, recorded the highest values in buildings A and M, while N and O had the lowest pump head and horsepower values. The percentage variation of the pump operating parameters from observed data and data available on the pump nameplate area is presented in (Table 5). All the pumps examined recorded a slight difference in either or all of the operating parameters from the field-observed data and the information available on the pump's nameplate. The difference in pump weight was observed to be the highest, with a percentage difference of twenty. This is because, during maintenance or repairs, lubrication or replacement of worn parts may incur additional weight. Additionally, the weight may vary depending on the extra components the pump's owners added for stability or to prevent corrosion. The variation in other parameters (power, head, and MFR) may be influenced by voltage variation (Hasan et al., 2016).

However, Kini et al., (2008) reported that the regular fluctuation of demands on power system networks leads to voltage imbalances and fluctuations. When such erratic voltages are used to power centrifugal loads, the system's efficacy fluctuates significantly. The field analysis results reveal a strong correlation between voltage and pump head. A zero or less variation in pump parameters for voltage equals the same in the pump head. This is because the power required by a pump is directly proportional to the flow and the head that it produces (Jain and Patel, 2014). As flow and, or head increase, so does the power required. Conversely, power is inversely proportional to hydraulic efficiency. For the same flow and head, an increase in efficiency reduces the power requirement.

It was also observed that the age of the pump invariably affected the variation in pump operating parameters. The extent of parameter variations in pumps with a shorter lifespan was relatively small compared to those with a longer lifespan. However, this assumption was not valid in all cases, and the reverse could be attributed to the wearing and tearing of the machine. Moreover, the variation among the individual pumps and brands did not follow a particular order, but the highest variation of operating parameters of 56% was seen in building L, and the brand of pump was DAB JET 102 M. Interestingly, DAB JET 102 M was also observed to have a percentage variation of 4% in building A. The variations in critical parameters such as power, voltage, and head could be a solid pointer to the overall efficiency and performance of the pump.

Table 5 Percentage variation in pump operating parameters

HRB	Pump type	Power (W)	Voltage (V)	Current (A)	Head (m)	MFR (l/m)	Weight (kg)
A	DAB JET 102 M	0.00	0.00	0.39	0.00	3.33	0.00
B	DAB JET 102 M	1.33	0.83	6.08	9.26	18.33	4.00
F	DAB JET 102 M	3.73	2.08	4.12	11.11	13.33	8.00
J	DAB JET 102 M	0.67	0.83	5.69	5.56	15.00	4.00
L	DAB JET 102 M	2.53	4.17	10.59	12.96	21.67	4.00
K	DAB JET 102 M	0.80	0.83	0.39	5.56	1.67	4.00
P	DAB JET 102 M	0.00	0.00	0.98	3.70	3.33	8.00
O	DAB JET 102 M	4.00	2.92	1.76	9.26	8.33	4.00
S	DAB JET 102 M	0.27	0.00	0.00	1.85	3.33	12.00
M	GRANAC JET 100 M (1.5HP)	1.55	0.45	1.88	4.00	12.50	10.00
T	GRANAC JET 100 M (1.5HP)	4.09	2.27	2.50	6.00	13.75	15.00
D	ATLAS 125	0.53	0.00	0.00	5.56	1.67	10.00
G	ATLAS 125	2.80	0.91	0.83	3.70	5.00	20.00
Q	ATLAS 125	0.00	0.00	0.21	9.26	3.33	10.00
C	ATLAS 125	0.27	0.45	0.00	3.70	3.33	20.00
E	GRANAC JET 100 M (1HP)	0.00	0.00	0.00	0.00	8.33	5.00
H	GRANAC JET 100 M (1HP)	0.53	0.91	0.42	2.00	10.00	10.00
I	GRANAC JET 100 M (1HP)	0.00	0.00	0.00	2.00	0.00	15.00
N	DAB JET 132 M	2.00	1.67	-0.39	6.25	5.00	8.00
R	DAB JET 132 M	0.30	0.00	0.00	2.08	2.50	4.00

Pump maintenance and some faults encountered by owners

For water pumps to run correctly, they require customary maintenance. Developing a water pump maintenance checklist will not only reduce cost, but it will also guarantee optimal performance. The maintenance and repair reports obtained during the field survey are presented in (Table 6). Data obtained during the study include frequencies and costs of maintenance and repairs. It was observed that all the pumps in the area are serviced annually, either biannually or quarterly, but repairs are only done when there is a pump failure. The cost of maintenance was seen to be drastically lower than the cost of repairs. The cost of maintenance and repairs was not uniform and was influenced by the extent of damage to the pump. It was also noticed that pumps that underwent regular maintenance still broke down and required repairs.

The prevalent failures in the area that needed repairs include motor coil damage and mechanical failure. These damages directly affect the hydraulic performance of the pump. However, most pump owners who encountered pump failure via electrical motor damage reported that it was because of power fluctuation from electricity distribution companies. Moreover, most mechanical failures were attributed to poor handling of the pump by the owners. The survey's findings recommend regular maintenance to extend the pump system's operating life, lower operating costs, and ensure a sufficient maintenance history for quicker problem identification.

Table 6 Pump maintenance and repairs records

HRB	Pump type	Age (years)	MF (p.a)	MC (p.m) ($)	Repairs (p.a)	RC (p.r) ($)	MF (lifespan)	Repairs (lifespan)
A	DAB JET 102 M	3	2	2	0	0	6	0
B	DAB JET 102 M	5	4	2	1	20	20	1
F	DAB JET 102 M	6	2	2	0	0	12	0
J	DAB JET 102 M	4	4	3	1	25	16	1
L	DAB JET 102 M	7	2	3	2	15	14	2
K	DAB JET 102 M	2	4	3	0	0	8	0
P	DAB JET 102 M	3	4	3	0	0	12	0
O	DAB JET 102 M	4	2	2	1	20	8	1
S	DAB JET 102 M	5	4	2	0	0	20	0
M	GRANAC JET 100 M (1.5HP)	4	2	2	1	20	8	1
T	GRANAC JET 100 M (1.5HP)	5	4	3	2	15	20	2
D	ATLAS 125	4	4	3	0	0	16	0
G	ATLAS 125	4	4	3	0	0	16	0
Q	ATLAS 125	5	4	3	1		20	1
C	ATLAS 125	4	2	2	0	0	8	0
E	GRANAC JET 100 M (1HP)	3	2	2	0	0	6	0
H	GRANAC JET 100 M (1HP)	5	2	3	1	20	10	1
I	GRANAC JET 100 M (1HP)	2	4	3	0	0	8	0
N	DAB JET 132 M	3	2	2	0	0	6	0
R	DAB JET 132 M	1	4	3	0	0	4	0

p.a= per annum; p.m=per maintenance; p.r=per repair; MF=maintenance frequency; MC=maintenance cost; RC=repair cost

Maintenance of a centrifugal pump for efficient performance, reduction or elimination of the cost of repairs, and prolonging the pump's operating life requires regular and consistent maintenance programs. We can classify the maintenance plans for centrifugal pumps into three categories: normal, quarterly, and yearly maintenance. Routine maintenance involves establishing a predetermined timetable to systematically examine, record, and fix various components. This study concentrates on the elements that serve as predictive signs of possible malfunction. Routine maintenance tasks include:

Bearing and Lubricant Condition: To keep track of vibration, lubrication level, and bearing temperature, the lubricant must be transparent and devoid of any bubbling. A sign that the bearings are getting too hot is bubbling, which should prompt one to add extra lubrication. An indication of imminent bearing failure might be increased vibration in the bearings.

Shaft Seal Condition: It means that the mechanical seals must be examined. No obvious indications of leaking should be detected. It is important to check the packing of the pump during downtime to ensure that it is adequately lubricated. According to the operation instructions, oil should be supplied, and the packing should be replaced if it seems compressed and dry.

Overall Pump Vibration: Monitoring the overall vibration of the pump might help one detect when it is about to break down. The alignment of the pump, bearing failure, cavitation, or blockages in the suction or discharge lines are some of the causes of excessive vibration.

Pump Discharge Pressure: The total produced head pressure of the pump is located where the pressure readings from the suction and discharge gauges vary. Check if this measurement falls within the pump's specified performance. This information is available in the user manual or manufacturer's website.

It is necessary to inspect the hold-down bolts for tightness and ensure the pump's base is solid as part of the quarterly maintenance. It is recommended to change the oil in oil-lubricated pumps after the initial 200 hours of operation. Subsequently, after 2,000 operating hours or every three months, whichever occurs first, the frequency and type of oil changes should be as specified in the operator manual. Greasing the bearings of a grease-lubricated pump should be done every three months or after 2,000 hours of operation, whichever occurs first. For further instructions on when and what kind of grease to use, refer to the operating manual. It is important to grease the motor bearings by the manufacturer's instructions. During the quarterly maintenance, one should also examine the alignment of the shaft. It is vital to ensure that all pump and motor bearings have their vibration spectrum assessed.

It is recommended to keep track of the pump's performance at least once a year as part of the annual maintenance. It is recommended to set the performance objectives for the pump early in its life. Pressure at the head, flow rate, amp draw from the motor, and vibration at each bearing should be the minimum of the benchmarking data. Preventable damage and overhead can only be avoided with consistent pump maintenance. The efficiency of water pumps may be enhanced in various ways, for example, by reducing the use of larger pumps that are not necessary, increasing the output with a little booster pump, or simply altering the pump's speed to make it work better.

Common problems faced by owners of pumps and cost of repair

During this study, various challenges experienced by pump owners were documented, and the respective cost of repair was also obtained. This in particular will inform the general public on the common problems to experience when using pumps. Below is a list of these problems and their respective costs.

Air blockage

It occurs when air gets in the way of the water pump's capacity to pump water. A pressure differential between the inner pipeline and the surrounding atmosphere causes an airlock in water pipes. The most common cause of water not flowing freely is an airlock in pipes, which occurs when air pockets get trapped by the flowing water. Another typical reason water pumps develop airlocks is when the water is running dry (Deulgaonkar et al., 2021). This happens when water pumps continue to run after all the water has been removed, leading to the pump sucking air and developing an airlock. When this happens, the water pressure reduces, the faucets splutter, or the water stops flowing altogether because it disrupts the pump's capacity to do its function. A water pump air lock must be resolved immediately, can potentially damage the pump and other system components. Moreover, an extended air lock may result in the pump motor experiencing overheating and a subsequent decline in efficiency.

Pumping dry

Regular home maintenance can fix the situation where there is no fluid in the pump before pumping, whether by mistake or design. It is essential to have a specific amount of fluid in any pump while it is operating. An example of dry running would be a pump operating but not producing the desired flow. Human error, as well as operational, monitoring, and control deficiencies, are common causes. As a result, mechanical seals degrade rapidly. According to Lee and Schwab, (2005), this results in pump leakage. A hazardous liquid, including chemicals, will undoubtedly leak and pose a danger to personnel and the environment if it is in motion. Cavitation, which can severely damage the pump impellers, is another potential outcome if the pump runs dry. After some time, the impeller will melt and grip the shaft as it runs along it. Now, if the impeller becomes stuck, it will halt and not rotate. It poses a threat to its survival and may reduce its efficiency. It may cause irreparable harm to a pump in certain instances.

Sand

A blocked pump outlet could be the result of water that contains solid particles, such as sand. Sand in water storage tanks can also wear down the impeller and motor of a pump, among other parts (Zhu et al., 2021). The pump may need to be repaired or replaced more often due to early wear and tear caused by the sand particles constantly coming into contact with its working parts. Sand, being abrasive, can wear down pump components, resulting in decreased efficiency and more frequent maintenance requirements. Sand can also get inside the pump and block the impeller, making it less effective at drawing water (Wang et al., 2022). Furthermore, sand can settle into the pipes, leading to clogs and decreased water flow. Your home's water pressure may drop, which might damage or turn off any fixtures or appliances that depend on a constant flow of water.

Corrosion

Reactions with the environment cause metallic materials to be wasted. Uniform corrosion is the most common corrosion seen in centrifugal pumps (Güner and Özbayer, 2019). When the rate of material loss is relatively consistent throughout the whole surface, we say that the corrosion is uniform. Rust is a consistent corrosion product. In most cases, cast-iron pumps will experience consistent corrosion (Thanikachalam, 2017). The reaction between iron (Fe) and oxygen (O) molecules in air and water produces iron oxide (FeO), the chemical responsible for rust. To avoid rust, keep iron away from water and air. Compromises in surface appearance, altered surface heat transfer and fluid flow characteristics, contamination, seizure, electrical contact failure, leakage, and general surface deterioration are all part of the impact. Preventing corrosion might be challenging, but using the suitable material to build a pump leaves almost little space for corrosion. Thus, we can use more resistant materials like stainless steel or nickel-based superalloys to prevent uniform corrosion. If the internal components of a pump corrode, rust may leak into the water supply.

Size of pipe

One crucial factor that affects the velocity and flow rate of a fluid is the diameter of the pipes. The diameter is the primary determinant of the available cross-sectional area for the fluid to pass through. To reduce fluid velocity and, by extension, friction losses, larger diameters allow increased rates of flow (Wang et al., 2017). The reverse is true for smaller diameters: they limit flow, which in turn increasing velocity and friction losses. Because the pump must operate in opposition to both the fluid's inertia and the resistive forces produced by the pipe walls, these variables have a direct bearing on pump requirements. The time it takes to provide water is directly proportional to the pipe diameter (Haider et al., 2014). The amount of time the pump can run depends on how long it takes to provide water to the system. Choosing the correct pipe diameter will solve this problem. To reduce energy consumption and maximize pump performance, it is necessary to achieve an appropriate balance between pipe diameter and length (Haider et al., 2014).

Electric motor damage

Depending on their design and use, electric pumps may generate a lot of heat. Pump failures are often attributed to excessive heat (Saracyakupoglu, 2022). Running an electric motor suck in airborne dust particles with relative ease. It does not require much for the particles to do significant damage once they reach the motor. The magnitude and physical characteristics of the particles will determine this. The motor's contact parts will wear down if the particles are abrasive, such as sand. They can obstruct the flow of electrical currents across components if they possess electrical properties. Excess heat might build up in the motor if there are too many particles obstructing the vents. Harmonic currents can be developed via modes of high-frequency switching and pulse width modulation, because of this, overloading and overheating might occur due to distorted current and voltage.

All of these things shorten the motor's lifespan and increase maintenance costs. There are a lot of other places than the electric motor where power surges may cause havoc. Electric motors are particularly vulnerable to the long-term effects of airborne moisture and humidity. These substances, on their own, might cause corrosion inside the engine. Motor damage can occur much more quickly in the presence of moisture and particles due to a phenomenon known as "negative synergy" (Wood et al., 2013). The lifespan of any electric pump or motor is reduced as a result of this.

Pumping efficiency

The calculated data on pump efficiency for the surveyed pumps shows that house M, with a pump efficiency of 58.996%, and house T, with a pump efficiency of 23.825%, have the highest pump efficiency. This is because pump efficiency is highly dependent on the rate of discharge of the pump, the power into the pump, and the height to be supplied (Kaya et al., 2021). Looking at Table 7, one can say that the GRANAC JET 100M (1.5HP) pump in building M, with a discharge rate of 0.0058 m3/s, supplying water to a height of 15.60 m, has the highest pump efficiency. The same GRANAC JET 100M (1.5 HP) pump in building T with a discharge rate of 0.0058 m3/s and a supply height of 6.3m had the second highest pump efficiency.

Table 7 Pumps hydraulic power and efficiency

HRB	Volume (m3)	Capacity, Q (m3/s)	Height (m)	Ps (KW)	Ph (KW) $\left[\frac{QH\rho g}{1000}\right]$	Efficiency η % $\left[\frac{P_h}{P_s}\right]$
A	3.75	0.0010	12.60	1.0	0.123	12.324
B	12.00	0.0008	15.75	1.0	0.123	12.324
C	2.50	0.0010	12.44	1.0	0.122	12.167
D	6.50	0.0010	9.15	1.0	0.089	8.949
E	3.50	0.0009	6.15	1.0	0.054	5.414
F	12.00	0.0009	12.45	1.0	0.110	10.959
G	7.00	0.0010	9.45	1.0	0.092	9.243
H	6.00	0.0009	12.45	1.0	0.110	10.959
I	3.00	0.0010	9.31	1.0	0.091	9.106
J	5.25	0.0009	8.42	1.0	0.074	7.412
K	3.75	0.0010	7.45	1.0	0.073	7.287
L	6.50	0.0008	9.45	1.0	0.074	7.394
M	10.00	0.0058	15.60	1.5	0.885	58.996
N	3.25	0.0013	6.45	1.36	0.082	6.030
O	10.50	0.0009	12.46	1.0	0.110	10.968
P	12.00	0.0010	12.40	1.0	0.121	12.128
Q	3.75	0.0010	8.75	1.0	0.086	8.558
R	3.50	0.0013	5.12	1.36	0.065	4.787
S	7.50	0.0010	8.41	1.0	0.082	8.225
T	12.00	0.0058	6.30	1.5	0.357	23.825

ρ = 997kg/m3; g= 9.81

It was understood that a reduction in pump shaft input power and an increment in the height of the point of supply for the rest of the pumps (DAB JET 102M, ATLAS 125, GRANAC JET 100M (1HP)) would give rise to and increase the various pump efficiency. Also, the higher the shaft input power, the more energy is required to deliver water to the required height. From the manufacturer's menu, centrifugal pumps can achieve 94 percent efficiency, but typical efficiencies are 55 percent for small and 70 percent for large pumps. But only one pump in the study was within the range of a typical small pump. Because of wear, pump efficiency decreases over time. For equal operating conditions, the wear rate depends primarily on the design and material of the wear ring (Findik, 2014). Also, the variation in the operating parameters observed in the pumps could be a contribute factor to the low efficiencies witnessed because these parameters contribute to the overall performance of the pump.

Some contributing factors to the low efficiency of the centrifugal pump in the study area

Electrical energy, which is then transformed into pressure energy, is vital for every pump to carry out its function. To achieve optimal efficiency, it is crucial to choose the pump according to the process and application requirements. An electromotor, shaft, stuffing box, gland packing, vane, impeller, and housing are all components that come together to make a centrifugal pump. If any of these small components are not functioning correctly, it will affect the pump's overall performance.

Energy Loss

The efficiency assesses the impact of different losses experienced by the centrifugal pump as it transforms mechanical energy into liquid energy. There are three different types of internal losses in centrifugal pumps: Mechanical, volumetric, and hydraulic. Similarly, there are three distinct types of pump efficiency: mechanical, volumetric, and hydraulic. This study did, however, emphasize on hydraulic loss. The energy (H) that is transferred from the impeller to the effective liquid cannot be used entirely because there are various forms of hydraulic resistance (local resistance) and hydraulic friction (resistance along the path) that occur during the liquid's flow in the over-flow portion of the pump. These include shock, de-flow, changes in velocity direction and size, and more. Hydraulic loss refers to the amount of energy the liquid loses per unit mass when the pump is overflowing. The amount of energy the impeller releases to the liquid per unit mass is greater than the amount of energy that the pump loses as liquid per unit mass.

Pump efficiency m is a measure of the pump loss. Hydraulic efficiency is restoring the liquid's power after it has been lost due to hydraulic pressure. The power ratio of the liquid is in a condition devoid of hydraulic loss. The study and analysis of centrifugal pumps' internal energy loss characteristics have advanced substantially thanks to the research efforts of many researchers. Lin et al., (2023) discovered that the energy loss of centrifugal pumps has an impact on their performance. Centrifugal pumps may be optimized and designed with a better grasp of the energy loss process in mind (Wang et al., 2020). Lin et al., (2021) used the enstrophy dissipation approach to examine the energy loss process of pumps acting as turbines (PAT) under various flow conditions. Using this procedure, they could pinpoint precisely where the hydraulic loss had occurred. The main focus of the study by Hou et al., (2016) was on the irreversible hydraulic loss of a two-stage cryogenic submersible pump for liquefied natural gas (LNG).

The study used the entropy production theory. Kara-Omar et al., (2017) developed a program to analyze centrifugal pump performance by integrating theoretical and empirical versions of the energy loss equation. Wu et al., (2015) changed the trailing edge of the blades on the suction plane of mixed-flow pumps and added a local Eulerian head to find out how energy is lost along the flow direction of the blades inside the impeller. Based on the principle of optimizing hydraulic performance, Singh and Nestmann, (2011) used a mixed-flow pump as a study model to examine the impact of impeller rounding. Energy loss and turbulent fluid motion may be well studied using endotrophy (Lai et al., 2017).

Impeller Blade Angle

Flow or pump efficiency are both determined by the impeller, which makes it the most critical component of a centrifugal pump. When considering pump efficiency, the impeller's design and diameter are of the utmost importance. The channels and vanes of the impeller are what measure the pump's capacity. Every one of the three varieties of impellers-the open, enclosed, and semi-open varieties-serves a unique purpose. Depending on their use, impellers can be made from cast iron, carbon steel, or specialized alloys. A rotor that increases or decreases the pressure and flow of a fluid is called an impeller (Matlakala et al., 2019). The impeller, which is the critical component that converts mechanical energy into pressure energy, directly affects the hydraulic performance and transport capacity of the centrifugal pump (Matlakala et al., 2019a). The successful operation of a centrifugal pump relies heavily on the impeller's optimized design (Han et al., 2018).

The vanes or blades that push the fluid into the impeller via the eye propel it as it flows through the channel. A driving shaft can be attached to the impeller through its bore. A new pump may be made simply by changing the impeller, a part of the pump that has the most impact on the pump. Flow, differential head, and speed are all adjustable. According to Luo et al., (2008), the flow increases as the impeller size increases. According to, centrifugal pumps can regulate their performance using the impeller. The angles and diameter of the impeller's design have a significant impact on pump efficiency. The vanes of the impeller determine the pump's capacity. Li et al., (2020) determined the effect of blade placement angle on the efficiency of plastic centrifugal pumps using the velocity modulus method. Using the procedure as a foundation, the plastic centrifugal pump's flow passage components were hydraulically designed, and a two- and three-dimensional model diagram of the flow components was developed.

The impeller model's flow field was modeled and studied under various operating circumstances. To investigate how the outlet angle affects the pump's performance, researchers established models of impellers with varying angles of discharge, and they used fluid-structure interaction to learn how the angle affects the impeller's structural properties. They suggested a wrap angle design approach and a blade inlet angle design method based on the Stepanoff velocity modulus method, which takes import prerotation into account. Experiments showed that impeller structural degradation might occur at working pressures of plastic centrifugal pumps that exceeded 5 atm. The plastic centrifugal pump acquired its maximum efficiency of 81.0161 % and H of 35.8029 at an output angle of 35°. According to Kan et al., (2019), as the outlet angle increased, so did the maximum deformation of the flow field load on the impeller produced. The plastic centrifugal pump's efficiency and H decreased as the input angle increased.

Head

If the back pressure on the flowing stream goes up, a centrifugal pump can't keep up its volumetric flow rate when it's working at a constant angular velocity (Shojaeefard et al., 2012). A pump's power consumption is proportional to its output in flow and head. Power needs to be raised proportionally to the increase in flow and, or head. On the other hand, there is a negative correlation between hydraulic efficiency and power. The use of power falls as efficiency rises for a given flow and head. Since the fluid column height is devoid of the liquid's specific gravity (weight), the head is a more suitable metric to use than pressure to assess a centrifugal pump's performance (Stan et al., 2018).

The pressure differential between the system's back pressure and the pump's input pressure is termed the pump head (ΔPpump). Centrifugal pumps can attain a maximum pump head mainly by changing the shaft angular velocity, the speed of the rotating shaft, and the outer diameter of the pump's impeller. Pumping more volume through the system causes a shift in the head as well. When the system head (back pressure) on the flowing stream increases, the centrifugal pump can only handle a lower volumetric flow rate (Li et al., 2020). This is because the pump rotates at the same speed. The inflow flow area of a blade is increased as the inlet angle of the blade is raised because the blade is bent less. According to Wang et al., (2023), this results in both an increase in pump head and efficiency.

Cavitation

Pump performance and lifespan are both impacted by cavitation (Kan et al., 2022). Although it can damage various parts of a pump, the impeller is usually the one that takes the most severe damage. Even if the impeller is new, it may appear to have been in use for a long time due to the eroded and damaged material resulting from cavitation. The process of cavitation happens when a liquid in a pump evaporates at low pressure. This occurs when the Net Positive Suction Head (NPSHa) is insufficient, indicating that the pressure at the suction vacuum of the pump end is too small. Gas bubbles are formed when the vapour pressure of a fluid falls below its vapor pressure; these bubbles continue to expand as the pressure decreases, and they eventually burst when they reach a higher-pressure zone (Eckhoff, 2014). Cavitation is characterized by the formation of low-pressure air bubbles.

The bubbles burst when the liquid moves from the impeller's suction side to its delivery side. A shockwave strikes the impeller, which causes vibration and mechanical damage to the pump. This, in turn, can cause the pump to fail entirely at some point (Zhu et al., 2023). Cavitation decreases a pump's effectiveness, damages its mechanics, increases noise and vibration, and can eventually cause the pump to fail. Cavitation symptoms, such as vibration, are often the initial indications of trouble (Al-Obaidi, 2020). A few of the components of a pump that could sustain damage from vibration include the shaft, bearings, and seals. According to Mousmoulis et al., (2021), cavitation happens in a pump when the vapour pressure is equal to the temperature and pressure of the liquid at the suction of the impeller. It is possible for it to occur at typical operating temperatures and low pressures. During cavitation, bubbles are formed.

The implosion of those bubbles, which is just as explosive as an explosion, occurs as the pump pressure rises. Shockwaves from the implosion cause the impeller to sustain mechanical damage (Černetič, 2009). According to Zhang et al., (2016), centrifugal pumps' cavitation performance is susceptible to changes in the impeller's geometric design. Hence, more rigorous control is needed throughout the design phase. This allows for efficient prediction of the centrifugal pump using experimental and numerical methods, allowing for the reduction or elimination of cavitation to an acceptable level. Induced centripetal forces and the three-dimensionality of the flow make the impeller inter-blade passageways quite complex.

According to Qixiang et al., (2021), cavitation may occur in several places, including the impeller pathways, the diffuser blades, and the spiral channel. In the initial phase, bubbles collapse close to the impeller channels. The remaining bubbles in the flow are pushed to the outside areas, such as the diffuser and volute passageways, where they burst after the stage is fully matures. Most attacks on the pump occur in low-pressure zones; for example, bubbles develop on the rear face of the blade inlet when the flow velocity abruptly increases, causing the pressure to decrease.

Types of storage tanks and piping systems in the study

During this survey, various types of storage tanks and piping systems were accessed and considered. This information was used to understand the reasons behind the quantity of water supply. It was also used as a consideration for low pumping efficiency, resulting from different losses experienced by various types of piping systems seen in this study. Below is a pictorial presentation of the prevailing kinds of storage tanks and the various piping systems in the study area. From the survey, it was observed that most house owners use plastic tanks, commonly referred to as GeePee tanks, as seen in Figure 8, and their choices were influenced by cost, availability, durability, and their anti-corrosion potential.

Although most rubber tank owners prefer it to steel and fiberglass tanks because of their price, if the steel and fiberglass tanks are adequately used, their lifespan is far longer than that of rubber tanks. These storage sizes range from 750 liters to 4000 liters. However, the piping system observed in the study area was not correctly done, as seen in Figure 9a, 9b. Also, it was observed that the pipes were leaking. This could be the reason for the poor pump efficiencies recorded. The prevalent types of pipe material used in the area were polyvinyl chloride (PVC) and asbestos cement pipelines.

Figure 8 Prevalent storage tanks in the study area

Chukwurah, (2018) describes the piping system in the research area as using old, frail asbestos cement and polyvinyl chloride (PVC) pipes. Many parts of the distribution systems rely on them for hydraulic pressure, but they are no longer sufficient. The type of material that makes up the pipes determines their quality, which determines their effectiveness and efficiency (Al-Homoud, 2005). This has resulted in a typical sight of pipes breaking and water seeping into every city corner in the study area. This resulted in the frivolous disposal of accessible water resources.

Pump pipework is designed to facilitates the transfer of liquids to and from a pump while ensuring the pump remains reliable and efficient. Conversely, insufficient system piping is the root or a contributing factor in many pump performance and reliability issues (Klingel, 2012). Regarding a pump's efficiency, the suction pipe is far more critical than the discharge pipe. To prevent cavitation and the damage it causes, suction pipework distributes the liquid flow to the pump suction in an even pattern while maintaining a pressure high enough to harm the pump. This situation poses many risks to the pump as it requires the suction pipe to convey the liquid to it.

Figure 9a Piping layout at reservoir area

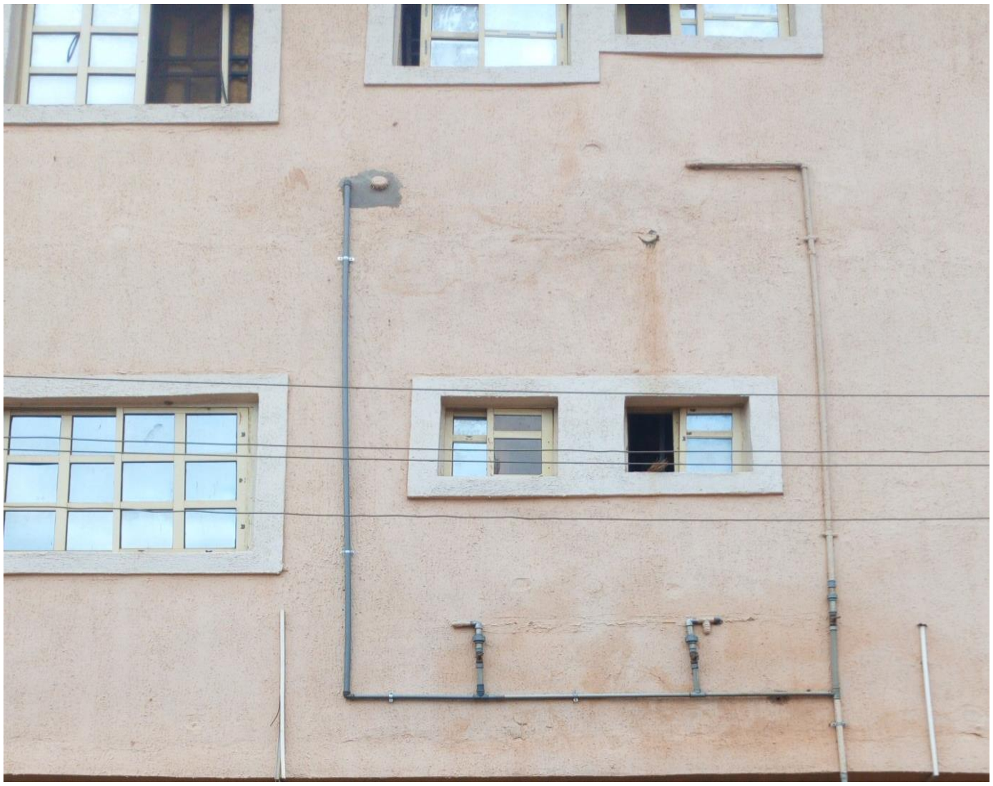

Figure 9b Piping arrangement supplying water to the building

4. CONCLUSION

The water supply in Nsukka, Enugu State, is less than satisfactory. People living in high-rise buildings in the southern part of Nigeria are greatly concerned about the lack of access to potable water. Considering this, it is clear that Enugu has a severe problem with a sufficient supply of clean water and that residents of this state have increasingly turned to other water sources in recent years. Residents of high-rise buildings use alternative methods to obtain potable water. Still, they must purchase pumps to ensure water is effectively delivered to the required heights, as the relevant authorities are not adequately addressing the water supply challenge to these buildings. An essential part of the water distribution system is the centrifugal pump. Factors such as electrical energy, pump flow rate, and impeller rotational speed determine the centrifugal pump's operational efficiency. The pumps in the study area are mainly below the required capacity, and their efficiency in supplying water is low, which also attributes to the fact that energy is lost in pumping water.

These energies lost in water pumping will reduce the amount of water supplied by the pump, not reaching the water demand. From the results of the analysis, it was observed that the current state of water demand in the study area is high, but the supply is relatively low. Also, most high-rise buildings in the study area that use water pumps suffer a significant loss in the amount of water to be supplied to their households. This is because there is a lack of awareness about the correct type of pump to be used and the required height at which it is designed to function effectively. Also, the erratic power supply in the area is a contributing factor to the inefficiency of the pump. Maintenance of these water pumps and improper piping systems are another factor that causes a reduction in the amount of water supplied. There is a need for both the authorities concerned and the people to adopt more vigorous strategies to improve the pathetic water supply situation in high-rise buildings.

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Conceptualization, CCN; methodology, CCN and UUU; formal analysis, CCN and UUU; investigation, CCN and UUU; resources, CCN, UUU and ARI; data curation, CCN and UUU; writing—original draft preparation, CCN, UUU and ARI; writing—review and editing, CCN, UUU and ARI All authors have read and agreed to the published version of the manuscript.

Informed Consent

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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