Water Demand Modelling and Estimation in a Developing Nigerian Public University: A Case Study of Federal University, Otuoke

Churchill Ebinimitei Simon[1], and Richard Ifeanyichukwu Emmanuel[2]
Department of Civil Engineering, Federal University Otuoke, P.M.B. 126, Yenagoa, Bayelsa State, Nigeria.
DOI: 10.56201/ijemt.vol.11.no4.2025.pg183.196

Abstract
University campuses within Nigeria are facing the problem of providing portable water of adequate quantity and quality and the sustainability of such supply. This paper examines the water demand status of a public University in Nigeria, Federal University Otuoke (FUO). Domestic, Industrial, Fire, Water losses and Landscape irrigation water uses were considered while population forecasting was done using regression analysis for a 30 years design period (2024 – 2054). Results revealed possible population increase of 26.6 % by 2054 when the institution will clock 43 years. Water demand is also expected to rise sharply from 2,136.9 m^3 day-1 (2024) to 22,164.4 m^3 day-1 (2054); the existing system of water supply cannot satisfy the current population not to talk of the projected demand hence, a reservoir of about 23,000 m^3 will be needed to service the university for the next 30 years. The non-residential population water demand was seen to be more than the residential population, owing to their increased number. Attracting more investments into the water supply system becomes imperative as the existing stand-alone boreholes supply system is totally not suitable and unsustainable.

Keywords: *Water Demand; Population; Forecasting; University; Design period*

1.0 Introduction

Water is a very vital resource for life on Earth, its impact on food and energy, security, human and environmental health cannot be over-emphasized. Water contributes to improvements in social well-being and inclusive growth, affecting the livelihoods of billions of people all over the world. It is the second most abundant substance in the universe and makes up 75% of our bodies (Wikipedia, 2024). Water is everywhere, covering approximately 71% of the Earth's surface and sustaining the existence of all living things (Wikipedia, 2024). All living things need water to survive, and without it, life as we know it would not exist. However, its distribution is uneven, leading to scarcity in many regions (BBC, 2024). It plays a pivotal role across sectors such as agriculture, industry, institutional, environmental and domestic consumption. According to UNICEF (2024), nearly half of humanity faces severe water scarcity during at least one month each year. As populations grow with urbanization, its demand is intensified leading to pressures on existing water supplies. Therefore, water demand refers to the quantity of water required to meet human needs within a specific area or system. Understanding water demand is crucial for managing water resources effectively and ensuring sustainable water supply, (Cypress Engineering, 2024).

Inadequate water supply in institutions of higher learning (universities) can be caused by a variety of factors, including poor water management, growing demand, water pollution, and droughts due to climate change (Mishra *et al.*, 2017). In addition, inadequate infrastructure and distribution systems, contamination, conflict, and poor management of water resources can also contribute to water scarcity. It is then crucial to recognize the unique challenges faced by growing institutions like Federal University Otuoke (FUO), which require reliable water supply systems to support their academic endeavors, research activities, and students well-being. This issue directly impacts on the daily operations and well-being of the university community. Addressing this problem is crucial for ensuring a conducive learning and working environment at FUO. By accurately estimating water demand and proposing solutions, the university can enhance its infrastructure and support sustainable water management practices.

1.1 Aim and Objectives

This project aims to develop a sustainable water demand design and estimation that will provide adequate water supply for FUO through the various objectives;

- To estimate the current and future water needs considering student population growth as well as University staff.
- To provide a correct estimated Per Capital Demand of water in FUO.
- To access Federal University Otuoke population growth trends over the years.
- To design a comprehensive water demand estimation model tailored to FUO.
- To provide recommendations for sustainable water management strategies based on the estimation outcomes.

2.0 Material and Methods

2.1 Study Area/Site

The Federal University Otuoke (FUO) is a federal university established by the Federal government in February 2011, about thirteen (13) years ago. It is located in Otuoke town within the Ogbia local government area of Bayelsa State, Southern Nigeria. The site for the University covers a total area of 192.6 hectares of land and located within coordinates of Latitude 4°47'52.91"N, and Longitude 6°19'16.36"E respectively (DoW FUO, 2024; Wikidata, 2024). Initially, the university began with 282 pioneer students in 2011. FUO's academic programmes started in earnest in 2012 with two Faculties; Science, and Humanities and Social Sciences.

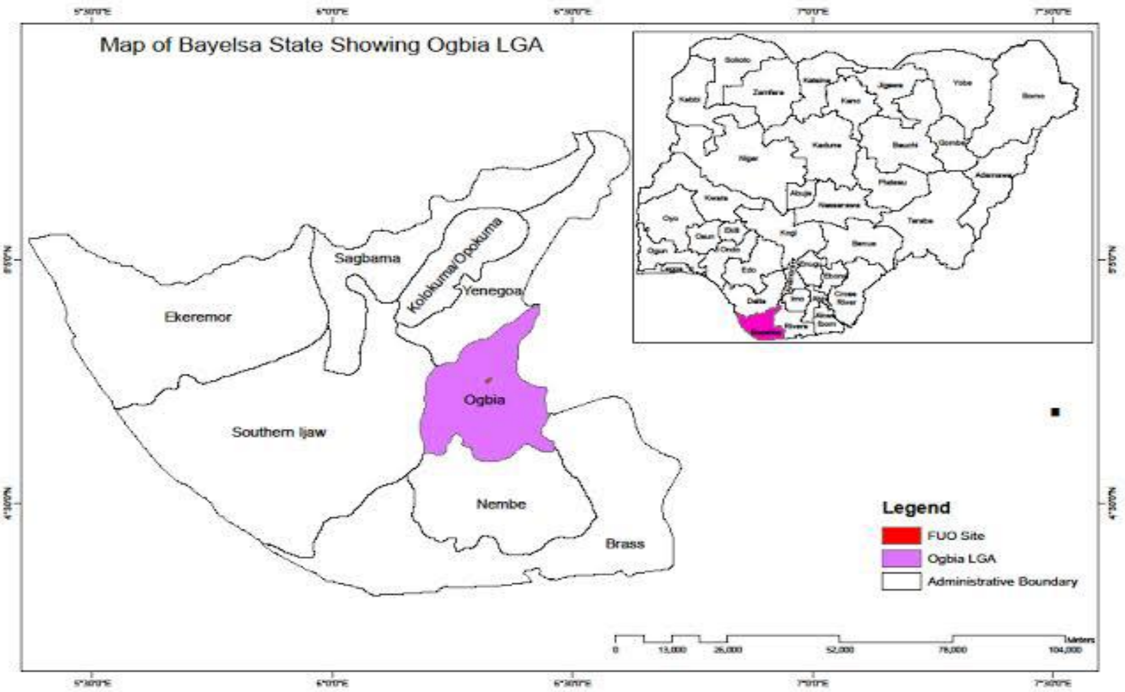

Figure 1.0: Map of Ogbia LGA in Bayelsa State showing location of our study area

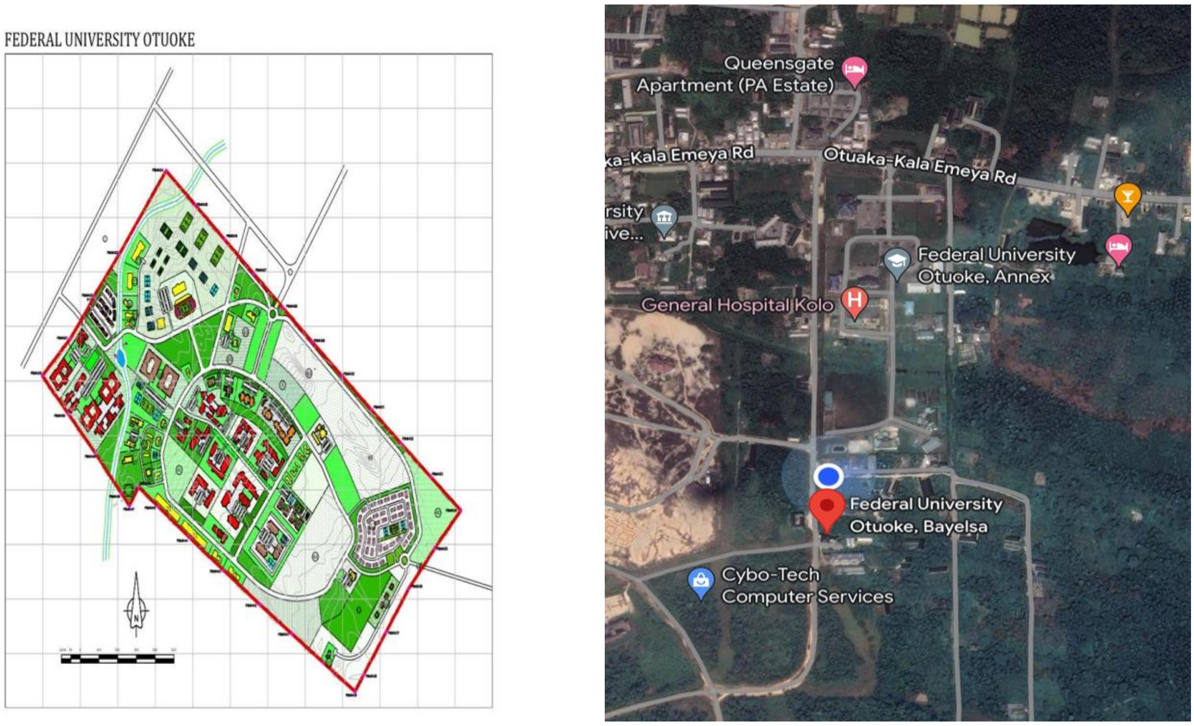

Figure 2.0: Master Plan and Satellite

Image of Federal University Otuoke (FUO) Campus

The university is still considered to be within its growing stages; however, it is important to state that it has witnessed tremendous growth and an ever-increasing students' population enrolled in eight (8) Faculties, with fifty (50) academic programmes, one (1) post graduate school, one (1) institute of foundation studies and one (1) School of basic studies.

At the time of this study, there was no centralized water supply system on the campus. The university is currently running sectionalized stand-alone water wells drilled into the basement complex rocks underlying the campus with very low yield that only provides for each department or faculty as the case may be. This has inadvertently led to the prevalent water scarcity which has continued unabated. The recent plan by the University administration to expand its carrying capacity according to the master plan by building the needed infrastructure, including a centralized water treatment and distribution system is commendable. This will bring to an end the difficulty of having individual boreholes that have negatively plagued us with water scarcity. This new development requires the evaluation of current and future water demand of the campus as the university is continually growing. The recent efforts to transform the university into a full fletched university with the addition of Colleges of Medicine, Law, post graduate programmes etc, will no doubt exacerbate the water crisis which cannot be ignored. There is therefore the need to plan for the expected increase, so that adequate water infrastructures can be provided on campus. The aim of this study therefore, was to model the water demand of the Federal University Otuoke, Bayelsa State, Nigeria as an important input for the development of a sustainable water supply system on the campus.

The student population has grown over the years to over 12,000 comprising eight faculties and operates on two campuses as at 2024. Faculties include Management Sciences, Social Sciences, Education, Engineering, Sciences, Humanities, Medical Sciences and Nursing. The university offers a range of degree programs at both undergraduate and postgraduate levels, (ICT FUO, 2024).

2.2 Data collection

Important data such as student enrolment, graduation, Staff population, University Master Plan and water distribution infrastructure were obtained from relevant units of the university such as Information and Communication Technology (ICT), FUO registry, admission office and Establishment office. Thematic maps of the campus and satellite imageries were obtained from the physical planning unit and some extracted from the internet (Google Earth®).

2.3 Study Assumptions

A university campus has a typical urban status regardless of how remotely sighted it might be, the modern infrastructures found in university campuses and the standard of living of its residents is an indication of the huge water demand. Science and Engineering based universities are among the heavy users of water because of the presence of many laboratories, workshops, industrial parks, hostels, residential quarters, beautifully maintained lawns and gardens, and even livestock housing as well as irrigated farms.

This study was based on the following assumptions:

I. The staff-to-student ratio provided by the Nigerian University Commission (NUC) was used to project academic staff numbers.
II. 30% of the student body, academic staff, and non-academic staff were assumed to reside on campus, after the survey.
III. Service providers, including taxi/bus drivers, cleaners, gardeners, canteen operators, visitors and shop operators, were estimated to comprise 1% of the total student and staff population.
IV. Industrial water demand was estimated at 1% of domestic water consumption due to minimal industrial activities presently on campus.
V. All proposed colleges (Law and Medicine) will be established within the 30-year design period.
VI. Adequate funding for expansion is assumed to be available throughout the design period.
VII. 10% of the total water demand was considered sufficient for landscape irrigation during the dry season.

2.4 Study Limitations

The study was constrained by the following limitations, which influenced its findings:

I. The data used for forecasting student population from 2011 to 2020 primarily included undergraduate students, whereas from 2021 to 2024, the data encompassed both undergraduate and postgraduate students.
II. The study did not consider students enrolled in sub-degree programs (Joint Universities Preliminary Educations Board, JUPEB), as well as those enrolled at the Center for Niger Delta Studies and Sustainability due to the fact that they just started.

2.6 Population Forecast

As stated by Donkor *et al. (*2014), a range of forecasting methods exists, with the choice depending on the quantity and quality of data, the desired forecast horizon, and the availability of time and resources. Time series modeling methods was used for the forecasting of future population.

The student population forecast involved fitting the available enrollment data to various statistical models such as exponential, linear, nonlinear, logarithmic, moving average, and exponential smoothing through regression and time series analysis. The model with the highest coefficient of determinacy (R^2) and minimal errors was chosen for projecting future years. To validate the accuracy of the forecast, the predicted data was plotted against the actual data.

2.7 Water Demand Estimation

The following water demands were considered, domestic water usage (for hostels, lecture halls, offices, and the health center), public water usage (for firefighting, landscape irrigation, and construction), and industrial water usage (including the FUO garden and livestock farms).

3.0 Results and Discussions

3.1 Population Modelling

Table 1.0 below showed an evaluation of the population distribution within the campus between staff and students reflecting the ideal Nigerian University Commission's (NUC) acceptable standards.

Table 1.0: Calculation of Present (2024) Population Distribution on Campus between Students and Staff.

Students & Staff Distribution	Ratio	Population	Source
Current Students' Population	-	14,609	FUO ICT
Academic Staff	1:20 (Average Academic Staff to Students Ratio)	731	NUC Recommendation
Administrative Staff	1:2 (Administrative Staff to Academic Staff Ratio)	365	Concluded after assessment of the various years from collected data.
	Total Staff Population	1,096	
Total Students and Staff Population		**15,705 Persons**	

Table 2.0 below showed the population distribution of the residential and non-residential population groups within the study to ascertain the actual population for water demand.

Table 2.0: Calculation of Population groups for Water demand

Reference		Study Assumptions/Data Computation	Population for Water Demand
Residential Population	Students	30% of Students Population	4,382.7
	Total Staff	30% of Staff Population	328.8
Non-residential Population	Students	70% of Students Population	10,226.3
	Total Staff	70% of Staff Population	767.2
Service Providers, Drivers, Gardeners, Visitors and Shop Operators, etc		1% of Total Population on Campus	157
Total Current Population for Water Demand			**15,862 Persons**

As per International Standards (IS 1172:1993), the standard for Urban water supply for low-income group has been assumed as 135 LPCD, whereas that of High-income group as 200 LPCD. However, the LPCD from various studies and research for on-campus resident is 150 LPCD, while that of non-residents is 50% of residential LPCD. The assumed volume of water used by service providers and others is 50 LPCD as reflected in table 3.0 below.

Table 3.0: Estimating Per Capita Demand of Water in Federal University Otuoke (FUO)

<table>
<tr><th colspan="2">Type of Water Demand</th><th>Liters Per Capita Demand (LPCD)</th><th>Study Computation/Formula</th><th colspan="2">Volume of Water Per Day</th></tr>
<tr><td rowspan="3">Domestic Water Demand</td><td>Residential Population</td><td>150</td><td>4711.5 people × 150 litres/day</td><td>706,725</td><td rowspan="3">1,539,088</td></tr>
<tr><td>Non-Residential Population</td><td>75</td><td>10993.5 people × 75 litres/day</td><td>824,512.5</td></tr>
<tr><td>Service Providers and others</td><td>50</td><td>157 people × 50 LPCD</td><td>7,850</td></tr>
<tr><td colspan="2">Industrial Water Demand</td><td>-</td><td>1% of total domestic water demand</td><td colspan="2">15,391</td></tr>
<tr><td colspan="2">Fire Demand</td><td>-</td><td>Using Kuching's formula ($Q = 3182\sqrt{P}$)</td><td colspan="2">12,728</td></tr>
<tr><td colspan="2">Water Losses</td><td>-</td><td>15% of total domestic water demand</td><td colspan="2">230,863</td></tr>
<tr><td colspan="2">Landscape Irrigation</td><td>-</td><td>10% of total domestic water demand</td><td colspan="2">153,909</td></tr>
<tr><td colspan="2">Total Water Demand</td><td></td><td></td><td colspan="2">1,951,979 Liters/day</td></tr>
<tr><td colspan="2">Calculating Average Per Capita Demand for the Entire Population</td><td></td><td>Total daily Water Consumption ÷ Total Population = $(\frac{1951979}{15862})$</td><td colspan="2">123.1 LPCD</td></tr>
<tr><td colspan="2">Adjusting for margins of Safety and Future Considerations</td><td></td><td>10% of LPCD</td><td colspan="2">12.31</td></tr>
<tr><td colspan="2">Actual Average Per Capita Demand</td><td></td><td>Per Capita Demand + Margin of Safety</td><td colspan="2">135.4 LPCD</td></tr>
</table>

3.2 Population Forecast Using Time Series Analysis

In various studies, making population forecasts in a university, the choice between using the number of students enrolled each year versus the total number of students presently studying on campus is crucial. Using the number of students enrolled each year is generally more effective.

Table 4.0: FUO Students Enrollment Data, 2011 - 2024 (FUO ICT, 2024)

S/N	Academic Session	Enrolled Number of Students
1	2011/2012	282
2	2012/2013	373
3	2013/2014	382
4	2014/2015	496
5	2015/2016	649
6	2016/2017	2347
7	2017/2018	2567
8	2018/2019	2689
9	2019/2020	2888
10	2020/2021	2433
11	2021/2022	2116
12	2022/2023	2332
13	2023/2024	4087

The existing student enrollment data was fitted into exponential, polynomial, logarithmic and moving average models as shown in Figures 3.1 – 3.2 below. The best model with the highest coefficient of determinacy (R^2) and least errors was the moving average model, where R^2 was 0.86 as shown in Figure 3.2.

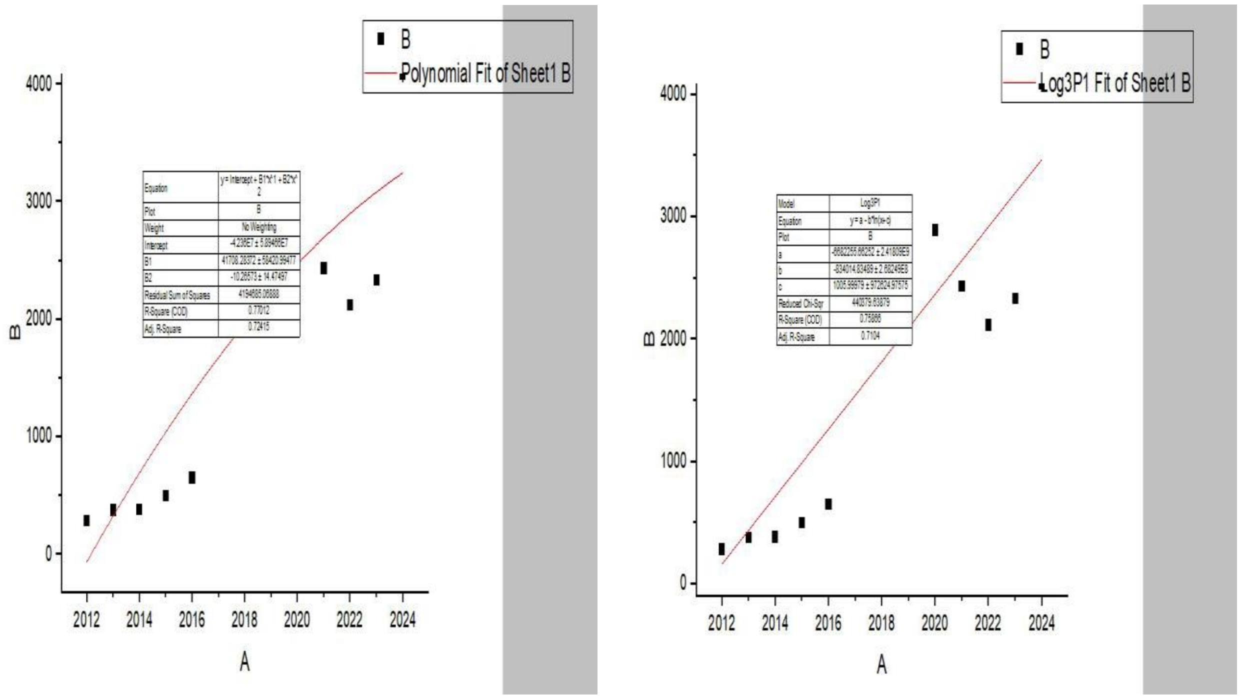

Fig 3.1: Fitting of Existing Student Enrollment Data Using the Polynomial and Logarithmic Models

The Index Year was 2011 – 2024, where the coefficient of determinacy (R^2) was 0.77 for the polynomial and 0.76 for the logarithmic models respectively. The logarithmic graph indicated a steady increase of growth in the University's population over the years however had a minimal Coefficient of determinacy compared to moving average model.

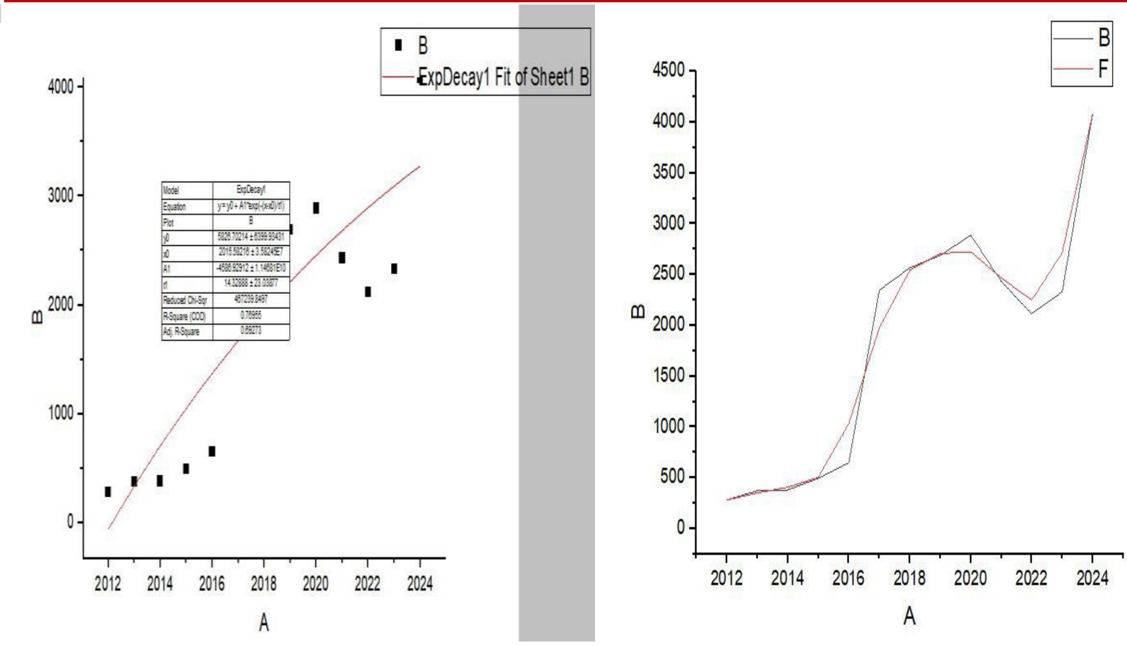

Figure 3.2: Fitting of Existing Student Enrollment Data Using the Exponential and Moving Average Models

Similarly, the Index Year was 2011 – 2024, where the coefficient of determinacy (R^2) was 0.77 for the exponential model and 0.86 for the moving average model, indicating that the moving average model was the best to be applied. Figure 3.1, and 3.2 illustrated the 13 years trend in student enrollment at the University, revealing a consistent growth in the student population over time. This increase is directly linked to the University's physical expansion and the subsequent rise in the number of academic programs offered. However, the moving average model showed a higher coefficient of determinacy and was further used for projection of future populations.

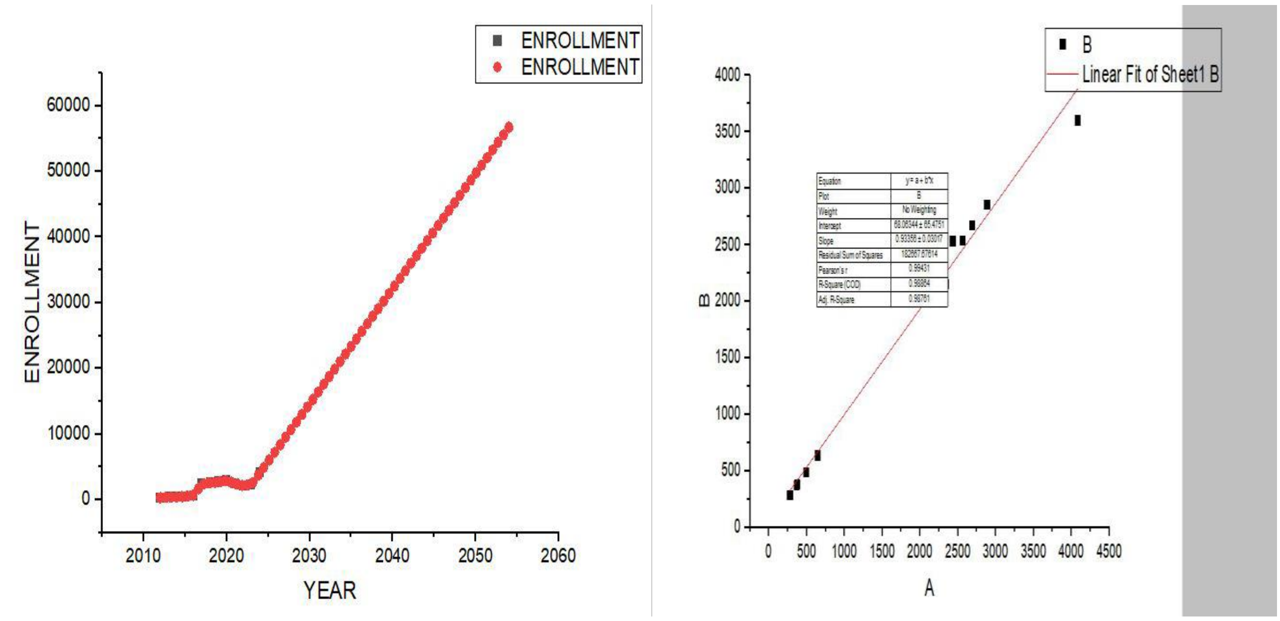

Figure 3.3: Student Population Forecast and its Verified Forecast Using the Moving Average Model

Figure 3.3 above showed the relationship between the Model student predicted enrollment represented with letter 'A', while the actual students' enrolment is denoted with letter 'B'. the coefficient of determinacy (R^2) is 0.98. To verify the Coefficient of determinacy (COD) of the forecasted population values in figure 3.3 above, the present (actual) data was plotted against the forecasted data which indicated a COD close to 1.
This showed that our forecasted values were in line with the data from the University's existing population.

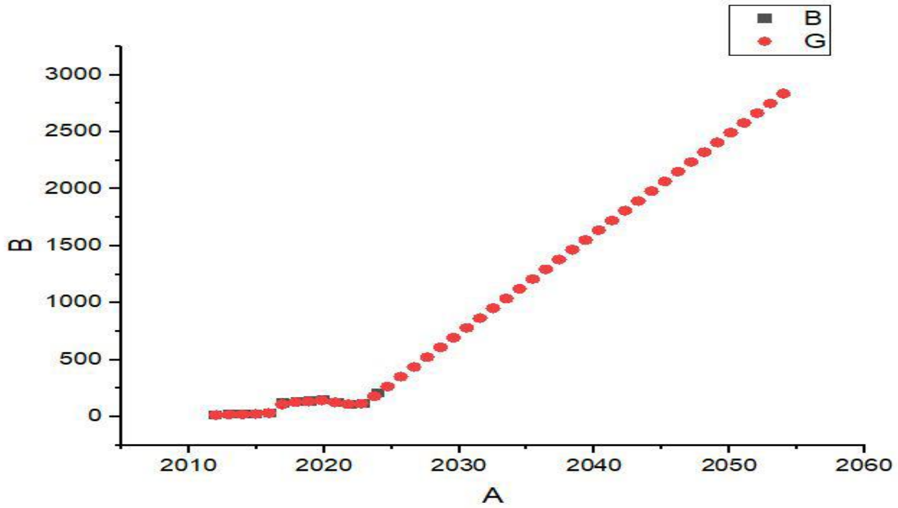

Figure 3.4: Staff Population Forecast Using the Moving Average Model

Currently, only a fraction of the University's students resides on campus, with no accommodation provided for academic or non-academic staff. This approach falls short of international best practices for higher education. It is essential for the university to offer housing for staff who are interested, fostering a better exchange of ideas and collaboration.
Figure 3.4 showed an increase in staff population in relation to the students population increase on campus.

Table 4.1: A Thirty (30) Years Design Period Predicted Population in FUO (2024-2054)

Year	Academic Session	Predicted Students' Population	Residential Population (30%)	Non-residential Population (70%)
1	2024/2025	5311.4	1593.42	3717.98
2	2025/2026	7025.6	2107.68	4917.92
3	2026/2027	8739.8	2621.94	6117.86
4	2027/2028	10454.1	3136.23	7317.87
5	2028/2029	12168.2	3650.46	8517.74
6	2029/2030	13882.4	4164.72	9717.68
7	2030/2031	15596.5	4678.95	10917.55
8	2031/2032	17310.7	5193.21	12117.49
9	2032/2033	19024.9	5707.47	13317.43
10	2033/2034	20739.1	6221.73	14517.37
11	2034/2035	22453.3	6735.99	15717.31

12	2035/2036	24167.5	7250.25	16917.25
13	2036/2037	25881.7	7764.51	18117.19
14	2037/2038	27595.8	8278.74	19317.06
15	2038/2039	29310	8793	20517
16	2039/2040	31024.2	9307.26	21716.94
17	2040/2041	32738.4	9821.52	22916.88
18	2041/2042	34452.6	10335.78	24116.82
19	2042/2043	36166.8	10850.04	25316.76
20	2043/2044	37881	11364.3	26516.7
21	2044/2045	39595.1	11878.53	27716.57
22	2045/2046	41309.3	12392.79	28916.51
23	2046/2047	43023.5	12907.05	30116.45
24	2047/2048	44737.7	13421.31	31316.39
25	2048/2049	46451.9	13935.57	32516.33
26	2049/2050	48166.1	14449.83	33716.27
27	2050/2051	49880.3	14964.09	34916.21
28	2051/2052	51594.4	15478.32	36116.08
29	2052/2053	53308.6	15992.58	37316.02
30	2053/2054	55022.8	16506.84	38515.96

Table 4.1 showed the predicted students' population of Federal University Otuoke (FUO) within a thirty (30) years design period between 2024 - 2054. It includes the 30% residential and 70% non-residential population of the University.

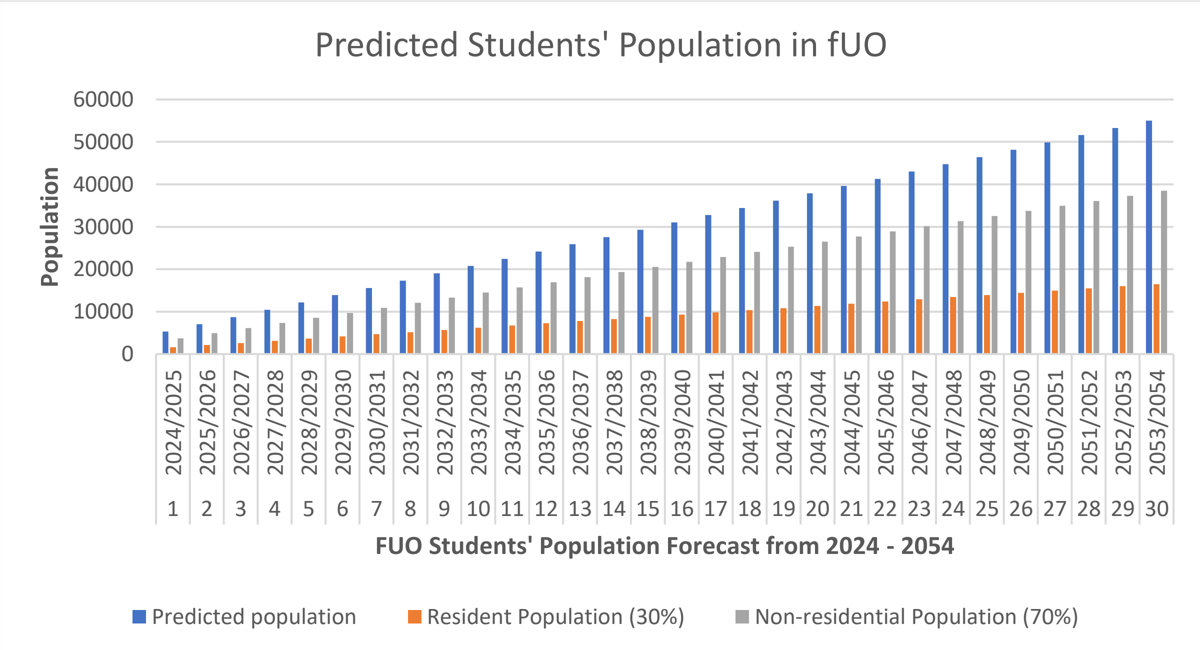

Figure 3.5: Predicted Residential and Non-residential Students' Population in FUO

Figure 3.5 showed the predicted residential and non-residential students' population forecast of FUO over the next 30 years design period. It showed that for every additional year, there is a corresponding increase in students population as also shown in table 4.1 above.

3.3 Calculation of Daily Water Demand of Thirty (30) Years Design Period

Total forecasted students population = 55,023 persons (Table 4.1)
Staff population analysis according to NUC guidelines;
Recall, if 1 staff = 20 students
∴ Number of academic staff = 55,023/20 = 2751.15 persons
Also, if 1 administrative staff = 2 academic staff
∴ Number of administrative staff = (2751.15)/2 = 1375.58 persons
Total number of staff = 4126.7 persons
Therefore, total population; Students + Staff = 55,023 + 4126.7 = 59,149.7 persons
Population of service providers and others = 1% of 59,149.7 = 591.5
Therefore, Total population for water demand = 59,149.7 + 591.5 = 59,741.2 ≈ 59,741 persons
Recall that Per Capita Demand of water have been estimated to be 135.4 Litres
Also;
Total daily water demand = Total population × Average Per Capita Demand ………………..1.0
Eqn 1, was used for the Annual daily water demand for the various years, as reflected in table 4.2 below.

Table 4.2: Predicted Annual Daily Water Demand in FUO (2024 - 2054)

Year	**Academic Session**	**Total Population for Water Demand (Student + Staff + Service providers and others)**	**Annual Water Demand (MCM)**
1	2024/2025	5766.9	0.78
2	2025/2026	7628.1	1.03
3	2026/2027	9489.2	1.28
4	2027/2028	11350.41	1.54
5	2028/2029	13211.58	1.79
6	2029/2030	15072.77	2.04
7	2030/2031	16933.9	2.29
8	2031/2032	18795.1	2.54
9	2032/2033	20656.3	2.80
10	2033/2034	22517.5	3.05
11	2034/2035	24378.4	3.30
12	2035/2036	26239.8	3.55
13	2036/2037	28101.0	3.80
14	2037/2038	29962.19	4.06
15	2038/2039	31823.4	4.31
16	2039/2040	33684.3	4.56
17	2040/2041	35545.7	4.81
18	2041/2042	37406.89	5.06
19	2042/2043	39268.1	5.32
20	2043/2044	41129.2	5.57
21	2044/2045	42990.4	5.82
22	2045/2046	44851.6	6.07
23	2046/2047	46495.5	6..30
24	2047/2048	48574.0	6.58

25	2048/2049	50435.1	6.83
26	2049/2050	52296.3	7.08
27	2050/2051	54157.49	7.33
28	2051/2052	56018.7	7.58
29	2052/2053	57879.2	7.84
30	2053/2054	**59741.0**	**8.09**

NB: Million Cubic Meters (MCM)

The study revealed an important need to expand the water supply infrastructure on campus if sustainable water supply is to be achieved within the life of the institution. Results of this study as shown in table 4.2 above, the annual water demand range between 0.78 – 8.09 million cubic meters (MCM) from 2024 – 2054, this implies a daily water demand of 2,136.9 – 22,164.4 m^3 of water. It is therefore appropriate to design a water supply system using the maximum demand within the design life of the system, hence, a distribution reservoir of about 23,000 m^3 capacity should be planned, to serve the campus for the next 30 years.

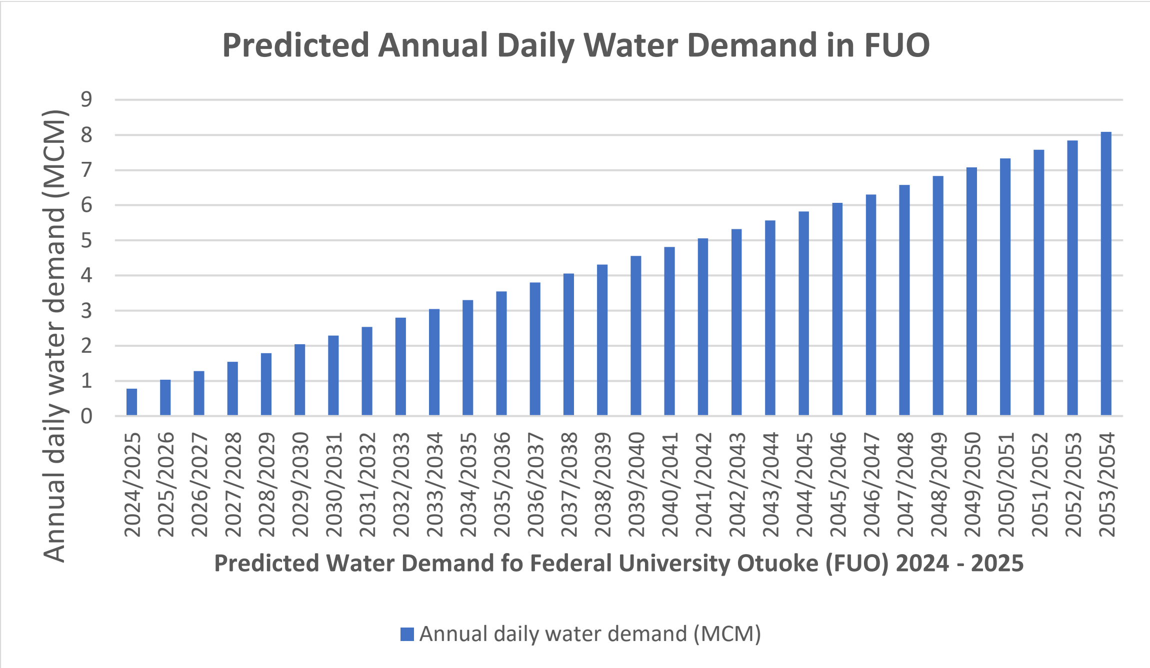

Figure 3.6: Projected Water Demand of FUO (2024-2054)

According to this study, the campus needs a distribution reservoir of about 2,500 m^3 capacity, which is a far cry from the projected or predicted demand in the next 30years of the institution's life to provide adequate water to support academic activities. In view of this, the university administration needs to have a long-term plan of mobilizing funds for this important development project either through sourcing for grants or public – private – partnership (PPP) arrangement.

4.0 Conclusion

Water demand analysis of the fast-growing Federal University Otuoke (FUO) had been evaluated. Results showed that the present water supply system is not suitable and sustainable for an institution such as this. Expected increase in the academic programmes and population of the university will exacerbate the problem, therefore, an additional investment in the water supply infrastructure is required urgently to ameliorate the impending water crisis. The study also revealed that the non-residential population water demand was more than the residential population, owing to their number. As a short-term measure to manage the water demand, the university is advised to implement the installation of water saving devices in departments and faculties where the stand-alone boreholes are functional.

5.0 Acknowledgement

The authors wish to acknowledge the support received from the ICT unit, Academic Planning Unit and the Physical Planning Unit of the Federal University Otuoke (FUO), Bayelsa, Nigeria.

Reference:

A.K Mishra and R.K Singh (2017). Water management in universities: A review of challenges and opportunities. *Journal of water resources planning and management,* 143(10), 12-34.

British Broadcasting Corporation(BBC). (2024). Water insecurity - the demand for water - Eduqas: Global distribution of water. Retrieved from https://www.bbc.co.uk/bitesize/guides/zwfcnbk/revision/1.

Cantin B., Shrubsole D. and Aït-Ouyahia M. "Using Economic Instruments for Water Demand Management: Introduction", Canadian Water Resources Journal, Vol. 30, Number 1, 2005, pp. 1–10

Cypress Engineering. (2024). What is water demand? - Factors and management strategies. https://cypressei.com/engineering/what-is-water-demand/

Directorate of Works (DoW) and physical planning, FUO (2024). Unpublished

Donkor E. A., Mazzuchi T. A, Soyer R. and Roberson J. A., "Urban Water Demand Forecasting: Review of Methods and Models", J. Water Res. Plan. and Mgt. Vol. 140, Issue 2 (2014).

Federal University Otuoke Master plan 2015. Unpublished

Information and Communication Technology (ICT) Unit, FUO (2024). Unpublished

United Nations International Children's Emergency Fund (UNICEF). (2024). Water scarcity; Addressing the growing lack of available water to meet children's needs. Retrived from https://www.unicef.org/wash/water-scarcity.

Wikidata, (2024). Federal University Otuoke, Bayelsa State. Link, https://www.wikidata.org/wiki/Q22080808 Accessed on the 20/12/2024.

Wikipedia (2024). Water. Retrieved from https://en.m.wikipedia.org/wiki/Water. Accessed 24/11/2024.