Socialscientia Journal of the Social Sciences and Humanities
Email: socialscientiajournal@gmail.com
Online access: https://journals.aphriapub.com/index.php/SS/

Spatio-Temporal Variability and Equity in Urban Water Distribution: Insights from Uyo Capital City, Nigeria

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Abstract

The provision of pipe-borne water is critical to ensuring access to clean and safe water, particularly in urban centres. This study investigates the spatio-temporal distribution of pipe-borne water supply in Uyo Capital City, Akwa Ibom State, Nigeria. The research aims to assess the extent, pattern, and variability of water distribution over time and across different locations within the city. A mixed-methods approach was adopted, combining spatial analysis using Geographic Information System (GIS) tools and household surveys to collect data on water access, reliability, and distribution infrastructure. The study also involved interviews with water utility authorities and local stakeholders to understand the challenges facing water supply systems in the city. The findings indicate that the distribution of pipe-borne water in Uyo is uneven, with certain areas receiving more consistent water supply than others. Peripheral regions of the city are particularly disadvantaged, experiencing irregular water access, while central districts tend to have better coverage and reliability. Temporal analysis reveals that water supply fluctuates significantly over different periods of the day, with early mornings and late evenings showing the highest water availability. This inconsistency in water supply is attributed to outdated infrastructure, population growth, and inefficient management practices within the water utility system. Additionally, the study highlights the socio-economic disparities in access to pipe-borne water, with wealthier neighborhoods generally having better access compared to poorer areas. The research concludes that the spatio-temporal distribution of water supply in Uyo Capital City poses significant challenges to equitable access and sustainability. It recommends that the government and relevant authorities invest in upgrading water infrastructure, particularly in underserved areas. The study also suggests the implementation of more efficient water management practices, the use of smart technologies for monitoring water distribution, and community engagement in water resource management. These steps are essential for improving access to pipe-borne water in Uyo and ensuring a more equitable and sustainable water supply system for its residents.

Keywords: GIS analysis, pipe-borne water, Spatio-temporal distribution, Uyo, water supply,

Introduction

Urban water demand continues to rise globally due to factors such as population growth, urbanization, and industrialization (Wu, Liu, & Deng, 2023). The increasing concentration of people in cities has intensified the strain on water supply systems, making the equitable

distribution of water a critical challenge for urban planners and policymakers (Hachaichi, & Egieya, 2023). According to Mishra, (2023), about 55% of the global population resides in urban areas, a number expected to increase to 68% by 2050, further exacerbating demand for essential resources like water. Urban water supply systems are essential for public health, sanitation, and economic activities, and the failure to meet this demand can lead to severe socio-economic impacts (Beker, & Kansal, 2024).

Water distribution remains a global concern, especially in regions experiencing water scarcity and uneven resource management (Scanlon, et al., 2023). In cities worldwide, the spatial variability in water access, combined with aging infrastructure and insufficient investment in water systems, leads to unequal access to clean water (Zhai, et al., 2023). In some urban areas, water distribution systems fail to reach informal settlements, while in others, the wealthier sections of society enjoy uninterrupted access, exacerbating social inequalities (Tayo, 2023). Additionally, global climate change has had a significant impact on water availability, with many regions experiencing prolonged droughts or unpredictable rainfall patterns, further straining water distribution networks (Jabal, Khayyun, & Alwan, 2023). These global challenges call for more innovative and inclusive water management strategies to ensure equitable access to water across urban centers (Keller, 2023).

In some African countries such as Nigeria, Kenya and Ghana, urban water distribution is fraught with challenges′ such as poor infrastructure, governance issues, and growing demand due to rapid urbanization (Mutandwa, & Vyas-Doorgapersad, 2023). Many African cities, such as Nairobi, Lagos, and Addis Ababa, struggle to provide reliable water access, with residents of informal settlements often bearing the brunt of inadequate water services (Ansah, et al., 2024). In sub-Saharan Africa, nearly 63% of the urban population does not have access to piped water, leading to significant inequalities in access (Frimpong, Mensah, & Ablo, 2024). Poorly maintained infrastructure, water theft, and mismanagement of resources further exacerbate the problem (Mokgobu, 2023). The lack of investment in water supply systems and the growing demand for water due to population growth have intensified these challenges (Tzanakakis, Paranychianakis, & Angelakis, 2020). As a result, Africa's water distribution systems need urgent reforms to ensure equitable and sustainable access to water for all urban residents.

Nigeria, one of Africa's most populous nations, faces severe challenges in urban water distribution due to rapid urbanization, infrastructural decay, and inadequate management of water resources (Shiru, et al., 2020). In many cities, including Lagos and Abuja, spatio-temporal variability in water supply is common, with significant disparities between different urban areas (Okikiola, & Alo, 2020). Akwa Ibom State, particularly its capital Uyo, is no exception. In Uyo, the water distribution network is characterized by frequent interruptions, outdated infrastructure, and inconsistent supply, resulting in a significant portion of the population relying on alternative sources such as boreholes and untreated surface water (Ikpeh, 2019). The rapid growth of the city has outpaced the expansion of the water infrastructure, leaving many residents without access to safe and reliable water. As a result, addressing the spatio-temporal distribution of water in Uyo is critical to improving urban water equity and ensuring that all citizens have access to clean water. This study seeks to assess these challenges and offer recommendations for more equitable water distribution in the city.

Problematic Access to clean and reliable water supply remains a critical challenge in Nigeria, significantly affecting the health and livelihoods of urban populations. In Uyo, the capital city of Akwa Ibom State, residents face persistent difficulties in meeting their daily

water needs due to inadequate infrastructure and inconsistent service delivery. Rapid population growth and urbanization have led to an increased demand for water, yet the existing supply systems are unable to cope, forcing many households to rely on alternative sources such as boreholes and unsafe surface water. This situation often results in health risks and the prevalence of waterborne diseases (Heidari, Arabi, Warziniack, & Sharvelle, 2021).

The spatial and temporal variability in water supply further exacerbates the difficulties faced by Uyo's residents. Many neighborhoods experience sporadic access to water, while others may go without it for extended periods. This inequity not only breeds frustration and social tensions among residents but also hinders local authorities' efforts to provide equitable services (Nigerian National Bureau of Statistics, 2020). Poor maintenance of infrastructure, inadequate funding, and limited community involvement in water resource management significantly contribute to the ongoing crisis (Eja, Essien, Itu, & Ekong, 2020).

Moreover, the environmental ramifications of inadequate water supply are noteworthy. The reliance on alternative water sources, often in the context of poor sanitation and waste management, leads to the degradation of local water bodies and exacerbates pollution. Climate change further complicates this issue by disrupting rainfall patterns and diminishing the availability of freshwater resources. Addressing these intertwined challenges is crucial for sustainable urban development and the overall well-being of Uyo's residents. Thus, this study aims to assess the spatio-temporal variability and equity in urban water distribution in Uyo, focusing on identifying the primary challenges faced by its residents in accessing safe and reliable water supply.

Material and Methods

Uyo, the capital of Akwa Ibom State in southeastern Nigeria, is located in Uyo Local Government Area. Geographically, it lies between latitudes 3º05' and 5º55' N and longitudes 7º50' and 8º02' E, covering an area of approximately 314 square kilometers, with Itiam Etoi as the central reference point. The study area encompasses over 110 communities spread across six local government areas, with Uyo Local Government containing over 40 percent of the villages, excluding those in Ikono Clan. Uyo is highly urbanized and bordered by Ikono to the north, Etinan to the south, Nsit Atai to the east, and Abak to the west.

This study adopted a mixed-method research design to assess the spatio-temporal variability and equity in urban water distribution in Uyo Capital City, Nigeria. A stratified random sampling technique was used to select participants from different neighborhoods, ensuring representation across various socio-economic groups. Data collection involved a combination of structured questionnaires administered to residents and semi-structured interviews with key stakeholders, including water utility officials and local government representatives. Additionally, geospatial analysis using GIS tools was employed to map water distribution patterns. The collected data were analyzed using descriptive statistics, including frequency distributions and cross-tabulations, while qualitative data from interviews were subjected to thematic analysis to identify key issues and patterns.

Result and Discussion

Spatio-temporal distribution of pipe-borne water supply The data presented in Table 1 highlights the spatio-temporal distribution of pipe-borne water in Uyo Capital City, Akwa Ibom State, from 1999 to 2023. Throughout this period, water distribution levels have

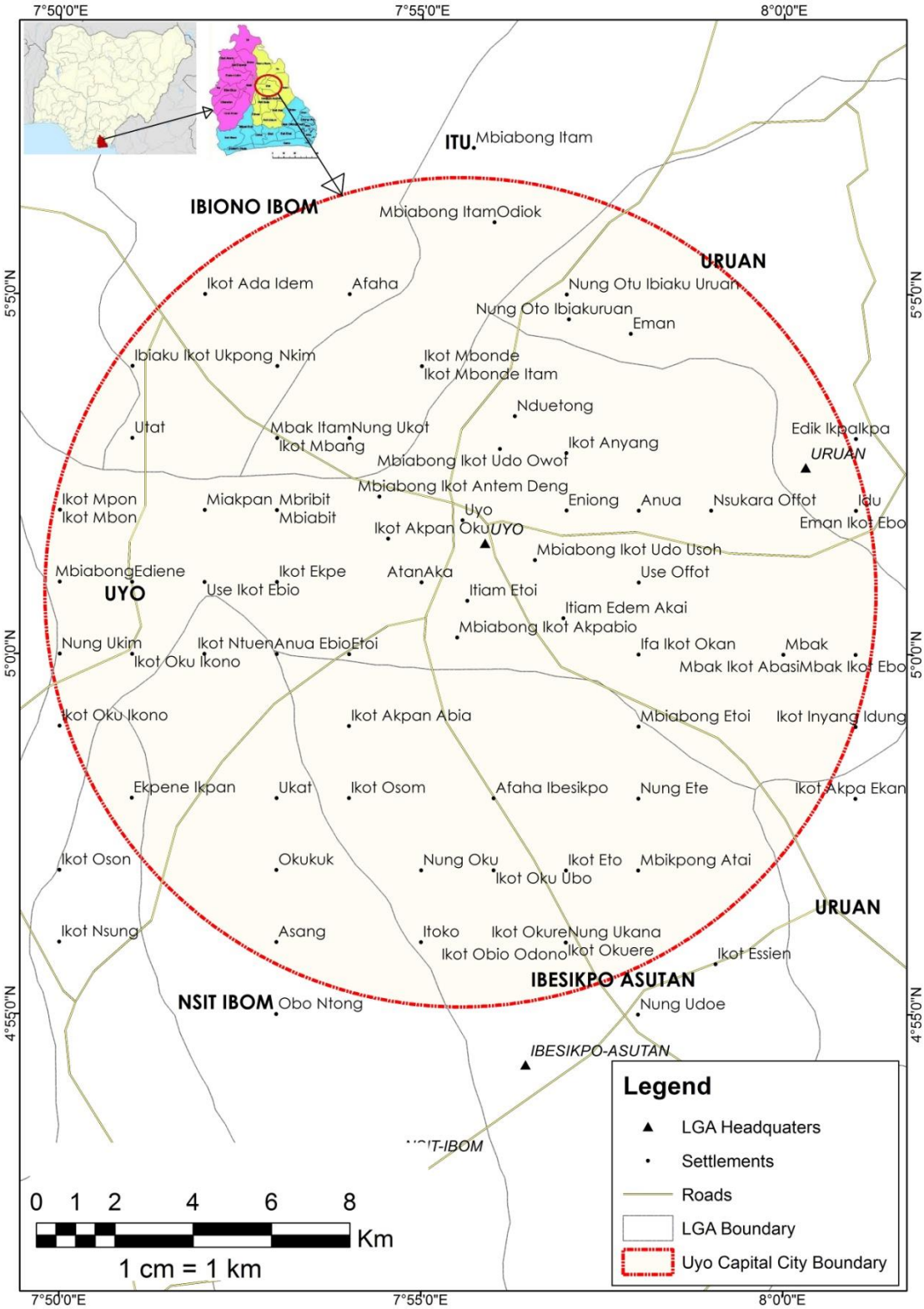

Figure 1: Study Area Map ***Source:*** *Adapted from Uyo Capital City Development Authority (2024)*

fluctuated significantly across various areas, with Uyo consistently receiving the highest share. However, despite these volumes, there remains a noticeable gap between the water supply and the ever-increasing demand fueled by the city's population growth. For instance, Uyo's water distribution peaked at 6,368,851 cubic meters (M3) in 2017 and 6,564,146 M3 in 2018. However, according to WHO standards, which recommend 50 to 100 liters of water per person per day for basic needs (Tchórzewska-Cieślak, et al., 2023), these figures fall short of adequately meeting the growing population's demands, particularly in highly populated areas.

Moreover, the disparity between the areas of Itu, Ekit Itam, and Etinan, which received significantly lower volumes of water, exacerbates water scarcity issues. This shortage of water access not only affects daily household activities but also underscores a broader challenge in the city's water distribution network. While Uyo's water supply has increased in certain years, the inconsistency and insufficiency of water to meet WHO standards indicate that the city's infrastructure is struggling to keep up with the population boom. As the population continues to grow, as projected, it becomes increasingly clear that strategic interventions are needed to enhance water access and ensure equitable distribution across all communities in Uyo. For further understanding, reviewing studies on urban water management and population growth's impact on resources could provide additional insights into sustainable solutions.

Table 1: SPATIO – TEMPORAL DISTRIBUTION OF WATER (CUBIC METRES) IN UYO

SPATIO – TEMPORAL DISTRIBUTION OF WATER (CUBIC METRES) IN UYO CAPITAL CITY FROM 1999 TO 2023					
S/N	**YEAR**	**AREA OFFICES**			
		UYO	**EKIT ITAM**	**ITU**	**ETINAN (NSIT IBOM)**
1	1999	2,273,924	1,121,114	984	1,212,771
2	2000	2,374,118	1,134,211	1,231,112	1,122,612
3	2001	2,163,661	1,144,103	1,121	1,223,661
4	2002	2,164,554	1,122,121	1,173,748	1,278,712
5	2003	2,173,069	1,421,971	1,272,339	1,421,111
6	2004	2,175,840	1,428,223	1,275,158	1,122,312
7	2005	3,174,288	1,412,224	1,269,519	1,291,114
8	2006	2,171,372	1,423,176	1,280,798	1,421,612
9	2007	2,143,634	1,434,722	1,258,240	1,321,121
10	2008	2,303,451	1,482,673	1,313,346	1,211,121
11	2009	2,124,897	1,462,736	1,123,125	77,442
12	2010	2,243,472	1,367,425	1,122,894	216,691
13	2011	2,326,267	1,247,862	1,213,112	19,990
14	2012	2,398,544	957,846	986	173,717
15	2013	2,359,234	878,781	2,234,122	96,853
16	2014	2,328,647	642,422	2,113,921	99,793
17	2015	2,329,347	561,742	2,133,624	102,746
18	2016	2,338,420	638,374	2,277,785	138,766

19	2017	6,368,851	584,754	2,329,762	66,726	
20	2018	6,564,146	641,254	2,198,377	53,121	
21	2019	5,627,552	488,872	189,234	143,412	
22	2020	4,848,476	488,926	2,178,622	108,115	
23	2021	4,586,468	279,884	2,313,798	59,924	
24	2022	6,752,711	396,614	2,169,910	98,267	
25	2023	2,459,886	327,848	1,413,310	125,764	
Total		**79,775,929**	**24,608,066**	**37,212,264**	**10,178,539**	
Grand Total		**151,774,798 (M^3)**				

Source: Adapted from AKWCL, 2024

The data in the table 2, shows the comparison between the projected population and the volume of pipe-borne water supplied in Uyo Capital City from 1999 to 2023. Over this 24-year period, the population steadily increased from 216,239 in 1999 to 482,422 in 2023, representing a significant rise in the number of residents. Despite this population growth, the quantity of water supplied did not increase consistently to match the demand. For instance, in 1999, with a population of 216,239, the water supplied was 4,608,693 cubic meters (M3), and in 2023, when the population had more than doubled to 482,422, the water supplied dropped to 4,326,808 M3, showing a decline in water availability despite the population growth.

Throughout the observed period, certain years like 2017 and 2018 saw a notable surge in water supply, with figures reaching 9,449,093 M3 and 9,456,898 M3 respectively, even though the population was smaller compared to later years. However, this trend was inconsistent, and by 2023, despite the continuous population growth, the water supply significantly decreased. This suggests that the water distribution infrastructure in Uyo may not have adequately expanded to keep pace with the rising demand driven by population growth. According to the World Health Organization (WHO), each individual requires at least 50 to 100 liters of water daily for basic needs (WHO, 2011), implying that the current water supply falls short of providing sufficient water for the rapidly growing population in Uyo. This discrepancy highlights a critical need for improved water resource management and infrastructure to ensure sustainable water access in the city. The result from the GIS output also shows water service level within the Uyo division of capital city.

Test of Hypothesis

Hypothesis one asserts that there is no variation in water supply in Uyo Capital City from 1999 to 2023. A one-way ANOVA was performed to determine if there was any statistically significant difference in the water supply across the specified years. The variables used in the analysis are outlined in Table 1, while Table 3 presents the ANOVA results, indicating whether there is a significant difference between the group means. The analysis returned a significance value of 0.00, which is below the 0.05 alpha threshold, indicating a statistically significant difference in water supply over the period. Consequently, the decision is to reject the null hypothesis and accept the alternate hypothesis, confirming that there is a significant variation in pipe-borne water supply in Uyo Capital City from 1999 to 2023.

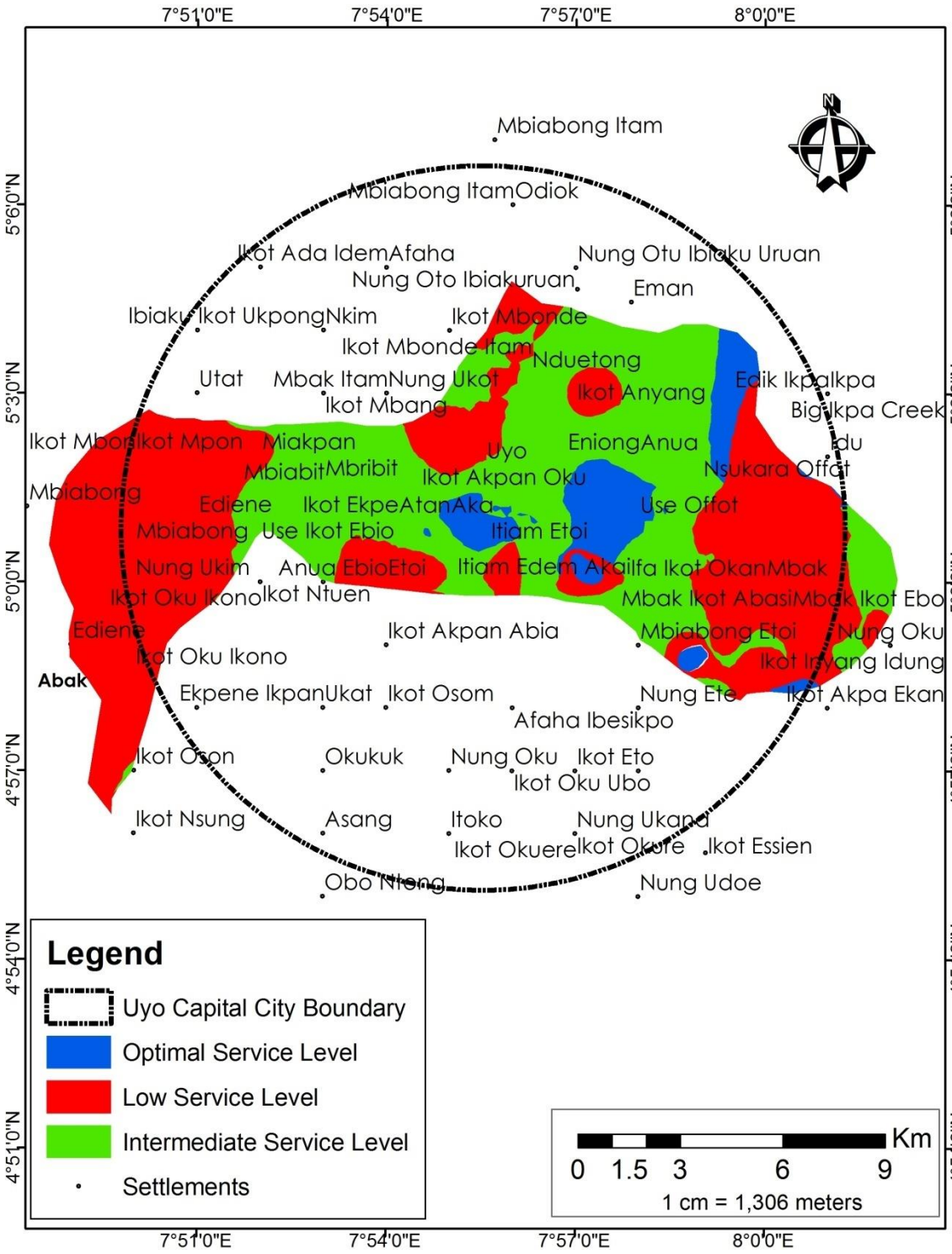

Figure 2: Map showing water service level within Uyo capital city

Source: Authors fieldwork, 2024

Table 2: POPULATION TREND AND VOLUME OF PIPE-BORNE WATER SUPPLY IN UYO CAPITAL CITY FROM 1999 TO 2023

Year	Projected Population	Volume of Water Supplied (M3)
1999	216,239	4608693

2000	223,591	5861053
2001	231,193	4532546
2002	239,054	6739135
2003	247,182	5298480
2004	255,586	6001433
2005	264,276	7047245
2006	273,261	6295958
2007	282,552	6144717
2008	292,159	6310591
2009	302,092	4788868
2010	312,363	4949482
2011	322,984	4807508
2012	333,965	3531293
2013	345,320	5568990
2014	357,061	5183783
2015	369,201	5127459
2016	381,754	5393245
2017	394,733	9449093
2018	408,154	9456898
2019	422,031	6449070
2020	436,381	7614139
2021	451,217	7240074
2022	466,559	9427502
2023	482,422	4326808

Source: NPC, 1999; Authors field computation 2024; AKWCL, 2024

Given these findings, it is clear that there is a statistically significant difference between the groups as a whole. To further explore these differences, the Tukey post hoc test results are provided in Table 4, which is commonly used following a one-way ANOVA. This test confirms the specific group differences. For instance, significant differences were found between Uyo and Itu (p=0.0), Uyo and Ekit Itam (p=0.0), and Uyo and Nsit Ibom (p=0.0). However, the comparison between Itu and Nsit Ibom revealed no statistically significant difference (p=0.815), highlighting that most groups showed variation, except for these two.

Table 3 RETICULATION ZONE VOLUME (**ANOVA**)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	82308159328984.670	3	27436053109661.560	121.931	.000
Within Groups	21601223490518.105	96	225012744692.897		
Total	103909382819502.780	99			

Table 4**:** DEPENDENT VARIABLE: RETICULATION ZONE VOLUME Tukey HSD **(Multiple Comparisons)**

(I) Reticulation Zone	(J) Reticulation Zone	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Uyo	Ekit Itam	1637614.782*	134167.878	.000	1286818.54	1988411.02

	Itu	2154128.388*	134167.878	.000	1803332.15	2504924.63
	Nsit Ibom	2272354.666*	134167.878	.000	1921558.43	2623150.91
	Uyo	-1637614.782*	134167.878	.000	-1988411.02	-1286818.54
Ekit Itam	Itu	516513.606*	134167.878	.001	165717.37	867309.85
	Nsit Ibom	634739.884*	134167.878	.000	283943.64	985536.12
	Uyo	-2154128.388*	134167.878	.000	-2504924.63	-1803332.15
Itu	Ekit Itam	-516513.606*	134167.878	.001	-867309.85	-165717.37
	Nsit Ibom	118226.278	134167.878	.815	-232569.96	469022.52
	Uyo	-2272354.666*	134167.878	.000	-2623150.91	-1921558.43
Nsit Ibom	Ekit Itam	-634739.884*	134167.878	.000	-985536.12	-283943.64
	Itu	-118226.278	134167.878	.815	-469022.52	232569.96

*. The mean difference is significant at the 0.05 level.

Conclusion and Recommendations

The study has shown that there is a statistically significant variation in the distribution of pipe-borne water supply across Uyo Capital City from 1999 to 2023. The one-way ANOVA results confirm that the water supply fluctuated considerably over the years, with certain areas, such as Uyo, Ekit Itam, and Itu, displaying significant differences in water distribution. The only exception was between Itu and Nsit Ibom, which exhibited an insignificant difference. This variation suggests that the growing population of Uyo Capital City may not be adequately served by the existing water infrastructure, pointing to an increasing gap between supply and demand, as evidenced by the findings. The water distribution system requires improvement to ensure a more equitable and sufficient supply for the city's growing population.

Based on the study findings, the following recommendations were reached; (a) The Akwa Ibom State government and relevant agencies should invest in upgrading the existing water supply infrastructure to meet the increasing population and demand in Uyo Capital City. (b) Authorities should establish policies that promote the equitable distribution of water across all districts in Uyo, particularly targeting areas with significant disparities like Itu and Nsit Ibom. (c) Introduce sustainable water management plans, including the exploration of alternative water sources and regular maintenance, to ensure a consistent and reliable supply in line with the growing population demands

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