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Posted Date: 27 November 2023

doi: 10.20944/preprints202311.1703.v1

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Article

Digitalization in Small-Scale Urban Recirculation Aquaculture: Data Analytics in Sub-Saharan Africa

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Abstract: Food and nutrition insecurity, affecting 30% of the global population in 2020, poses a significant challenge to achieving Sustainable Development Goal (SDG) 2 - Zero Hunger. Urbanization, particularly in sub-Saharan African cities e.g. Lagos, Nigeria, exacerbates these issues, impacting resources and contributing to informal settlements. There is emphasis on innovative solutions in urban farming, with Recirculating Aquaculture Systems (RAS) emerging as one of the promising approach due to its efficiency in space and capital utilization. However, maintaining optimal conditions in RAS, crucial for SDG 2 and 11, requires robust water quality monitoring. This study explores the availability of digital tools for water quality monitoring in small-scale urban RAS, evaluating handheld devices and IoT sensors' reliability through *t*-test statistical method. The results aim to guide practitioners in selecting effective monitoring tools, contributing valuable insights for sustainable aquaculture in urban areas, particularly in sub-Saharan Africa, where access to affordable digital solutions is pivotal for success and can attract youth to agri-food technologies.

Keywords: recirculating aquaculture system; water quality; (peri-)urban farming; Nigeria; sub-Sahara Africa

Introduction

According to the United Nation (2022) food and nutrition insecurity is on the rise as about 30 percent of the global population is food insecure in 2020. This casts serious doubt in achieving the sustainable development goal (SDG) 2 - Zero Hunger. The high rate of urbanization (>50%) in parts of sub-Saharan Africa such as Lagos, Nigeria, also implies that food and nutrition insecurity will become more prevalent in urban areas (United Nation, 2018). As African cities grow, so does the pressure on resources such as land and, water as well as the amounts of waste generated. This high level of urbanization, plagued by informal settlements, also has consequences for urban agricultural land and green space that are often turned into housing units contrary to the objective of SDG 11 that emphasizes sustainable cities and communities. To this end, a number of studies (Benjamin *et al.*, 2022, FAO. 2018, CoSAI. 2020) advocate for innovation in urban farming to meet the aforementioned SDGs in sub-Saharan Africa. Recirculating Aquaculture System (RAS) is one of the innovations that has the potential to contribute to SDG 2 and 11 especially in an urban context because it requires relatively little land and capital (Benjamin *et al.*, 2021). However, in this context water quality monitoring is of utmost importance for maintaining optimal conditions for fish growth and avoiding effluent discharge, i.e., environmental degradation (Naughton *et al.*, 2020). According to Lin *et al.*, (2021) parameters such as potential hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), and temperature play vital roles in assessing water quality. Accurate and reliable measurements of these variables are essential for determining the health and productivity of the system (Tumwesigye *et al.*, 2022). This is where the use of appropriate digital tools becomes inevitable in propagating efficient and circular agri-food technologies in cities.

This study intends to provide an overview of the availability of digital tools for water quality monitoring in small-scale RAS as well as potential cost implications for practitioners. The study assesses the reliability of handheld digital tools and IoT or sensors in monitoring water quality of RAS in cities and built-up areas. To assess the reliability of the digital devices, statistical and

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parametric methodologies, such as the t-test, are employed. The t-test allows for a comparison of the means of two sample sets (Myoung, 2009), in this case, the readings obtained from the simplified handheld digital tool and the IoT or sensors. By analyzing the data collected, the study aims to evaluate the performance of the monitoring devices. Specifically, the focus is on comparing the values obtained from the digital tools and identifying statistically significant differences in their readings.

The existence of statistical differences between the values obtained from the digital devices drawn from a single RAS system carries profound implications for aquaculture water quality and corrective measures. Thus, accurate and consistent data is crucial for making informed decisions regarding water treatment, but also fish feeding, and overall system management (Shifeng *et al.*, 2007). Therefore, reliability and accuracy monitoring tools are vital for achieving sustainable aquaculture in urban areas (Liu *et al.*, 2018).

The results obtained from this study will contribute to the body of knowledge surrounding affordable water quality monitoring tools for small-scale RAS. By highlighting the limitations and disparities between different water quality monitoring devices in the aquaculture sector, practitioners can make informed decisions about the selection and implementation of digital technologies. This knowledge will be especially valuable in the context of sub-Saharan Africa, where access to affordable and reliable digital solutions can play a vital role in improving the efficiency and profitability of small-scale RAS in urban, but also rural environments (Benjamin *et al.*, 2021; Benjamin *et al.*, 2022). Digital solutions may also increase the attractiveness of agri-food technologies for youths and young adults in their search for income generating activities.

Literature review

Urban RAS and aquaculture in developing countries

Aquaculture, defined as the cultivation of aquatic organisms such as fish, molluscs, crustaceans, and aquatic plants (FAO, 2006), has the potential to address the food security requirements of millions in developing nations by offering affordable protein (Dighiesh, 2014; Wally, 2006).

The conventional urban aquaculture system, known as pond culture (Timmons and Ebeling 2013), has historically played a significant role in providing animal protein to urban and peri-urban areas in developing nations (Adeogun *et al.*,2007). However, this system is facing numerous challenges, encompassing restricted access to resources like land and water, alongside environmental concerns (Benjamin *et al.*, 2022).The viability of conventional pond culture aquaculture has been questioned due to the shrinking availability of suitable land and water resources in urban areas. As urban areas expand, the competition for land intensifies, making it increasingly difficult to allocate sufficient space for traditional pond-based aquaculture systems. Furthermore, the discharge of effluents from these systems into nearby water bodies can contribute to eutrophication, a process that leads to excessive nutrient enrichment in the water, causing detrimental ecological effects (Benjamin *et al.*, 2022).

To tackle these challenges and promote sustainable urban agriculture, there has been a growing focus on innovative agri-food systems as such urban recirculating aquaculture systems (Benjamin *et al.*,2021; Benjamin *et al.*, 2022). RAS is a technology that enables the cultivation of fish and other aquatic organisms within a carefully controlled, land-based environment (Martins *et al.*, 2010). In RAS, water is continuously recirculated through mechanical and biological filters, removing waste components and maintaining adequate water quality for fish growth (Mangéra *et al.*, 2022). This system reduces water consumption significantly compared to conventional pond culture, as water is reused within the system.

The adoption of RAS offers several advantages, one key advantage is the minimal use of resources, particularly land and water by utilizing a closed-loop system, RAS maximizes resource efficiency and allows for high stocking densities this is particularly beneficial in urban areas where available space is limited (Timmons and Ebeling 2013; Benjamin *et al.*, 2022).

However, the adoption of RAS in developing countries faces a range of challenges. One major challenge is the high upfront investment needed to establish a RAS facility; this includes the cost of

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equipment, infrastructure, and technical expertise (Schneider *et al.*, 2006). Clough *et al.*, (2019) identified a number of challenges confronting the implementation of RAS in Kenya, the study highlighted the issue of lack of steady power supply, establishing effective biosecurity measures, and coping with the elevated expenses associated with treating water due to extensive pollution in Kenyan waterways. Furthermore, there is often insufficient awareness and technical expertise about RAS among potential users and stakeholders in developing countries (Aich *et al.*, 2020). In addition to financial and knowledge-related challenges, supportive policy frameworks are crucial for the successful adoption of RAS in developing countries. Governments and relevant authorities play a vital role in creating an enabling environment by implementing policies that promote sustainable aquaculture practices, provide incentives for investment, and support research and development efforts.

Availability of digital tool for water quality monitoring in urban RAS and aquaculture

Over the past few decades, the scientific community has demonstrated a profound research interest in water quality monitoring. With the enactment of the Water Framework Directive in Europe in 2000, the biological and chemical assessments of water quality have gained significance for comprehensive monitoring worldwide, including in sub-Saharan Africa (Dube *et al.*, 2015). The traditional method of water quality assessment, known as the colorimetric method, relies on collecting water samples and analyzing them in a laboratory. While these methods offer high accuracy in monitoring, they come with the disadvantage of being costly and labor-intensive, time-consuming, as well as high costs associated with transporting samples to and from the laboratory. Also, the need to wait for lab results introduces delays in obtaining crucial information for water quality management (Rao *et al.*, 2013).

In contrast, the conventional approach of water monitoring involves periodic onsite measurements using handheld meters or sensors. While these instruments provide immediate measurements when staff members are available during office hours, they are limited in their ability to capture unexpected variations, changes or alterations in water parameters that may occur outside of these hours (Chen *et al*., 2022). It is during these unmonitored periods that one or more key water parameters can deviate beyond safe levels, potentially leading to detrimental consequences that go unnoticed until the next scheduled measurement.

To tackle these challenges, there is an urgent need for real-time, on-site water quality monitoring systems capable of delivering continuous, high-quality data at a reasonable cost (Rao *et al.*, 2013). Fortunately, the swift evolution of technology has yielded a diverse array of sensors and monitoring devices designed specifically for real-time water quality assessment (Ismail *et al.*, 2020). These technological advancements have been significantly augmented by the incorporation of the Internet of Things (IoT) and artificial intelligence (AI) techniques into monitoring processes (Zhang *et al.*, 2023). By harnessing the power of IoT-based systems, interconnected devices and sensors can collect data in real-time, removing the necessity for manual sampling and laboratory analysis (Miller *et al.*, 2023). These systems enable continuous assessment of diverse water quality parameters, including temperature, pH, dissolved oxygen, conductivity, turbidity, and more. The collected data is transmitted wirelessly and can be analyzed using AI algorithms, which can detect patterns, identify anomalies, and provide warnings or alerts in critical situations. Rao *et al.* (2013) have emphasized the advancements in Information and Communication Technologies (ICT) and the accessibility of affordable small sensors. These developments have made it feasible to monitor multiple parameters simultaneously through wireless sensor networks (WSNs). The integration of IoT-based systems, AI techniques, and WSNs in water quality monitoring has transformed the field by enabling real-time measurements and timely warnings of critical situations.

Espinosa-Faller (2012) investigated a water monitoring system utilizing Wireless Sensor Networks (WSN), for data capture and storage in a database. The system incorporates sensors to measure temperature, pressure, and dissolved oxygen (DO) continuously. Upon detecting a problem is detected, the system sends an alert in the form of a Short Message Service (SMS) or an email to notify the responsible personnel.

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Lin *et al.,* (2021) created a comprehensive system that combines diverse sensors, such as those for measuring dissolved oxygen, pH, and water temperature, to monitor each water layer. Employing Modbus TCP/IP communication, this system transmits the gathered data, accessible to breeding managers via web interfaces and mobile devices.

Zhang et al. (2010) suggested a WSN-based water monitoring system designed for measuring pH, water temperature, water level, and dissolved oxygen. The acquired data is transmitted to a database, accessible to software for immediate monitoring. Their system features a modular software structure that segregates logic, display, and data layers, improving scalability and reusability. Moreover, the system allows the dispatch of warning notifications to users through SMS.

Zhang *et al.* (2010) proposed WSN-based water monitoring system capable of measuring pH, water temperature, water level, and dissolved oxygen. The collected data is transmitted to a database, which is then accessed by software for real-time monitoring. Their system features a modular software structure that segregates logic, display, and data layers, improving scalability and reusability. Moreover, the system allows the dispatch of warning notifications to users through SMS.

The advent of low-cost sensors has expanded the availability of digital water monitoring devices and thus accessibility of water monitoring solutions for all sizes of aquaculture systems. There is a wider range of options of digital water monitoring tools available in the market specifically designed for aquaculture water monitoring. This availability gives fish farmers and/or aquaculturists the opportunity to choose sensors that meet their specific requirements, budgets, and operational needs. These sensors can be easily deployed and operated, allowing fish farmers and/or aquaculturists in remote locations to monitor their water quality without the need for expensive infrastructure or specialized equipment.

Use of digital tool in RAS and aquaculture in Africa

While the use of digital water tools in recirculating aquaculture systems (RAS) and aquaculture has gained significant attention worldwide, in the context of sub-Saharan Africa, there is a paucity of literature(Benjamin *et al*., 2022; Lehto, 2023). Despite the growing body of research on aquaculture and RAS in Africa, there is insufficient focus on the integration of digital technologies for water management purposes (Obiero, 2019). However, some studies and reports (Clough *et al*., 2020; Antony & Sweeney, 2019) provide valuable insights into the potential applications and benefits of digital water tools in African aquaculture systems.

Clough et al. (2020) established a trial Nile Tilapia (Oreochromis niloticus) hatchery in Kisumu, Kenya, employing locally adapted RAS. The facility utilizes a real-time monitoring and alarm system, crafted by OxyGuard International A/S. This online monitoring system empowers farmers to retrieve farm data from the fish tanks, facilitating continuous monitoring and control. The study recorded successful reproduction of Tilapia with low mortality rate.

Antony & Sweeney (2019) developed a device in Kenya designed for remote monitoring, effectively alleviating the data collection burden on fish farmers while enhancing data acquisition frequency. The device transmits data gathered from pH and temperature sensors, which is then processed and made accessible through a dedicated app.

The limited literature highlights several potential applications of digital water tools in African aquaculture. These tools can facilitate real-time monitoring of crucial water quality parameters, enable remote system control and support decision-making. The benefits of implementing digital water tools in African aquaculture include improved production efficiency, enhanced environmental sustainability, reduced water and energy consumption, increased profitability, and better overall management practices.

Given the paucity of literature on the topic, future research should focus on exploring and documenting the use of digital water tools in RAS and aquaculture across different regions (De Carmago *et al.*, 2023). Such studies should investigate the accuracy and reliability of specific digital tools, and identify strategies to overcome the challenges associated with their implementation. Additionally, collaborations between researchers, policymakers, aquaculture practitioners, and

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technology providers should be encouraged to promote knowledge exchange, capacity building, and the development of context-specific solutions.

Cost of digital tool in Africa aquaculture

The cost and affordability of standard water monitoring tools pose significant challenges, particularly in sub-Saharan Africa. Standard water monitoring tools, such as laboratory-grade sensors and probes, are often expensive and require significant investments (Medina *et al.,* 2022; De Camargo *et al*., 2023). De Camargo *et al.* (2023) reported that a solution offered by Libelium may be as costly as 17 times the minimum wage in developing nations. Likewise, a probe for the Hanna 9829 multiparameter probe is priced at approximately 1000 USD. Many small-scale farmers in sub-Saharan Africa found these tools to possess sophisticated technologies, calibration procedures, and maintenance costs and hence unaffordable (Medina *et al.,* 2022). The high cost of these tools creates barriers to entry and restricts access to crucial water quality information necessary for effective fish farm management. The limited affordability of standard water monitoring tools has several implications for farmers in Africa. Firstly, without access to accurate and real-time water quality data, fish farmers face challenges in identifying and addressing potential issues such as water pollution and disease outbreaks. This lack of information can lead to decreased yields, increased production costs, and negative environmental impacts. Additionally, the absence of reliable monitoring tools hampers the ability to implement precision aquaculture practices and optimize resource allocation, further hindering the overall sustainability and productivity of fish farming operations.

To address the challenge of cost and affordability of standard water monitoring tools, researchers have been investigating the development of low-cost sensors integrated with IoT technologies (Lorena *et al*., 2018, Medina *et al*., 2022, Miller *et al*., 2023). The cost of water monitoring tools is influenced by many factors such as the number of parameters being measured, sensor durability, precision, sensitivity and the features of the device itself, including its materials, software, cable length, display, peripherals, and other characteristics. These sensors leverage advancements in miniaturization, wireless connectivity, and data processing capabilities to provide cost-effective and accessible solutions for water quality monitoring (De Camargo *et al*., 2023). De Camargo *et al*., (2023) opined that there is a lack of consensus or precise definition of low-cost water quality sensors in the literature. They suggested a range between 10 and 200 USD but emphasized that this price range will depend on the development stage and should not be solely relied upon as a benchmark.

Lorena *et al.* (2018) developed and installed a low-cost WSN for tracking fish feeding process and assessing water quality in aquaculture tanks. The WSN is constructed from basic electronic components, enhancing aquaculture efficiency and the WSN cost less than EUR 90. Medina *et al.* (2022) also designed water quality monitoring tool for aquaculture using cost-effective equipment, low-power consumption, collects data remotely, and is open-source. The developed prototype is a battery-operated data buoy designed for measuring temperature, dissolved oxygen, and pH, with the potential for extension to other water quality variables. The estimated cost of the device is approximately 658 USD. In a systematic literature review to identify the low-cost sensors utilized in remote water quality monitoring De Camargo *et al*., 2023, found that three main vendors supply the sensors discussed in the papers selected, with prices ranging from US$6.9 to US$169.00, but occasionally reaching up to US$500.00.

These low-cost sensors enable wider adoption and accessibility, allowing small-scale fish farmers to benefit from precise and reliable water quality monitoring. These tools empower farmers to monitor critical parameters such as temperature, pH, dissolved oxygen, and nutrient levels, aiding in disease prevention, water management, and optimal nutrient application. Real-time data provided by low-cost sensors integrated with IoT also facilitates early detection of anomalies, timely interventions, and improved overall farm management practices.

Data and methods

Data

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Data collection on a small-scale urban RAS took place in the Sustainable Aquaponics for Nutritional and Food Security in Urban Sub-Saharan Africa (SANFU) II project in Lagos, Nigeria from December 2022 to May 2023. The RAS consists of a plastic fish tank, sump tank, biofiltration unit, solid sedimentation unit with aerators, and a submersible pump. The plastic fish tank (1000 liters) measuring 120cm x 100cm x 100cm was filled with six hundred (600) liters of water. The tank was stocked with 5 Pangasius (*Pangasianodon hypophthalmus*) and 25 tilapia (*Oreochromis niloticus*). Adequate aeration was maintained in the fish tank throughout the study. Daily measurements of temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were conducted using handheld digital tools and an IoT device (ph-W3988). The handheld digital tools were pH100 ATC (Voltcraft pH-value measuring device version 11/12) which was used to measure the pH-value and the MEASURY TDS & EC METER which was used to measure temperature, TDS, and EC (see Figure 1 below). Values of temperature, EC, TDS & pH gotten from the handheld digital tools were compared with the values obtained from an affordable multiparameter IoT device (ph-W3988).

Handheld TDS, EC and Temp. meter (Measury TDS & EC Meter)

Handheld pH meter (pH100 ATC)

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IoT integrated device (ph-W3988).

Figure 1: handheld digital tools and an IoT device used for measurements

The values obtained from the handheld digital tools were compared with the readings from an affordable multiparameter IoT device (ph-W3988). For the ph-W3988, the probe was rinsed with distilled water, dried with tissue paper, and then inserted into the RAS. After a minimum of thirty minutes, the readings were taken. For the handheld meters, water samples from the RAS were collected in sterile plastic containers (to minimize electromagnetic interference). The probes of the handheld pH and TDS meters were rinsed with distilled water, dried with tissue paper, inserted into the water samples, and briefly stirred to remove any trapped air bubbles. After allowing the readings to adjust and stabilize for a few minutes, the meters were left in the samples for some time before the final readings were taken. The probes were then rinsed with distilled water.

Methods

Two-Sample t-test

This study uses a two-sample *t*-test approach to estimate the differences in the mean between the two types of digital tools used for water quality monitoring in the small-scale RAS based on independent sampling recorded from each tool. The different types of digital tools represent a different population or treatment condition. This approach fulfills the independence criteria as the digital tools and corresponding samples are different and unrelated to each other. Furthermore, for the results of the *t*-test to be unbiased the data collected via digital tools and corresponding sample should show a normal or approximately normal distribution. However, Pallant, 2007, Ghasemi *et al.*, 2012 and Lumley *et al.* 2002 argue that non-normal distribution in large data $n > 30$ does not cause bias in t-test and linear regression. The samples were obtained from a single small-scale RAS with the digital tools randomly divided into two groups with each group subjected to one testing per day. The two-sample t-test is a statistical test used to compare the means of two independent groups to determine if there is a significant difference between them. The null hypothesis in the study assumes that there is no significant difference between the means of the handheld devices and affordable multiparameter IoT device (ph-W3988). The *p*-value and significance level provide the basis for accepting or rejecting the null hypothesis. For instance, if the p-value is less than the significance level, the null hypothesis is not valid.

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Let the aforementioned water parameters reading from the IoT and sensor be denoted $X_{1,1}, X_{1,2}, \dots, X_{1,n}$ and that of the handheld device $X_{2,1}, X_{2,2}, \dots, X_{2,n}$ with both having an independent normal distributions and means of $\infty_1$and ∞_2,respectively. The ordinary variance is denoted as σ^2 . The unbiased estimators for the means and variance can be rewritten as:

$$\overline{x}_j = \frac{1}{n_j} \sum_{i=1}^{n_j} x_{i,j} \quad (1)$$

$$s_j^2 = \frac{1}{n_j - 1} \sum_{i=1}^{n_j} (x_{i,j} - \overline{x}_j)^2, \quad j = 1, 2 \quad (2)$$

The estimation of the maximum likelihood can be denoted as:

$$\hat{\mu}_1 = x_1, \hat{\mu}_2 = x_2, \hat{\sigma}^2 = \frac{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}{n_1 + n_2 - 2} \quad (3)$$

This results in the test statistics:

$$t(x_1, x_2) = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)(\hat{\sigma})^2}} \quad (4)$$

The test statistic, measures the difference between the means of the two groups relative to the variability within each group i.e. the standard error of the difference.

This can be further simplified base on a t-distribution:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\left(\frac{\hat{\sigma}^2}{n_1} + \frac{\hat{\sigma}^2}{n_2}\right)}}$$

With $n_1 + n_2 - 2$ degrees of freedom.

Results and discussion

The descriptive statistics of the data collected using the IoT or sensors as well as handheld devices (HH) are presented in Table 1 below. The results suggest that on average, there some difference in the measurement of certain fish water quality parameters taken from the same sample i.e. RAS, using IoT or sensors as well as handheld devices. According to the results of Table 1 the biggest difference in the means of the water quality parameters recorded using IoT or sensors and handheld devices were below 22%.

Table 1. Descriptive statistics of water quality parameters values using IoT or sensors as well as handheld devices (HH) .

Parameters	Count	Mean	SD	Minimum	Maximum
TDS (ppm)	134	184	50	84	305
TDS (ppm) HH	134	140	38	64	220
EC (ms/cm)	134	358	97	168	584

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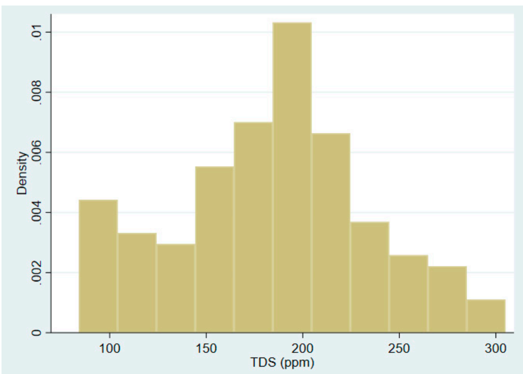
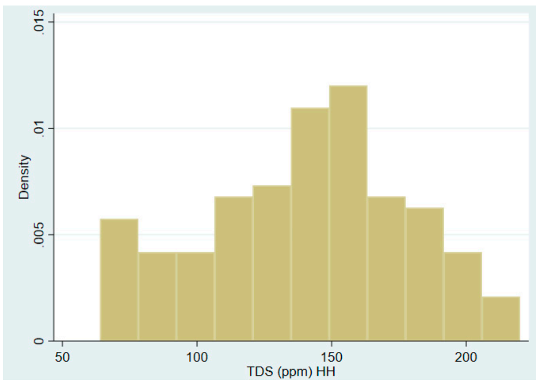
EC (ms/cm) HH	134	281	75	120	440
Temperature (oC)	134	27.4	1.2	24	30
Temperature (oC) HH	134	26.6	1.7	21	30
PH (absolut)	134	6.3	0.4	5	7.2
PH (absolut) HH	134	6.1	0.4	5.2	7.2
Observations *n*	134				

In order to fulfill the criteria of normal distribution of the data to ensure an unbiased two sample *t*-test, a Shapiro–Wilk W test for normality for each parameter in the descriptive table was conducted and the results presented in Figure 2 below. The results suggest that water quality data recorded using the HH, except temperature, have a normal distribution. Conversely, most of the data recorded through the IoT and sensor are not normally distributed. The presence of dataset that is not normally distributed in the sample does not pose a serious risk to the analysis as long as the number of observations is >30. Given that our n is greater implies that the results of the analysis are valid.



W= 0.97; Prob> 0.00620



W= 0.99; Prob> 0.91

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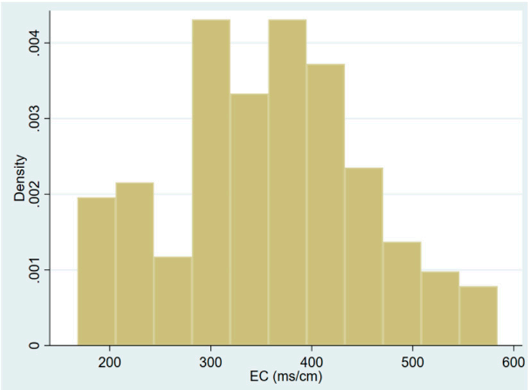
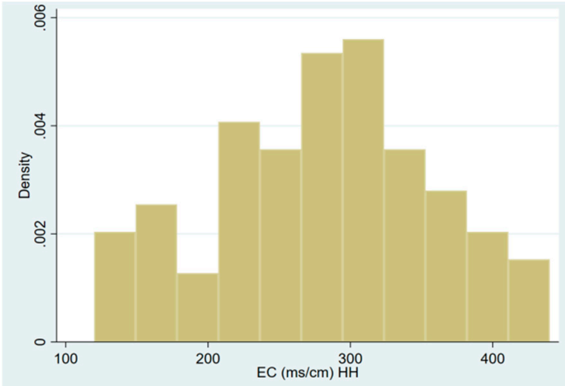
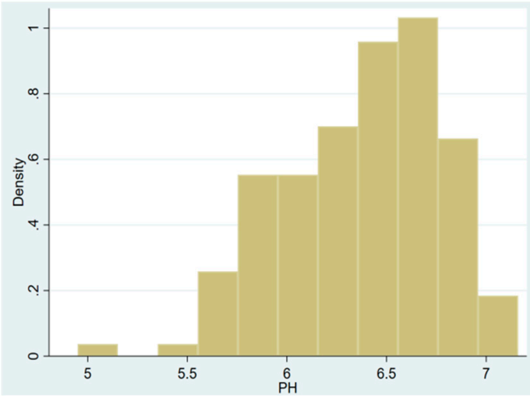


W= 0.99; Prob> 0.42



W= 0.98; Prob> 0.06



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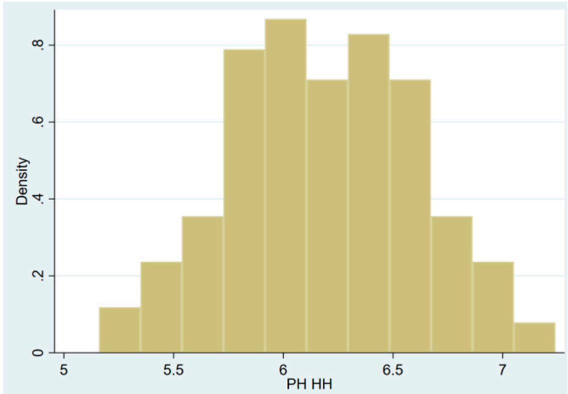
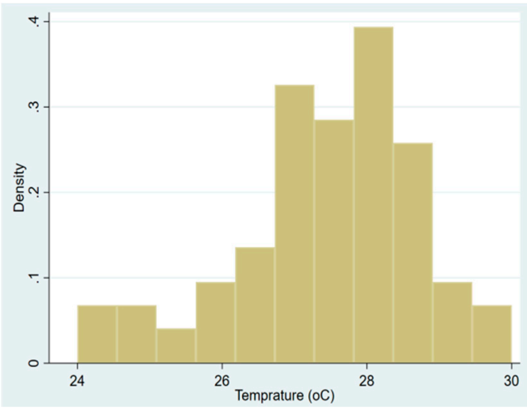
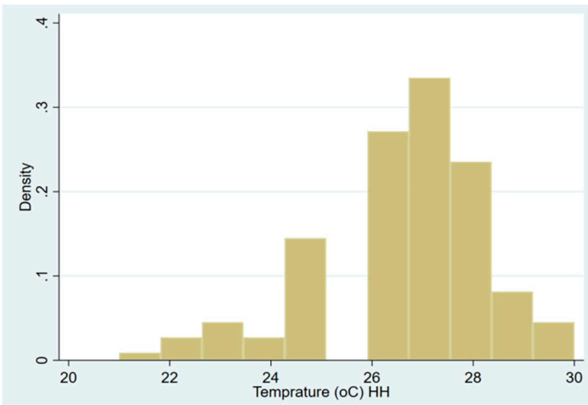


W= 0.99; Prob> 0.91



W= 0.95; Prob> 0.00



W= 0.97; Prob> 0.00

Figure 2: Shapiro–Wilk W test for normality.

The *t* stands for the value of each test statistic, df implies the degrees of freedom (df), *p* is the p-value and decision implies statistical interpretation of analysis.

The results (see Table 2) suggest that there are statistical significant differences in the results obtain from for the IoT or sensors compared to handheld devices (HH) on all of the water quality parameters under consideration. This could implies that the combined use of these devices over time in small-scale urban RAS may become complicated and complex. This may not aid the right decision-making or timely intervention of water quality corrective measure for fish farmers. The fatality could be either high mortality or effluent discharge resulting in environmental degradation.

Table 2. Two sample test for IoT or sensors as well as handheld devices (HH) .

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Two Sample Test	t	df	p	Decision
TDS (ppm) l TDS (ppm) HH	8.1	266	0.00	Reject H_0
EC (ms/cm) l EC (ms/cm) HH	7.3	266	0.00	Reject H_0
Temprature (oC) l Temprature (oC) HH	4.6	266	0.00	Reject H_0
PH (absolut) l PH (absolut) HH	3.9	266	0.00	Reject H_0

Discussion

The digitalization of aquaculture water monitoring has gained significant importance due to the pivotal role that water management plays in aquaculture. In recent times, there has been an influx of novel, cost-effective, and user-friendly water testing instruments and kits in the market. It is imperative to subject these tools to rigorous evaluation to ascertain their suitability for assessing water quality in both agricultural and aquaculture systems. This evaluation serves the critical purpose of empowering farmers and aquaculturists to make informed decisions regarding their adoption and their consequential impact on farm management.

This study primarily focus on assessing the performance of two affordable water analysis devices when applied to small-scale urban Recirculating Aquaculture Systems (RAS) in Lagos State, Nigeria, spanning a period of six months. The specific objectives encompassed:

1. A comparative analysis of outcomes derived from an Internet of Things (IoT)-integrated device and a handheld water analysis device
2. The determination of the applicability of these devices in facilitating informed decision-making concerning water quality management,
3. The evaluation of the accuracy of the measurements obtained through these tools.

The comprehensive analysis of water parameters, comprising pH, temperature, Total Dissolved Solids (TDS), and Electrical Conductivity (EC), was conducted over a period of six (6) months. The ensuing evaluation of these parameters is crucial in the context of their significance towards fish welfare. The mean values of the assessed water parameters fall within the optimal range for facilitating fish welfare. The mean TDS values recorded from the IoT device and the handheld device were 184 ± 50 and 140 ± 38, respectively. Temperature readings provided by both devices yielded values of 27.4 ± 1.2 (IoT) and 26.6 ± 1.7 (handheld), which conformed to the recommended temperature range for the growth and development of tilapia, as proposed by Chervinski (1982) and DeWalle *et al.*, (2011). Regarding EC, the values reported by the IoT and handheld devices were 358 ± 97 and 281 ± 75, respectively, and fell within the optimal range for fish welfare, aligning with the findings of Russell *et al.*, (2011) and Stone *et al.*, (2013). The pH measurements obtained from the IoT and handheld devices were 6.3 ± 0.4 and 6.1 ± 0.4, respectively, and were consistent with the ideal pH range for tilapia culture, as documented by BEAR (1992), Crane (2006), Bryan *et al.*, (2011), and Bolorunduro and Abba (1996).

However, the result of the two sample t test to compare the means of the values showed a statistically significant ($p < 0.05$) difference between the means of all the water parameters collected

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using the two devices (IoT and Handheld). The difference in mean between the values obtained from the two sensors can be as a result accuracy variation between the two sensors. Without accuracy and discrepancy reading RAS system management decisions becomes difficult. Another source of discrepancy can be due to both sensors having different components. During the cause of the study the reading of the handheld pH sensor became very erratic and took more time to stabilize. This could as a result of degrading components overtime making the readings more likely to drift overtime. De Carmago *et al.*, (2023) in a review found that a number of studies (31) also reported inadequate or inconclusive results for water quality sensor and IoT.. The reasons for this unsatisfactory performance ranged from maintenance, technical problems, to sensors rapid degradation. RuthEllen *et al.*, (2011) also found that water parameter testing strips were highly inaccurate while electronic meters were the most accurate but costly and require greater degree of care and maintenance. The findings of this study align with the research conducted by Xavier *et al.* (2022), which assessed the data obtained from a turbidity sensor (DFRobot turbidity sensor SEN0189) in comparison to a reference device. The study revealed that during the initial 8-hour test period, the SEN0189 provided results closely resembling those of the reference sensor. However, beyond this timeframe, the response curves of the SEN0189 and the reference device exhibited a continuous increase in the difference.

Naigaga *et al*., (2018) in a study compare the decisions made by farmers using water-analysis kits with the decisions made by those employing the traditional methods. The findings revealed that in most cases, the decisions made by farmers using water-analysis kits closely matched those made using traditional methods except for nitrate levels where the Tetra and API test strips didn't quite align. The study found that the strongest agreement was observed with the Hach and SalifertProi test kits for measuring dissolved oxygen (DO) and the API test strip for measuring total hardness. While the result suggests that these kits can be a valuable choice for farmers local knowledge remains indispensable.

In a study by Kratky (2002), the results of an A HANNA Model HI 93750 Ion-specific meter were compared with flame emission spectrophotometry for potassium concentrations in low-salinity water (2–10 ppt). The study found that the results obtained by the meter were similar to those obtained by flame emission spectrophotometry. Regression analyses of potassium concentrations revealed correlation coefficients (r) of 0.999 for samples from ponds and 0.997 for a series of standards. The conclusion drawn from the study was that the relatively inexpensive meter is sufficiently precise and accurate for monitoring potassium concentration in low-salinity water for pond aquaculture.

De Camargo *et al.* (2023) emphasize the importance of comparing results obtained from affordable sensors with those of reference devices, like multiparameter probes, to ensure their validity. This not only showcases the functionality of low-cost sensors but also contributes to establishing the accuracy and reliability of the obtained results. Furthermore, comprehensive research on locally developed and affordable water quality monitoring sensors and IoT in sub-Saharan Africa for RAS, aquaponics, hydroponics as well as other soilless innovations ideal for urban areas needs to conducted.

Conclusion and recommendation

This study conducted an evaluation of water parameter data obtained from affordable Internet of Things (IoT) and handheld probes. The results revealed a statistically significant difference in the means of values obtained from these devices, which raises questions about their accuracy and reliability in the context of fish farm management decision-making. Hence, it is imperative for users to meticulously scrutinize the accuracy of the sensors they employ to ensure that these sensors align with the data quality requirements specific to their intended applications. While affordable probes and sensors may appear financially attractive, they may not consistently deliver the requisite accuracy, precision, and reliability demanded by particular use cases. Furthermore, there is a notable absence of information regarding the accuracy, precision, durability, calibration procedures, and reliability of affordable sensors utilized in the domain of aquaculture water monitoring. Consequently, this study advocates for further research encompassing multiple comparisons of low-

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cost sensors to assess their accuracy, comparisons between affordable sensors and reference devices, as well as the utilization of colorimetric methods. Additionally, prolonged in-field assessments of affordable devices are recommended to ascertain their stability and durability over extended periods of time and use.

Author Contributions: A. U. V.: methodology & writing-review; E.O.B.: conceptualization, data analysis, writing-original draft; G.B.: validation & supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This paper is supported by the European Union under Horizon Europe, grant agreement No 101083790, project "Integrated and Circular Technoloigies for Sustainable city region FOOD Systems in Africa (INCiTiS-FOOD). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authoriy can be held responsible for them. Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the management team (www.aglobedc.org, accessed on 23 September 2022) and staff of Aglobe Development Center, Lagos, Nigeria, especially Sulaimon Babalola, Abiola Adegoka and Hikimot Babalola.

Conflicts of Interest: The authors declare no conflict of interest

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