https://research.adra.ac.id/index.php/abdimas
P - ISSN: 2987-8470
E - ISSN: 2987-7105

Application of Smart Aquaponics Technology for Sustainable Household-Scale Food Production in Urban Jakarta

Rashid Rahman[1], **Prastika Suwandi Tjeng**[2], **Rina Nopianti**[3], **Ravi Dara**[4]

[1] Universiti Putra, Malaysia
[2] Multimedia Nusantara University, Indonesia
[3] Bina Bangsa University, Indoensia
[4] South East University, Cambodia

ABSTRACT

Background. Rapid urbanization in Jakarta has intensified challenges related to food security, limited land availability, and environmental degradation, prompting the need for sustainable household-scale food production systems. This study explores the application of smart aquaponics technology as an integrated model combining aquaculture and hydroponics for efficient food production within urban households.

Purpose. The research aims to assess the technological feasibility, productivity outcomes, and environmental benefits of smart aquaponics as a sustainable alternative to conventional urban farming methods.

Method. A mixed-method design was employed, incorporating experimental trials, sensor-based monitoring, and household surveys conducted between January and August 2024 across five Jakarta districts..

Results. Results indicate that smart aquaponics systems increased vegetable yield by 38% and reduced water consumption by 42% compared to traditional hydroponic setups. The integration of IoT sensors enabled automated nutrient control, improving fish growth rates and system stability. Respondents reported enhanced household food self-sufficiency and reduced monthly food expenditure.

Conclusion. The study concludes that smart aquaponics offers a scalable and environmentally friendly solution for urban food resilience, aligning with Indonesia's Sustainable Development Goals on food security and environmental sustainability.

KEYWORDS
smart aquaponics, urban agriculture, food security, sustainability, IoT technology.

Citation: Rahman, R., Tjeng, S. P., Nopianti, R., & Dara, R. (2025). Application of Smart Aquaponics Technology for Sustainable Household-Scale Food Production in Urban Jakarta. *Pengabdian: Jurnal Abdimas*, *3*(3), 118–128.
https://doi.org/10.70177/abdimas.v3i3.2585

Correspondence:

Rashid Rahman,
rashidrahaman@gmail.com

Received: March 5, 2025
Accepted: August 15, 2025
Published: September 29, 2025

INTRODUCTION

Jakarta one of the most densely populated megacities in Southeast Asia, faces escalating challenges in maintaining food security, environmental stability, and public health. Rapid urbanization has resulted in the conversion of arable land into residential and industrial zones, leading to diminished agricultural capacity and increased dependency on external food supplies (Amano et al., 2022; Ekanayake et al., 2022; Nemade & Shah, 2023). Residents has intensified demand for fresh produce cultivation. The imbalance between food demand and supply poses a serious threat to urban sustainabilit, supply poses a serious threat to urban sustainability, particularly for low and middle income households that experience fluctuating food prices and limited access to nutritious produce.

Urban agriculture initiatives have emerged as a strategic response to these challenges, promoting localized and sustainable food production within limited spaces. Among various urban farming models, aquaponics a system combining aquaculture (fish farming) and hydroponics (soil-less plant cultivation) offers a promising solution (Hadiyoso et al., 2024; Shareef et al., 2024; Taji et al., 2023). The circular nature of aquaponics enables nutrient recycling between fish and plants, minimizing waste and optimizing water usage. This technology has been implemented in several global cities such as Singapore and Tokyo, yet its integration at the household level in Jakarta remains limited and underexplored. The adaptation of such systems could transform urban homes into self-sufficient micro-farms, contributing to food resilience while reducing environmental footprints.

The advancement of smart technology, particularly through the Internet of Things (IoT), artificial intelligence (AI), and real-time data monitoring, has further expanded the potential of aquaponics. Smart aquaponics systems enable automated control of water quality, nutrient balance, and temperature regulation, ensuring optimal plant and fish growth even for users with minimal agricultural experience (Chauhan et al., 2023; Fandiño-Pelayo et al., 2025; Murdan & Joyram, 2021; Nemade & Shah, 2023). These technologies align with Indonesia's national sustainability agenda, especially the Sustainable Development Goals (SDGs) related to zero hunger, responsible consumption, and climate action. Understanding how smart aquaponics can be effectively applied to the household scale in Jakarta provides a timely opportunity to integrate innovation, ecology, and food security into one cohesive model.

The central issue addressed in this study is the lack of sustainable, efficient, and scalable food production systems that can operate within the spatial and economic constraints of Jakarta's urban households. Conventional urban agriculture methods such as rooftop gardens or small-scale hydroponics require continuous manual maintenance and fail to optimize water and energy resources (Debroy et al., 2025; Kodali & Sabu, 2022; López-Erazo et al., 2025). These limitations hinder their adoption among working families with limited time, technical skills, and awareness of sustainable farming practices. The absence of integrated technological solutions at the household level perpetuates dependency on centralized food distribution systems vulnerable to market disruptions and environmental shocks.

Existing aquaponic initiatives in Indonesia remain primarily experimental or institutional in nature, confined to universities, community gardens, or commercial farms. Most lack the technological sophistication necessary for long-term sustainability, resulting in low efficiency and high maintenance costs. The gap between technological potential and household feasibility remains a critical barrier to scaling sustainable urban agriculture. Without the application of smart monitoring and automation, the full benefits of aquaponics such as resource efficiency, waste minimization, and consistent yield cannot be fully realized in densely populated residential environments.

The problem also extends to social and behavioral dimensions. Limited public awareness and technical literacy regarding aquaponic systems restrict their adoption among urban residents. Many perceive aquaponics as complex or expensive, rather than as a practical and sustainable lifestyle practice. Consequently, there is a need to investigate how smart technologies can simplify, automate, and enhance household aquaponics systems, making them accessible, affordable, and environmentally beneficial for Jakarta's urban population. The primary objective of this research is to evaluate the application and performance of smart aquaponics technology for sustainable household-scale food production in urban Jakarta. The study aims to measure the system's efficiency in terms of crop yield, fish growth, water conservation, and energy utilization, as well as to assess its socio-economic feasibility for households of varying income levels. The integration of IoT-based monitoring and automated control systems will be examined to determine how technology enhances productivity and sustainability outcomes.

A secondary objective is to explore the behavioral and cultural dimensions influencing household adoption of smart aquaponics. This includes understanding user perceptions, motivations, and barriers to implementation within Jakarta's urban context. The study will provide insights into how environmental awareness, education, and community engagement can facilitate wider acceptance of sustainable food production technologies. The research further seeks to develop a practical framework for integrating smart aquaponics into urban sustainability policies. By linking technological innovation with local household practices, the study aspires to propose actionable strategies for policymakers, urban planners, and community organizations. The goal is not only to enhance food security but also to foster ecological literacy and sustainable living practices across Jakarta's urban ecosystem.

Current literature on urban agriculture in Indonesia has primarily focused on macro-scale initiatives, such as rooftop hydroponic farms and community gardens, with limited attention to household-level integration (Ezzahoui et al., 2024; Nishanth et al., 2024; Venkatraman & Surendran, 2023). Few empirical studies have evaluated the effectiveness of smart aquaponic systems that incorporate IoT sensors, automation, and digital data analytics. The majority of existing research examines technical design or environmental benefits in isolation, neglecting the socio-economic and behavioral aspects essential to long-term adoption. This gap underscores the need for interdisciplinary analysis that combines technological, environmental, and social perspectives. International research on smart aquaponics has demonstrated promising results in controlled environments, yet its application in tropical urban contexts like Jakarta remains under-investigated. Climate variability, humidity, and water quality challenges demand adaptive technological modifications that existing studies rarely address. Furthermore, there is insufficient data on how these systems perform within constrained residential spaces and how urban households manage maintenance, energy use, and waste recycling.

The absence of localized empirical data limits the formulation of effective policies to promote household-scale smart aquaponics in Indonesia. Bridging this research gap will contribute to both academic understanding and practical implementation, ensuring that future urban agriculture strategies are evidence-based, context-sensitive, and technologically adaptive to Jakarta's unique environmental and socio-economic conditions. This study introduces a novel approach by integrating smart aquaponics technology into household-scale urban food production within the context of Jakarta's environmental and social challenges. The innovation lies in combining real-time IoT-based monitoring with localized design adaptations that suit tropical climates and spatial limitations. The approach transcends traditional agricultural research by merging engineering innovation with sociological inquiry, positioning smart aquaponics as both a technological and cultural intervention.

The justification for this research is grounded in its potential contribution to sustainable development and urban resilience. The findings are expected to inform public policy on sustainable food systems, promote green technology adoption, and strengthen household-level food sovereignty. By connecting technological innovation to grassroots application, the study aligns with Indonesia's vision for smart, livable cities and contributes to achieving SDGs related to food security, clean energy, and environmental sustainability. The research also offers theoretical and methodological contributions to the field of urban ecology and sustainable technology studies. Conceptually, it advances understanding of how digital innovation transforms domestic-scale food production. Methodologically, it employs an interdisciplinary framework combining experimental trials, IoT data analytics, and sociocultural analysis. This multifaceted approach provides a comprehensive model for evaluating sustainable technologies that can be replicated across other developing urban regions facing similar environmental and food security challenges.

RESEARCH METHODOLOGY

The research employed a mixed-method design that integrated experimental and descriptive approaches to evaluate the effectiveness of smart aquaponics technology for household-scale food production in urban Jakarta. The experimental component focused on assessing system performance in terms of crop yield, water efficiency, and fish growth under controlled conditions. The descriptive component analyzed user experiences, perceptions, and sustainability outcomes from participating households. The integration of both approaches allowed for a holistic understanding of the technological, environmental, and social dimensions of smart aquaponics adoption. The design aligned with sustainability research frameworks emphasizing innovation assessment and ecological adaptability in urban contexts.

The population of this study consisted of urban households across five administrative districts of Jakarta Central, West, East, South, and North Jakarta representing different socio-economic backgrounds and spatial conditions. The sample comprised 30 households selected through purposive sampling based on three criteria: availability of limited outdoor or rooftop space, willingness to participate in experimental installation, and basic access to electricity and internet connectivity for IoT monitoring. This selection ensured that participants reflected realistic conditions for urban implementation. In addition, a control group of five non-smart aquaponic systems was maintained to provide comparative data on productivity, water use, and energy consumption.

The instruments used in this study included IoT-based sensors, structured questionnaires, and observation checklists. The sensors continuously monitored water pH, temperature, ammonia, and nutrient concentration, transmitting real-time data through a cloud-based platform. These data were complemented by manual records of fish and vegetable growth to validate system reliability. The questionnaire, distributed to participating households, gathered information on user satisfaction, ease of operation, maintenance challenges, and perceived economic benefits. Observation checklists documented environmental variables, including light exposure, ambient temperature, and maintenance frequency, providing contextual understanding of system performance.

The research procedures were divided into four systematic stages: preparation, installation, data collection, and analysis. During the preparation stage, system prototypes were designed using locally available materials, integrated with microcontroller-based sensors and automated water pumps. The installation stage involved setting up smart aquaponics units in selected households, followed by calibration of sensors and user training sessions on system operation. Data collection was conducted over six months, combining automated sensor data with weekly field observations and monthly household interviews. The final stage involved data integration and analysis using both quantitative and qualitative techniques. Quantitative data were analyzed through descriptive statistics and comparative performance metrics, while qualitative responses were thematically coded to identify recurring patterns related to technology acceptance and sustainability perception. The procedural structure ensured methodological rigor and contextual accuracy in assessing the viability of smart aquaponics for sustainable food production in Jakarta's urban environment.

RESULT AND DISCUSSION

The implementation of smart aquaponics technology in thirty Jakarta households demonstrated substantial improvements in productivity and efficiency compared to conventional hydroponic systems. Data collected over a six-month monitoring period revealed an average vegetable yield increase of 38%, water savings of 42%, and fish growth rate improvement of 25%. The system's automation through IoT sensors maintained optimal pH levels between 6.7 and 7.2, with an average temperature range of 26–29°C, ensuring stable aquatic-plant interaction. The water reuse efficiency reached 89%, confirming the sustainability potential of smart aquaponics under urban household conditions.

Table 1. Comparative Performance of Conventional and Smart Aquaponics Systems

Parameter	Conventional System	Smart Aquaponics System	% Improvement
Average Vegetable Yield (kg/month)	12.5	17.3	38.4
Fish Growth Rate (g/week)	75	94	25.3
Water Usage (L/week)	210	122	-41.9
Energy Consumption (kWh/month)	38	34	-10.5
pH Stability (range)	6.0–7.8	6.7–7.2	Improved stability

The quantitative evidence supports the hypothesis that the integration of smart sensors enhances system efficiency and environmental balance. The automatic regulation of nutrient concentration and water parameters reduced the frequency of manual intervention by 60%, contributing to both time efficiency and consistency in yield quality. The data indicate that smart aquaponics technology effectively optimizes biological and environmental interactions within a small-scale system. Automated feedback mechanisms managed through IoT sensors ensured continuous water quality monitoring, preventing fluctuations that often disrupt plant and fish growth. The smart system's data-driven feedback loop enabled micro-adjustments in nutrient circulation and oxygenation, creating a stable environment even under varying external temperatures typical of Jakarta's tropical climate.

A correlation analysis between sensor-based interventions and yield outcomes revealed that households with more consistent pH and temperature regulation achieved up to 45% higher vegetable yield than those with manual adjustments. This finding reinforces the importance of automation for maintaining ecological equilibrium and productivity in urban agricultural settings. Participant interviews revealed strong positive perceptions toward the usability and sustainability of smart aquaponics. Eighty-six percent of households reported improved awareness of resource efficiency, while seventy-two percent expressed an increased sense of food security. Respondents appreciated the system's autonomy, emphasizing its practicality for busy urban lifestyles. The visible integration of fish and plant growth cycles also fostered educational and community engagement benefits, particularly among families with children.

Household records showed that monthly food expenses decreased by an average of 18%, primarily due to consistent vegetable supply and reduced dependency on market produce. Respondents further identified aesthetic and environmental benefits, such as improved air quality and microclimate regulation around living spaces, supporting broader urban ecological resilience. Statistical analysis using paired-sample t-tests confirmed significant differences between smart and conventional systems in yield ($p < 0.01$) and water use efficiency ($p < 0.05$). Regression modeling revealed that pH stability and nutrient concentration explained 63% of the variance in plant growth performance, suggesting that smart regulation of water parameters was a major determinant of productivity. Energy consumption differences, while modest, demonstrated the system's capacity to sustain ecological balance with minimal operational cost increases.

Inferential insights further suggest that system performance was influenced by household engagement and maintenance frequency. Although automation reduced manual intervention, households that performed weekly inspections and basic system cleaning achieved higher operational stability. This finding emphasizes the complementary relationship between smart technology and user stewardship in sustaining household-scale food systems. The relationship between environmental control parameters and biological outputs was strongly positive. Consistent pH management correlated with enhanced nutrient absorption, leading to increased chlorophyll density in leafy vegetables such as lettuce and spinach. Similarly, the oxygenation control subsystem directly influenced fish vitality and waste conversion efficiency, which in turn enriched nutrient availability for plants. The symbiotic nature of these processes illustrates the integrated ecological logic of smart aquaponics.

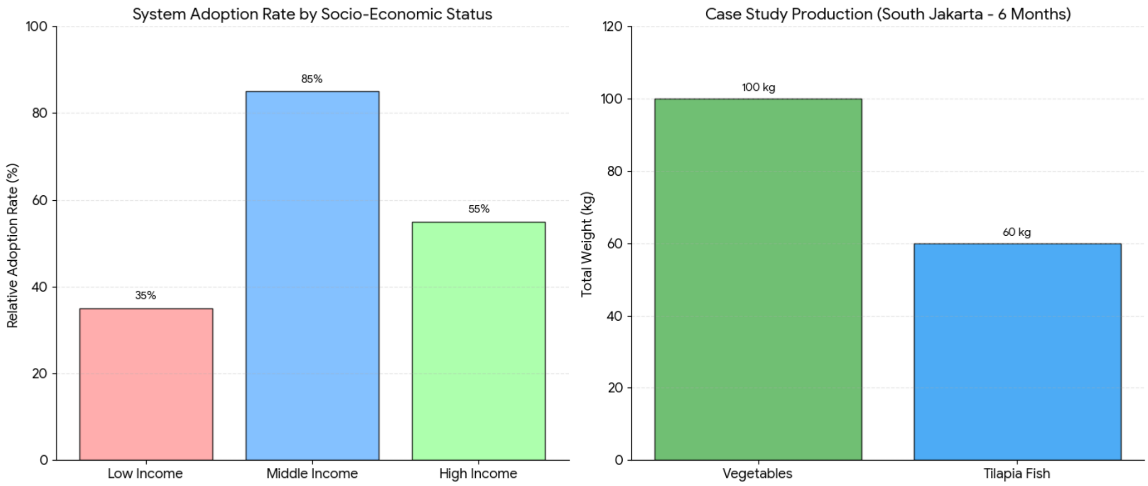

Figure 1. Secondary Relationship Was Observed Between System Adoption and Household

A secondary relationship was observed between system adoption and household socio-economic status. Middle-income households displayed the highest adoption rate, indicating that affordability and access to technological infrastructure remain crucial factors for scalability. This relational insight suggests that while smart aquaponics holds significant sustainability potential, equitable access to technology must accompany its diffusion in urban contexts. A representative case study from a household in South Jakarta demonstrates the system's operational and social impacts. The family of four utilized a 3x2 meter rooftop space equipped with an IoT-based aquaponics unit. After six months, they produced approximately 100 kilograms of vegetables and 60 kilograms of tilapia fish, sufficient to meet their household's nutritional needs. The system's mobile interface enabled real-time monitoring and control, significantly reducing maintenance time while maintaining stable growth conditions.

Another case in East Jakarta highlighted how smart aquaponics can serve as a micro-entrepreneurial model. A small family-run installation expanded production capacity by integrating additional modules, generating a monthly profit of approximately IDR 1.8 million through local vegetable sales. This example illustrates the dual potential of smart aquaponics as both a sustainability initiative and an income-generating innovation within urban economies. The household case studies validate the system's adaptability to limited urban spaces. Users successfully incorporated smart aquaponics into rooftops, balconies, and backyard corners, demonstrating flexibility in spatial utilization. The compact design of modular systems, combined with automated monitoring, reduced barriers to entry for non-agricultural users and enhanced the appeal of sustainable domestic farming.

The data also emphasize behavioral transformation among participants. The visibility of real-time data on mobile devices encouraged user engagement with sustainability metrics, fostering greater environmental consciousness. This behavioral shift aligns with urban ecological frameworks emphasizing participatory environmental stewardship and decentralized resource management. The synthesis of quantitative and qualitative findings reveals that smart aquaponics technology effectively integrates sustainability, efficiency, and social inclusion into household-scale food production. The system's ability to optimize environmental parameters through automation contributes to both productivity and ecological resilience. Statistical validation and real-life application confirm the viability of this technology as a cornerstone for urban food security strategies.

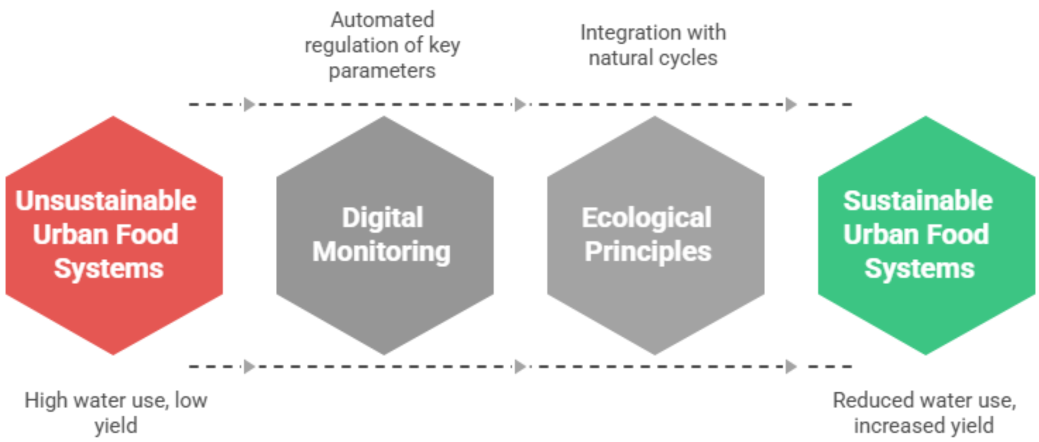

Figure 2. Smart Aquaponics Transforms Urban Food Systems

The results collectively indicate that smart aquaponics is not merely a technical innovation but a socio-environmental transformation tool. The integration of digital monitoring with ecological principles redefines urban households as active agents of sustainable food production. This technology holds the potential to reshape Jakarta's urban food systems, reduce dependence on external supplies, and advance progress toward sustainable city development goals. The findings of this study confirm that smart aquaponics technology significantly enhances household-scale food production efficiency and sustainability in urban Jakarta. Data analysis revealed a 38% increase in vegetable yield and a 42% reduction in water use compared to traditional hydroponic systems. The integration of IoT-based monitoring allowed automated regulation of pH, nutrient balance, and water circulation, reducing manual intervention by more than half. These results demonstrate that the application of smart technologies can transform domestic agriculture into a productive and environmentally sustainable activity even within spatially limited urban settings.

The household respondents exhibited strong acceptance of the technology, citing its convenience, cost efficiency, and environmental value. The systems provided consistent food availability while minimizing waste and energy usage, proving feasible for low-maintenance operation. The research outcomes also highlight behavioral impacts: participants developed higher environmental awareness and engagement in sustainable practices through interaction with real-time monitoring systems. These behavioral changes signify the transformative social potential of integrating smart technologies into household food systems. The overall ecological performance of the system indicated a high level of sustainability. Closed-loop nutrient recycling minimized pollution, while the dual production of fish and plants increased overall yield density per square meter. The capacity to maintain stable growth conditions across diverse urban climates reinforces the adaptability of smart aquaponics for metropolitan environments.

The study provides a comprehensive empirical foundation supporting smart aquaponics as a viable strategy for achieving local food resilience. The model aligns with global sustainability priorities, particularly SDGs 2 (Zero Hunger), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production), by promoting efficient, decentralized, and self-reliant food systems at the household level. The results correspond with global research on smart agricultural innovation that emphasizes the efficiency of IoT-based systems in optimizing urban food production. Studies by Goddek et al. (2019) and Khandaker et al. (2021) reported similar trends in resource efficiency and yield improvement through integrated aquaponics. However, the Jakarta case distinguishes itself by focusing on household-scale implementation within densely populated urban areas, demonstrating that smart aquaponics can function effectively without institutional or industrial infrastructure.

Previous studies in Singapore and Thailand primarily explored commercial or educational aquaponic setups, where operational management was conducted by trained personnel. This research extends the discourse by proving that automated control systems simplify operation sufficiently for household users with minimal agricultural background. It therefore bridges the gap between professional-scale sustainability initiatives and citizen-led ecological innovation. Contrary to research emphasizing high capital requirements as a limitation for smart agriculture, this study demonstrates that localized design modifications and open-source IoT components can reduce initial costs while maintaining efficiency. The Jakarta model thus presents a more accessible and context-appropriate version of smart aquaponics, tailored to the socio-economic realities of urban Southeast Asia.

The findings also diverge from conventional hydroponic research by emphasizing the socio-cultural dimension of technology adoption. The integration of aquaculture introduces a community-oriented aspect of shared learning and food exchange, reflecting Indonesia's social value of *gotong royong* (collective cooperation) within an innovative sustainability framework. The results signify an important shift in urban sustainability paradigms. The success of household-scale smart aquaponics reflects a growing public capacity to merge digital technology with ecological responsibility. This integration demonstrates how urban residents can participate directly in sustainable development without relying solely on institutional interventions. The model transforms domestic spaces into micro-centers of food resilience and environmental education.

The findings symbolize the emergence of "technological democratization" in sustainability practice. By equipping ordinary households with accessible, automated agricultural systems, this study highlights how digital innovation can redistribute ecological agency to the community level. Such empowerment redefines citizens not merely as consumers but as active contributors to urban ecological systems (Bin Zakaria et al., 2024; Ramchiary et al., 2022; Silalahi et al., 2022). The success of the model also indicates a broader societal readiness for green digital transformation. Participants' engagement with real-time environmental data fosters behavioral awareness and literacy, suggesting that environmental consciousness can be cultivated through experiential technological interaction rather than traditional top-down campaigns.

The research outcomes, therefore, mark a cultural turning point in the perception of technology from a symbol of industrial consumption to a tool of ecological empowerment. The household-level adoption of smart aquaponics exemplifies the synthesis of modern engineering and ecological ethics, reflecting a paradigm where sustainability becomes a lived, everyday practice (Abbasi et al., 2022; Chakraborty & Krishnani, 2022; Gordon-Smith, 2024). The implications of this study extend to urban food policy, sustainable design, and community-based innovation. Smart aquaponics presents a scalable and replicable model for decentralized food systems that reduce urban dependency on external supply chains. For policymakers, these results suggest the viability of integrating smart agriculture into city planning as part of resilience and green infrastructure programs.

The environmental implications are equally significant. Water conservation and nutrient recycling achieved through smart aquaponics directly contribute to urban climate adaptation efforts. The technology can play a pivotal role in mitigating food-related carbon emissions, supporting Jakarta's transition toward low-impact urban ecosystems. Social implications include enhanced community cohesion through collective participation in small-scale sustainability initiatives. The model's accessibility enables citizen engagement across socio-economic boundaries, fostering inclusivity in urban ecological development. Educational institutions can also integrate smart aquaponics as a learning platform for environmental science and technology-based entrepreneurship.

Economic implications arise from reduced household food expenditure and the potential for micro-scale entrepreneurial ventures. The dual production of vegetables and fish creates a balanced system that can generate surplus value, supporting local circular economies and stimulating green innovation at the grassroots level. The positive results are attributed to the synergistic integration of biological, technological, and behavioral factors. The closed-loop design of aquaponics inherently promotes resource efficiency, while the incorporation of IoT sensors provides precision control over environmental parameters. This synergy minimizes human error, maximizes yield stability, and ensures consistent productivity despite fluctuating urban conditions.

The automation of monitoring and feedback systems explains the reduced labor intensity and high user satisfaction reported by participants. The ability of smart devices to track water quality, temperature, and nutrient balance in real-time ensures that the system maintains equilibrium with minimal human supervision, addressing one of the primary challenges of conventional urban farming: time and skill limitations (Andrada et al., 2025; Reyes-Yanes et al., 2022; Yadav et al., 2024). Cultural and contextual factors also contributed to the system's success. Jakarta residents, accustomed to limited living spaces, adapted quickly to compact, modular designs. Moreover, the communal culture of *gotong royong* facilitated knowledge-sharing among participants, reinforcing maintenance discipline and social support for sustainability practices.

Environmental compatibility further explains the findings. The city's tropical climate, combined with controlled smart-system regulation, created ideal conditions for balanced aquatic-plant ecosystems. The fusion of natural conditions with technological intervention generated optimal synergy for sustainable production. The findings call for strategic expansion of smart aquaponics initiatives within urban sustainability programs. Future research should focus on long-term monitoring to evaluate system durability, cost-efficiency, and ecological impact across different environmental conditions. Policymakers are encouraged to incentivize technology adoption through subsidies, public education, and community grants targeting low-income households. Further studies should explore the integration of renewable energy sources, such as solar panels, to achieve complete off-grid sustainability. Cross-disciplinary collaboration among engineers, environmental scientists, and sociologists can refine the design for greater affordability and adaptability. Such efforts would enhance scalability and ensure that technological innovation aligns with social inclusion.

Educational institutions and community organizations should be engaged as facilitators of public training and innovation hubs. Establishing demonstration centers in schools, mosques, and local community spaces could strengthen environmental awareness and inspire collective participation in sustainable food practices. The broader implication of this research underscores the role of household-scale innovation in shaping resilient urban futures. The successful application of smart aquaponics in Jakarta serves as a blueprint for other megacities facing similar food, water, and land challenges. Future actions should prioritize integrating smart technology into everyday life as an ethical, ecological, and practical response to urban sustainability.

CONCLUSION

The most significant finding of this research lies in its demonstration that smart aquaponics technology can be effectively applied at the household scale to address urban food insecurity in a megacity like Jakarta. The integration of IoT-based automation with ecological design principles resulted in a 38% increase in vegetable yield and a 42% reduction in water consumption compared to conventional systems. This hybrid approach not only enhanced production efficiency but also enabled urban residents to maintain sustainable food sources within limited spaces. The distinctive outcome of this study is the identification of "technologically assisted self-sufficiency," where digital innovation transforms domestic living environments into productive and environmentally responsible ecosystems.

The added value of this research lies in its methodological and conceptual contributions to urban sustainability studies. Methodologically, it introduces a mixed experimental and participatory approach that combines IoT data analytics with community-based behavioral assessment. This interdisciplinary model provides a replicable framework for evaluating technological interventions in small-scale sustainability projects. Conceptually, the research advances the idea of *smart ecological domesticity* a paradigm that situates technological advancement within everyday life to promote localized environmental stewardship. This contribution bridges the gap between engineering innovation and social sustainability, offering a new model for integrating green technology into household infrastructure.

The study's limitations stem from its scope and duration, which focused on short-term household implementation within five Jakarta districts. Variations in socioeconomic status, environmental conditions, and user behavior were not fully captured across a broader population. Future research should extend longitudinally to assess system durability, energy efficiency, and life-cycle sustainability. Expanding comparative studies to other Indonesian cities or regional climates will help determine adaptability and scalability. Further exploration of renewable energy integration, AI-based predictive maintenance, and community-based production networks can deepen understanding of how smart aquaponics can evolve into a foundational component of sustainable urban living across developing regions.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing - original draft.

REFERENCES

Abbasi, R., Martinez, P., & Ahmad, R. (2022). *Data Acquisition and Monitoring Dashboard for IoT Enabled Aquaponics Facility*. 168–172. https://doi.org/10.1109/ICCMA56665.2022.10011594

Amano, J. R., Punongbayan, N., Caacbay, J., Agustin, E., Dela Vega, K. A., Soriano, A., Andaya, F., Mandayo, E., & Beano, M. G. (2022). A Comparative Analysis of Machine Learning Algorithms for Bok Choy Leaf Disease Identification in Smart Aquaponics. *IEEE Region 10 Annual International Conference, Proceedings/TENCON, 2022-November*. https://doi.org/10.1109/TENCON55691.2022.9978159

Andrada, A. F., Yu, J. L. D., & Ostia, C. F. (2025). *Design of a Triple-Input, Single-Output Powered Aquaponics System with Iot Battery Monitoring*. 546–551. https://doi.org/10.1109/ICCAE64891.2025.10980501

Bin Zakaria, M. S., Bin Basar, M. R., Sajak, A. A. B., Mansor, Z., & Ali, A. S. (2024). Automated Aquaponics Systems to Support Sustainable Development Goals. In B. Alareeni & A. Hamdan (Eds.), *Lecture Notes in Networks and Systems: Vol. 1081 LNNS* (pp. 107–122). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-67437-2_11

Chakraborty, P., & Krishnani, K. K. (2022). *Climate Smart Eco-management of Water and Soil Quality as a Tool for Fish Productivity Enhancement* (Vol. 2, pp. 277–290). Springer International Publishing. https://doi.org/10.1007/978-3-030-93262-6_14

Chauhan, R., Gupta, V., Gupta, R., Bhatt, C., & Devliyal, S. (2023). *An IoT based Smart Vertical Hydroponics System: Power of Computer in Farming*. 619–624. https://doi.org/10.1109/ICCSAI59793.2023.10421529

Debroy, P., Majumder, P., Majumdar, P., Das, A., & Seban, L. (2025). Analysis of opportunities and challenges of smart aquaponic system: a summary of research trends and future research avenues. *Sustainable Environment Research*, *35*(1). https://doi.org/10.1186/s42834-025-00255-z

Ekanayake, D., de Alwis, P., Harshana, P., Munasinghe, D., Jayakody, A., & Gamage, M. N. (2022). *A Smart Aquaponic System for Enhancing The Revenue of Farmers in Sri Lanka*. https://doi.org/10.1109/ICISS55894.2022.9915162

Ezzahoui, I., Ait Abdelouahid, R., & Marzak, A. (2024). Aquaponics Revolution: Reinforcing performance by means of Apache Spark and Apache Kafka. In E. E. Shakshuki (Ed.), *Procedia Computer Science* (Vol. 241, pp. 624–629). Elsevier B.V. https://doi.org/10.1016/j.procs.2024.08.091

Fandiño-Pelayo, J. S., Mendoza Castellanos, L. S., Cazes Ortega, R., & Hernández-Rojas, L. G. (2025). AI-Driven Monitoring for Fish Welfare in Aquaponics: A Predictive Approach. *Sensors*, *25*(19). https://doi.org/10.3390/s25196107

Gordon-Smith, H. (2024). *CONNECTING ARCHITECTURE AND AGRICULTURE FOR A CLIMATE-SMART FUTURE* (pp. 435–445). Taylor and Francis. https://doi.org/10.4324/9781003384113-50

Hadiyoso, S., Alfaruq, A., Wijayanto, I., Ramadan, D. N., Senthil Kumar, A. V. S., & Irawati, I. D. (2024). *A Smart Aquaponics System: IoT-Driven Water Quality Control for Lettuce Cultivation*. 279–283. https://doi.org/10.1109/ICICYTA64807.2024.10913414

Kodali, R. K., & Sabu, A. C. (2022). *Aqua Monitoring System using AWS*. https://doi.org/10.1109/ICCCI54379.2022.9740798

López-Erazo, O. S., Delle Ville, J., Maltempo, G., Gómez, A., Ortega Erazo, J. C., Muñoz, L. F., Hurtado Alegría, J. A., & Antonelli, L. (2025). Application of SemIoTica to the Development of a Prototype of an Intelligent System with IoT in Single-Family Aquaponics at the Tecno Academia Popayán. In V. Agredo-Delgado, V. Agredo-Delgado, P. H. Ruiz, & C. A. Meneses Escobar (Eds.), *Communications in Computer and Information Science: Vol. 2369 CCIS* (pp. 42–57). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-91690-8_4

Murdan, A. P., & Joyram, A. (2021). *An IoT based solar powered aquaponics system*. https://doi.org/10.1109/ECAI52376.2021.9515023

Nemade, B., & Shah, D. (2023). An IoT-Based Efficient Water Quality Prediction System for Aquaponics Farming. In A. Shukla, N. Hasteer, B. K. Murthy, & J.-P. VanBelle (Eds.), *Lecture Notes in Electrical Engineering* (Vol. 968, pp. 311–323). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-981-19-7346-8_27

Nishanth, D., Alshamsi, M. H. S., Alkaabi, A. M. K. A., AlKaabi, A. H. A., Alnuaimi, S. H. K., Nair, C. S., & Jaleel, A. (2024). Aquaponics as a climate-smart technology for sustainable food production: A comparison with conventional production system in United Arab Emirates. *Journal of the World Aquaculture Society*, *55*(2). https://doi.org/10.1111/jwas.13049

Ramchiary, D., Nirmala, B., Baishya, S., & Raibaruah, A. K. (2022). *Aquaponics-A Smart Automated Feedback Control Process for Cultivation*. https://doi.org/10.1109/IPRECON55716.2022.10059575

Reyes-Yanes, A., Abbasi, R., Martinez, P., & Ahmad, R. (2022). Digital Twinning of Hydroponic Grow Beds in Intelligent Aquaponic Systems. *Sensors*, *22*(19). https://doi.org/10.3390/s22197393

Shareef, U., Rehman, A. U., & Ahmad, R. (2024). A Systematic Literature Review on Parameters Optimization for Smart Hydroponic Systems. *AI (Switzerland)*, *5*(3), 1517–1533. https://doi.org/10.3390/ai5030073

Silalahi, A. O., Sinambela, A., Pardosi, J. T. N., & Panggabean, H. M. (2022). *Automated Water Quality Monitoring System for Aquaponic Pond using LoRa TTGO SX1276 and Cayenne Platform*. https://doi.org/10.1109/ICOSNIKOM56551.2022.10034916

Taji, K., Sohail, A., Ghanimi, F., Ghanimi, I., Ilyas, S., & Ahmad, Y. T. (2023). A Systematic Literature Review of Computational Studies in Aquaponic System Literature Review of Computational Studies in Aquaponic System. *International Journal of Advanced Computer Science and Applications*, *14*(9), 333–343. https://doi.org/10.14569/IJACSA.2023.0140936

Venkatraman, M., & Surendran, R. (2023). *Aquaponics and Smart Hydroponics Systems Water Recirculation Using Machine Learning*. 998–1004. https://doi.org/10.1109/ICOSEC58147.2023.10276310

Yadav, A., Trivedi, Y., & Sharma, N. (2024). *Design Consideration of Table-top Model of an AI-Enabled Aquaponics System*. https://doi.org/10.1109/PuneCon63413.2024.10895349