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DESIGN AND IMPLEMENTATION OF A SMART LOW ENERGY RAM PUMP SOLAR- POWERED ARDUINO AQUAPONICS (SLERSOPAA)

BARNABAS KAYIL

2024

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DESIGN AND IMPLEMENTATION OF A SMART LOW ENERGY RAM PUMP SOLAR - POWERED ARDUINO AQUAPONICS (SLERSOPAA)

BY

BARNABAS KAYIL

Thesis submitted to the Department of Physics of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirement of the awards of Master of Philosophy Degree in Physics

FEBRUARY 2024

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: 16/04/2024

Name: Barnabas Kayil

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's Signature: .... Date: 16/04/24

Name: Dr. Kwadwo Anokye Dompreh

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ABSTRACT

Aquaponics is a system of farming that combines both fish and crops within a closed-loop ecosystem. However, high setup costs (HSC), high operational costs (HOC), and high energy demands (HED) pose significant challenges, particularly in regions with limited access to electricity. In this thesis, Smart

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Low Energy Ram Pump Solar-Powered Arduino Aquaponics (SLERSOPAA) was designed. This innovative approach aims to reduce HSC, HOC, and HED of aquaponics by integrating bamboo grow beds, solar-powered Arduino automation (SPAA), and hydraulic ram pump (HRP), also known as ram pump (RP), into the system. The integration of HRP and SPAA results in a remarkable reduction of HED by 70.25%, while using of bamboo reduces the HSC by 80%. The effect of the reduced HED on water quality parameters in SLERSOPAA within the six months is: a potential hydrogen (pH) range of 7.22–8.05, dissolved oxygen (DO) range of 4.00–5.71 mg/L, electrical conductivity (EC) range of 1.30–1.81 mS/cm, and total dissolved solids (TDS) range of 0.986–1.160 g/L. Besides that, the results of growth rates for the following vegetables, such as hot pepper, tomato, cabbage, and cucumber, in just four weeks were reported. The growth rate of catfish was monitored closely. The obtained average mass of 209.3 g and length of 11.3 cm were recorded within three months. Aside from the bamboo reducing the HSC, it also provides the following antioxidant compounds, such as phenols, flavonoids, vitamin C, and E, which are natural alternatives for the developing functional foods and nutraceuticals within the system for vegetable growth. The SLERSOPAA offers a promising solution to food shortages, promotes clean energy usage, reduces household vulnerabilities, creates employment opportunities, and enhances resilience in sub-Saharan Africa.

KEY WORDS

Aquaponics

Arduino Uno

Bamboo

Low energy

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Ram pump

Solar power

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Finally, I am grateful to my entire Kayil family for their unwavering moral support during this study. May God bless each and every one of you.

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DEDICATION

To my beloved wife, Madam Vivian A. Aduko, and my children, Johnson Kayil Ipiin, Esther U. Kayil, and Isaac Uwomborbi Khumbaya Kayil.

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TABLE OF CONTENTS

Page

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

Digitized by Sam Jonah Library

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

LIST OF TABLES

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

LIST OF FIGURES

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

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LIST OF ABBREVIATIONS

RP	Ram Pump
HRP	Hydraulic Ram Pump
SPAA	Solar - Powered Arduino Automation
HSC	High Setup Cost
HOC	High Operational Cost
HED	High Energy Demand
EC	Electrical Conductivity
pH	Potential Hydrogen
DO	Dissolved Oxygen
SP	Solar Pump
NFT	Nutrient film technique
DWC	Deep Water Culture
RAS	Recirculation Aquaculture System
NGMA	National Greenhouse Manufacturers Association
UV	Ultraviolet
SWO	Sweet Water Organics
CERES	Centre for Education and Research in Environmental Strategies
HES	Hybrid Energy Systems
IoT	Internet of Things
GSM	Global system for mobile communication
LED	Light Emitting Diode
CEA	Controlled Environment Agriculture
BEI	Blue Economy Initiative

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TDS	Total Dissolved Solids
IDE	Integrated Development Environment
DC	Direct Current
SOC	State of Charge
EPC	Equipment Power Consumption
HLR	Hydraulic Load Rate
SL	Standard length
TL	Total length

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CHAPTER ONE

INTRODUCTION

This thesis deals with designing and implementing a Smart Low Energy Ram Pump Solar Powered Arduino Aquaponics (SLERSOPAA). It involves raising fish and cultivating vegetables such as hot pepper, tomato, cabbage, and cucumber, powered by solar energy within an ecosystem; the circulation of water within the aquaponics system is aided by the use of a Ram Pump (RP), which serves two purposes: (1) Lift the water for circulation and (2) aid aeration in the fish pond. This chapter presents a brief overview of the design of SLERSOPAA, the problem statement, its significance, its limitations, and its delimitation. Further, the thesis's scope, objective, and organisation are also presented.

Background of the Study

Aquaponics is a soilless farming method that integrates growing plants in hydroponic beds and fish in aquaculture tanks (Nagayo, Mendoza, Vega, Al Izki, & Jamisola, 2017). In this integrated system, fish and plants thrive in a closed-loop system. Fish are raised in tanks or ponds where they produce waste. This waste includes direct excretion from the fish, feed, and organic matter broken down by microbes (Hasan, 2014). Nitrifying bacteria are a crucial in converting fish waste into nitrates, which serve as plant nutrients. The plant roots and beneficial rhizobacteria remove these nutrients as biofilters by eliminating harmful substances like ammonia, nitrites, nitrates, and phosphorus. The freshly cleansed water from the hydroponic beds was recirculated back into the fish tanks. This closed-loop system minimises water usage (Fox, Howerton, & Tamaru, 2010a). In an era of climate change,

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developing access to scientific and technological systems for sustainable agriculture and fisheries, including methods like aquaponics, promise to advance the United Nations General Assembly's adopted Sustainable Development Goals (SDG 2).

The design and implementation of SLERSOPAA have enormous potential to address these challenges of food mentioned. This thesis involves the designing and constructing SLERSOPAA to raising fish and vegetables in a limited space. It also involves measuring concentrates in the pond, such as electrical conductivity (EC), total dissolved solids (TDS), potential hydrogen (pH), nitrate (NO_{3-}), and potassium (K), and plant and fish growth.

Statement of the Problem

Aquaponics is tipped to be the cleanest and safest way to produce food (Junge et al., 2020; Laidlaw & Magee, 2014). However, high energy demand (HED), high setup cost (HSC), and high operational cost (HOC) of the existing systems present a significant barrier to the adoption of aquaponics in Africa, especially in regions with limited access to electricity and water.

On energy and water use in aquaponics systems (Love, Uhl, & Genello, 2015b), their study revealed that, in 2013, the total electricity consumption amounted to 10,903 kWh, while in 2014, it was slightly lower at 10,844 kWh. On resource optimization (Ondruška, How, Netolický, Máša, & Teng, 2022), studies in aquaponics using a standard meter found that lighting used the most electricity, making up over 80% of the total daily usage, which is about 36.95 kWh. An essential concern in the advancement of vertical aquaponics, as underscored by Love, Uhl, et al. (2015b) lies in the formidable challenge of start-up capital. Hart et al., (2013) studied the implementation of

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aquaponics in education; technical obstacles were frequently cited, such as difficulties with nitrogen cycling, establishing an effective system setup, and ensuring long-term maintenance. Notably, Abraham et al., (2020) suggests that employing locally available and inexpensive materials for constructing the aquaponics production system can significantly reduce financial barriers. Laidlaw & Magee, (2014) revealed in their work that the inability to ensure a consistent and affordable power source hampers the scalability of aquaponics technology and cited the need for further research to explore innovative solutions. (Vázquez-Romero et al., (2022) studied techno-economic analysis of a recirculating tilapia-lettuce aquaponics system. They reported that the annual operating expense was $33,100-$3,300, with labour being the major contributor (52%).

Purpose of the Study

The purpose of the study is to find a solution to high energy demand (HED) in aquaponics by using solar panels, ram pumps, bell siphons, and cheap batteries to mitigate the high cost of electricity in aquaponics. In addition, the study addresses the high setup cost (HSC) using local materials such as bamboo, a homemade greenhouse, and a fish tank made of tarpaulin and the high operational cost (HOC) by using microcontrollers to automate the system, which does not need a human presence to function, and also to measure concentrations such as electrical conductivity, dissolved oxygen, total dissolved solids, potential hydrogen, nitrate, and potassium, as well as plants and fish growth rate in the SLERSOPAA.

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Objectives of the Study

The objectives are to;

i. reduce the energy needed to operate the SLERSOPAA by employing the innovative Ram Pump (RP) technology.
ii. utilises Arduino technology to monitor and control the operation of the Solar Pump (SP)
iii. measure concentrates in the pond such as electrical conductivity (EC), total dissolved solids (TDS), potential hydrogen (pH), nitrate (NO_{3-}) and potassium (K), as well as plant and fish growth rates.

Significance of the Study

SLERSOPAA is a game-changer in agriculture, offering a sustainable and eco-friendly way to grow food. It's a big deal because it cuts out the need for harmful chemicals in farming, making the produce healthier for people. The cost savings come from using less water and eliminating the need for expensive fertilisers and pesticides. It only requires a little space, to be setup in various places, including urban areas. Higher crop yields, help meet the increasing demand for sustainable farming. In terms of economic benefits, there are multiple income streams such as selling fish and produce, creating unique products, and offering workshops and consulting services. This benefits not only individual farmers but also contributes to broader agricultural practices. Aquaponics addresses environmental issues and offers a practical and profitable way forward for agriculture, involving various stakeholders, from individual farmers to the broader community.

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Delimitations

The study specifically looks at a medium-sized aquaponics system within a locally built Greenhouse that is scalable. The system is made of three bamboo A-stands with 21 grow beds, supporting 252 plants and 350 African catfish. It is powered by 120W solar panel, one 100Ah solar battery, one Ram Pump, one Solar Pump. An Arduino Uno microcontroller regulates water pumping to a reservoir.

Limitations

The system has a few limitations that should be noted. Firstly, the ram pump does not have an automatic start-up feature, which could require manual intervention. Secondly, while bamboo was used in constructing the grow beds, it may have a shorter lifespan compared to more durable materials like PVC pipes. Additionally, the use of tarpaulin to line the pond carries the risk of potential water leakage. Finally, the African catfish fingerlings were sourced from an external vendor, which might affect consistency and quality control.

Organisation of the Study

The thesis covers five chapters, each with distinct focuses and contributions. Chapter One provides the primary context for the study, commencing with a brief introduction clarifying the research problem at hand, the significance of the study, the purpose of the study and the objectives of the study. Chapter Two constitutes the wide-ranging literature review, offering an extensive survey of scholarly works explaining the foundational concepts that serve as the bedrock for the subsequent discourse within the thesis. Chapter Three delves into the experimental methodology, elaborating on the complexities of the system configuration and showcasing the practical results

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obtained from hands-on experiments. Chapter Four captures the graphical representation, analysis, and discussion of the results derived from the model, facilitating a comprehensive understanding of the research outcomes. Chapter Five concludes the thesis by drawing conclusive insights from the preceding chapters, and offering pertinent recommendations to guide future endeavors within this domain of study.

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CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter surveys the scholarly works on various aquaponics. It reviews the brief history of aquaponics, the aquaponics cycle, and types of aquaponics. In addition, it presents smart aquaponics and the challenges in aquaponics.

Brief History of Aquaponics

Aquaponics research began in the 1970s and continues worldwide, making contributions over the past 25 years (Ragnheidur, 2015; Ramsundar, 2015). Okomoda et al., (2023) did a review of historical perspective, opportunities, and challenges of its adoption and stated that while the system's origins have sparked considerable debate, the various historical attempts at development have collectively contributed to the present complexity and effectiveness of these systems (Okomoda et al., 2023)

Nowadays, people are finding new ways to improve aquaponics. They use deep-water culture and biogas to make it work (Delaide et al., 2017). Aquaponics can help feed more people and make sure they eat healthy food (Janni & Jadhav, 2022). As people learn more about the benefits of eating vegetables, the demand for aquaponics will keep growing (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014). Danish et al., (2021), researched into a cutting-edge method to design and develop sustainable aquaponics systems. Their goal was to develop a comprehensive solution that includes technical, managerial, social, economic, institutional, and environmental aspects. The model they suggested provided a step-by-step approach for building and

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running aquaponics and aquaculture systems that are both efficient and sustainable (Danish et al., 2021).

Aquaponics Cycle

In aquaponics, two naturally occurring aerobic (oxygen-consuming) bacteria are crucial in supporting fish cultivation. The initial bacteria, Nitrosomonas, utilises oxygen to transform harmful ammonia into nitrite. While nitrite can be detrimental to fish, a second type of bacteria, nitrobacter, coexists and utilises oxygen to convert nitrite into nitrate (Junge, König, Villarroel, Komives, & Jijakli, 2017). Nitrate, in high concentrations rarely observed, is generally harmless to fish. The bacteria detoxify nitrogen in the system and produce nitrate, a more plant-friendly form of nitrogen than ammonia (Truchado et al., 2012).

This biological process, known as "nitrification," is facilitated by a "biofilter," where "bio-" signifies "living" and "-filter" denotes "purify" or "separate." By providing surfaces for bacterial colonization, a biofilter is created (Junge et al., 2019). The autotrophic bacteria, nitrosomonas and nitrobacter, colonize various surfaces, such as the growing media in the aquaponic tray and tank walls. After the initial month, the tank and tray walls should feel slippery, indicating the presence of these beneficial bacteria, with the majority residing on the lecastone in the aquaponic tray (Figure 1).

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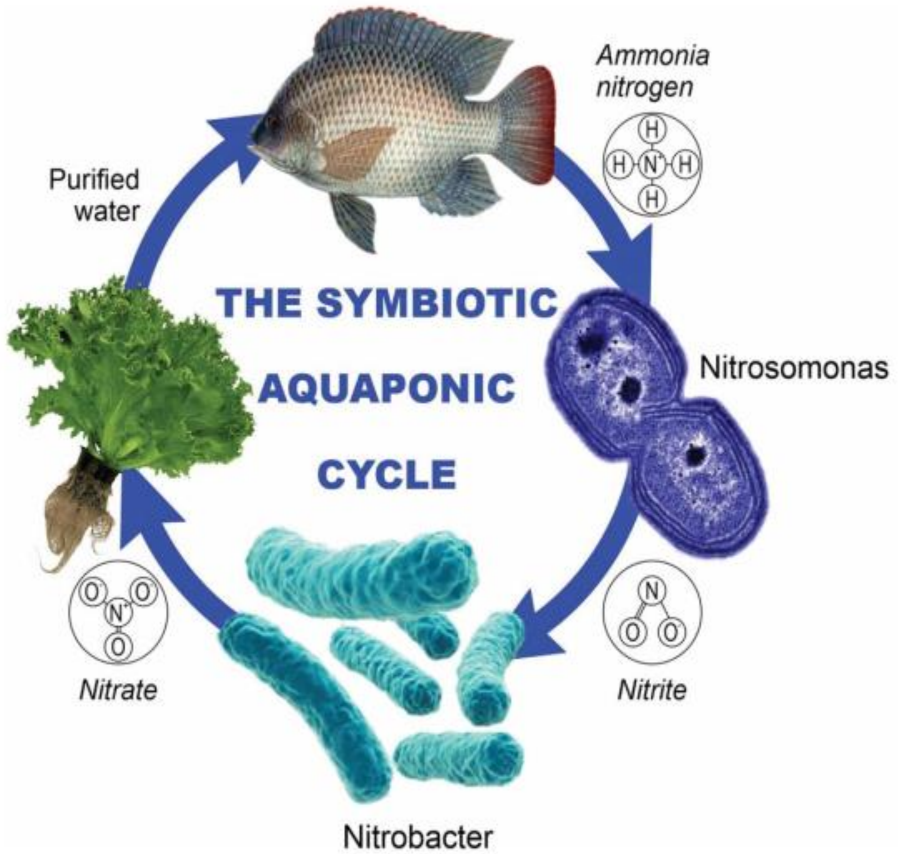

Figure 1: The Scheme of the Aquaponics Circle (Krastanova, Sirakov, Ivanova-Kirilova, Yarkov, & Orozova, 2022)

The bacterial ecosystem in aquaponics is complex and diverse. It plays a crucial role in the biological filtration of water through the mineralization of nutrients required for plant growth in an integrated system (Kasozi, Abraham, Kaiser, & Wilhelmi, 2021; Okomoda et al., 2023). Recent reports on the bacterial populations of aquaponics systems using new DNA sequencing technologies reveal a complex and diverse microbial ecosystem. At the phylum level, proteobacteria and bactericides dominate aquaponics systems (Zhang, Howerton, & Tamaru, 2010b; Kasozi et al., 2021).

The establishment of bacterial ecosystems is essential for the optimal functioning of aquaponics. Approaches for establishing a bacterial ecosystem during the setup of an aquaponics system, as well as the microbiological safety

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of aquaponics products are also highlighted in the literature (Eck et al., 2019; Kasozi et al., 2021).

The study by Eck et al., (2019) found that the bacterial communities in the aquaponic systems were more diverse than those in the aquaculture systems. The authors also found that the bacterial communities in the biofilters were more similar to those in the plant roots than those in the water. The study provides valuable insights into the bacterial communities in aquaponic systems and their role in nutrient cycling and plant growth.

Types of Aquaponics

There are several types of aquaponics systems, including Media-Based, Nutrient Film Technique (NFT), Deepwater Culture (DWC), Vertical Aquaponics System, Hybrid Aquaponics System and Commercial aquaponics systems.

Media-Based Aquaponics

Media-Based aquaponics is the most common and widely used aquaponics system. It consists of a grow bed filled with a medium such as gravel, expanded clay pellets, or coconut coir Fang et al., (2017). Afsharipoor & Roosta, (2010) studied the effect of different planting beds on growth and development of strawberries in hydroponic and aquaponic cultivation systems (Afsharipoor & Roosta, 2010). Also, Johari et al., (2023) studied carbonized rice husk and cocopeat as alternative media beds for an aquaponic systems. Their work evaluated the suitability of carbonized rice husk and cocopeat substrates as alternative media beds in aquaponics units for cultivating red Nile tilapia and Gynura procumbens. In the research, the survival rate for fish

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was 98%, with a specific growth rate (SGR) of 6.9% per day and a feed conversion ratio (FCR) of 1.13. Also, nutrient deficiency was not evident and plants showed healthy growth with harvest yields ranging between 3.6 and 3.9 kg·m^{-2}. Results attained signified the suitability of utilizing carbonized rice husk and cocopeat as alternatives media beds compared to commercial media (Malaysiana, Bakar, Kelapa, Alternatif, & Akuaponik, 2020).

Media grow beds excel in space utilization, boast a modest initial investment, and are particularly beginner-friendly due to their stable and straightforward nature *(*Junge et al., 2020*)*. The media support the plants and acts as a biofilter to convert fish waste into plant nutrients.

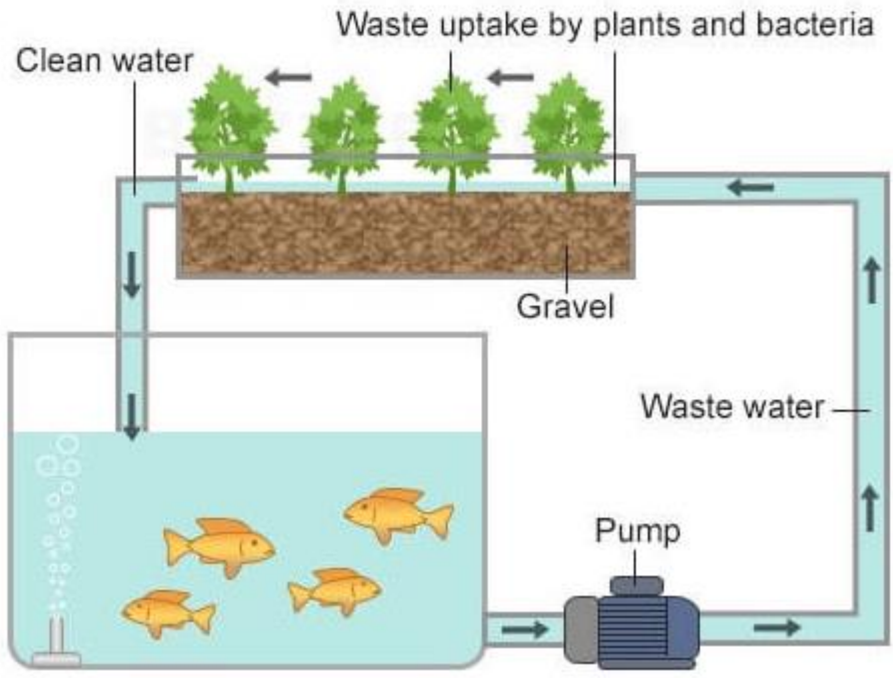

Figure 2: Media-Based Aquaponics (Junge et al., 2020)

Nutrient Film Technique (NFT)

The nutrient film technique consists of the plant roots being exposed to a thin layer of nutrient water that runs through most often a PVC pipe. The

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idea is that the shallow water flow only reaches the bottom of the thick layer of roots that develops in the trough while the top of the root mass is exposed to the air, thereby receiving an adequate oxygen supply. Channel slope, length, and flow rate must all be calculated to ensure the plants receive sufficient water, oxygen, and nutrients. If properly constructed, NFT can sustain very high plant densities (Goddek, Joyce, Kotzen, & Burnell, 2020).

In aquaponic NFT systems, the biofilter becomes crucial as there is no large surface area whereby bacteria communities can develop (Nelson, 2008). Hussan et al., (2020) studied the design and development of a portable and streamlined nutrient film technique (NFT) aquaponic system (Hussan et al., 2020). Suhl et al., (2019) also worked on oxygen consumption using aquaponics' recirculating nutrient film technique. They try to explore the oxygen concentration in nutrient solutions employed in two systems: conventional hydroponics and double-recirculating aquaponics. Specifically, the investigation focused on the oxygen levels within the cultivation trenches of conventional hydroponics. The study found that when fish waste in the water is used in systems like double recirculating aquaponic systems, there's a risk of low oxygen levels in the nutrient solutions, especially in the summer during the daytime. This is because fish waste in the water has more microorganisms and solids compared to fresh water, leading to higher oxygen consumption. Additionally, when fish wastewater is transferred and stored, it significantly increases the oxygen consumption of the pure nutrient solution (Suhl et al., 2019; Zaini et al., 2018).

Another research group, Zaini et al., 2018, studied the use of the Internet of Things for monitoring and controlling nutrient film technique

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(NFT) aquaponic. In their work, a smartphone application was created to manage and monitor NFT Aquaponics' environment. This app ensures proper nutrition and keeps the water conditions stable. The system introduced enhances nutrient absorption through a nitrification process, leading to improved plant growth compared to systems without control measures (Zaini, A., Kurniawan, A., & Herdhiyanto, 2023).

The Figure 3 indicate the example of NFT.

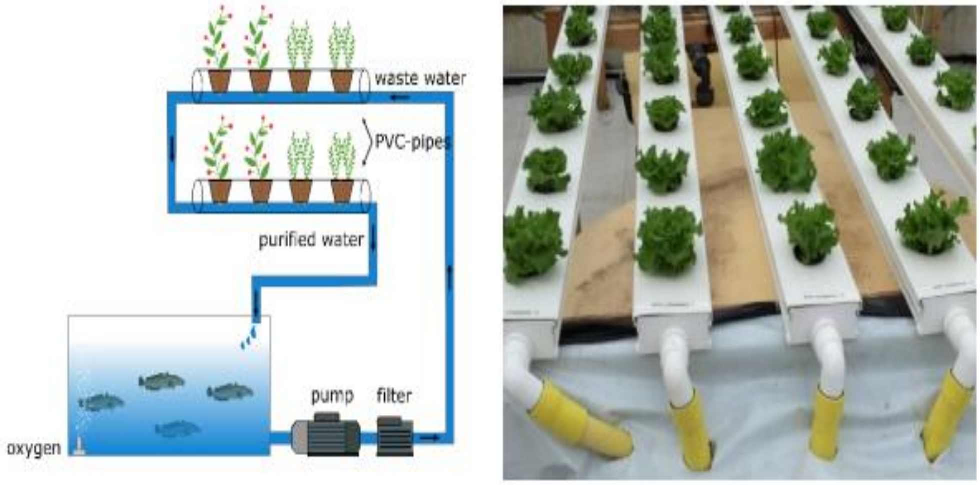

Figure 3: The Diagram on the Left and Photo on the Right, Shows Nutrient Film (Junge et al., 2019)

Deep Water Culture

Deep Water Culture (DWC) systems employ a buoyant polystyrene platform that rests on approximately 30 cm of water (Somerville et al., 2014). This platform features perforations where plants are cultivated in net pots, allowing their roots to submerge in the water. The platform can either float directly within a fish tank or be connected to a filtration system, with water pumped from the tank to irrigate channels housing a sequence of platforms (Eck et al., 2019). An aerator is used to oxygenate the tank water and the water

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surrounding the platforms. Because the roots lack a solid medium for anchorage, this system is suitable solely for cultivating leafy greens or herbs and isn't conducive to larger plants. Nonetheless, it remains the preferred choice for commercial ventures owing to its efficient and rapid harvest capabilities (Junge et al., 2019). Salem, (2019), studied the assessing DWC and Sand-Bed aquaponics systems for lettuce (*Lactuca sativa*) yield and water consumption. Their research revealed that lettuce grown in DWC had longer roots compared to lettuce in the sand-bed system, likely due to the larger area available for root growth in the DWC plant bed. Moreover, the lettuce yields in the DWC system, at 1.42 kg/m^2, were 27% higher than those in the sand-bed system, which yielded 1.03 kg/m^2. These findings were supported by additional evidence, such as increased lettuce growth, plant height, leaf length, the number of fresh leaves, and higher nutrient content in lettuce from the DWC system (Salem, 2019).

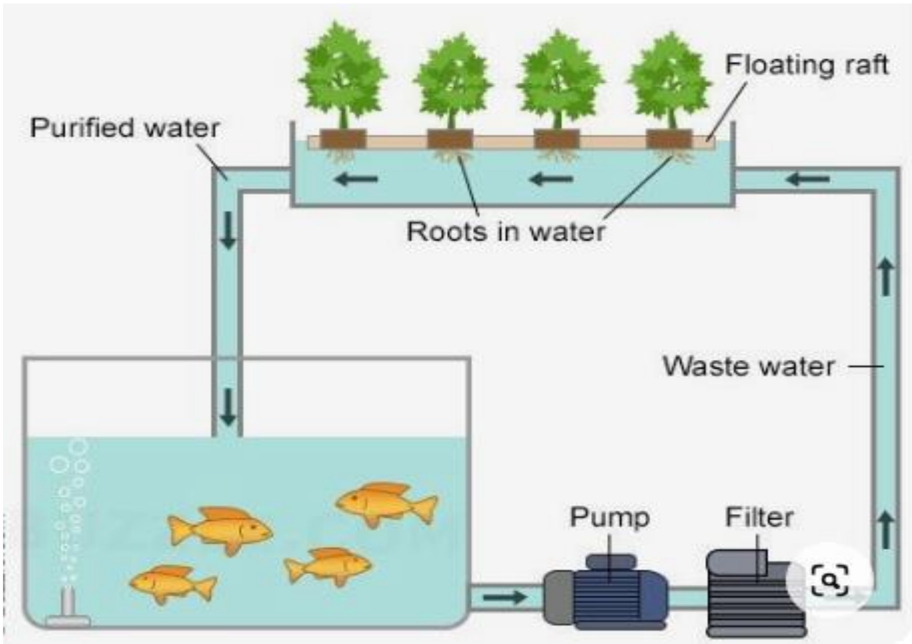

Figure 4: Floating Rafts Deep- Water Techniques (Janni & Jadhav, 2022)

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Vertical Aquaponics

Vertical systems, as the name suggests, enable plant growth in three dimensions, optimizing growing space. The nutrient solution is pumped to the apex of each grow tower and cascades down to nourish each plant. The system can use either a nutrient-based or media-based approach (Walraven, 2014).

This type of agriculture uses most of the available space and works very well with green leafy vegetables, strawberries, and other crops that do not require any support for their growth (Junge et al., 2020). Further efficiently utilises vertical space by stacking grow beds or using vertical towers. It is especially useful in limited space environments where maximizing production is crucial (Shafah and Woolston, 2014). (*Maryam*, 2023) studied vertical farming, particularly the aquaponic systems in Oslo.

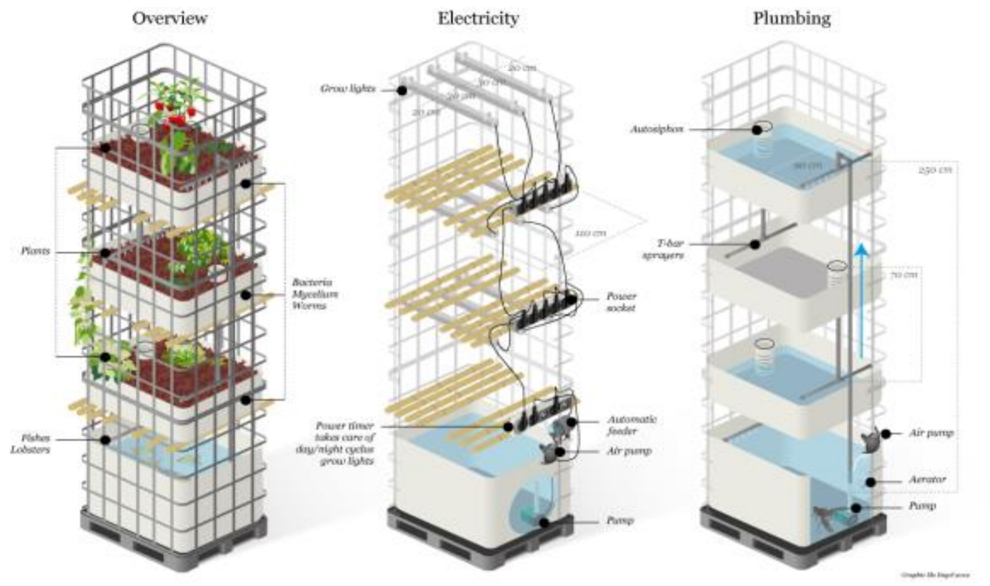

Figure 5: Mediatic IBC Vertical Aquaponics Farm (Maryam, 2023)

Hybrid Aquaponics

Hybrid systems combine aquaponics with other cultivation methods, such as traditional soil-based farming or aeroponics. This method of

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aquaponics allows for more diversity in crop selection and growing techniques. Mester et al., (2019), studied the development of a new hybrid aquaponic system for increasing chili pepper production efficiency. Their work aimed to address the limitations of aquaponic systems by adopting alternative solutions while adhering to the principles of sustainable agriculture principles. To tackle these challenges, a hybrid automated aquaponic system was implemented. In their system, soil is not entirely removed from partially closed systems, allowing fish to receive fresh water and maintaining low growth-inhibiting hormones (Mester et al., 2019). Also, Ogah et al., (2020) reported on the biological filtration properties of selected herbs in an aquaponic system. Their study was conducted to determine the biological filtration capabilities of some culinary herbs co-cultured with lemon fin barb hybrid in a nutrient film technique (NFT) recirculating aquaponic system. Their findings indicated that the water parameters were broadly consistent across the tanks, except for nitrate levels, which were lowest in the peppermint treatment. Comparable patterns were also noted in the water quality parameters following biofiltration, both microbial and herbal (Ogah et al., 2020).

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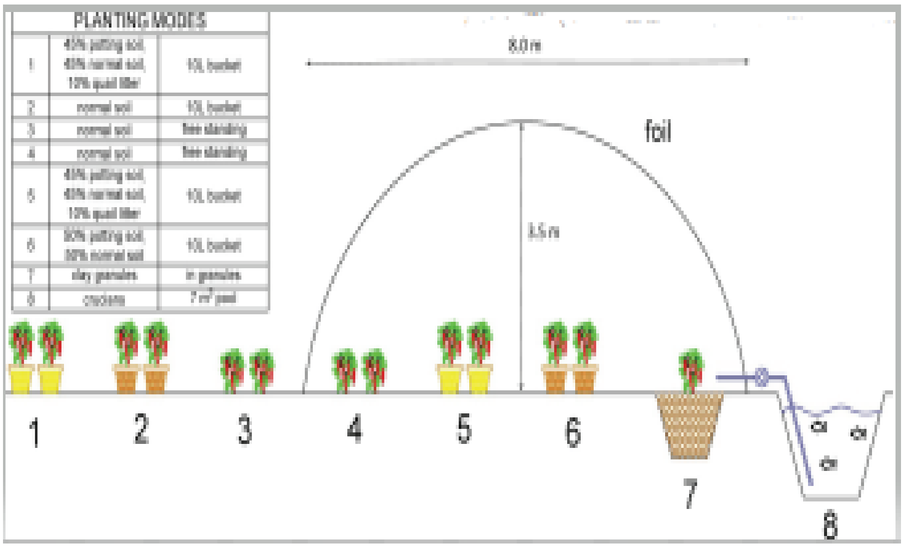

Figure 6: Hybrid Aquaponics System (Ogah et al., 2020)

Commercial-Scale Aquaponics

Commercial aquaponic systems are designed for large-scale production and often involve sophisticated technology and automation. They can include multiple tanks, extensive filtration systems, and advanced monitoring and control systems (Goddek et al., 2020). It's worth noting that these are just a few examples, and there are many variations and combinations of aquaponics systems depending on specific requirements, available space, and the crops and fish being cultivated. Commercial aquaponics offers the opportunity to utilize otherwise neglected spaces within cities, like rooftops and abandoned warehouses, repurposing them effectively (Walraven, 2014). (Khater et al., 2023), reported that different aspects of plant and fish growth, nutrient levels in leaf tissue, and water quality were assessed to assess their response to three types of fish food: commercial and two cheaper alternatives. Lettuce and common carp, commonly used in Nepal, were used in the experiment, which was conducted in triplicate. The findings revealed similar plant production across all three diets, but carp grew notably slower on the homemade diet

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compared to the others (Khater et al., 2023). Also, Rakocy et al., (2011) developed a commercial-scale aquaponic system at the University of the Virgin Islands. Their results show that the system is versatile, and suitable for both small-scale and large-scale use, whether for personal subsistence or commercial purposes. It boasts simplicity, reliability, and durability. Its continuous and sustainable production has been proven through nearly a decade of uninterrupted operation in its current setup (Rakocy et al., 2011).

Figure 7: Commercial Aquaponics Systems (Rakocy et al., 2011)

Monitoring, controlling, and managing aquaponics requires intensive labor. Therefore, various research attempts have been made toward actual implementations of technology feasibly and reliably at large commercial scales and adopting it as a new precision technology (Effendi, Kassim, Sulaiman, & Shahbudin, 2020). The advancement of wireless sensors and communication protocols empowered the implementation an Internet of Things (IoT) based system for real-time monitoring, control, and management

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in aquaponics (Ntulo et al., 2021). Mahkeswaran et al., (2020). studied the smart and sustainable home aquaponics system with feature-rich mobile applications from the Internet of Things. Their work suggested that the home aquaponics setup shows promise in tackling food security concerns, but opportunities remain for enhancement. One suggestion involves integrating a sump tank containing fresh water as a substitute reservoir, automatically refilling the fish tank as needed. Additionally, the system could benefit from incorporating a solar panel array with an automated solar tracker to provide reliable power (Mahkeswaran & Ng, 2020). Despite the diverse concepts and techniques developed to manage, monitor, and control aquaponic agriculture, power consumption in aquaponic systems remains a significant problem, prompting researchers to investigate this area more.

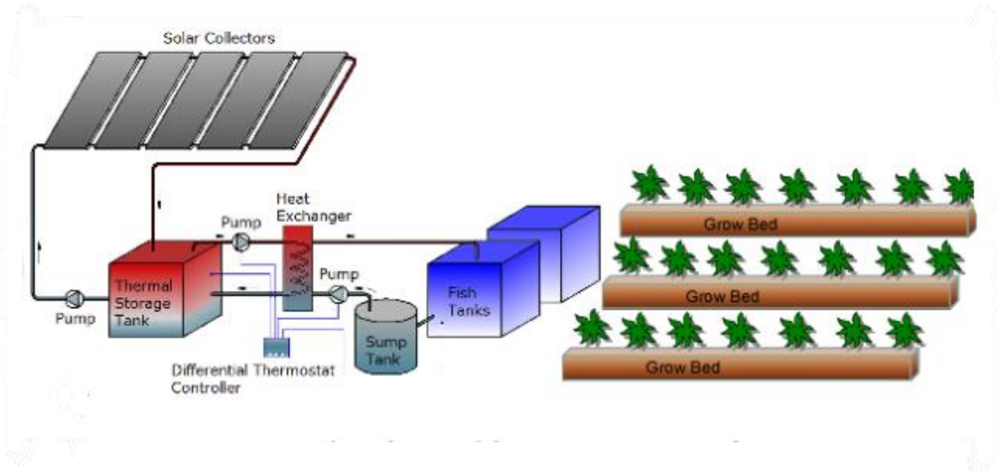

Figure 8: Solar Thermal Heating System Schematic (Anderson et al., 2015)

Aquaponic systems need energy in a variety of ways, including heat, sunlight, electricity, etc. Pumps, aerators, heaters, coolers, feeders, propagators, lights, and other standard actuator components of an aquaponic system require electrical energy to run. In terms of energy issues, hybrid energy systems (HES) can assist in enhancing the economic and

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environmental sustainability of aquaponic systems. One of the most important aspects of running the HES is energy management, which needs to be optimized in light of present and upcoming changes in generation, demand, market pricing, etc. The study by (Bracino et al., 2022) proposed a cost-effective aquaponics system with a centralized testing chamber for water quality monitoring in which the power consumption in aquaponics systems was estimated to be 1.832 kW/hr per day, while Karimanzira et al., (2018) also presented a decision support system for optimal energy management in aquaponic systems, emphasizing the integration of different energy sources and storage mechanisms. The proposed method (Karimanzira & Rauschenbach, 2018) can significantly increase the utilization of hybrid energy systems, reduce the exchange with the power grid and district heating, and consequently reduce running costs.

Rearing tilapia in aquaponics was a net loss when a comparison was made between market price and energy cost (Love, Uhl, et al., 2015b). Accordingly, Barbosa et al., (2020) reviewed hydroponic systems in aquaponics and suggested that the nutrient film technique may be less efficient than other hydroponic methods. As water flows between 0.8 L min^{-1} and 8.0 L min^{-1}, the system performed best in terms of fish and plant development as well as nutrient removal from the water. However, Zambrano et al., (2019) also stressed on the loss of water in aquaponics resulting from plant growth in hydroponics. Again, Ariffin et al., (2022) examined a small-scale raft aquaponics system and reported that the average energy use was 19,526 kWh per year, with the largest electricity usage in in-tank water heaters. Further investigation was made on the energy and water use of this same small-scale

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raft aquaponics system, finding that water loss can be replenished by rainfall and that raising crops is more economically viable than raising tilapia.

A comparison between two techniques, root floating and dynamic root floating, was done by Silva et al., (2018) and it was found that the dynamic root floating technique reduces electric power consumption using a nature-based solution. However, no total ammonia nitrogen or nitrite nitrogen levels could have hampered tilapia growth. In addition, Ismail, (2020) discussed the electricity and caloric energy consumed by a recirculating aquaculture system, highlighting the energy needed for equipment operation and water heating and cooling. The energy used to circulate the water in a recirculating aquaculture system accounts for the largest portion of the system's overall energy consumption (about 42%). This consumption can be decreased by building recirculating aquaculture systems with pumping height requirements as low as feasible, minimizing needless water pumping, and carefully planning hydraulic networks. Thermal energy prices are another substantial component of overall energy use, totaling about 32%.

Aquaponics is the fusion of hydroponics and aquaculture. Water is continuously cycled back and forth between the plant bed and the fish tank in an aquaponic system. Chandana et al., (2023) Designed and created a working prototype that controls and monitors an aquaponic system using Internet of Things (IoT) technology. Ntulo et al., (2021) investigated the use of IoT-based smart aquaponics systems using Arduino Uno. The system controls and monitors water quality using microcontrollers, sensors, and actuators. The system was said to increase aquaponics yields and decrease water waste. In addition, Murad et al., (2017) presented a design for an aquaponics water

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monitoring system using an Arduino microcontroller, which includes sensors for pH, temperature, water flow, and automated features like pH adjustment and fish feeding. The designed system can deliver messages to mobile phones via GSM while also sensing pH value, water temperature, siphon outlet water flow, servo, and peristaltic pump. The peristaltic pump and LED turn on when the pH of the water is out of range, and the LED turns on when the temperature of the water is out of range. Okomoda et al., (2023) review a historical perspective, opportunities, and challenges of aquaponics adoption.

In their work, Although they have highlighted the aquaponics production system's potential to address numerous challenges in Africa and guarantee food security, it's disheartening that there's a lack of strategies for adopting this technology domestically (Goddek et al., 2020; Okomoda et al., 2023; Pettersen et al., 2004). Consequently, additional expenses for solar plants might be necessary for constructing and operating aquaponics systems in Africa. They further stated that research should also prioritize examining such ventures future sustainability and profitability (Okomoda et al., 2023).

It is highlighted that the integrating water, plants, and fish in aquaponics is crucial, representing the lifeblood of heat and light (Sutono & Selvia Lorena, 2020). The system necessitates continuous aeration pumps and circulation to provide essential oxygen to the tank (Sutono & Selvia Lorena, 2020). Furthermore, there is a recommendation to employ controlled environment agriculture (CEA) to enhance the output of the aquaponic system which involves using heat for fish tanks and grow lights for plants, for examples. Grow lights are essential for providing full-spectrum lighting to meet the plants' needs. Simultaneously, heat for fish tanks regulates water

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temperature, contributing to increased output. However, both components demand precise power, incurring potentially high costs. To address this issue, solar energy is proposed as a more cost-effective solution to power aquaponics systems. For instance, a well-constructed 200-watt solar power system with two deep-cycle batteries and a 20-amp maximum power point, when applied to a single fish tank system with grow lights, can adequately support the system even in challenging conditions, provided proper construction and insulation are in place.

The paper delves into the complexities of the nitrogen cycle, including nitrification, and underscores the critical role of bacteria in maintaining a balanced aquaponic system. It provides a comprehensive analysis of the three key components of the aquaponic ecosystem: bacteria, plants, and fish. Additionally, the paper explores management strategies, troubleshooting approaches, and associated issues, specifically focusing on utilizing local and sustainable inputs for aquaponics (Somerville et al., 2014). The study is pertinent to researchers as it elucidates critical parameters for initiating small-scale aquaponics and outlines the variables to consider during system setup. By presenting integrated agricultural intensification through aquaponics, the paper addresses the challenges posed by water scarcity projects. It underscores the global need for enhanced agricultural practices to alleviate rural poverty and foster food security.

The ecological approach of aquaponics, has gained attraction in response to population growth and escalating concerns about food safety (Wei et al., 2019). The concept revolves around fostering a balanced relationship where crops, fish, and microbes engage in a mutually beneficial symbiosis,

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promoting harmony and coexistence. The literature extensively examines and consolidates information on the equipment employed in aquaponics for planting and breeding and the monitoring and control of the environment. Simultaneously, the researcher's work concentrates on advancing a solar-powered aquaponics system to achieve a higher crop yield than traditional methods. The cited literature and the study employ various sensors to optimize and regulate water resources and the aquaponics system's overall planting and breeding environment. The key distinction lies in the researcher's use of a solar panel to power the entire aquaponics system and the use of a ram pump, emphasizing a sustainable and energy-efficient approach (Wei et al., 2019).

Creating an Arduino-based urban-friendly smart aquaponics system (Garcia, 2023; Murad et al., 2017). The study explores three distinct aquaponic setups to assess system efficiency. In contrast, the researchers aim to pioneer an off-grid solar-powered sustainable smart aquaponics system, integrating water sensors and microcontrollers. Drawing insights from the cited study, the researchers aim to comprehend diverse aquaponic setups that share components similar to their proposed system. Noteworthy differences include the choice of components and measurements, particularly using Total Dissolved Solids (TDS) sensors to monitor water quality manually slated to be integrated.

Enhancing energy efficiency in Aquaponic systems through hybridized renewable energy and IoT monitoring was studied (Karimanzira & Rauschenbach, 2018). The study delved into optimizing energy utilization in aquaponic systems, concentrating on managing energy consumption. Employing diverse hybridized renewable energy systems to power the

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aquaponics setup, the researchers developed an approach for effective energy management. This is pertinent to our current investigation, offering insights into optimizing the power source for the system.

Challenges in Aquaponics

In the context of vertical aquaponics, the mentioned challenges hold particular relevance. Vertical aquaponics, which involves the cultivation of crops and fish in a vertically stacked system, offers several advantages such as efficient space utilization, reduced water usage, and integrated nutrient cycling (Chavan et al., 2020; *Maryam,* 2023; Somerville et al., 2014; Walraven, 2014). However, to fully realize its potential, certain considerations must be addressed.

As underscored by Love, Fry et al., (2015), an essential concern in advancing vertical aquaponics lies in the formidable challenge of start-up capital. Their survey reveals a critical threshold, indicating that a minimum area of 1000 m^2 is requisite for farmers to achieve a break-even point during the initial year of commercial aquaponic system utilization. The survey participants acknowledged investments ranging from $5000 to $9999 in start-up costs. Notably, the median yield of fish and plants varied between 23 – 45 kg/year and 45 – 226 kg/year, respectively (Love, Fry et al., 2015) Intriguingly, the survey did not establish a direct correlation between the initial investment amount and self-reported profitability, painting a somewhat bleak outlook on the economic viability of aquaponic investments. Fang et al., (2017) researched into economic and environmental benefits of media-based aquaponics through optimizing aeration patterns. In their study, two methodologies were employed to diminish aeration intensity, namely semi-

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aeration and intermittent aeration to enhance the economic and environmental advantages of media-based aquaponics. The findings indicate that semi-aeration aquaponics exhibited significant enhancements in energy efficiencies for both fish and crop cultivation, with respective improvements of 78.20% and 77.61% compared to the Control setup, thereby demonstrating its potential for greater economic returns. Semi-aeration and intermittent aeration strategies effectively halved aeration costs by reducing aeration flux and time. semi-aeration aquaponics maintained product yields without significant loss, unlike intermittent aeration aquaponics (Science & Engineering, 2017). Love et al., (2015) studied Energy and water use of a small-scale raft aquaponics system in Baltimore, Maryland, United States, reveal that, in 2013, the total electricity consumption amounted to 10,903 kWh, while in 2014, it was slightly lower at 10,844 kWh.

The fluctuations in electricity usage on a monthly basis were attributed to seasonal temperature changes (Love, Uhl et al., 2015b). Ondruška et.al., (2022) studied resource optimization in aquaponics facilities via process monitoring and a graph-theoretical approach (Ondruška et al., 2022). In their work, they checked how much electricity each appliance used separately using a standard meter, and they found that lighting used the most electricity, making up over 80% of the total daily usage, which is about 36.95 kWh. Also, conventional fishing is declining worldwide, whereas aquaculture has been steadily rising in recent times and is placing higher demands on energy resources (Ismail, 2020). Hart, (2013) studied on the implementation of Aquaponics in Education: An Assessment of Challenges, Solutions and Success. In his work, the authors highlighted challenges that fall into two main

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categories: aquaponics and those intrinsic to educational environments. Specifically, technical obstacles were frequently cited, such as difficulties with nitrogen cycling, establishing an effective system setup, and ensuring long-term maintenance.

Additionally, challenges related to funding and the knowledge gap were identified as inherent to aquaponics due to the substantial resources and expertise required by the technology (Hart et al., 2013). Decision Support System (DSS) for optimal energy management of an aquaponic system that integrates different energy sources and storage mechanisms was also highlighted by Karimanzira and Rauschenbach, (2018) as in important measure to integrated models like solar panels, wind turbine, water power, biomass plant, combined heat and power (CHP), gas boiler, energy and heat storage, and connection to the power grid and district heating. Their work findings indicate that the suggested approach substantially enhances HES utilization, resulting in decreased reliance on the power grid and district heating exchange, ultimately leading to lowered operational expenses (Karimanzira & Rauschenbach, 2018).

This financial challenge is particularly pronounced for growers in developing nations like ours, where aquaponics may represent a crucial means of livelihood. However, promising avenues exist for mitigating start-up costs. Notably, Abraham et al., (2020) suggest that employing locally available and inexpensive materials for constructing the aquaponics production system can significantly reduce financial barriers. Furthermore, exploring innovative solutions, such as recycling plastic waste as a component of the system,

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presents a dual opportunity—both in terms of cost reduction and waste-to-wealth conversion.

It is crucial to highlight that the concept of adapting and improvising the structural elements of aquaponics production systems is not novel. As documented by Love et al., (2015a) and Oladimeji et al., (2020), prior research endeavours have delved into modifications in plant troughs, media beds, filters, sludge collectors, and substrates. These creative solutions not only increase cost-effectiveness but also demonstrate how aquaponics systems can be tailored to fit a variety of environmental and financial circumstances.

The power supply issue poses a significant hurdle to the productivity and profitability of aquaponics, particularly in regions where stable electricity is a luxury. The vision of aquaponics as a solution to hunger, malnutrition, and an additional income stream (Tyson, Treadwel, & Simonne, 2011) encounters a substantial roadblock in areas with unstable and epileptic power supplies, standard in many third-world countries like Ghana. In these regions, reliance on conventional power sources for water pumps, aeration systems, sensors, and lighting become impractical, given the intermittent nature of the power grid. Despite a few users incorporating solar and wind energy as supplements to fossil fuels, the widespread commercial use of alternative power sources remains unrealized. The challenge becomes evident in the survey conducted by (Laidlaw & Magee, 2014), which highlighted the struggles of community-driven aquaponic farms, such as Sweet Water Organics (SWO) in Milwaukee and the Centre for Education and Research in Environmental Strategies (CERES) aquaponics in Melbourne. These farms could not sustain viable

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production on a large scale within five years, primarily attributed to power costs and other contributing factors.

In the context of developing countries, where aquaponics could have a transformative impact on local food production and economic stability, the irregular power supply exacerbates the adaptability challenge. The inability to ensure a consistent and affordable power source hampers the scalability of aquaponics technology in these regions. Consequently, there is a pressing need for further research to explore innovative solutions. One potential avenue is investigating the usability and efficacy of intermittent recirculation time in aquaponics production systems. Understanding how intermittent power supply affects the production characteristics of fish and crops could lead to the development of strategies to optimize resource utilization and cut down on power costs. This research direction aligns with the imperative to make aquaponics more feasible and sustainable in regions with unreliable power infrastructure.

Theoretical Framework

The efficiency of the RP is calculated using equation below (Dhaiban, 2019; Inthachot, Saehaeng, Max, Müller, & Spreer, 2015)

$$\eta = q.h / Q.H \tag{1}$$

where η = pump efficiency; q = the pumped flow rate (l/s); Q = the feeding flow rate (l/s); H = the height of the water source (m), and h = the pumping height (m).

The volume flow rate or the feeding flow rate, Q, is calculated by using flow meter as:

$$Q = v . A \tag{2}$$

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where v = inlet velocity, m/s; A = cross section area, m^2.

q can be determined by using the simple ways of the flow rate by using a cylinder beaker know volume and timer as

$$q = V / t \tag{3}$$

where V = volume in m^3; t = time in s.

The product of potential difference V and current I give power (P)

$$P = v \times I \; watts \; (W) \tag{4}$$

Using Ohm's P is expressed as;

$$P = I^2 R = \frac{V^2}{R} \tag{5}$$

$$\text{Electrical energy} = \text{Power} \times time \; (W/s) \text{ or } KW - hr \tag{6}$$

Daily energy requirement (E_{daily}) for the pump,

$$E_{daily} = P_{pump} \times t_{daily} \tag{7}$$

The definition of power (P) in an electrical circuit, which is given by

$$P = \frac{W}{t} \tag{8}$$

where;

W is work done (or energy consumed) by the circuit. In an electrical circuit, the work done is also given by

$$W = Q^2 R \tag{9}$$

According to Joule's Law;

$$W = I^2 R t \tag{10}$$

where;

I is the current

So, substituting equation 2.8 into equation 2.9, we get

$$\text{Power consumption} = \frac{Q^2 R}{t} \tag{11}$$

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where;

Q = quantity of electrical charge in Coulomb (C)

R = resistance in Ohms (Ω)

t = time in seconds (s)

The formula in equation 2.11, represents the power consumption in an electrical circuit.

$$PV\ Power\ = \frac{daily\ consumption\ (Wh)}{sunpeak\ hours\ (h)} \times 1.3 \tag{12}$$

where the energy losses in the system is 1.3.

$$No. of\ PV\ Panels\ = \frac{PV\ Power\ (W)}{PV\ Panel\ rating\ (W)} \tag{13}$$

$$Battery\ Bank\ size(KWh) = \frac{Daily\ energy\ use \times Number\ of\ days\ of\ autonomy}{1 - SOC} \tag{14}$$

with SOC as the State of charge.

The formula for Amp-hours is given by:

$$Amp - hours = \frac{100 \times energy\ storage\ (KWh)}{Battery\ voltage\ (volt)} \tag{15}$$

The plant growth rate (GR) was determined using the following equation:

$$\mathrm{GR}\ = \frac{final\ size\ -\ Initial\ size}{time\ elapsed} \tag{16}$$

where *final size* represents the size of the plant at the conclusion of the growth period, *Initial size* corresponds to the size of the plant at the beginning of the growth period and *time elapsed* indicates the duration of the growth period.

The length-weight relationship was then calculated using the equation by Ricker (1973).

$$W = aL^b \tag{17}$$

where

W is the body weight of the fish in grammes

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L is the Total length of fish in centimeters

a is the regression intercept and

b is the regression slope.

The equation was then linearized by a logarithmic transformation into:

$$\log W = \log a + b \log L \qquad (18)$$

Equation (17) was the computed using Microsoft Excel to estimate "a" and "b" values. The condition factor (K) was calculated using the means of the total length and weight of catfish using equation (17) below provided by Pauly (1983).

$$K = 100w/L3 \qquad (19)$$

The following equations can also use to calculate the catfish growth rate, specific growth rate, and percentage of survival.

$$\text{Growth rate (g/d)} = \frac{w_2 - w_1}{t_2 - t_1} \qquad (20)$$

where w_1= initial weight (g), w_2= final weight (g), and t_2- t_1= duration between w_2 and w_1, days.

$$\text{Specific growth rate (\% / days)} = \frac{log_e w_2 \text{-} log_e w_1}{t_2 - t_1} \qquad (21)$$

$$\text{\% Survival} = \frac{fish\ stocked\ - mortality}{fish\ stocked} \times 100 \qquad (22)$$

Chapter Summary

The chapter reviewed literature on the field of aquaponics. The early beginnings of aquaponics (a brief history of aquaponics) and aquaponics cycle were touched on, starting with the onset of publications in the 1970s and other developments as climate change made the field more relevant. Its applicability

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was stressed, especially in urban and rural crop growth. The term aquaponics and its meaning are then defined in detail. The types of aquaponics are touched on, namely: media-based aquaponics, NFT, DWC, vertical aquaponics, hybrid aquaponics, commercial scale aquaponics, and also smart aquaponics. A core component of the study which is the gap it seeks to fill is tackled extensively in the sub-section titled; The Challenges in Aquaponics, including the theoretical framework.

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CHAPTER THREE

METHODOLOGY

Introduction

This chapter presents the design and implementation of SLERSOPAA. Here, the organogram, the schematic, the construction of the entire system, and the design of the fish pond are presented. Also, the procedure for setting the grow beds, the bell siphons, the A-stand raft, the Ram Pump (RP) set-up, and the electronic components are discussed. Further, the power calculations and assembling the entire system are treated.

Design and Implementation

The organogram of SLERSOPAA is illustrated in Figure 9

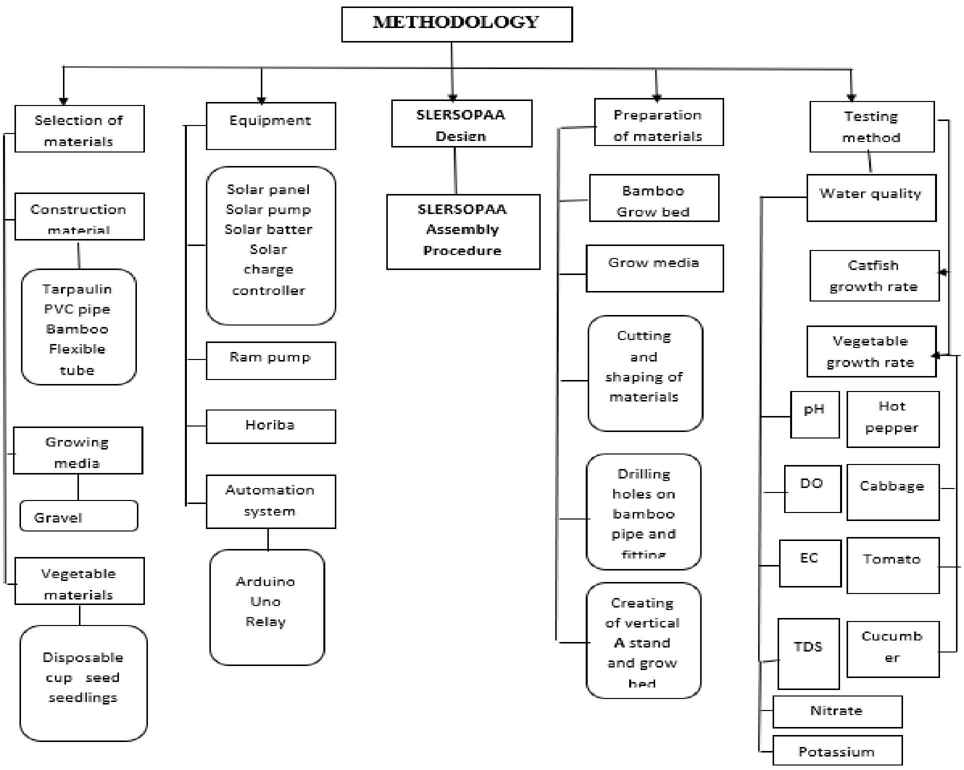

Figure 9: The Organogram of the SLERSOPAA

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The interconnection of the various parts in the organogram is shown in Fig.10

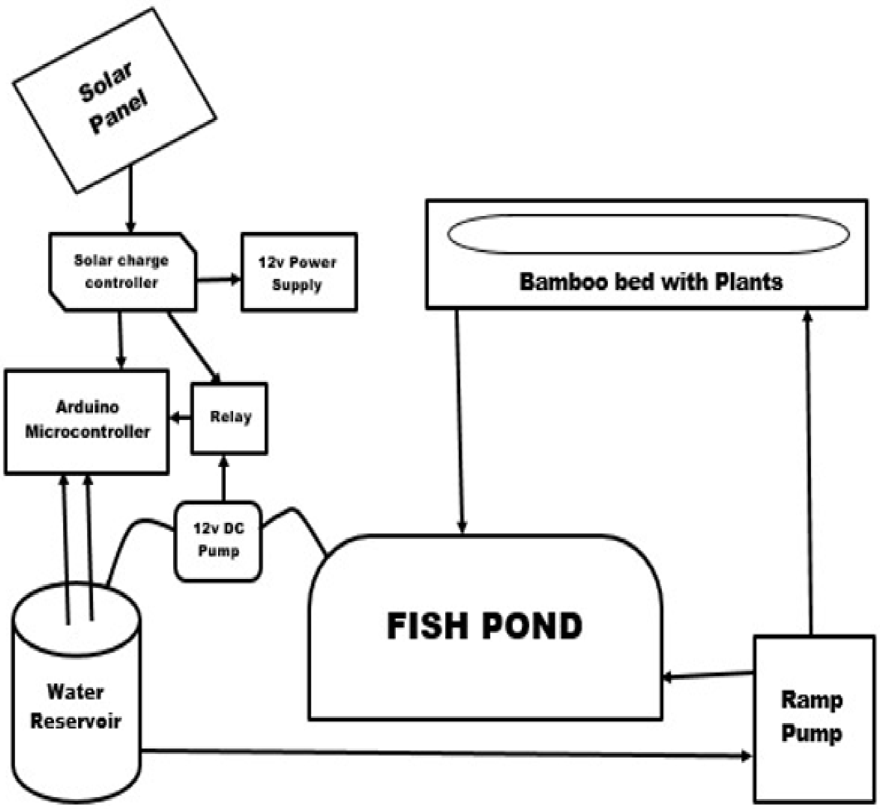

Figure 10: Block Diagram of the SLERSOPAA

The schematic block diagram outlining a sustainable SLERSOPAA system integrated with solar power and automated water management. Here's a breakdown of the connections and functionalities:

Solar Panel

The solar panel serves as the primary power source for the system, providing energy to run the components.

Solar Charge Controller

The device acts as a bridge between the solar panel and the battery. It ensures optimal battery charging by carefully controlling the amount of

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electricity flowing from the solar panel. This prevents overcharging and extends battery life

12V Power Supply Battery

The power supply battery can act as a backup power source to ensure continuous operation of essential components such as SP, and microcontroller during the night or cloudy weather. The battery is crucial to maintain optimal conditions for the fish and plants.

Arduino Uno Microcontroller

The Arduino Uno, a programmable microcontroller, powers the system's automation and control functions. It receives power from the solar charge controller and interacts with sensors to operate different system components according to programmed commands.

DC Pump (solar pump)

(i) Connected to the solar charge controller for power.

(ii) Used to pump fish wastewater from the fish pond to a reservoir.

(iii) Controlled by the Arduino Uno microcontroller to regulate its operation based on water level or other parameters.

Fish Pond

(i) Contains fish and their waste water which is pumped out by the DC pump.

(ii) Some fish waste water is lifted by the ram pump to the bamboo grow beds, providing nutrients for the plants.

Reservoir

(i) Receives fish wastewater pumped from the fish pond.

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(ii) Feeds the ram pump for lifting water to the bamboo grow beds.

(iii) Contains Arduino Uno water sensors for regulating the DC pump operation.

Ram Pump

(i) Lifts part of the fish wastewater from the reservoir to the bamboo grow beds.

(ii) Uses the flow of water to pump without external power, powered by the kinetic energy of the flowing water.

Bamboo Grow Beds

(i) Receive water from the ram pump containing fish waste nutrients for plant growth.

(ii) Purify water through plant filtration, reducing nitrate levels in the water.

(iii) Some purified water is redirected back to the fish pond to increase dissolved oxygen levels and reduce nitrate concentration.

(iv) Acts as a habitat for mosquito larvae, which are then flowed into the fish pond by the running water as fish feed.

Fish Pond (Return)

(i) Receives water from the bamboo grow beds, enriched with oxygen and reduced nitrate levels.

(ii) Provides a source of dissolved oxygen for the fish.

(iii) Serves as a channel for returning purified water and mosquito larvae to the fish pond.

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This SLERSOPAA demonstrates sustainable aquaponics practices, using renewable energy, automation, and natural processes to create a closed-loop ecosystem supporting both vegetable plants and fish growth.

The interconnection of the entire system is as shown in the schematics diagram (see Figure 11).

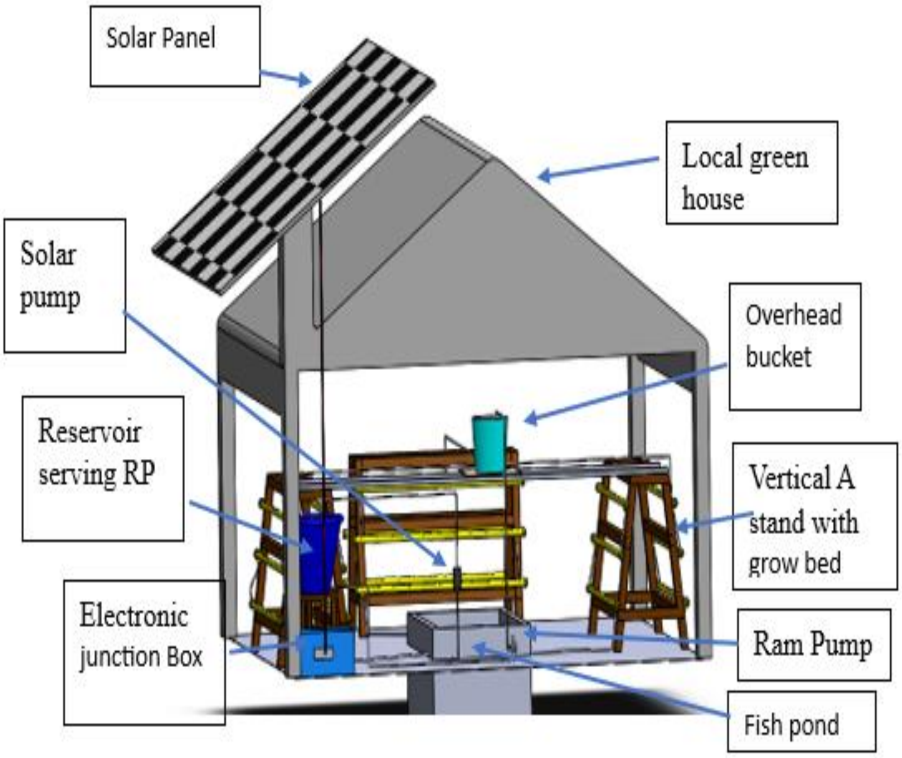

Figure 11: Front view of the Design for the Aquaponics.

The system in Figure 11 is made of four integral systems:

(i) Greenhouse, the A-stand, grow bed and bell siphon made from Bamboo containing 252 plants

(ii) Circulation system made of the RP, the SP

(iii) Electronic setup which comprises of the Solar systems, 100 AH battery, a converter and an Arduino microcontroller

(iv) Fish pond for raising 350 catfishes,

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The Local Greenhouse

The local greenhouse in Figure 11 is made from bamboo as a main framework and covered with High-Density Polyethylene (HDPE). It is a type of plastic that comes from oil. It's really handy because it can be used for lots of different things. It's super versatile and used in many everyday items! It was selected due to inexpensive, lightweight, and non-corrosive nature of the material. In addition, it is widely used and readily available in many places. The greenhouse stands at a height of 3.0 meters, measured from the ground to the tip of the solar panel, with a length of 4.10 meters and a width of 4.00 meters.

Bamboo A-stand and Grow bed

The A-stand and the grow bed are made of bamboo. The organic nature of bamboo allows for easy adaptation of plants and bacteria, making it suitable for use in the construction of grow beds for aquaponics systems. Using bamboo aligns with both ecological and economic considerations, showcasing a scientifically feasible and environmentally friendly approach in designing and implementing SLERSOPAA. The sizing of the bamboo for the A-stands and the grow beds, was conducted at the UCC science workshop, as shown in Figure 12.

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Figure 12: Sizing the Bamboo at UCC Science Workshop.

Plant holes were strategically created on the culm and internode of the bamboo, with the last node at each end left closed, as shown in Figures 12 and 13. These plant holes on the internodes facilitated the easy formation of water channels through the bamboo.

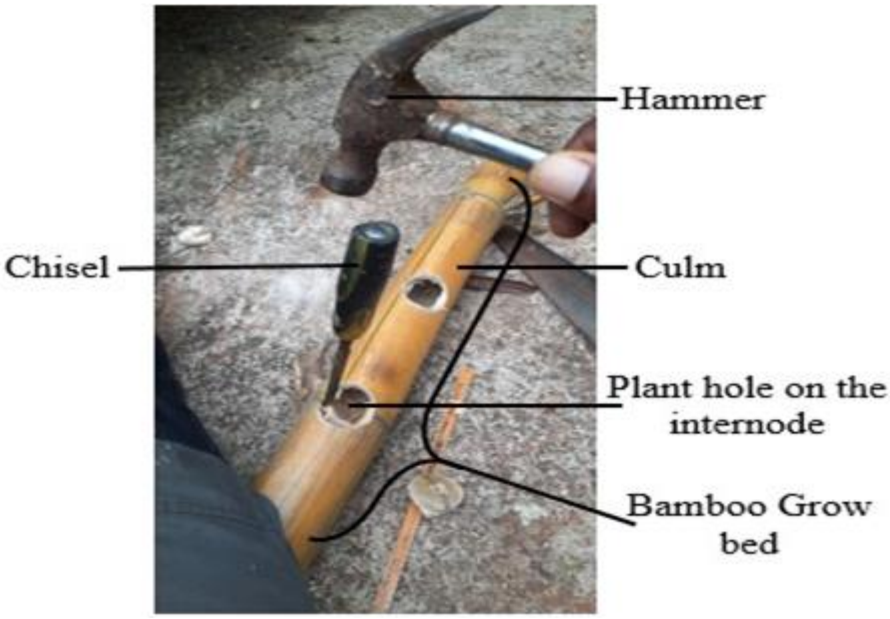

Figure 13: The Creation of a Plant Hole on the Bamboo internode.

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Bell Siphon

A Bell Siphon is commonly used in aquaponics and hydroponics systems to regulate water flow in a grow bed or media-filled container. It comprises a vertical standpipe (usually bell-shaped) and an outlet pipe. As the water level in the bamboo grow bed surpasses the height of the bamboo stand pipe, the excess water flows through the inside of the bamboo stand pipe. It drains into the next bed until it reaches the last bed and ultimately drains directly into the fish pond. An additional bamboo pipe, "the bell," is introduced into the system (see Figure 14b). This bell pipe has a diameter twice that of the bamboo standpipe and is slightly longer (see Figure 14a). It features, a head on one end, and notches or "teeth" are carved into the bottom end of the bell. The bell is positioned with its teeth facing down over the bamboo standpipe. A hole is drilled into the head end of the bell, and an air tube is inserted into this hole as shown in Figure 14 (b). This air tube, called "snorkel," serves as a mechanism to break the siphon. It extends down the length of the bell, concluding just above the level of the teeth. To maintain a crucial relationship, the height of the bamboo standpipe in the bamboo grow bed was set to level with the bottom of the bell cap on the bell pipe, as illustrated in Figure 14 (c). This alignment is vital to ensure an adequate volume of air resides at the top of the bell pipe to facilitate the initiation of the siphon, as outlined by (Zhang et al., 2010a).

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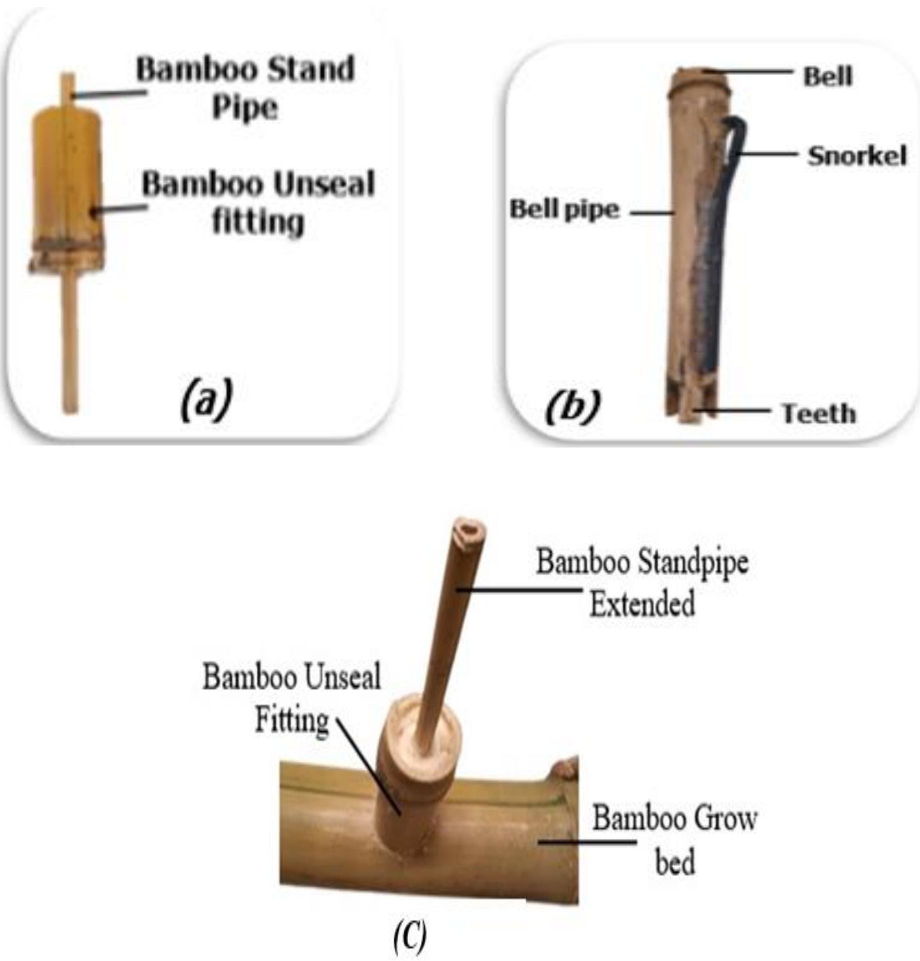

Figure 14: Illustration of the Bamboo Bell Siphon; (a) Bamboo Unseal Fitting, (b) Bell and (c) Bamboo Grow Bed.

How a Bamboo Bell Siphon Works

1. As the water level surpasses the height of the bamboo stand pipe and the drain starts to fill, a siphon is initiated.
2. The majority of the water in the bamboo grow bed is subsequently drawn out by the siphon until the water level reaches the elevation of the teeth and the tip of the snorkel.
3. At this point, air is forced through the snorkel, leading to the breaking of the siphon. Consequently, the grow bed begins to refill, initiating a cyclic repetition of the entire process.

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The Ram Pump

The integration of RP presents a promising avenue for enhancing efficiency in aquaponics, with a particular focus on coupling these systems with SP. Figure 15 shows the Ram pump's diagram which comprises the following parts; drive pipe, impulse or waste valve, delivery valve, air chamber and delivery pipe or outlet.

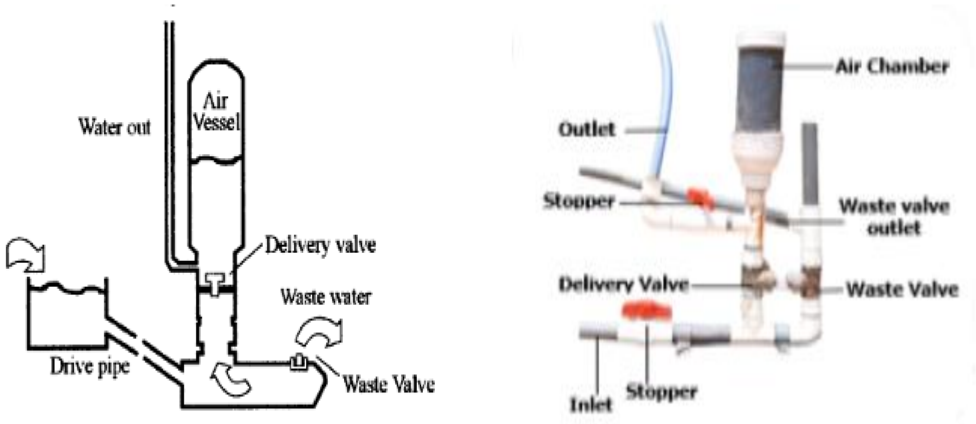

Figure 15: A Schematic Diagram of Ram Pump (left) (Suraj et al., 2018) and a Build 0.013 m Valve Ram Pump.

It involves converting the kinetic energy of water entering the system into pressure energy through the pump mechanism (Pawlick, Chesser, Grguras, Benson, & Sagerman, 2018; Suraj, S., D, & V, 2018). The RP uses the energy from flowing water to pump some of that water to a higher place (Cai & Kim, 2005; Loverude, Kautz, & Heron, 2002; Warren, 2006). It does this without needing any extra power source. The RP has two moving parts: waste and delivery valves. It also has an air chamber that builds up pressure (Dhaiban, 2019; Mebrat, Tadesse, & Beyene, 2022; Sampath, Shetty, Pendanathu, Javaid, & Chithirai Pon Selvan, 2015; Suraj et al., 2018)

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The RP works in cycles, with three main phases: acceleration, delivery, and recoil. When the waste valve opens, water rushes down a pipe, and the flow increases until it starts to close the valve. Then the valve closes quickly. As the waste valve closes, it stops the flow, creating a surge in pressure known as a water hammer. This pressure forces water through the delivery valve, which stays open until the pressure drops. The remaining water in the pipe bounces back against the closed delivery valve, lowering the pressure enough for the waste valve to reopen. This cycle repeats, with the air chamber helping to keep the flow steady.

The pump works fast, and even though it only pumps a small amount of water each cycle, it can move a significant amount of water over time. The water that doesn't get pumped out is considered waste, but it's this waste water that provides the energy to pump the water that is delivered. In this study, the wastewater considered to be waste-water is redirected into the fish pond to serve as the source of aeration. This concept is illustrated in Figure 17 of the system diagram.

Building of the Ram Pump

In this study, RP models was constructed, varying valve diameters (0.019 m and 0.013 m). The primary objective was to identify the most practical combination of parameters that could seamlessly integrate with the SP, aiming to achieve optimal efficiency in running the SLESOPAA.

The components of the RP, including dimensions and flow rates, are detailed in Table 2. This selection marks a deliberate and informed decision based on the observed improvements in performance, noise reduction, and waste water management. The successful integration of the 0.013 m valve RP (see Figure

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16) represents a crucial step towards achieving the highest possible efficiency in the SLERSOPAA under investigation.

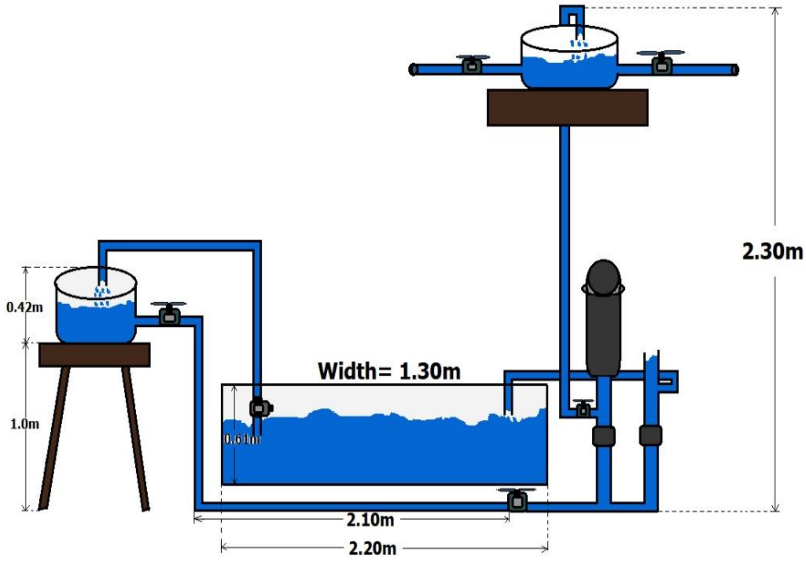

Figure 16: Schematic view of the 0.013 m Valve RP Coupled with SP.

Efficiency of Ram Pump

The efficiency of RP depends primarily on the pump's installation, with a specific focus on the relationship between the pumping height or supply head (H) and the height of the delivery head (h). The effectiveness of the pump is intricately linked to the relationship between these critical parameters (Inthachot et al., 2022; Mado, Johanis, & Budayawati, 2019; Sampath et al., 2015).

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Table 1: Efficiency of the Ram Pump Depending on the Height

H/h	2	3	4	6	8	10	12
ε	0.85	0.81	0.76	0.67	0.57	0.43	0.23

Source: (María & Zúñiga, 2018)

As seen in the Table 1, the height of the pumping must not exceed more than 12 times the height of the feeding tank (María & Zúñiga, 2018; Sampath et al., 2015).

Ram Pump Flow Rate Analysis

The RP used in the SLERSOPAA system features two crucial outlets: the delivery valve outlet and the waste valve outlet. Researchers comprehensively analysed the flow rates (FR) from both outlets to optimize the system's performance. This is to ensure the efficient and synchronized operation of the ram pump to support the aquaponics system.

Flow Rate Calculation Formula for the Ram pump

The formula in equation 3 was used in determining the flow rates (FR) of both delivery valve (D) and the waste valve (W) of the RP.

Flow Rate at the Delivery Valve (D)

The flow rate at the delivery valve (D) signifies the useful water pumped to the desired location. The calculation for the flow rate is as follows using equation 3, FR, at D $= \frac{0.5\,L}{38\,S} = 0.013\,L/S$

Flow Rate at the Waste Valve (W)

The flow rate at the waste valve (W) represents water released during the pump's operational cycle. This excess or wastewater, which is not directed

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to the delivery point, was ingeniously repurposed by researchers. The redirected waste valve water is a resource in the aquaponics system, replacing the need for additional aerator pumps. The calculation uses equation 3, FR, at

$$\mathrm{W} = \frac{0.5\,L}{13\,S} = 0.038\,L/S$$

Analyzing the flow rates at both the D and W, has given us insights into the operational efficiency of the ram pump in the SLERSOPAA. The findings contribute to the sustainable integration of solar-powered technologies and waste repurposing strategies, enhancing the overall functionality of the SLERSOPAA setup.

Electronic Setup and Equipment Used

The primary components of the PV system encompass PV panels, a charge controller, a solar battery with a capacity of 100 ampere-hours (AH), a relay, an Arduino Uno microcontroller, a 2N7000 transistor, and a submersible pump. The subsequent paragraphs will delve into a detailed explanation of each component and its specific function within the system.

Solar Charge Controller

The solar charge controller plays a pivotal role in safeguarding the battery from overheating, a critical function to ensure the optimal performance and longevity of the energy storage system. Its reliability is paramount, given that the entire system functionality hinges on its ability to regulate and maintain an optimal charging temperature.

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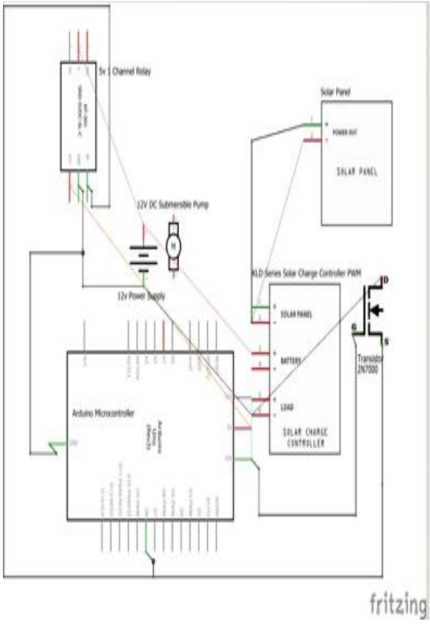
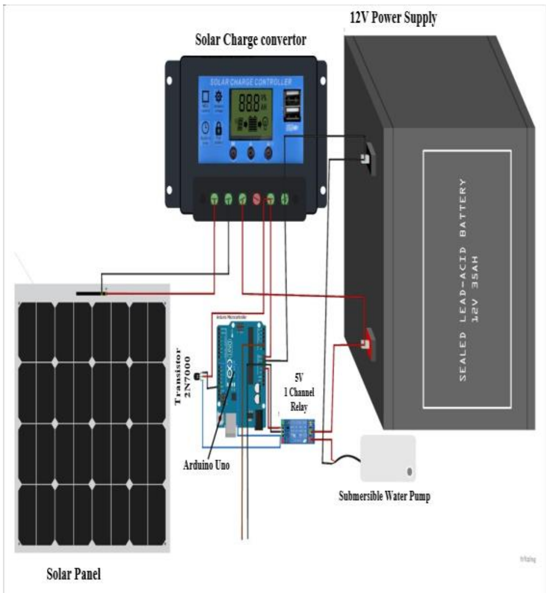


(a)



(b)

Figure 17: Schematic of Electronic Components (a) Fritzing Circuit and (b) Power Connection.

Additionally, the solar charge controller enhances overall energy efficiency by preventing overcharging or undercharging, thereby maximizing the battery lifespan. The selection and implementation of a dependable solar charge controller is an integral designing a robust and efficient solar power system.

Relay

The relay commanded by the microcontroller board works as a switch to connect and disconnect the SP used to pump water into the RP bucket source.

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Arduino Uno Microcontroller

The Arduino microcontroller serves as the brain of the system, controlling and coordinating the actions of different components based on programmed instructions (Refer to Appendix B)

2N7000 Transistor

The 2N7000 transistor likely plays a role in controlling the power supply to specific devices, offering an acceptable level of control and automation.

The accompanying electronic schematic (Figure 17) illustrates the key electronic components, their configurations, and their interconnections.

Programming the Arduino

The design goals for the control system were to be modular and easily configured or expanded to meet the required purpose and objectives of the study. To meet these goals, a system that uses an Arduino Uno for the controller and an off-the-shelf relay board for the actuation was developed. The software, which ran on the Arduino Uno microcontroller was built using MATLAB – SIMULINK BLOCK as shown in Figure 18. Arduino Uno board was chosen as the hardware for our control components.

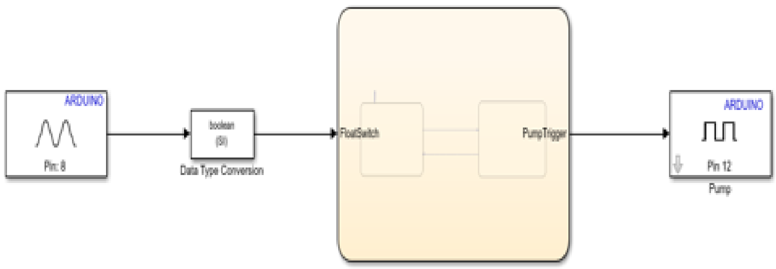

Figure 18: Simulink Programming Interface.

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Solar-powered water pumps are essential for harnessing renewable energy for agricultural and domestic water supply. In this study, MATLAB and Simulink were used to program a solar pump, ensuring it operates in a specific on/off cycle—specifically, turning on for 2 minutes and off for 6 minutes.

Electronic Housing

As illustrated in Figure 19, a durable metal box was constructed, complete with a secure lid and a padlock mechanism to house electronic components and ensures their protection against water splashes. The housing design incorporates a thoughtfully crafted cutout from the underside, allowing wires to pass through seamlessly while maintaining the lid's security.

Figure 19: Electronic Metal Housing.

Power Estimation

Power estimation for SLERSOPAA involves assessing the electrical requirements of various components within the system. Key considerations include; SP and Arduino Uno microcontroller. The electrical power equations

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in chapter two were used by the researchers to generate the load analysis table (see Tables 2 & 3).

Table 2: The Load Analysis of the SLERSOPAA Setup

Equipment	Power /W	QTY	Total power /W	Duration /hrs.	Power consumption /Wh
Solar pump	24	1	24	7	168
Microcontroller	0.2	1	0.2	24	4.8

Source: (Researcher, 2023)

Total Power Consumption from Table 2 Is 172.8 W h / day or 0.1728 kWh.

After identifying the diverse loads and specifications, Table 2 illustrates the overall anticipated load of the entire system. The Total Power in the table is derived by multiplying the power rating of each component by its respective quantity. Subsequently, this Total Power is multiplied by the duration, representing the operating time of each component in a day, to compute the total power consumption per watt-hour. To obtain the daily power consumption in watt-hours, the researchers sum up the total power consumption.

To determine the PV Power or the overall efficiency of the Solar Panels catering to the Total Expected Load, the researchers employed the following calculation:

Sun peak hours at cape coast is 4.50 hrs. /day. Equations 12 and 13 are used in calculating the rating of PV panels.

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$$\text{PV Power} = \frac{172.8}{4.5} \times 1.3 \qquad = 49.92\ \text{W}$$

$$\text{No. of PV Panels} = \frac{49.92}{120} \qquad = 0.416$$

The daily consumption or total expected load should be divided by the sun peak hours, which amount to 4 hours and 30 minutes per day. This quotient is then multiplied by 1.3 to account for energy losses in the system (Nsengimana, Han, & Li, 2020). Consequently, the researcher approximated a PV power of 0.0499 KW equivalent to 49.92 Watts.

To determine the number of required PV panels, the PV power is divided by the PV panel rating. In this case, the 49.92 Watts is divided by the 120 watts rating of the solar panels under consideration by the researcher. As a result, the solar-powered aquaponics system will necessitate approximately 0. 416 or roughly one PV panel but for the smooth running of the system, we used one of the 120 W solar panels.

Using the set-up where the energy requirement is 0.1728 kWh per day, the total energy needed in battery storage is calculated by multiplying the daily energy use by the number of days of autonomy and then dividing by one minus the state of charge (SOC). It's worth noting that standard sizing typically involves planning for 3 days of autonomy with an SOC of 50% according to Beckers. The equation 14 is used for calculating the battery bank size as follows; Plugging in the values for our set up:

$$\text{Battery bank size (kWh)} = \frac{0.1728 \times 3}{1 - 0.5} = 1.04\ \text{kWh}$$

Therefore, the required battery bank size our system is 1.04 kWh to meet the daily energy needs with a 3-day autonomy period and a 50% state of charge. This value 1.04 kWh, represents the total energy capacity that our battery bank must be able to hold when fully charged. However, when dealing

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with batteries, it's often more practical to work with Amp-hours (Ah), a metric that indicates the amount of current the batteries can deliver for one hour before being depleted. The calculating of Amp-hours which depends upon the battery capacity voltage equation 15 is used.

Substituting the valves of the set up into equation 15,

$$\text{Amp-hours} = \frac{1000 \times 1.04}{12} = 86.7 \text{ Ah}$$

Therefore, the battery should have a capacity of 86.7Amp-hours at a 12 Volt configuration to meet the specified energy storage requirement.

Based on the aforementioned calculations, the researcher opted not to perform a separate calculation for the solar charger controller. Instead, proceed directly with the selection of a PWM solar charge controller with a capacity ranging from 40 A to 100 A and a voltage range of 12 V to 24 V. The chosen controller features auto-focus tracking, a solar charge controller panel regulator, and dual USB ports. This decision is motivated by the pursuit of a cost-effective and reliable solution, particularly suited for smaller systems.

Table 3: Load Analysis, if the Setup Equipment's were to Operate 24 Hours Daily.

Equipment	Power /W	QTY	Total power /W	Duration /hrs.	Power consumption /Wh
Solar pump	24	1	24	24	576
Microcontroller	0.2	1	0.2	24	4.8

Source: (Researcher, 2023)

Total power consumption: 580.8 W h / day or 0.5808 kWh / day.

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From Table 3, it reveals exciting insights into the potential power consumption situations. If the system's equipment's were to operate continuously for 24 hours daily, the projected power consumption would have been 580.8 Wh/day, translating to a monthly total of 17424 $Wh/month$.

To quantify the tangible reduction in power consumption, the following formula was applied:

$$Percentage\ reduction = \left(\frac{24\ h\ EPC - 7\ EPC}{24\ h\ EPC}\right) \times 100 \qquad (23)$$

where 24 *hrs* EPC denotes 24 *hrs* equipment power consumption = 17424 *Wh/day* and 7 *hrs* EPC denotes 7 *hrs* equipment power consumption = 5184 *Wh /day*.

Substituting the valves of set up into equation 23 the percentage reduction can be calculated as follow;

$$Percentage\ reduction = \left(\frac{17424 - 5184}{17424}\right) \times 100$$

$$= \left(\frac{12240}{17242}\right) \times\ 100 = 70.30\%$$

To determine the percentage reduction of power consumption for operating SLERSOPAA for a growing period of 183 days (six months), equation 23 is used as follow;

For 24 *hrs* EPC; 183 *days* x 580.8 = 106286.4 *W h / days*

7 *hrs* EPC; 183 *days* x 172.8 = 31622.4 *W h / day*

$$Percentage\ reduction = \left(\frac{106286.4 - 31622.4}{106286.4}\right) \times 100$$

$$= \left(\frac{74664}{106286.4}\right) \times\ 100 = 70.25\%$$

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Design and Construction of the Fish Pond

The fish pond in this study is a carefully constructed aquaculture facility designed with cost efficiency in mind. Its dimensions are shown in Table 4, resulting in a total water capacity of 1733.4 liters. The pond construction embraced a cost-effective approach by opting for a tarpaulin lining instead of traditional concrete. This decision not only contributed to a reduction in overall construction expenses but also facilitated a quicker and more flexible setup. The tarpaulin lining method, while being budget-friendly, offered a practical solution without compromising the structural integrity of the pond.

Figure 20: Tarpaulin Lining in the Constructor Fish Pond.

The installation of the tarpaulin lining was meticulously carried out as shown in Figure 20, to ensure water retention and durability. This lightweight yet robust material proved to be a suitable alternative, providing a secure barrier for the pond. Moreover, the flexibility of tarpaulin allowed for easy

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adjustments to the pond's dimensions, accommodating the specific requirements for optimal fish farming conditions.

The fish pond, is made up of a tarpaulin with dimensions of 5 x 3 m^2 is utilized and placed beneath the fish pond, which itself measures 2.20 x 1.30 x 0.16 meters. The aquaponics system incorporates 21 bamboo grow beds, totaling 252 plant holes with 21 bell siphons drain holes. Each plant hole has a diameter of 0.05 meters and is spaced 0.18 meters apart from the others. These bamboos grow beds is arrange and then placed horizontally on the three A-stands raft.

Assembly Procedures

Once the bamboo grow beds and bell siphons are in position, the subsequent step involves interconnecting the bell siphons of the various bamboo grow beds, linking them sequentially until reaching the final bamboo grow bed on the vertical stand. Subsequently, the last bell siphon drain is channeled through a bamboo pipe leading to the fish pond. This process is replicated across all three vertical stands, and the bamboo pipes are directed to three different sides of the fish pond.

To facilitate the water circulation, a 0.013 m diameter PVC pipe is utilized to convey water pumped by a SP from the fish pond to an elevated 50L bucket serving as the RP source. The RP delivery pipe, with a diameter of 0.006 m, is employed to elevate water into a distribution bucket (5 L) positioned at a height of 2.30 m. From this point, the water is directed to the three vertical stands carrying bamboo grow beds. Additionally, a 0.08 m diameter bamboo pipe redirects water from the last bell siphons on the bamboo grow beds back to the fish pond.

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RP is strategically placed at the front side of the bamboo A- stands, as illustrated in Figure 9. Subsequent steps involve the installation of water level sensors into the RP bucket source and the corresponding electronic wiring.

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Design Procedures

Table 4 Indicates Construction Dimensions of the Various Components used in the Design and Implementation of SLERSOPAA.

Table 4: Construction Dimensions of the SLERSOPAA

MATERIAL	DIMENSION
Greenhouse	Height (from the ground to the tip of solar panels) = 3.10 m Total area = 4.0 x 4.10 m^2 Canopy height = 3.0 m
Bamboo grow bed (21 grow beds on 3 vertical stands, containing 252 plants)	Length = 2.60 m Width = 0.07 m Depth = 0.08 m Diameter (plant hole) = 0.05 m Distance between beds = 0.40 m
Bamboo bell siphon (21 in number on each grow bed)	Standpipe / drain size (diameter) = 0.01 m Bell pipe (diameter) = 0.07 m Snorkel tube size (diameter) = 0.01 m Bamboo unseals fitting (diameter) = 0.07 m
Fish pond (1733.4 of water and 350 catfish stock)	Length = 2.20 m Width = 1.30 m Depth = 0.61 m
Tarpaulin	5 x 3 m^2
Ram pump	Non-return valve and waste valve = 0.013 m 0.013 m drive pipe (diameter) = 0.013 m 0.006 m delivery pipe (diameter) = 0.006 m Delivery height = 2.30 m Ram pump bucket source = 50 L Distribution bucket = 5 L
Solar panel (120 W, 2 in number)	Module = 1.24 x 0.67 x 0.03 m
Solar battery (100 AH, 12V)	
Solar pump (5A, 12V)	Outlet diameter = 0.013 m Inlet diameter = 0.013 m

Source: (Researcher, 2023)

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Plants Cultivation

Aquaponic systems offer a versatile environment where a wide variety of plants can thrive successfully. This versatility allows for the cultivation of various herbs, leafy greens, fruits, and vegetables in aquaponic setups. From culinary herbs like basil and cilantro to nutrient-rich greens like lettuce and kale, and even fruiting plants such as tomatoes, okras, and strawberries, the adaptability of aquaponics makes it conducive to the successful cultivation of diverse plant species.

For this study, vegetable seeds (i.e. hot pepper, tomato's, cucumber, cabbage etc.) were nurtured on square cushions measuring 0.02 m x 0.02 m (see Figure 21a). These cushions featured a strategically placed hole of 0.01 m, designed for seed placement. The seeding phase for the plants or vegetables extended for a duration of two to three weeks before they were transplanted into the aquaponic system, as illustrated in Figure 21(c).

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(a)

(b) (c)

Figure 21: Planting of Vegetables on SLERSOPAA Processes; a) seedlings on the square cushions, b) Small Disposable Cup and c) seedling in Small Disposable Cup supported by gravels.

During the transplanting of seedlings, they were carefully placed in small disposable cups with a volume of 180 ml (see Figure 21 b). These cups were equipped with perforated holes, facilitating water flow when inserted into the bamboo grow beds, as depicted in Figure 21 (b). To provide support for the seedlings within the disposable cups, small and appropriately sized pebbles and gravels were used as a growing medium as shown in figure 21 (c).

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Catfish Cultivation

In this study we adopted African catfish, scientifically known as Clarias gariepinus. 350 catfish tails were introduced into the SLERSOPAA, with sizes ranging of 4 cm to 5 cm. The fish culture involved the use of commercial pellets as their primary food source, constituting 6% of the total body weight. This feeding regimen was administered twice daily, following the approach outlined by (Mamat, Shaari, & Wahab, 2016). However, due to the continuous accumulation of bacteria in the system due to organic material (bamboo) use as grow beds (Ines, 2019). adjustments were made, and the catfish were occasionally fed only once a day to maintain optimal system health. Figure 22 depict catfish fingerling of 3.0 – 4.0 cm.

Figure 22: Fingerling of a Catfish

Sampling of Fish

Three months after stocking 350 catfish, 10 catfish were sampled randomly from the SLERSOPAA site located within the botanical gardens of the University of Cape Coast between 8:00 am and 9:00 am in August, 2023 by means of a scoop net and transported in a bucket to the USAID/ UCC fisheries and Coastal Management Laboratory (Figure 23)

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Determination of Catfish Length – Weight Relation

The sex of the fish was determined using visual observation and recorded. The weight of the fish was measured using an electronic weighing scale. The total length and standard length of the fish was measured using a measuring board. The total length was measured from the tip of the snout to the end of the caudal fin and the standard length was measured from the tip of the snout to the posterior end of the last vertebra (Figure 23).

Figure 23: Photo Showing Adult Catfish Length Measurement

Management of the Biotic Environment

Maintaining an optimal habitat for the species is of paramount importance. Some critical parameters that need to remain steady are temperature, non-ionized ammonia and nitrites, the concentrations of DO and CO_2, pH, and the hydraulic load rate (HLR), i.e. the water flow rate. In this study, only pH, DO, EC, TDS, nitrates, and potassium were checked due to certain constraints. However, this did not adversely affect the work as it was

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carried out in the tropics and thus seemingly benefitted from the optimum development of bacteria, aquaculture species, and plants that are typical of warmer climates as cited in Krastanova et al., (2022).

Water Quality Parameters

Nitrate – UV Spectrophotometric Method

Principle:

Nitrate is determined by measuring the absorbance at 220nm in a sample containing 1 mL of IN hydrochloric acid in a 50 mL sample. The concentration is calculated from the graph from standard nitrate solution in the range of 1-11 mg/L as N.

Apparatus:

Spectrophotometer, for use at 220m and 270nm

Reagents:

1. Nitrate-free water: Deionized water was used to prepare all solutions.
2. Stock Nitrate Solution: This was prepared by dissolving 0.7218g KNO_3 (which is pre-dried in a hot air oven at 105°C overnight and cooled in a desiccator) in DI water diluting to 1L. it must be preserved with 2 mL Chloroform ($CHCl_3$); 1 mL=100µg NO_3-N, stable for 6 months.
3. Standard Nitrate Solution: this was prepared by diluting 100mL of the stock solution to 1000mL with DI water, preserved with 2 mL chloroform ($CHCl_3$); 1 mL= 10µg NO_3^-N, stable for six months.
4. Hydrochloric Acid Solution (HCl), 1N: 83mL conc. HCl was cautiously added to about 850 mL DI water while mixing; it was cooled and diluted to 1000 mL.

Procedure:

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Treatment of Sample: 1 mL of 1N HCl was added to 50 mL clear or filtered sample and mixed.

1. Preparation of Standard Curve: calibration standards in the range of 0-7 mgNO_3^-N/L were prepared by diluting 1,2,4,7… 35 mL to 50 m L. 1 mL of HCl was added and mixed.
2. Spectrophotometric measurement: absorbance or transmittance against re-deionized water set at zero absorbance or 100% transmittance was read. A wavelength of 220 nm was used to obtain a NO_3^- reading, and a wavelength of 275 nm was used to determine interference due to dissolved organic matter.

Calculations:

For samples and standards, two times the absorbance reading at 275 nm was subtracted from the reading at 220 nm to obtain absorbance due to NO_3^-. A standard curve was prepared by plotting absorbance due to NO_3^- against the NO_3^-N concentration of standards. Sample concentrations are obtained directly from the standard curve.

Potassium – Flame Photometry (L.O.D – 0.2ppm)

Principle

Flame photometry measures the light emitted by an atom when it returns to its lower energy states after being excited in a flame. The intensity of the emitted light is directly proportional to the concentration of the element being analyzed.

Apparatus/ Reagents

1. Flame photometer

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2. Potassium stock solutions: Weigh accurately 0.477g of dry KCl. Dissolve with deionized water into a 500mL volumetric flask and top up quantitatively to the mark.
3. Standard potassium solutions: Dilute the stock solution to 1 in 50, which gives a standard of 1mg K/100mL = 10ppm K.
4. Deionized water
5. Sample solution

Procedure

- Ensure the instrument is in good condition before analysis is done.
- Close the fuel valve by turning fully clockwise
- Depending on the fuel being used, turn the fuel valve the required number of turns anti-clockwise (LPG – 3.5 turns)
- Turn on the fuel supply source (i.e., cylinder)
- Turn on the electrical power and have the flame lit for about 5 minutes while aspirating deionized water to ensure stability
- Select the potassium filter
- Aspirate deionized water and set the readout to zero by adjusting the blank control
- Aspirate a standard solution of slightly higher concentration to be tested. Adjust fine and coarse control until a positive reading is obtained.
- Adjust the fuel valve in a clockwise direction until a peak reading is obtained
- Aspirate deionized water and set the readout to zero
- Aspirate the highest standard solution to be tested. Adjust fine and coarse controls until a positive reading is obtained.

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- Aspirate the remaining standard solutions to construct a calibration curve
- Repeat the above for samples to be analyzed.

Calculations:

Once the calibration curve is plotted, the readings for the sample solutions are compared with the curve to allow the sample concentrations to be established.

Data Collection

For this study, a comprehensive approach was taken to gather both qualitative and quantitative data over a six-month growth period. The qualitative data collection involved daily observations of each system. Field notes and photographs were utilized to document the evolving characteristics of plants, fish, water, and other miscellaneous phenomena. The observations of plants and fish were particularly focused on their physical responses to the environment, behavioral characteristics, and the quality of the produced yield.

On the quantitative front, daily measurements of plant growth were recorded. Additionally, from the start of June 2023 to November 2023, fish growth was meticulously documented. Water quality tests were conducted every three days using a Horiba instrument. The tests involved assessing nitrate and potassium levels, and measurements were recorded in milligrams per liter (mg/L). The UV spectrophotometric method was employed for these water quality tests, providing a detailed and accurate analysis of the aquatic environment. Further details on the methodology of the water quality tests are outlined chapter four. This dual approach to data collection aimed to capture a holistic understanding of the aquaponics system, combining qualitative insights with precise quantitative measurements.

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Daily Management of SLERSOPAA

The daily management of our setup involves a comprehensive routine to ensure optimal system performance and the well-being of both catfish and vegetable plants. This routine includes:

- Fish Feeding: Conducted twice a day to provide the necessary nutrition and monitor the overall health of the fish.
- Observing Fish Behaviour: Regularly monitoring of the fish's behaviour to detect signs of stress, illness, or abnormal activity.
- Checking Water Flow: Continuously assessing the water flow within the system, including the bamboo pipes, Ram pump, and solar pumps, to identify and address any irregularities promptly.
- Verifying Air Flow: Regular checks on the air flow in the system, ensuring adequate oxygenation for fish and plant health.
- Inspecting Plants: Thorough examination of plant health, growth, and overall condition.

In addition to daily tasks, periodic duties include:

- Filter Cleaning: Scheduled every three days to maintain water quality and filtration efficiency.
- Harvesting: Gathering produce from plants with continuous yields, such as hot peppers, cucumbers, and tomatoes.
- Monitoring Water Parameters: Regularly measuring and adjusting the water temperature, nitrate level, potassium, pH, dissolved oxygen levels, total dissolved solids (TDS), electrical conductivity (EC), and bacterial growth.

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- Vegetation Management: Clearing vegetation around the site to prevent interference with system components.
- Maintenance: Addressing issues such as repairing leaking bamboo pipes, unblocking bamboo stand pipes, and managing the overall growth of both plants and fish.

This systematic approach to daily and periodic tasks ensures the smooth functioning of the aquaponics system, promoting a balanced and thriving ecosystem for aquatic and plant life.

Chapter Summary

This chapter presents the detailed design and construction of the SLERSOPAA aquaponic system, which incorporates a ram pump (RP) and a solar panel (SP). The chapter includes the mathematical calculations used to determine optimal system parameters. Additionally, it outlines the procedures for fish stocking and vegetable cultivation within the system. To support the research, both qualitative and quantitative data collected during the study are presented in detail.

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CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents the research results and discussion from June 1, 2023, to November 30, 2023. The various parameters such as power consumption, EC (electrical conductivity), DO (dissolved oxygen), TDS (total dissolved solids), pH levels, nitrate concentrations, and potassium (K) levels in the system are analysed. The effect of the low energy on bacterial counts and the growth dynamics of both catfish and crops, including hot pepper, tomato, cucumber, and cabbage, are discussed.

Fully Implemented SLERSOPAA

Figure 24 illustrates the complete implementation of the SLERSOPAA system, which integrates the cultivation of 252 vegetable plants and the rearing of 350 African catfish. Figures 25 through 34 present a series of images documenting the progressive growth of the vegetables, demonstrating their healthy development under this innovative system. Figure 35 highlights the thriving population of African catfish, showcasing the effectiveness of SLERSOPAA in supporting robust aquatic life. Together, these figures provide compelling evidence of the system's high performance and potential for sustainable food production.

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Figure 24: A Full View of the Implemented SLERSOPAA.

Figure 25: Hot Pepper and Okra Growing up on the Grow Beds.

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Figure 26: Tomato Growing up on the Grow Beds.

Figure 27: (a) Euro- Garden Egg on the Grow Bed (b) Okra on the Grow Bed.

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Figure 28: Ripping Tomato Fruit on the Grow Bed.

Figure 29: Unripe Tomato Fruit on the Grow Bed.

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Figure 30: Cucumber Flowering on the Grow Beds.

Figure 31: Fruiting Cucumber on the Growth Bed.

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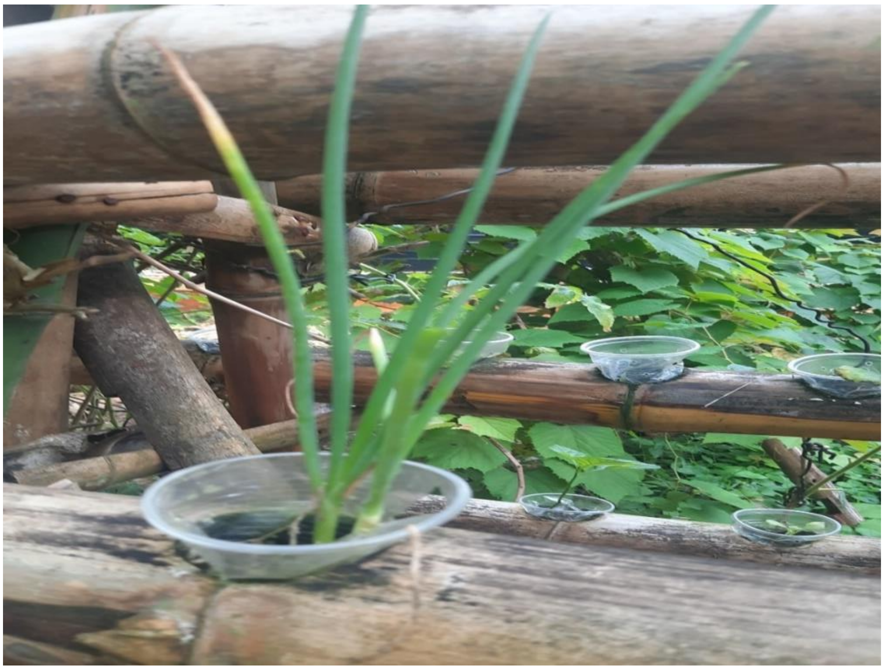

Figure 32: Spring Onions on the Growth Bed.

Figure 33: Flowering Hot Pepper on the Growth Bed.

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Figure 34: Ripe Fruits of the Hot pepper on the Growth Bed.

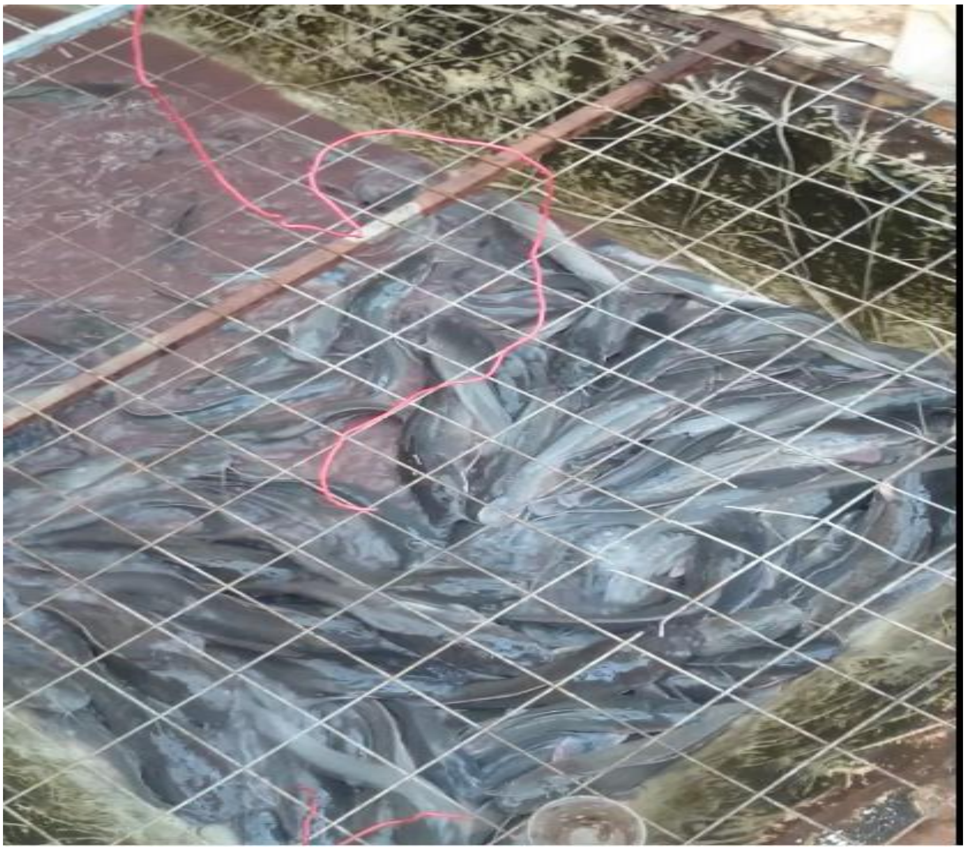

Figure 35: African Catfish in the SLERSOPAA Pond.

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Power Consumption

The study initiative commenced by collecting data on the trigger time intervals of the SP within an hour. This data was examined to determine its alignment with the programmed time on the Arduino Uno microcontroller, facilitated through MATLAB Simulink blocks. The results presented in Table 5 unequivocally affirm that the SP functionality adheres to the specified timing programmed into the microcontroller.

Table 5: An Average Recorded SP Operational Time within an Hour.

Start time /Min	Stop time /Min	SP Operational time /Min	Waiting time /Min
00:00	02:00	2	0
08:00	10:00	2	6
16:00	18:00	2	6
24:00	26:00	2	6
32:00	34:00	2	6
40:00	42:00	2	6
48:00	50:00	2	6
56:00	58:00	2	6
		16	42

Source: (Researcher, 2023)

Based on the Table 5, data shows that, in each operational hour of the SP within 24 hours; there will be 2 minutes remaining time. To determine the actual working time of the SP within 24 hours, we multiply the remaining 2 minutes by 24, resulting in 2 * 24 = 48 minutes. During these 48-minutes, the SP's operational time is 12 minutes. Additionally, if we multiply 16 minutes

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by 24, we get 384 minutes. Adding the remaining 12 minutes, we will obtain 396 minutes of SP operational time within 24 hours. This duration is approximately equivalent to 7 hours.

The percentage reduction for a day was calculated approximately to be 70.30%. Over 183 days, representing six months (1st June – 30th November, 2023), the system was actively utilized. During this period, the total power consumption amounted to 31622.4 W h / days. In contrast, if the equipment were to operate continuously for 24 hours every day for the same duration, the total power consumption would reach 106286.4 W h / days.

Applying equation 3.1, the power consumption percentage reduction for operating the SLERSOPAA—comprising 350 catfish and 252 vegetables—for 183 days was determined to be 70.25%. This substantial reduction in power consumption stands as a significant achievement in this study. A plot of SLERSOPAA power consumption verse time is shown in Figure 34.

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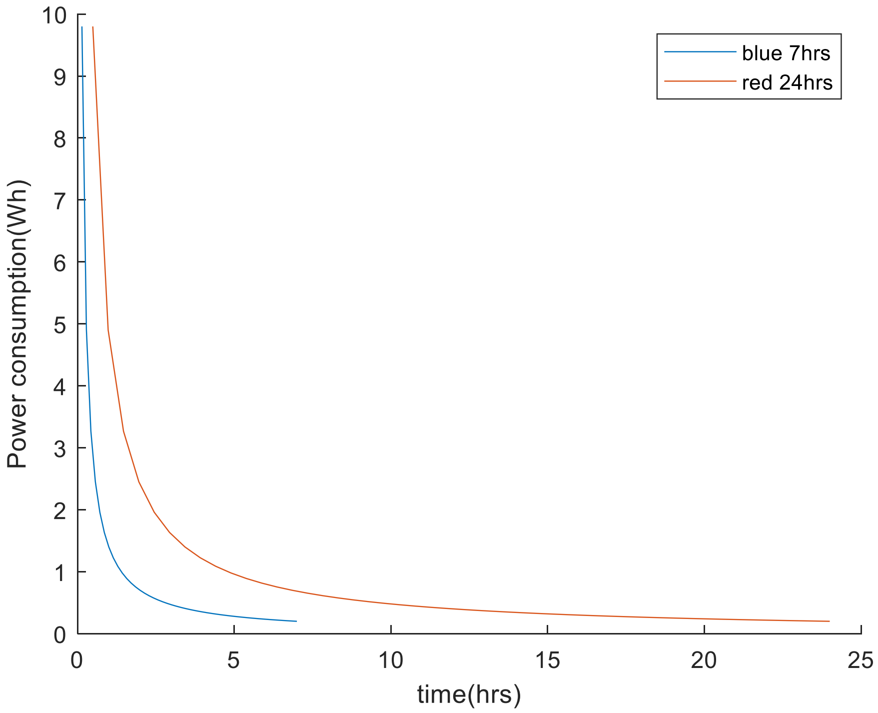

Figure 36: A Plot of Power Consumption against Time in Hours.

Ram Pump Efficiency Result

In Table 1, the impact of varying parameters on the efficiency of the ram pump is evident, particularly for a height of the water source (H) of 1.42 m and a corresponding height of pumping (h) of 2.30 m. The efficiency is calculated to be 64.8% using equation 2.1, with values for Q and q derived from equations 2.2 and 2.3.

Additionally, it is noteworthy that the pump exhibits accelerated performance when the impulse valve is fully open. This acceleration proves advantageous when assessing the daily water pumping capacity within the SLERSOPAA setup.

The integration of the RP into the aquaponics system is pivotal, particularly in the strategic redirecting of both the RP waste valve water and the water from bamboo grow beds back to the fish pond. This process plays a

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critical role in the setup by providing a continuous supply of dissolved oxygen. This constant oxygen infusion is of paramount importance in intensive aquaculture systems, eliminating the need for traditional diffused air aerators such as compressors, blowers, paddle wheel aerators, vertical pump aerators, pump spray aerators, and propeller-aspirator pump aerators in our system.

The significant outcome of this integration is a notable reduction in the overall operational energy consumption. The efficient utilization of the RP facilitates a closed-loop system wherein waste water and excess water from grow beds contribute to maintaining optimal oxygen levels in the fish pond. This innovative approach not only ensures a sustainable and oxygen-rich environment for the aquaponics system but also minimizes reliance on external energy sources, aligning with a more energy-efficient and environmentally conscious operational model.

Nitrate and Potassium Dynamics Analysis

Nitrate, the primary form of nitrogen found in fish pond water, serves as a crucial nutrient for both plant and algal growth. It is highly soluble and stable in water. The acceptable nitrate concentration for fish, hydroponic plants, and bacteria ranges from 5 to 150 mg/L Bracino et al. (2022). The results of nitrate content analysis in the SLERSOPAA test samples, conducted using the UV spectrophotometric method, are presented in Figure 35.

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Table 6: Results of Established Nitrate Concentrations in the Samples Collected

Samples	Concentrations mg/L		
	1	2	3
01/10/2023	6.67	6.70	6.73
07/10/2023	1.47	1.49	1.49
13/10/2023	0.23	0.26	0.31
19/10/2023	5.34	5.35	5.35
25/10/2023	10.47	10.50	10.50
31/10/2023	10.57	4.60	4.66

Source: (Researcher, 2023)

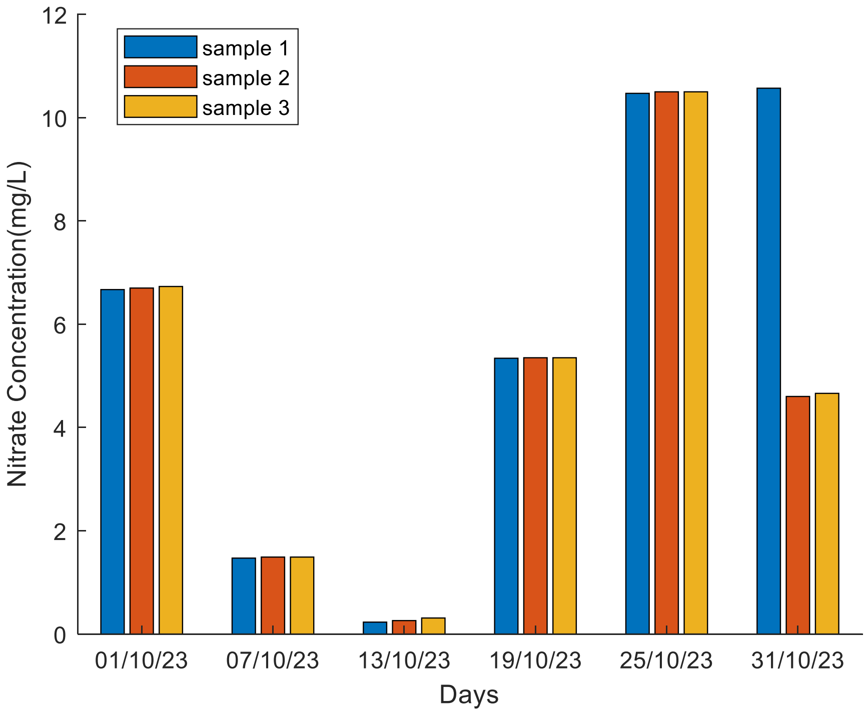

Figure 37: Display Variation of Nitrate Concentrations within one Month.

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From Figure 37, the nitrate concentrations on the 1st, 19th, 25th, and 31st days in SLERSOPAA samples 1, 2, and 3 were notably high, suggesting that the nitrifying bacteria were effective in converting nitrites into nitrates. However, this did not correlate with rapid plant growth. Between the 7th and 13th of October 2023, a decrease in nitrate concentrations was observed, particularly on the 13th day, where all samples from both the 7th and 13th days indicated that the bacteria were effectively reducing ammonia, allowing plants to absorb the nitrate (Endut, Jusoh, Ali, Wan Nik, & Hassan, 2009). The decline in nitrate concentration in the SLERSOPAA system reflects the active role of nitrifying bacteria. Nitrogen is crucial for enhancing the vegetative growth of plants; a deficiency in nitrogen can inhibit growth and result in stunted plants (Krastanova et al., 2022).

During the study, the nitrate concentration slightly exceeded 10 mg/L by 0.66 on the 13th day. Despite this slight exceedance, the higher nitrate levels had a positive impact on the SLERSOPAA system, including a high catfish survival rate of 99%, rapid growth of vegetables and catfish, and the benefits of continuous water agitation by the ram pump. The water from the bamboo grows beds, purified and returned to the fish pond, contributed to strong aeration and oxygenation in the pond.

Potassium Analysis

Table 7 shows the concentrations of potassium mg/L in SLERSOPAA on different dates (samples 1, 2, and 3). Potassium is an essential nutrient for plant growth and plays a vital role in many physiological processes, including photosynthesis, respiration, and enzyme activation. In aquaponics systems,

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potassium is primarily derived from fish waste and can become depleted over time by plant uptake (Deswati, Yani, Safni, Norita Tetra, & Pardi, 2022).

Table 7: Results of Established Potassium Concentrations in the Samples Collected.

Samples	Concentrations mg/L		
	1	2	3
01/10/23	18	20	20
07/10/23	20	20	18
13/10/23	20	20	20
19/10/23	26	26	26
25/10/23	26	26	24
31/10/23	20	20	22

Source: (Researcher, 2023)

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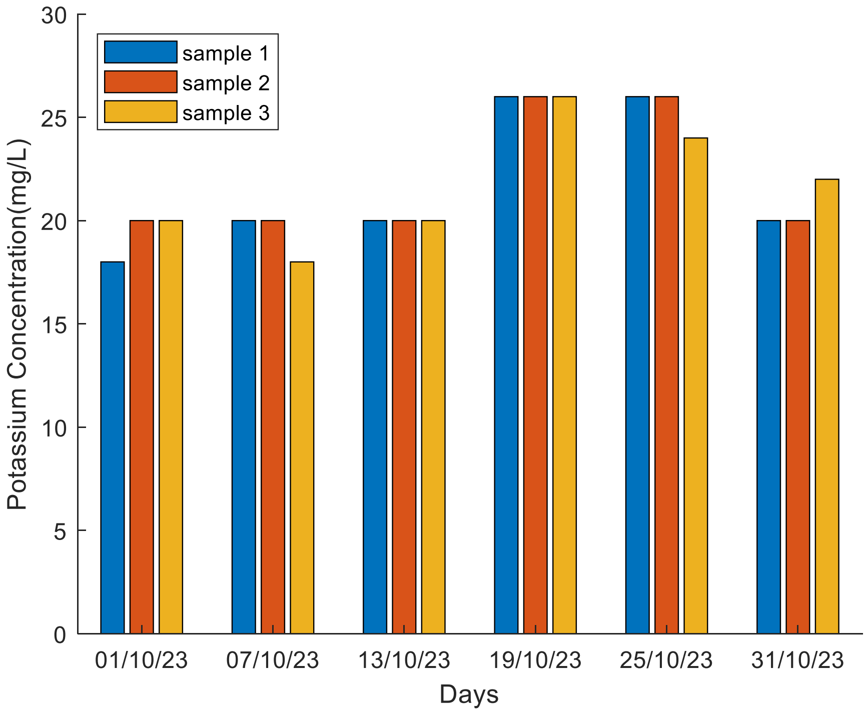

Figure 38: Display Variation of Potassium Concentrations within one Month.

The concentrations vary on different dates, indicating potential fluctuations in the potassium levels in our system. The concentrations of potassium in SLERSOPAA as displayed in Figure 38, show an average potassium concentration in the water ranged from 18 mg/L to 26 mg/L between days 01/10/2023 and 31/10/2023. The study suggests that uneaten fish feed settling at the bottom of the SLERSOPAA pond increased potassium levels. This can lead to higher concentrations of dissolved ions and a more active nitrogen and carbon cycle, along with increased dissolved minerals (macronutrients and micronutrients) like potassium (K+) (Deswati, 2021). The recommended potassium range for aquaponics systems is 156-300 mg/L (Deswati, 2021; Krastanova et al., 2022). While high potassium can benefit plants, it can harm fish. Therefore, monitoring and adjustments to maintain optimal potassium levels are essential for the health of the aquaponics system.

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Table 8: Average Monthly Water Parameters Recorded

Month- 2023	pH	DO mg/L	EC ms/cm	TDS g/L
June	7.22	4.00	1.30	0.986
July	7.38	4.50	1.36	1.024
August	7.40	4.25	1.38	1.071
September	7.45	4.74	1.40	1.105
October	7.96	5.36	1.50	1.140
November	8.05	5.71	1.81	1.160

Source: (Researcher, 2023)

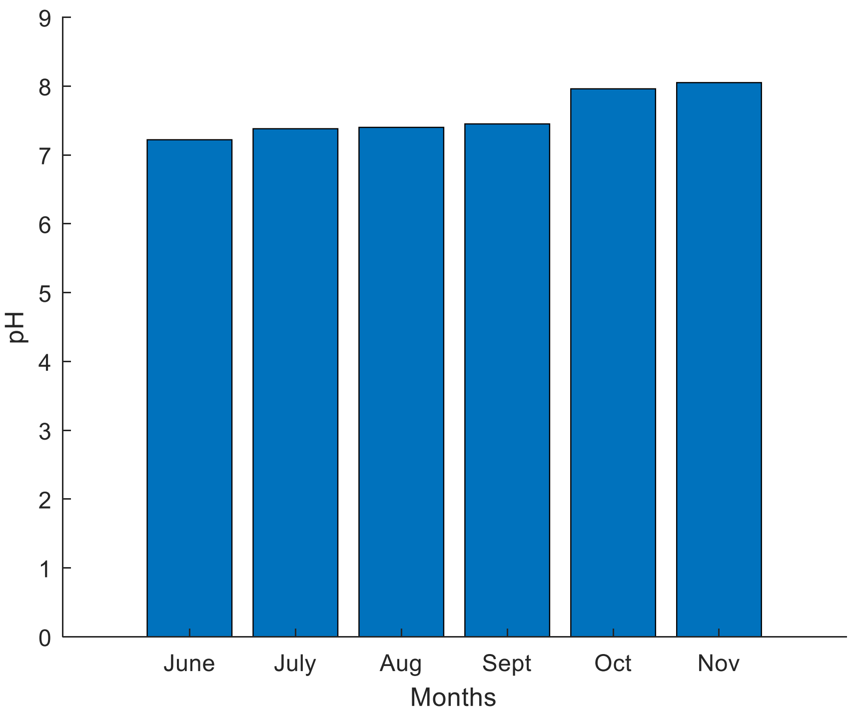

Figure 39: Variation of pH during the Study Period (183 days). A Graph of Months against pH

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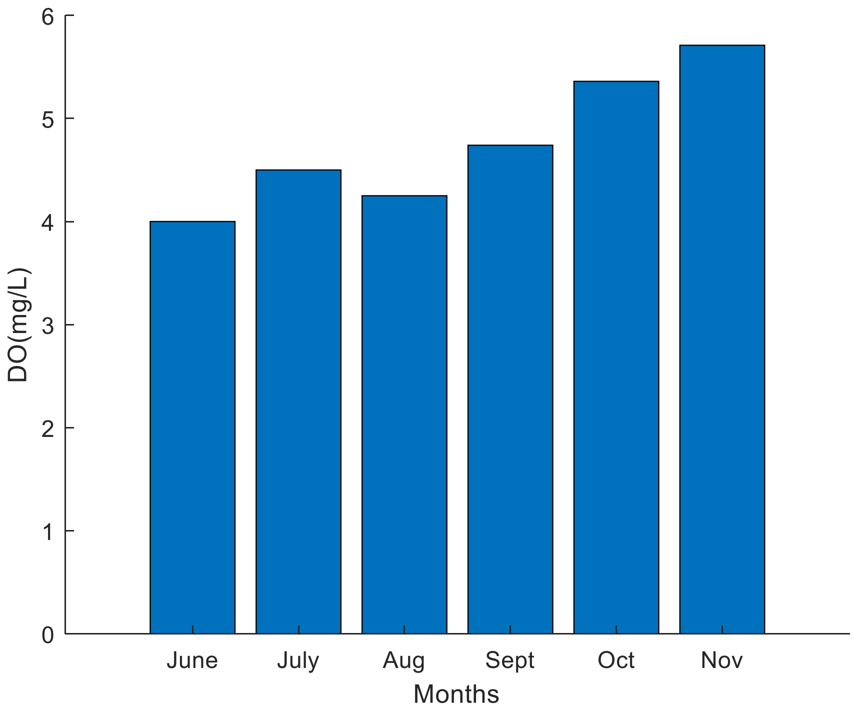

Figure 40: DO (mg/L) Variation during the Study Period (183 days). A Graph of Months against DO (mg/L).

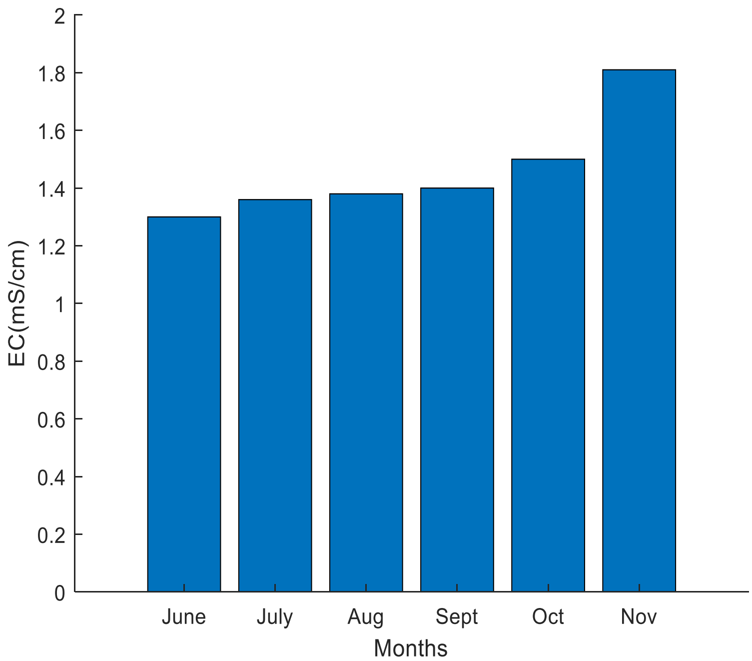

Figure 41: EC (mS/cm) Variation during the Study Period (183 days). A Graph of Months against EC (mS/cm).

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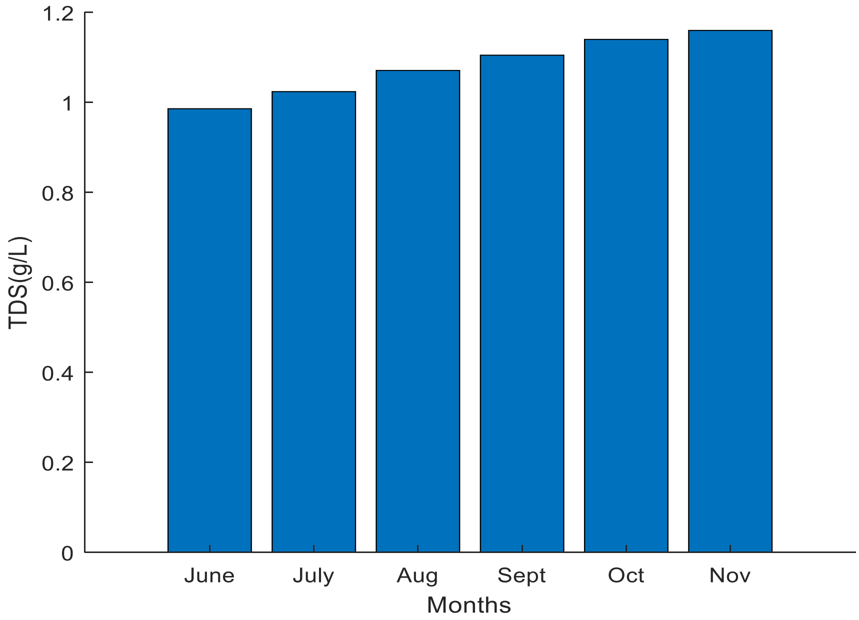

Figure 42: TDS g/L Variation during the Study Period (183 days). A Graph of Months against TDS g/L.

The fluctuating pH levels, evident from the data presented in Table 8 and Figure 39, demonstrate a dynamic interplay of biological processes within the SLERSOPAA. Photosynthesis and respiration play a pivotal role in influence the pH levels in the system significantly. During daylight hours, the process of photosynthesis predominates, outpacing respiration. This leads to a gradual increase in pH levels as CO_2 is absorbed by aquatic plants from the surrounding water (Kumar, Engle, & Tucker, 2016).

Dissolved oxygen is a critical parameter for aquatic organisms. Our study system maintained a relatively stable DO level, ranging from 4.00 mg/L in June to 5.71 mg/L in November as shown in Figure 40. Adequate DO levels are vital for the well-being of fish and beneficial bacteria in the aquaponics system. The observed consistency suggests efficient aeration and oxygen

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exchange within the system, contributing to a healthy environment for the aquatic organisms.

EC and TDS values are indicators of the concentration of dissolved ions in the water. Both EC and TDS exhibited an increasing trend over the monitored period as displayed in Figure 41 and 42. In June, EC was 1.30 mS/cm and TDS was 0.986 g/L, while in November, EC increased to 1.81 mS/cm, and TDS rose to 1.160 g/L. This rise may be associated with nutrient accumulation or changes in water composition due to plant and microbial activity. Regular monitoring and adjustment of nutrient levels were crucial in maintaining an optimal growing environment throughout the study period (Khater et al., 2023; Krastanova et al., 2022).

Plant Growth Rates

Table 9 presents the average growth rates of various vegetables, including hot pepper, tomato, cabbage, and cucumber, during the germination period. The seedlings of these vegetables demonstrated rapid and uniform growth across all square cushions placed on the growing troughs. They appeared healthy, with a vibrant green color, indicating strong vitality. Following their transplantation onto bamboo grow beds, the plants continued to exhibit rapid and uniform growth, maintaining their healthy appearance throughout the early stages of development. Throughout the 31-day growth period, there were no discernible signs of mineral deficiency or disease. The heights of the plants were diligently measured and recorded at three-day intervals over one month. The graphics below document plant growth over a month-long period (refer to Figure 26 for some pictures of plants on grow beds).

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Table 9: Plant Average Growth Rates

Date	Height/cm			
	Hot pepper	Tomato	Cabbage	Cucumber
05/10	5.0	5.0	6.0	11.5
08/10	5.4	7.0	7.0	12.5
11/10	5.5	10.0	8.0	13.0
14/10	6.0	12.0	9.0	13.5
17/10	6.5	14.5	10.0	15.0
20/10	6.5	17.0	12.0	18.0
23/10	7.0	22.0	14.0	21.0
26/10	7.4	28.0	14.5	29.0
29/10	7.8	34.0	15.0	40.5
01/11	8.2	39.0	16.0	55.0

Source: (Researcher, 2023)

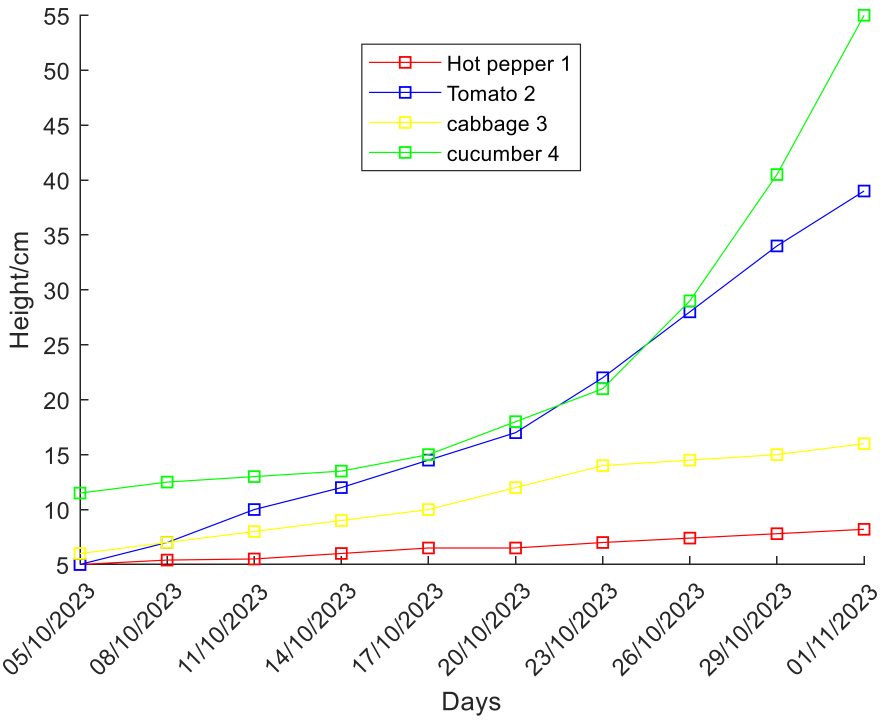

Figure 43: A Graph of Plant Heights against Days.

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Over a 31-day monitoring period of vegetable growth, including hot pepper, tomato, cabbage, and cucumber in the SLERSOPAA system, it was observed that the growth was positively influenced by sufficient water, environmental conditions, nutrition, and water quality. The taller the vegetables, the better their growth and development, as increased height typically leads to more leaf formation (Khater et al., 2023). The growth in vegetable height observed during the study is detailed in Table 9 and Figure 43.

In the SLERSOPAA method, the height and growth of vegetables continued to increase at regular intervals. Additionally, the vegetables showed no signs of nutritional deficiencies, such as stunted growth, color changes to yellow, white, or brown, or necrotic spots on the leaves (Deswati et al., 2022). Based on these observations, the SLERSOPAA technology effectively supports vegetable growth, as evidenced by the continuous increase in height. The system provides sufficient nutrients, preventing nutrient deficiencies in the plants.

Catfish Growth Rates

Table 10 presents growth parameters of catfish reared in SLERSOPAA. The data includes the weight (in grams), standard length (S length, in centimeters), and total length (T length, in centimeters) of 10 individual catfish. All the catfish in the dataset are female (denoted by 'F'). The weight of the catfish ranges from 65.0 grams to 334.2 grams with corresponding standard lengths ranging from 7.2 cm to 12.2 cm, and total

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lengths ranging from 8.1 cm to 13.5 cm. This data provides insight into the growth patterns and variability among catfish reared in SLERSOPAA.

Table 10: Growth Parameters of Catfish Reared in SLERSOPAA

No_	SEX	W / g	S L/cm	T L /cm
1	F	223.2	10.5	11.7
2	F	312.6	12.2	13.5
3	F	185.0	10.1	11.1
4	F	218.2	10.6	11.2
5	F	334.2	12.0	13.0
6	F	295.4	12.0	13.0
7	F	137.4	9.5	10.2
8	F	133.8	9.2	10.1
9	F	187.8	10.5	11.3
10	F	65.0	7.2	8.1

Source: (Researcher, 2023)

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Table 11: The use of Microsoft Excels to Estimates 'a', 'b' Values and Calculated k Values.

L/cm	W/g	log L (x)	log W(y)	x y	x^2	y^2	a L^b	k value
11.7	223.2	1.068185862	2.34869419	2.508841928	1.141021035	5.516364399	0.744404451	299.8370035
13.5	312.6	1.130333768	2.494988974	2.820170289	1.277654428	6.224969979	1.181368655	264.6083411
11.1	185.0	1.045322979	2.267171728	2.369926705	1.09270013	5.140067646	0.628088978	294.5442549
11.2	218.2	1.049218023	2.338854746	2.453968552	1.100858459	5.470241524	0.646535025	337.4913832
13.0	334.2	1.113943352	2.524006446	2.811600201	1.240869792	6.370608537	1.045892209	319.5357965
13.0	295.4	1.113943352	2.470410491	2.751897344	1.240869792	6.102927994	1.045892209	282.4382833
10.2	137.4	1.008600172	2.137986733	2.156373786	1.017274306	4.570987269	0.478081338	287.3987943
10.1	133.8	1.004321374	2.126456113	2.135645325	1.008661422	4.521815602	0.463118762	288.910774
11.3	187.8	1.053078443	2.273695588	2.394379811	1.108974208	5.169691627	0.665351591	282.2567835
8.1	65.0	0.908485019	1.812913357	1.647004625	0.82534503	3.286654839	0.227190213	286.1038741
113.2	2092.6	10.5	22.8	24.0	11.1	52.4	7.1	2943.1

Source: (Researcher, 2023)

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The data on the sex, standard length, total length and body weight was measured and recorded for further analysis as shown in table 10. The average standard length, total length and body weight recorded was 10.4 cm, 11.3 cm and 209.3 g respectively. The "*b*" value was 3.22, the correlation coefficient "*r*" was 0.98 and average condition factor K was 2943.1 as shown in table 11 and also (refer to Appendix I). A regression analysis whose graphical representation is shown below in Figure 44 was performed to confirm the results obtained from the calculations stated above.

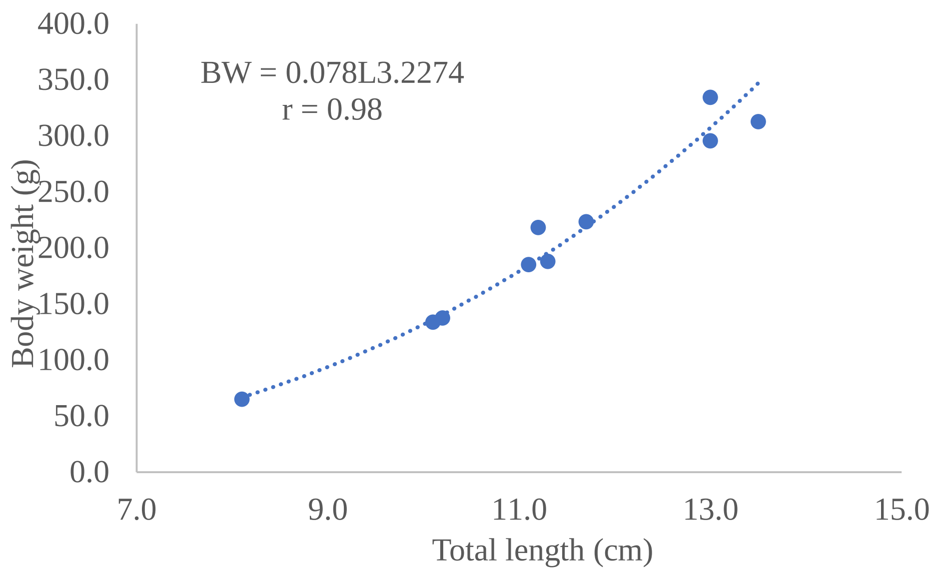

Figure 44: Graphical Representation of Catfish Body Weight against Total Length.

The significance of this aspect of the work is to estimate the condition and growth of the fish reared with the SLERSOPAA. The results obtained implies that, the "b" value of 3.22 means that the fishes are undergoing an isometric growth which further implies that they are in good condition and that the length and weight of the fishes are increasing in equal proportions,

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indicating good feeding conditions complimented by a suitable environmental status (Exploration, 2004) With respect to the condition factor “K” which is a variable of the observed and calculated weights, the value obtained was ≥ 1 which is within the normal recommended ranges and implies that values greater than or equal to one are indication of a good feeding and environmental condition of fish (Ismail, 2020). Ideally fish reared are best for sales and consumption if they exhibit conditions observed and estimated using the above standards.

Chapter Summary

This chapter presents the impressive results of the SLERSOPAA system. A remarkable 70.25% reduction in operational power consumption was achieved over six months by integrating a ram pump (RP) and solar panel (SP) controlled by an Arduino Uno. This groundbreaking achievement is particularly significant in regions with high energy costs, such as developing countries. The successful cultivation of hot peppers, tomatoes, cabbage, and cucumber, alongside the thriving catfish population, demonstrates the system's viability for sustainable food production.

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CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

Overview

The study aimed to minimize HED, HSC and HOC in an aquaponics system using RP, SP, and Arduino technology. The system consisted of 21 bamboo grow beds with 252 vegetable plants (hot pepper, cabbage, tomatoes, and cucumber) and a pond with 350 catfish. The study also measured the growth of the plants and fishes, as well as the water quality parameters such as pH, EC, TDS, NO^{3+}, K, and explored the mathematical relation of the growth of the plants and fishes in the system. This chapter focuses on the conclusions of the study with regards to the SLERSOPAA. The recommendations and other relevant suggestions made for further study are also addressed in this chapter.

Summary

This research aimed to create a sustainable aquaponics system. By combining ram pumps, solar power, and automated controls, the study sought to reduce environmental impact, improve human health, and lower operating costs. The system cultivated various vegetables alongside catfish, while monitoring water quality and plant/fish growth to optimize the process. Incorporating both the RP and artificial intelligence (using Arduino Uno microcontroller and relay to regulate SP), the actual daily energy usage or power consumption amounted to 172.8 W h / day, leading to a significantly reduction in monthly power consumption of 5184 W h / month.

The system was actively utilized over 183 days, representing six months (1st June – 30th November, 2023), the system was actively utilized.

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During this period, the total power consumption amounted to 31622.4 W h /days. In contrast, if the equipment entirely operated continuously for 24 hours daily for the same duration, the total power consumption will reach 106286.4 W h /day.

The findings suggest that the fishes are experiencing isometric growth. This signifies that the fishes are in optimal condition, with length and weight increasing proportionally—a clear indicator of favorable feeding conditions and a conducive environment. The SLERSOPAA system demonstrated an impressive 99.1% survival rate over a six-month growing period. This high efficiency underscores the system's potential in addressing food shortages, promoting the blue economy, advancing clean and renewable energy, and mitigating household shocks—ultimately contributing to resilience-building in Africa.

Conclusion

These solutions are focused on the following priority topics: space-efficient innovations, soil-saving innovations, water-saving innovations, renewable energy solutions, and blue economy. The subsequent paragraphs outline the noticeable effects of this research on numerous institutions.

The possible advantages encompass heightened recognition of an alternative approach to planting and cultivating crops. This method allows researchers to explore the dynamic interactions among fish, plants, and microbes (such as larvae, isopods, amphipods, etc.) within a live ecosystem. Additionally, it facilitates the conduction of water quality assessments. It enables the evaluation and monitoring of the growth rates of both fish and crops, serving as valuable data for diverse academic studies. The system is

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poised to spark ingenuity among engineering students, inspiring the generation of novel ideas to enhance ecosystem sustainability and create secure habitats for marine life. Moreover, it serves as a demonstration of the efficiency of solar power in enhancing crop production (Singh, 2013).

The aquaponics system aims to offer farmers insights into creating a sustainable and economical cultivation approach that actively combats diseases and fosters a healthier lifestyle. Furthermore, the integration of solar power not only enhances the overall system and its outputs but also translates into long-term cost savings for farmers, as it provides the necessary energy without additional expenses on their part (Henkel, 2015).

The study successfully demonstrated the feasibility and efficiency of SLERSOPAA using RP, SP and Arduino technology. The system achieved a high yield of vegetables and catfishes, with an average power consumption of 0.1728 kWh/day. The system maintained optimal water quality conditions for the vegetable plants and catfish due to the organic materials (bamboo) used as growth beds.

The study found a positive correlation between the growth of the plants and fishes in the system. The study substantially reduced power consumption by approximately 70.30% monthly and 70.25% for the six months for 183 days periods, respectively.

Recommendations

The study recommends regular monitoring and testing of the water quality parameters to ensure the health and productivity of the plants and fishes.

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The study advises using organic fertilizers and biofilters to enhance the bacterial activity and nutrient cycling in the system. Exploring the nutritional profiles of vegetables and fish within the current framework can pave the way for further postgraduate research across various academic disciplines.

The study encourages the adoption and promotion of SLERSOPAA as a sustainable and profitable method of food production. It also serves as a model for sustainable coastal development within the blue economy, fostering economic resilience and environmental stewardship in coastal communities.

Further in-depth work will have to be carried out to tease out and elucidate what exactly makes the various systems tick and to correct some flaws observed, such as yellowed vegetable leaves indicative of some level of nutrient deficiency.

The study suggests the following for further research;

(i) bacterial counts or growth in SLERSOPAA

(ii) optimal design and configuration of the ram pump and the Arduino controller for different aquaponics systems.

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APPENDICES

APPENDIX A

Table 12: SLERSOPAA BUDGET

ITEM	QUANTITY	UNIT COST GHs	TOTAL COST GHs
Pond (2.20× 1.30m^2)	1	800	800.00
Tarpaulin (15 ft)	1	1000	1000.00
Bucket	2	50	100.00
Bamboo pipe	62	10	620.00
Ram pump	1	350	350.00
½ inches PVC	5	65	325.00
Adhesives	-	500	500.00
Solar panels (120 W)	2	1800	3600.00
Solar battery (100 AH)	1	2500	2500.00
Solar stand	1	300	300.00
Microcontroller set up	1	600	600.00
wire	1 coil	250	250.00
Fish stock	350	2	700.00
Plant	252	100	100.00
Workmanships'	-	5000	5000.00
T&T	-	1000	1000.00
Contingency	-	1055	1055.00
TOTAL COST GHs			18800.00

Source: (Researcher, 2023)

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APPENDIX B

THE ARDUINO UNO MICROCONTROLLER

The Arduino Uno microcontroller is an open-source hardware controller, designed to easily interface with various sensors (to register user inputs), and to drive the responses and behaviour of external components such as LEDs, motors, and speakers (to respond to user inputs). One of its most important features is its ease of programmability, even for users with little technical expertise. This aspect has made it a tool of choice for artists and designers when creating interactive objects and spaces.

Arduino comprises two major parts: the Arduino board as shown in Figure 9, which is the piece of hardware one works on when buildings objects, and the Arduino IDE, the piece of software one runs on computer. One uses the IDE to create a sketch (a little computer program) that one uploads to the Arduino board. The sketch tells the board what to do.

Figure 45: Arduino Uno microcontroller board (Badamasi, 2014)

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APPENDIX C

MEASUREMENT OF CATFISH BODY WEIGHT AND LENGTH

Below are the pictures taken during the measurement of catfish body weight, along with their corresponding standard and total length, at the USAID/UCC Fisheries and Coastal Management Laboratory.

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APPENDIX D

GENERATED VALUES OF "a" and "b" USING MICROSOFT EXCEL

$$b = \frac{n\sum xy - \sum x \sum y}{n\sum x2 - (\sum x)^2} \quad \text{(I1)}$$

where n = 10 representing the number of samples collected

$$b = \frac{240.4981 - 239.2453}{110.5423 - 110.1541}$$

$$b = 3.227405$$

$$a = \frac{\sum y - b\sum x}{n} \quad \text{(I2)}$$

$$a = \frac{22.8 - 33.87301}{10}$$

$$a = antilog\ of\ \ obtained\ value$$

$$a = 0.07800$$

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APPENDIX E

ASSESSMENT AND TEST FOR FUNCTIONALITY SLERSOPAA

Solar Panel

The solar panel's performance will undergo testing by employing a multimeter set to DC voltage in direct sunlight. The procedure entails connecting the negative lead of the multimeter to the negative wire of the panel and the positive lead to the positive wire of the panel.

Battery Capacity

To assess the battery's performance, the multimeter's negative lead will be connected to the battery's negative terminal, and the positive lead will be connected to the positive terminal.

Solar Water Pump

To assess the effectiveness and dependability of the water pump, it is necessary to examine whether the pump's capacity is sufficient to propel water from the fish pond to the upper section of the pipe and facilitate the upward flow of water to the RP bucket source.

Ram Pump (RP)

In evaluating the functionality of the RP, key parameters such as efficiency, lift height, and flow rate are crucial for assessing its performance. The setup involves installing the pump in a water source with proper pipes, closely observing its ability to lift water against gravity, and recording lift height and flow rate under various conditions. Validation is essential, comparing observed results with expected values based on the pump's specifications. Fine-tuning adjustments may be required, considering factors like pipe diameter and waste valve settings. The overall conclusion is drawn.

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Functionalities of the SLERSOPAA

The aquaponics system is designed to operate with a series of interconnected functionalities, ensuring a symbiotic relationship between fish cultivation and plant growth. The key processes are outlined as follows;

Water Circulation and Pump Control

The system begins with water being pumped from the fish pond to a 50 L bucket, serving as the water source for the RP.

The SP is controlled by an Arduino Uno and facilitated by a two-terminals water sensor in the bucket, operates through a relay. It is programmed to switch on and off at predefined intervals.

Gravity-Driven Water Distribution

The 50 L bucket, elevated 1 m above ground, allows water to descend by gravity through a 2.10 m pipe to the RP. The RP then lifts a portion of the water into bamboo grow beds, while the remaining water through the waste valve is filtered, and returned in to the fish pond.

Bamboo Siphon System

Water from the first upper bamboo grow bed drains out when it reaches the upper limit of the bamboo siphon bell. The drained water then flows through bamboo stand pipes to subsequent grow beds until reaching the last bed, after which it is directed back into the fish pond. This cyclic process provides plants with nutrients and purifies water via bamboo bell siphons back in to the fish pond.

Aeration and Stagnation Prevention

The returned water from the RP waste valve and bamboo grow beds plays a crucial role in preventing stagnation and promoting aeration. Continuous water disturbance, facilitated by the return processes, enhances oxygen exchange between water and the atmosphere. Aeration is vital for fish respiration, and preventing stagnation ensures even oxygen distribution throughout the pond.

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