AN ASSESSMENT OF HYDROPONICS FARMING TECHNOLOGY IN URBAN AND PERI-URBAN AREAS OF NAIROBI CITY, KENYA

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DECLARATION

I declare that this research project is my original work and has never been submitted or presented in any university for examination.

Signature **Date** October 20, 2023
Joab Odero

This research project has been submitted for official examination with our approval as the University of Nairobi supervisors

October 24, 2023
Signature **Date**
Prof. Samuel Owuor

Signature **Date** October, 24, 2023
Mr. Lincoln Karingi

DEDICATION

I dedicate this research project to all urban and peri-urban hydroponics farmers, experts and organizations that are determined to advance it to the larger population of farmers in Kenyan urban centres.

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ABSTRACT

Although conventional crop farming has been the dominant urban and peri-urban agricultural practice in most sub-Saharan African cities, it faces several challenges hindering its potential to generate both economic and environmental benefits to urban residents. These challenges include limited farmlands, high costs of renting off-plots for farming, insecure land tenure, and pollution of field crops, among others. One of the solutions for the aforementioned challenges is hydroponics farming technology, a soilless production of clean, green and gourmet crops in limited urban spaces throughout the year. However, in urban and peri-urban areas of Nairobi city, little is known about nature of hydroponics farming, especially production processes, the role of non-state organizations in promoting hydroponics farming, and its economic and environmental benefits and constraints. This study focused on four objectives, namely, 1) the nature of hydroponics farming; 2) the role of non-state organizations in promoting hydroponics farming; 3) the economic and environmental benefits of hydroponics farming; and 4) the constraints of hydroponics farming – in urban and peri-urban areas of Nairobi. Since the uptake of hydroponics farming technology is still low in Nairobi, the study applied Actor-Network Theory and an exploratory study of hydroponics farmers to understand adoption and practice of hydroponics farming in the study area. The study sampled 40 hydroponics farmers using proportionate stratified random sampling. Data was collected using semi-structured interviews, key informant interviews and field observations to gain more insights on hydroponics farming technology in the urban and peri-urban areas of Nairobi. Quantitative aspects of the data were analyzed using frequency distributions and cross-tabulations, while the qualitative aspects were subjected to content analysis. The study had one hypothesis: "There is no difference between the type of hydroponics farming technique and income from sale of farm produce". This was analyzed using chi-square test. The study findings indicate that hydroponics farming is technologically intensive with 55% of farmers noting high start-up capital. It is mostly undertaken by more males (62.5%) against women (37.5%), all with secondary education and above. Additionally, there are various hydroponics farming techniques meant for different types of crops, and as such, require varying types of inputs and installation. A number of non-state organizations provided information and training to 88.5% of farmers, setting up hydroponics farms for 75%, and spearheading farmers' access to startup costs, inputs and market for 47.5% of the sampled farmers. Economically, 35% of farmers realized reduced production costs, 100% noticed raised income from produce and 25% noted creation of job opportunities to the local community. Environmentally, the farming technology reduces pollution as observed by 20% of farmers and saves water (35%), energy (30%) and space (15%). However, hydroponics farmers are characterized by such constraints as very high (initial) start-up and installation costs, inadequate system operational skills, limited crop management skills, limited access to water and access to (rental) land for hydroponics farming, poor plumbing, inconsistent power supply, and spoilage of crops. Hypothesis testing found that there was no enough evidence to reject this null hypothesis. As such, there is no difference between the type of hydroponics farming technique and income from sale of farm produce. The study recommends enhancing partnerships between state and non-state actors to promote urban and peri-urban hydroponics farming. Hydroponics farming technology economically and environmentally benefits both urban farmer and non-farmer residents. Efforts to lessen its constraints would expand its adoption and practice in Nairobi city and its peripheries.

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ACRONYMS AND ABBREVIATIONS

ANT	Actor Network Theory
ARC-VOPI	Agricultural Research Council-Vegetable and Ornamental Institute
CBOs	Community Based Organization
CEA	Controlled Environmental Agricultural
DFT	Deep Flow Technique
DWC	Deep Water Culture
FAO	Food and Agriculture Organization
GDARD	Guateng Department of Agriculture and Rural Development
HTH	High Tech Hydroponics
HTUA	High-Tech Urban Agriculture
IUFV	Indoor Urban Vertical Farming
JICA	Japanese International Cooperation Agency
KIIs	Key Informant Interviews
KNBS	Kenya National Bureau of Statistics
LED	Light Emitting Diodes
NFT	Nutrient Film Techniques
PFAL	Plant Factory with Artificial Lighting
SH	Simplified Hydroponics
USDA	United States Department of Agriculture

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Globally, rapid rate of urbanization facilitates expansion of urban spatial areas. While Angel *et al.* (2011) estimated that urban land cover would rise globally from 300,000 km^2 in the year 2000 to 770,000 km^2 in 2030 and further to 1.2 million km^2 in 2050, the United Nations (2018) approximated that 55% of world's population were already residing in urban centers and would increase to 68% in 2050. Paradoxically, the reverse is decrease in urban open spaces for agricultural productivity, yet the growing urban populace increasingly overwhelms its food and income generation, and sustainable resource use. Urban agriculture has been one of the ways to improve food and income security (Lee-Smith, 2010), resource saving and to some extent, manage wastes (Avgoustaki & Xydis, 2020).

Despite aforementioned significance, urban conventional crop farming in sub-Saharan African cities, including Nairobi, faces a number of environmental, socio-economic, health-related, and regulatory challenges. The environmental challenges include air pollution, water pollution, contaminated soil, scarcity of water for irrigation, and seasonal drought and flooding (Ogendi *et al.*, 2014). The socio-economic challenges include costly farm inputs, theft of produce, insecurity of tenure, high cost of renting farmlands, and increase in urban density. The health-related challenges include irrigation using untreated sewage and intensive use of agrochemicals (Karanja *et al.*, 2012). Lastly, the regulatory challenges include varying and contradicting policies, as well as threats and harassment from urban authorities (Kinuthia, 2019).

Hydroponics farming, therefore, becomes one of the remedies to open-field farming challenges. This farming system maximizes limited urban spaces for food production, as well as for economic and environmental merits all year round (Wood *et al.*, 2020). As noted by Ogendi *et al.* (2014), hydroponics farming is practicable on balconies, walls, rooftops, in shipping containers, greenhouses, storey-buildings and disused warehouses. As urbanization occurs, there is need for food security in the growing number and populations of urban centres in sub-Saharan Africa. Considering aspects of sustainable urban and peri-urban crop farming, hydroponics farming technology is less labour intensive to operate and manage crops. It also uses less space, less water, recirculates nutrients, and has the potential of producing high yield crops throughout the year, especially in urban and peri-urban areas, and therefore increasing food production and improving urban food and nutrition security.

For example, Nairobi city occupies a land size of 696km^2 with a population of 4.3 million people (KNBS, 2019). This growing population needs food and income security, as well as a healthy environment. According to the Nairobi City County Food Systems Strategy of 2022, the current Nairobi's food system is not able to provide enough food to all the city residents (Nairobi City County, 2022). This study argues that the current conventional urban farming practices and sourcing of food from the rural areas may not be sustainable in the near future. As such, the practice of innovative and sustainable hydroponics farming needs to be encouraged. However, little is known about nature of hydroponics farming, its involved promoters such as non-state organizations, potential economic and environmental benefits, and challenges in urban and peri-urban areas of Nairobi city and most of sub-Saharan African cities.

1.2 Statement of the Research Problem

Urban expansion and population increase have hindered the scale and quality of urban and peri-urban conventional crop farming in sub-Saharan African cities in terms of reduced farmland sizes, high cost of renting farmlands, pollution of field crops, and insecure land tenure (Al-Kodmany, 2018). One of the technological solutions is hydroponics farming which is given little attention yet stealthily gaining momentum in sub-Saharan African cities (Soethoudt *et al.*, 2016). Kalantari *et al.* (2020) describe hydroponics farming as a farming technique for mass production of food through control of nutrients, water and direct sunlight, vertically in urban limited spaces.

While a lot of literature concentrates on hydroponics techniques, operations and comparison of productivity to traditional agriculture, less is known about the role of non-state organizations in promoting the adoption and practice of hydroponics farming, as well as its economic and environmental benefits in sub-Saharan African cities, including Nairobi (Nerantzis *et al.*, 2018). Furthermore, although data on hydroponics farming in the global south exists, more specific data needs to be gathered to fully understand the nature of hydroponics farming at the city level (Assefa *et al.*, 2018). In addition, despite previous studies theoretically emphasizing the contribution of hydroponics farming to food security, they barely analyze its empirical economic and environmental benefits, yet hydroponics farming is capital and technologically intensive (Mugambi, 2020). This is not to say that hydroponics farming does not have challenges. There are challenges related to costly installation, energy use, and use of other inputs. An in-depth understanding of these constraints is important to unlock the potential role of hydroponics farming in urban and peri-urban food production.

As such, this study is an assessment of hydroponics farming in urban and peri-urban areas, using Nairobi city as a case study. Specifically, the study provides evidence-based data on the nature of hydroponics farming, the role of non-state organizations in promoting the adoption and practice of hydroponics farming, the economic and environmental benefits of hydroponics farming, and the constraints to hydroponics farming in Nairobi's urban and peri-urban areas. The study argues that hydroponics farming in Nairobi's urban and peri-urban areas is a relatively new farming technology that is being gradually adopted by interested farmers. However, the adoption and practice of this new farming technology is largely being promoted by non-state organizations.

1.3 Research Questions

1. What is the nature of hydroponics farming in urban and peri-urban areas of Nairobi?
2. What is the role of non-state organizations in promoting hydroponics farming in urban and peri-urban areas of Nairobi?
3. What are the economic and environmental benefits of hydroponics farming in urban and peri-urban areas of Nairobi?
4. What are the constraints of hydroponics farming in urban and peri-urban areas of Nairobi?

1.4 Research Objectives

1. To establish the nature of hydroponics farming in urban and peri-urban areas of Nairobi.
2. To assess role of non-state organizations in promoting hydroponics farming in urban and peri-urban areas of Nairobi.
3. To analyze the economic and environmental benefits of hydroponics farming in urban and peri-urban areas of Nairobi.
4. To determine the constraints of hydroponics farming in urban and peri-urban areas of Nairobi.

1.5 Research Hypotheses

H_0: There is no difference between the type of hydroponics farming technique and income from sale of farm produce.

H_1: There is difference between the type of hydroponics farming technique and income from sale of farm produce.

1.6 Justification of the study

An assessment of hydroponics farming in Nairobi's urban and peri-urban areas would (a) expand farmers and non-state organizations' understanding of the extent of challenges affecting hydroponics farming, and through their networks, condense priority actions for mitigation; b) encourage urban farmers and non-farmer residents to develop relevant agribusiness models for hydroponics farming investment to scale up its economic and environmental benefit and; (c) inform urban policymakers and relevant state-actors that adoption and practice of hydroponics farming is one of the urban circular-economic aspects and agro-ecological practices that conserves irrigation water, saves energy, prevents agrochemical pollution of city's aquatic ecosystems and attains reduced food miles due to readily available city market. Academically, this was an exploratory study that opens up research windows for instance, on crop diversification, cost-benefit analysis of hydroponics farming crops and in-depth sustainability research on hydroponics farming technology in urban and peri-urban areas of Nairobi and other Kenyan cities.

1.7 Scope of the Study

Geographically, the study covered hydroponics farming in Nairobi city and those located in the neighbouring peri-urban areas of Kiambu and Kajiado counties. In order to understand adoption and practice of hydroponics farming technology in the study area, non-state organizations that promote its adoption and practice were also covered to achieve objective 2 of the study. A list of hydroponics farmers who were getting services or supported by the non-state organizations wad drawn, depicted by their hydroponics farm distribution in Nairobi city and its peri-urban areas of Kiambu and Kajiado counties. The focus on non-state organizations in promoting the adoption and practice of hydroponics farming is based on the fact that the farming technology is relatively new to Nairobi urban and peri-urban farmers. As such, the adoption of the farming technology is largely being promoted by non-state organizations who are keen on the farming system.

1.8 Limitations of the Study

The study was limited from generalizing that all hydroponics farms were homogeneous. The 40 sampled hydroponics farmers had varied farm sizes depending on one's start-up costs, choice and preference. There was also difficulty in accessing absolute information on book keeping records in order to verify accurate data on total hydroponics farming expenditures and sales of farm produce for calculation of net profit of each hydroponics farmer. Additionally, not all the hydroponics farmers were open for directly revealing their net income from hydroponics farming considering individual financial privacy rights. However, the study managed to collect field data on sale of produce per kilogram and total production quantities of every type of crop per harvesting period from each hydroponics farming technique. This was logical for calculating income from hydroponics farming for every farmer. Despite these constraints during data collection, the study obtained rich data on the nature of hydroponics farming, role of involved non-state organizations, economic and environmental benefits, and constraints for inference purposes.

1.9 Operational Definitions and Concepts

- **Conventional crop farming:** Cultivation of crops in open spaces effected by weather conditions, pests and diseases and pollutants.
- **Controlled environment agriculture:** Farming in enclosed structures with all necessary growth requirements and crop protection from adverse weather conditions, pests and diseases.
- **Urban vertical farming:** Production of crops upwards, laterally or via inclined structures.
- **High-tech hydroponics farming:** Use of complex and automated equipment, nutrient solution and water to grow crops under controlled environmental conditions and other elements.
- **Simplified hydroponics farming:** The utilization of locally available materials to construct small-scale structures for soil-less crop production.
- **Plant factories with artificial lighting:** Large-scale indoor hydroponics farms with all automated inputs, including light emitting diodes for crop production.
- **Indoor urban vertical farming:** Any form of interior soilless farming, including hydroponics farming.
- **Urban environment:** Urban ecological setting comprising surface and underground waters, solar energy and soil under human influence.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on hydroponics farming systems in terms of its technologies, merits, demerits and suitability of crops grown. It also presents relevant global, regional and national empirical studies on the nature of hydroponics farming; the role of non-state organizations in promoting the adoption and practice of hydroponics farming; the economic and environmental benefits of hydroponics farming; and the constraints of hydroponics farming. Major research gaps from the reviewed sources, as well as theoretical and conceptual frameworks are also presented.

2.2 Hydroponics Farming Systems

Hydroponics farming comprises Greek words *hydro* for water and *ponos* for labour, thus, 'water doing labor' (Al-Kodmany, 2018). Hydroponics farming system involves growing crops with their roots suspended or partially immersed in soil-free nutrient solution under controlled environmental conditions (humidity, temperature, light), pests and diseases, irrigation water, nutrients, potential hydrogen and electrical conductivity (Nerantzis *et al.*, 2018; Wood *et al.*, 2020).

2.2.1 Nutrient Film Technique (NFT)

In nutrient film technique, nutrient solution is recirculated periodically around plant roots in a thick root-mat developed at the bottom and upper surface of the channel. As such, the plant root systems obtain enough oxygen, water and nutrients supply (Soethoudt *et al.*, 2016). In this system, less irrigation water is used and plants can be stacked in layers to ease cleaning and customizing the system. However, a pump failure could cause drying out of plants, while stagnant nutrient solution due to compromised slope and flow rate hinders root aeration (Chidiac, 2017). The nutrient film technique is commonly used for production of fast-growing vegetables such as lettuce, basil and other leafy greens.

2.2.2 Deep Flow Technique (DFT)

In this system, plant roots are partially submerged in aerated/non-aerated nutrient solution from which are floating rafts holding plant net cups (Nerantzis *et al.*, 2018). The frequent aeration takes place using air compressor in un-aerated solution while solution level is lowered for roots above it to get enough oxygen. According to Ssentambi *et al.* (2020), the deep flow technique is easy to construct and operate unlike other hydroponics systems. It is best used for growing of lettuce, basil, spinach and other leafy greens because of their faster maturity and less root support. However, clogging of drip lines or emitters could lead to plants drying out (Yuvaraj & Subramanian, 2020).

2.2.3 Drip Irrigation Hydroponic System

In this system, plant root zones receive nutrient solution and water via nozzles along polythene hose pipes and get recirculated (Giro *et al.*, 2016). The commonly used substrates include rock wool, perlite, coco-peat/coir, and pumice. However, several factors such as high-water retention capacity determines the substrate selection. For example, Giro *et al.* (2016) noted that coir gains high water retention capacity and when mixed with sand, sub-acid PH conditions are produced thus good for tomatoes. The system favours the growth of cucumbers, strawberries, peppers, eggplants, kale and melons, with much more water conserved.

The structure, scale and nature of operation of the above discussed hydroponics systems/technologies determine whether they are High-Tech Hydroponics (HTH) or Simplified Hydroponics (SH) farming systems. In developed countries, hydroponics systems are automated for mass production and faster achievement of return of investment thus termed as HTH farming systems whereas SH farming systems could be practiced manually at household level or in large scale using locally available materials and considerable labor (FAO, 2015).

2.3 The Nature of Hydroponics Farming

2.3.1 Crop Varieties and Hydroponics Farming Sub-Systems

Different hydroponics farmers select certain crop varieties depending on the applicable hydroponic sub-techniques, purpose and scale of farming. In most of the US cities, the dominant crops are lettuce, tomatoes, culinary herbs, pepper, strawberry, fresh cut herbs, spinach, basil, and other leafy greens and vegetable varieties (Kaufmann, 2018).

In Africa, Giro *et al.* (2016) noted that horticultural crops are common for urban hydroponics farming due to their short-cycle system, less water requirement, high marketability and limited land per unit area of crop. Waldhauer & Soethoudt (2015) give examples of lettuce varieties, tomatoes, herbs, kale, chard and baby leaf salad mixes that are hydroponically produced in

Cairo. NFT, DFT and gutter techniques favors hydroponic growing of leafy greens and herbs (Soethoudt *et al.*, 2016). In South Africa, Plooy *et al.* (2012) noted that leafy vegetables such as lettuce have been hydroponically grown through Gravel Flow Technique (GFT).

In Kenya, Kibiti (2017) identified kale, spinach, onions, pepper and tomatoes as short-cycle plants hydroponically farmed in Meru town. Mugambi (2020) observed that NFT is commonly used by hydroponics farmers in the same town to produce the aforementioned food crops. In Naivasha, Ketter (2015) observed that coco-peat hydroponics farming systems resulted in production of high-quality roses in terms of stem weight and length classes. On the other hand, Njima (2016) observed that 80% of hydroponics farmers in Kiambu sub-County grew hydroponic fodder using barley. Barley was preferred because of its availability in the market, being less expensive, has high water uptake, and its wholly palatable germinated seeds and shoots can be used by livestock, hence zero nutrient waste (Naik *et al.*, 2015).

2.3.2 Production Area and Quantity of Produce

Sizes of hydroponics farms vary depending on capital and technological inputs. At household level, hydroponics farm could be 1m^2 though a number of household farmers have gardens of between 10-20m^2 and communities having bigger than 20m^2, a more viable size for food and income generation (FAO, 2015). A case study by Kaufmann (2018) details that after 3 weeks, Green Spirit Farms in New Buffalo, Michigan could produce 100lbs (45.35kg) of lettuce in a growing space of 36 sq. ft. Brooklyn Grange in New York also produced 50, 000lbs (22,675.74 kg) of vegetables yearly in a growing space of 2.5 acres, while in Massachusetts, Boston Medical Centre Rooftop farm yielded 2,266kg of cucumbers, carrots, eggplant, green beans, herbs, tomatoes, peppers and beets from a 223m^2 area.

In Africa, pilot projects and small-acreage hydroponics farms are of different sizes with different quantities of produce. Plooy *et al.* (2012) noted that tomato and pepper population of 3 plants/m^2 led to increased yields and marketability in South Africa. In the same country, Giese (2016) estimated that a 120x25m polytunnel of a hydroponics farm can accommodate 36,000 holes for plants and 600kg/month of dried kale could be harvested. In Kampala, Uganda, 1kg of soaked barley grains, sprouted hydroponically for chicken production, yielded 4.1kg in the 4th day of sprouting and 6.8kg after one week (Alinaitwe *et al.*, 2019).

In Kenya, hydroponics farming is still in small-scale considering its gradual rate of adoption and practice. However, Njima (2016) observed that hydroponics fodder farming requires less acreage, and that $12m^2$ area is adequate to produce fodder for two dairy cattle throughout the year and this equals to 600 acres' open field pasture. In Meru, Mugambi (2020) found that most hydroponics farms were 8x15m and 8x30m, yielding approximately 5 and 10 tons of tomatoes, respectively, in a year. On the other hand, Ketter (2015) observed that hydroponically produced roses weighed 9.2 kg/m^2 higher than 5kg/m^2 of those raised in soil-based greenhouse, with all the roses from both systems grown after 12 months in Naivasha.

2.4 Non-State Organizations and Hydroponics Farming

Non-state organizations are involved in promoting the adoption and practice of hydroponics farming. According to Goodman & Minner (2019), New York has 6 commercial Controlled Environment Agriculture (CEA) farm companies, 133 institutional farms (schools, universities), 6 social service agencies, and 5 youth-based NGOs, all practicing hydroponics farming. On the other hand, Singapore city also hosts a number of company-based hydroponics farms (Wood *et al.*, 2020). Other than HTH farming systems actors, there are smallholder and community group SH farming systems farmers. For example, Fecondini *et al.* (2009) identified 10 mothers' groups (*Clubes de maes*) that hydroponically grew food crops in Teresina city in Brazil.

In Africa, most non-state organizations prefer SH farming systems to HTH farming systems. Kaufmann (2018) argues that SH farming systems are suitable for vegetable production in resource-limited areas due to minimal inputs and garden construction using locally recyclable materials. In Cairo, non-farming market players such as retailers, restaurants and hoteliers, and dealers in hydroponics equipment were commercially working with about 10 hydroponics farmers in 2015 (Waldhauer & Soethoudt, 2015; Soethoudt *et al.*, 2016). Away from Egypt, a study by Assefa *et al.* (2018) shows presence of smallholder hydroponic fodder growers supported by hydroponics farming organizations in urban and peri-urban areas of Mekele, Gondar and Tachi-Gayint towns in Ethiopia.

In Kenya, Mwaura *et al.* (2021) identified 9 hydroponic farms within the urban and peri-urban areas of Nairobi. Examples of such actors are Granduer Africa Limited, Hydroponics Africa Limited and Miramar International College. On the other hand, Njima (2016) identified 157 hydroponics growers in Kiambu sub-county, with majority of them neighboring Kiambu town and Nairobi city. In addition, Ogam (2016) interviewed 87 hydroponics fodder growers from three administrative districts of Kajiado County (Loitokok, Ngong and Isinya), with the last two farming in the urban and peri-urban areas of Nairobi.

Hydroponics farmers form networks with non-state organizations through which they practically learn about hydroponics farming techniques, operations, challenges, and access to credit, among others. For example, Vertical Harvest founders in Wyoming, initiated public-private-partnerships to raise funds through grants, crowd funding and equities for the construction and initial startup of their hydroponics farm (Cox & Horton, 2019). Additionally, citywide establishment and operation of CEA, including hydroponic farms in New York, heavily receive local authorities, urban planners and business investments support for contributing to social, physical and economic health of the city residents (Goodman & Minner, 2019). Furthermore, the Upgrown Farm Company in Singapore offers training on indoor farming to new growers interested in starting up small-scale hydroponics farms and later scaling up their production (Kaufmann, 2018).

Evident in African cities, Giro *et al.* (2016) noted that hydroponics farming actor networks resulted to the “Cairo Model” of SH farming system spearheaded by NGO *Love in Slums* and funded by Municipality of Milan, Italy. This ensured a wide spatial dissemination of SH farming systems knowledge and skills to majority of low-income urban residents of Al-Quarafa informal settlement in Cairo. In South Africa, Agricultural Research Council, Vegetable and Ornamental Institute (ARC-VOPI) offered research and trained farmers on hydroponics vegetable production, while Guateng Department of Agriculture and Rural Development (GDARD) provided access to necessary hydroponics facilities to farmers (Plooy *et al.*, 2012).

According to Ogam (2016) and Kibiti (2017), Hydroponics Africa Limited, Granduer Africa Limited and Joe Hydroponics are among organizations that network with hydroponics farmers in Kenya. They offer training on setting up of farms, use of inputs, and access to markets for hydroponics farmers. Mugambi (2020) adds that some of them even charge training fee of Kshs. 1,000. However, some farmers in Meru County acquired knowledge on hydroponics farming from seminars and workshops, and media (print and social). Credit institutions such as banks, merry-go-rounds, savings and credit cooperative organizations provide farmers with loans and credits to start up hydroponics farming.

2.5 Adoption of Hydroponics Farming

In North America, Europe and some Asian nations, hydroponics farmers are more of companies, social service institutions (schools, hospitals and charity) and NGOs that practice HTH farming systems at high capital and technological investments (Goodman & Minner, 2019; Wood *et al.*, 2020). It is thus impractical to analyze their characteristics based on age, gender, sex, and education level.

However, gender determines hydroponics farming adoption and practice in sub-Saharan African cities and those of developing regions such as Latin America. In their study of 10 mothers' groups practicing SH farming systems in the city of Teresina in Brazil, Fecondini *et al.* (2009) noted that 57% of the farmers were women. In Kenya, hydroponics farming is male-dominated. Ogam (2016) stated that from 87 respondents, 54 males against 33 females were practicing hydroponics farming in Kajiado County. In an interview of 157 farmers, Njima (2016) reported that 62.7% of them were men and 37% women practicing hydroponic fodder production for dairy cattle in Kiambu sub-county. In Kenya, a higher percentage of men than women who practice hydroponics farming suggests an enthusiasm of men to dive into what is considered a new technology with the pursuit to upscale their income and environmental benefits.

Age is another significant social determinant of income and food production through farming. In the context of urban hydroponics farming, youths are more interested in practicing a new technology, thus sustainable urban income generation and youth employment (Njima, 2016). Empirically, out of 87 hydroponics farmers in Kajiado County in Kenya, Ogam's (2016) study revealed that 17 of them were youth aged 20-29 years and 20 more energetic farmers aged 30-39 years though majority were farmers ranging 40-49 years. Without much disparity, Mugambi (2020) also found out that Meru town hosted 26 young hydroponics farmers aged 18-35 years old despite the fact that the majority of the farmers were aged between 45 and 55 years.

Level of education also influences hydroponics farming practice at different levels and scales. Education enhances farmers' awareness in new farming techniques, and increases their understanding during training and rate of adopting and practicing such technologies. According to Assefa *et al.* (2018), 24.4% of hydroponics fodder growers in Mekele, Gondar and Tachi-Gayint towns of Ethiopia were both college and university graduates. In Kenya, Kibiti (2017) affirmed that 49.3% of hydroponics farmers in Meru town had completed secondary education, while 16.7% and 9% held college and university qualifications, respectively.

2.6 Economic and Environmental Benefits of Hydroponics Farming

2.6.1 Economic Benefits of Hydroponics Farming

Economies of hydroponics farming range from employment to income generation. Full-time employees are needed for technical operations, crop management, and harvesting, among others, in indoor urban vertical farming (IUFV) facilities (Avgoustaki & Xydis, 2020). Goodman & Minner (2019) approximated that 150 people are employed by 6 commercial CEA farms in New York with Gotherm Greens (a hydroponics farm) having 66% of all the employees. In Cairo, implementation of SH farming technologies to the community by *Love in Slum* NGO reduced the cost of purchasing food and created jobs for the slum dwellers (Giro *et al.*, 2016). In Kajiado County of Kenya, Ogam (2016) observed that the number of employees increased from 47% to 51% after establishment of hydroponics fodder farms for dairy production.

Hydroponics farming produce are highly marketable and income generating. In Teresina city of Brazil, FAO's Decentralized Cooperation Project trained 10 groups of mothers (*Clubes de maes*) on simplified hydroponic and they generated income through selling surplus of hydroponically produced vegetables (Fecondini *et al.*, 2009). In Egypt, Cairo's upper and middle classes, foreign tourists, hotels and restaurants increased demand for hydroponics farm produce and the growers could pocket 80 EGP/kg for baby leaf salad, 10EGP/kg of lettuce head, and 70-80 EGP/kg of herbs (Waldhauer & Soethoudt, 2015). In Kenya, Njima (2016) outlined that Kiambu hydroponics fodder farmers increased their access to market, as 87% of them could sell their milk within 2km radius.

Hydroponics farming reduces production costs and increases productivity. This is evident in HTH farms such as Sky Greens (in Singapore city), Brooklyn Grange and Intergrow in New York (Kaufmann, 2018; Goodman & Minner, 2019; Wood *et al.*, 2020). Regionally, Morifi (2017) noted that 44% of hydroponics farmers increased productivity because of their training on hydroponics in South Africa. In Kampala, Uganda, hydroponic barley fodder production cost was UGShs. 900 less than UGShs. 2,180/kg of basal poultry chicken feed (Alinaitwe *et al.*, 2019). In Naivasha, Kenya, Ketter (2015) documented that coco-peat hydroponics roses generated 80,000 Euros more than 40,000 Euros from soil-based ones. This was due to high marketability of high-quality leaves, stem length and weight of hydroponic roses.

2.6.2 Hydroponics Farming and the Urban Environment

Hydroponics farming significantly relates to urban environments. For example, hydroponics farming reduces water consumption and recirculates nutrients thus resulting to zero runoffs. In Cairo, Egypt, Waldhauer & Soethoudt (2015) observed that hydroponics farming addressed water scarcity challenges in the process of food production. A study by Ketter (2015) in Naivasha, Kenya, affirmed that the average daily water intake in hydroponics rose production was 2.41 liters/m^2 (58% water savings/day), less than 5.71 liters/m^2 for soil-based roses. Ogam (2016) elaborates that semi-aridity in Kajiado County limits napier grass growth hence facilitating hydroponic fodder production throughout the year.

Though considered a key factor in urban CEA, energy is still conserved in hydroponics farms, especially in tropical regions. According to Wood *et al.* (2020), Sky Greens hydroponics farm in Singapore city uses sunlight directly, switches off LED lights at daytime, and only consumes 40W of electricity (equivalent to one light bulb) to power a one-9m tall tower of crops. In some sub-Saharan African cities, including Kenya, hydroponics farming demonstrates sustainable harnessing and utilization of renewable energy. According to Mugambi (2020), most hydroponics crops in Meru directly use sunlight, while solar powered for irrigation system. This saves costs of on-grid electricity that would have been used in the entire farming system.

2.7 Constraints of Hydroponics Farming

Urban hydroponics farming undergoes some downsides which could be categorized as financial and social. Financially, HTH farming systems require high start-up costs for installing energy, irrigation systems and other inputs (Romeo *et al.*, 2018; Wood *et al*., 2020). This has been witnessed in Singapore and New York cities. High costs of inputs affected hydroponics farmers of Gondar, Mekele and Tachi-Gayint towns in Ethiopia, who decried of costly barley seeds and nutrient solution going for 12 Birr/kg and 220 Birr/litre, respectively (Assefa *et al.*, 2018). In Kenya, Mugambi (2020) observed that minimal access to financial services by smallholder farmers in Meru town hindered the rate of practicing hydroponics farming. Installing and managing an 8x15m and 8x30m hydroponics farm in Meru cost about Kshs. 812,000 and 1.5 million, respectively.

Socially, inadequate skills to correctly prepare nutrient solutions, measure electrical conductivity, potential hydrogen and general crop management affect SH farmers. It is estimated that about 60% of the hydroponics greenhouse projects in Mexico failed at initial stage because of limited training of growers (Anda & Shear, 2017). Furthermore, hydroponic product consumption in some regions are considered inferior compared to soil-grown food. In Kenya, Njima (2016) observed limited awareness about hydroponics farming among smallholder farmers in Kiambu sub-county, and that hydroponics farming is still a relatively 'new' concept. In Naivasha, Ketter (2015) cited human error in management of hydroponic roses, leading to breakage and rejection of their stems yet stems and flowers are key market qualities for roses.

2.8 Legal Frameworks on Hydroponics Farming in Kenya

Though Nairobi City County through its Agriculture, Livestock and Fisheries docket has developed several urban and peri-urban agriculture promotion strategies, policies and other regulations, minimal and/or no entry points have been established for recognition, promotion and expansion of hydroponics farming, yet agriculture is a devolved functional unit under the county governments. Table 2.1 shows key urban and peri-urban agriculture-related legal frameworks and entry windows for hydroponics farming technology.

Table 2.1: Urban farming Regulations and Hydroponics Farming Technology

Policies and Acts	Tenets	Hydroponics farming entry
The Nairobi City County Urban Agriculture Promotion and Regulation Act of 2015	• Promotion of sustainable urban agriculture in the county • Urban agriculture is practicable in structures such as greenhouse, tool-shades, fish structures, etc. • Adequate funding of agricultural programs by the county government.	• Hydroponics farming aspects of sustainability (circular flow of inputs during crop production cycle, income generation and quality food production). • Need for controlled environment agriculture, greenhouses suit hydroponics farming technology. • County government financial allocation to hydroponics farming would enhance its adoption and practice augmented by non-state organizations roles.
Physical Planning Act, Cap 286	By-laws on urban land use zoning and density of developments.	Hydroponics farming requires limited space (doable on walls), no compromise on other urban development land uses.
The Agriculture Act, Cap 318	Agriculture is practicable on purposefully planned agricultural land defined by a town's boundary.	High urbanization rate and urban densification in Nairobi drastically shrink agricultural land, hydroponics farming remains a viable option.
The Public	The Ministry of Health has mandate	No single urban public health

Health Act, Cap 242	to regulate or forbid unhealthy and unsanitary cultivation/irrigation at intervals within 3 miles of a town's boundary.	nuisance is associated with hydroponics farming. Clean, green and gourmet food are its products.

2.9 Knowledge Gaps from Literature Review

There is no doubt that HTH farming systems blossom in developed regions due to the active role non-state organizations play in promoting the adoption and practice of hydroponics farming technology. However, role of non-state organizations in promoting the adoption and practice of hydroponics farming technology in sub-Saharan African cities, including Nairobi, is little known and documented. The reviewed literature presents information on hydroponic systems and crop varieties, but with limited context-specific data on hydroponics farmers' profile, farm sizes, and quantity of produce, among others. Despite hydroponics farming being capital and technologically intensive, analysis of its potential economic and agro-ecological benefits to urban residents needs to be comprehensively analyzed and understood. Furthermore, constraints of hydroponics farming seem generalized, yet these may vary geographically, including in Nairobi city and its environments. This study intends to provide evidence-based data to fill some of these research gaps on hydroponics farming in urban and per-urban areas of sub-Saharan African cities.

2.10 Theoretical Framework

This study applied the Actor Network Theory (ANT) as applied by Callon (1984). The ANT analyzes human (social entities) – material (technological entities) interconnections to create and maintain networks in which diverse interests are embedded, while in the trajectory of technology transition and adoption. According to Walsham (1997), actors are both human and non-humans that influence/transform others to be dependent, whereas networks comprises activities undertaken by actors which contain their interests. The Actor-Network Theory is relevant to this study because in the context of hydroponics farming, human actors comprise farmers, experts, companies and knowledge institutions, while non-human actors (technological components) are composed of computer system, media, hydroponics facilities and other related physical infrastructure. Human-non-human actor networks thus measure, standardize and bring hydroponic production lines into practicality. This theory had been applied in other research that closely relate to this study. For example, Ogam (2016) adopted the theory to study the determinants of hydroponics technology adoption in the implementation of dairy farming projects in Kajiado, Kenya. Birke & Knierim (2020) also used ANT to study

ICT use in agricultural extension for the establishment of agricultural knowledge centres in South Wollo in Ethiopia.

2.11 Conceptual Framework

The conceptual framework (Figure 2.1) illustrates relationships between variables under this study by bringing the Actor Network Theory into reality. Non-state organizations, and urban and peri-urban farmers problematize potentiality of hydroponics farming technology over open-field (conventional) farming challenges. The non-state organizations that promote hydroponics farming technology build networks, trust in farmers and assemble technological components and advocate for adoption and practice of hydroponics farming technology. Networks create avenues for hydroponics farming training, system installation, and access to inputs as farmers aim at gaining economic and environmental benefits. The non-state organizations and farmers work towards maximizing economic and environmental benefits, while minimizing constraints of hydroponics farming in order to make it a sustainable urban and peri-urban farming system.

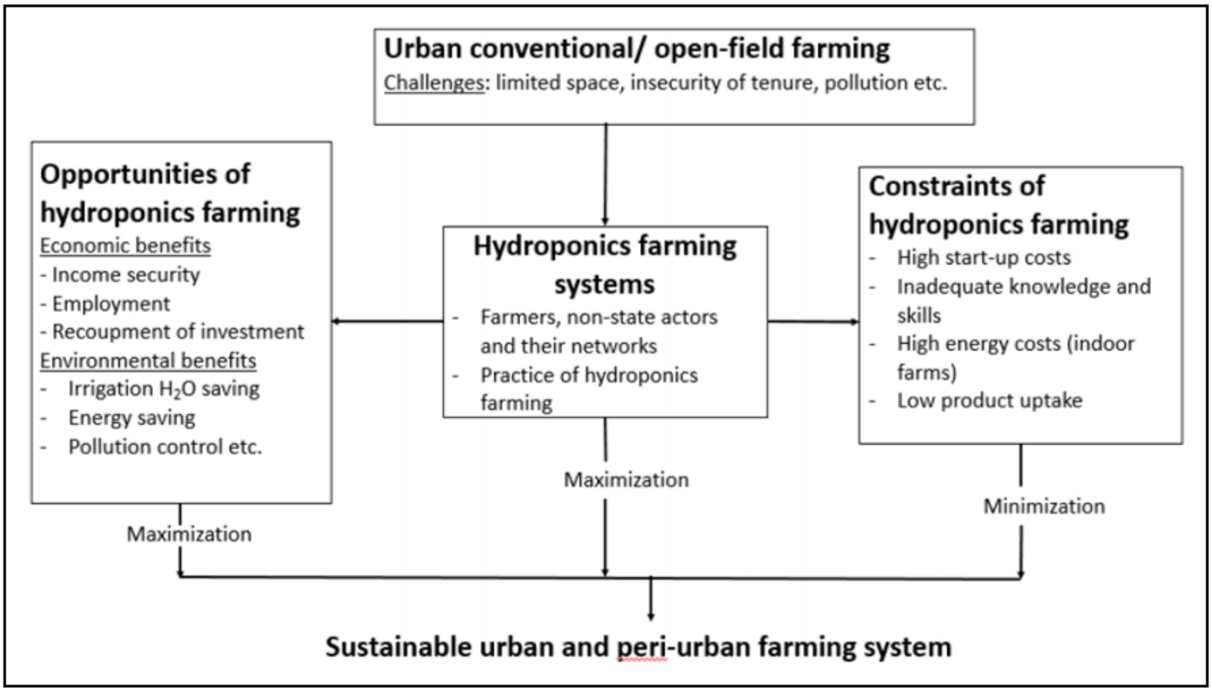

Figure 2.1: Conceptual Framework

Source: Researcher (2022)

CHAPTER THREE
THE STUDY AREA AND RESEARCH METHODOLOGY

3.1 Introduction

The chapter highlights relevant aspects of the study area, as well as the research methodology. In particular, the chapter highlights locational characteristics, physical characteristics, human characteristics, and farming and food system of the study area. On the other hand, the methodological aspects discussed in this chapter are the study design, target population and unit of analysis, sampling procedure and sample size, sources and methods of data collection, data analysis and hypothesis testing, and ethical considerations.

3.2 The Study Area

The study area covers the urban and peri-urban areas of Nairobi City County. This is because some of the hydroponics farmers are located in the peri-urban areas of Kiambu County and Kajiado County that borders Nairobi City County. Given that the focal point is Nairobi city, this section discusses the aspects of Nairobi City County – as the focal study area.

3.2.1 Locational Characteristics

Nairobi City County (Figure 3.1) lies between latitudes 1^0 9'S and 1^0 28'S and longitudes 36^0 4'E and 37^0 10'E and covers an area of 696km^2 (KNBS, 2019). Three counties border Nairobi City County, namely, Kiambu County (North and Northwest), Kajiado County (South and Southwest), and Machakos County (East and Southeast). The margins of these counties contain municipalities and towns such as Thika, Ruiru, Kiambu, Limuru and Kikuyu (in Kiambu County), Mavoko, Kangundo and Machakos (in Machakos County), Olkejuado (in Kajiado County), and some parts of Murang'a County. These form the Nairobi Metropolitan Region which occupy an area of about 3200km^2. The Nairobi City County comprises 11 sub-counties: Dagoretti, Embakasi, Kamukunji, Kasarani, Kibra, Lang'ata, Makadara, Njiru, Mathare, Starehe and Westlands (KNBS, 2019).

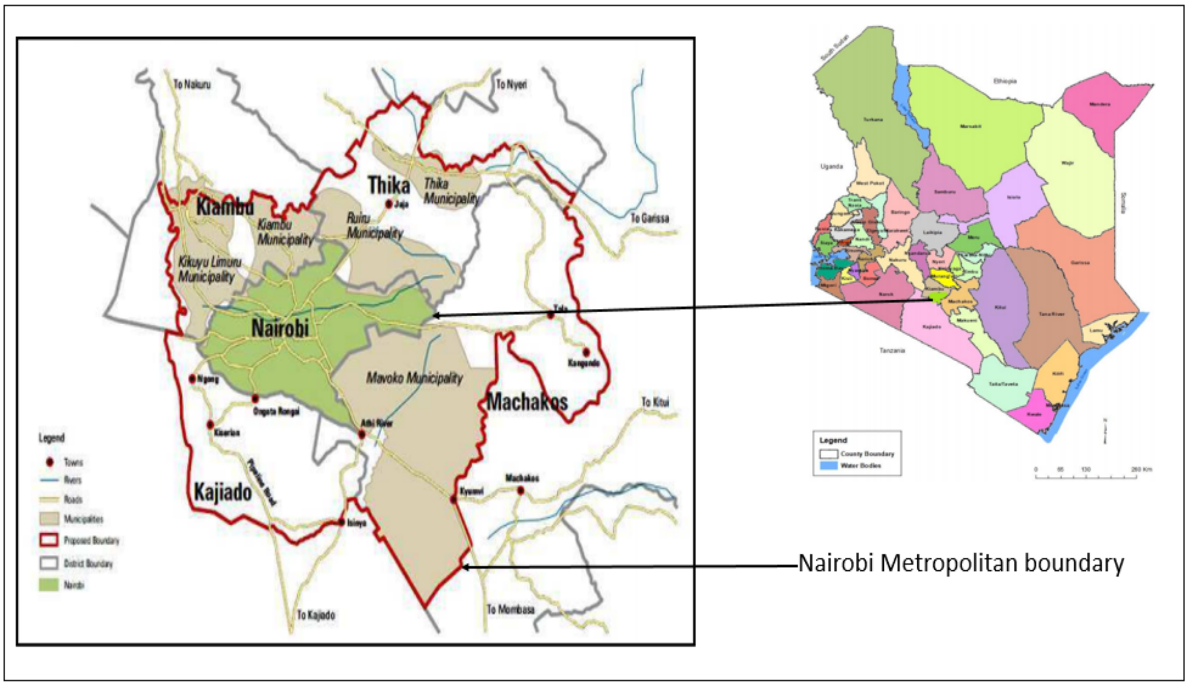

Figure 3.1. The Study Area
Source: Republic of Kenya (2008)

3.2.2 Physical Characteristics

Nairobi City County slopes from the western to the eastern parts (towards Athi River) at about 1460 to 1920m above sea level (JICA, 2014). Three main rivers, Nairobi, Ngong and Mathare, dissect the city while draining from Ngong Hills into Athi River. These rivers cannot support any healthy agriculture because of heavy pollution from residential, commercial and industrial sites. The eastern parts of the city comprise black cotton soil, while red volcanic soil dominates the western part, as impermeable phonolite volcanic rocks cover Nairobi west, south, industrial area and Embakasi regions. In terms of climate, Nairobi city is a sub-tropical highland with dry and cool conditions from June to August, and hot and dry spell in January and March. The city experiences two rainy seasons: long rains (April-May) and short rains (November-December), thus recording an average annual rainfall of between 850 and 1050mm. The mean daily maximum temperature varies between 22 and 28^0 C, whereas the minimum daily temperature ranges from 12 to 14^0 C.

3.2.3 Human Characteristics

Nairobi city experiences high population growth. For example, the population of Nairobi increased from 3.1 million people in 2009 to 4.3 million people in 2019 (KNBS, 2019). The average population density was 6,247 persons/km^2 in 2019, with Embakasi sub-county registering the highest density of 988,808 persons/km^2, while Langata sub-county with 911 persons/km^2. The 2019 Kenya Population and Hosing Census reported a total number of 1.5

million households with an average household size of 2.9 persons (KNBS, 2019). In 2022, Nairobi city population had reached 5.1 million people and the UN World Population Prospects (2023), project it to be 5.7 million in 2025 and 7 million people by 2030. The eastern parts of the city have a number of unplanned settlements triggered by rapid population growth (JICA, 2014). Examples include Mathare, Kibera, Mukuru and Korogocho. These informal settlements are characterized by increasing urban poverty and food and nutrition insecurity.

Formal and informal economy drive the city. Light and heavy industrial and manufacturing activities are concentrated in Nairobi's industrial area, while informal enterprises dominate informal settlements and several residential neighbourhoods. Land use is mainly city-wide residential housing development and other commercial activities (Figure 3.2). Nairobi's attractive physical, social and economic features provide great opportunities for all types of land uses and activities. It also houses three gazetted forests, namely, Karura, Ngong and Arboretum.

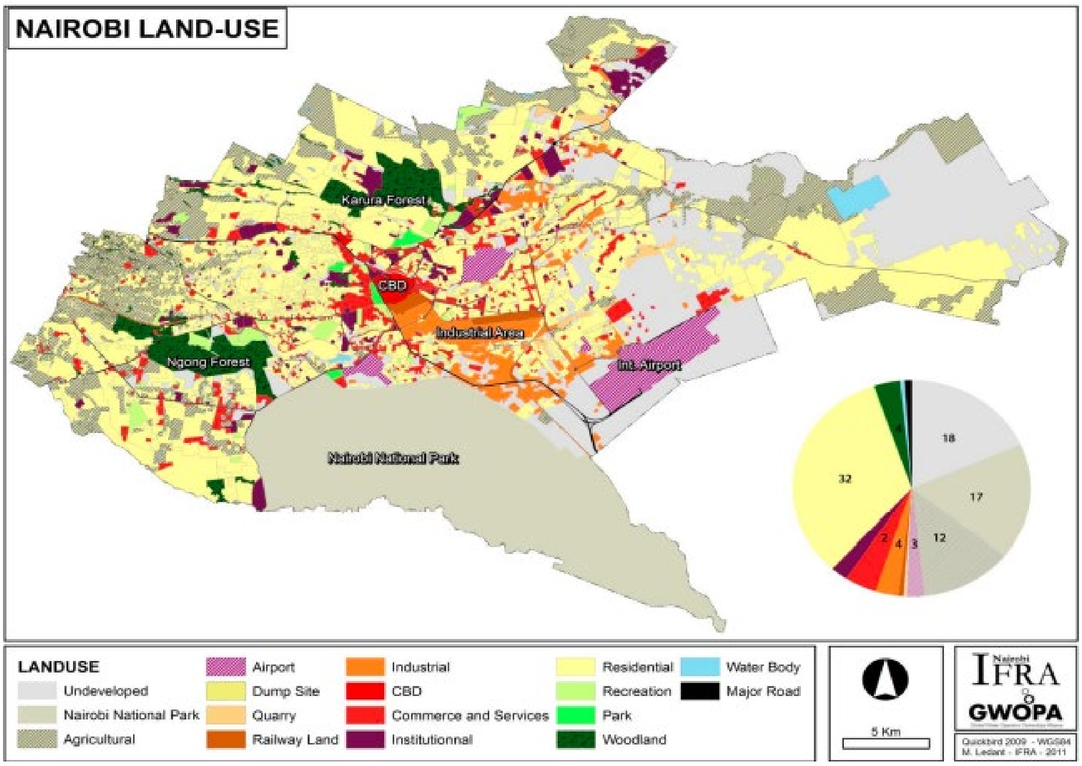

Figure 3.2: Land Use in Nairobi City County
Source: Mbatia (2016)

3.3.3 Farming and Food System in Nairobi

According to the Nairobi City County Annual Development Plan of 2021/2022, Nairobi has a great untapped potential for urban and peri-urban agricultural activities through adoption of modern agricultural technologies that use minimal water, soil and space (Nairobi City County, 2020). It is estimated that Nairobi's agricultural production contributes only 20% of the food consumed in the city, and that the land under crop production is about 751.5 hectares, with an average farm size of 0.0295 hectares (Nairobi City County, 2020). Common crops grown conventionally include vegetables (kales, spinach, *managu*), Irish potato, beans and bananas. Small scale conventional agriculture both on-plot and off-plot is evident in Embakasi, Njiru, Langata, Ruai, Mihango, Karen, Mukuru Kwa Njenga, Kasarani, Kawangware, Pangai, Dagoretti and Kangemi residential neighbourhoods (Nairobi City County, 2002; Kinuthia, 2019).

Despite the fact that there are a number of urban and peri-urban farming activities in the city for subsistence purposes, the main constraints have been the lack of water and space for conventional crop farming. Only 37.5% of agriculture takes place in urban set-ups while 71.8% occurs in peri-urban areas of Nairobi city (Nairobi City County, 2015). This depicts highly shrinking of, and limited access to urban land for farming. Crop production in dumpsites and irrigation using contaminated water (grey water, untreated sewage and industrial effluents loaded with heavy metals), pests and diseases, and weed infestations have also become common problems affecting conventional crop farming in Nairobi City County.

3.3 Research Methodology

3.3.1 Study Design

This study adopted an exploratory research design that seeks to gain more insights of unknown phenomena – possibly for future in-depth investigation. This is because little is known about nature of hydroponics farming technology, role of involved non-state organizations, economic and environmental benefits and constraints in urban and peri-urban areas, especially in sub-Saharan African cities like Nairobi. What is well known and documented is conventional urban and peri-urban crop farming.

3.3.2 Target Population and Unit Analysis

The study target population was urban and peri-urban hydroponics farmers in the urban and peri-urban areas of Nairobi City County. The study defined hydroponics farmers as farmers involved in growing crops with their roots suspended or partially immersed in soil-free nutrient solution under controlled environmental conditions (humidity, temperature, light), pests and diseases, irrigation water, nutrients, potential hydrogen and electrical conductivity (Nerantzis *et al.*, 2018; Wood *et al.*, 2020). As such, the unit of analysis in this study is hydroponics farmers. However, to achieve the second study objective, references are made to non-state organizations who are involved in promoting the adoption and practice of hydroponics farming technology in urban and peri-urban areas of Nairobi.

3.3.3 Sampling Procedure and Sample size

The study used stratified random sampling to determine the hydroponics farmers that were included in the study. The sampling procedure was achieved through three main steps:

- The first step was to determine the non-state organizations that are involved in promoting the adoption and practice of hydroponics farming in Nairobi's urban and peri-urban areas in order to get a list of the hydroponics farmers that they serve or support. Seven non-state organizations were identified, namely, Agrotunnel lnternational in Karen, Ganduer Africa Limited in Kitengela, Miramar International College and KCB Group Foundation, Hydroponics Africa Limited in Zambezi area (near Kinoo in Kiambu), Joe Hydroponics, and Pan African Agribusiness Consortium. These organizations were identified through referrals and initial personal communications for instance with, Hydroponics Africa Limited.
- The second step involved contacting the seven non-state organizations for the lists of hydroponics farmers that they serve or support in Nairobi's urban and peri-urban areas.
- Lastly, a sub-sample of hydroponics farmers was proportionately drawn from each of the seven non-state organizations – based on their list of hydroponics farmers.

Table 3.1 gives a summary of the sampling process. A sample size of 40 was determined largely based on the availability of the farmers and their spatial distribution in Nairobi's urban and peri-urban areas. In addition, available time and resources to conduct the research was also considered. On the other hand, Table 3.2 provides a summary of distribution of sampled hydroponics farmers in urban and peri-urban areas of Nairobi.

Table 3.1: Summary of the Sampling Process

Non-state organizations that promote hydroponics farming	**No. of hydroponics farmers**	**No. of hydroponics farmers selected for the study**
Granduer Africa Limited	30	10
Hydroponics Africa Ltd	26	9
Joe Hydroponics	15	5
Miramar International College and KCB Group Foundation	14	4

Pan-African Agribusiness Consortium	11	4
Agro-tunnel International Limited	24	8
Total	**120**	**40**

Source: Researcher (2022)

Table 3.2: Distribution of Hydroponics Farmers in Urban and Peri-Urban Areas

Area	Number of sampled hydroponics farmers
Urban area in Nairobi	8
Peri-urban area bordering Kiambu County	27
Peri-urban area bordering Kajiado County	5
Total	**40**

Source: Researcher (2022)

3.3.4 Sources and Methods of Data Collection

The study used both primary and secondary sources of data to achieve its objectives. A semi-structured interview schedule was used to collect primary data from hydroponics farmers, while key informant interviews were subjected to the non-state organizations. This was to gain more insights on hydroponics farming in urban and peri-urban areas of Nairobi. In addition, field observation supplemented the collection of primary data. On the other hand, secondary data were sourced through systematic literature review, which involved identification, evaluation and analysis of the reviewed literature.

3.3.5 Data Analysis and Hypothesis Testing

The quantitative data was summarized using frequency distributions and presented in tables and graphs to produce meaningful information relevant to achieving the study objectives. On the other hand, qualitative data was subjected to thematic content analysis. Chi-square test was used to test the study null hypothesis: There is no difference between the type of hydroponics farming technique and income from sale of farm produce. The chi-square test is a test of differences between two categorical variables. It is a non-parametric test of the aggregate difference between observed frequencies and those expected under a null hypothesis. Table 3.3 gives a summary of variables, indicators, data collection and analysis.

Table 3.3 Summary of Variables, Indicators, Data Collection and Analysis

Variables	Indicators	Data collection	Data analysis
Nature of hydroponics farming	• Characteristics of farmers (gender, age, education level, experience) • Farming techniques, crop varieties, farm sizes, farming inputs, and production	Semi-structured questionnaire Field observations	Frequency distributions Content analysis

	• Information acquisition and training, start-up costs, operation and maintenance		
The role of non-state organizations	• Dissemination of information • Training of farmers • Setting-up and installation of hydroponics farms • Access to start-up capital, inputs and market	Semi-structured questionnaire Semi-structured interviews	Frequency distributions Content analysis
Economic benefits	• Sales of produce, income, and employment opportunities	Questionnaire	Frequency distributions
Environmental benefits	• Irrigation water use, energy use, land (space), pollution control	Questionnaire	Frequency distributions
Constraints	• Start-up costs, access to credit, farming skills, products consumption, access to inputs	Questionnaire	Frequency distributions

Source: Researcher (2022)

3.3.6 Ethical Considerations

The respondents' rights to privacy, consent and confidentiality were prioritized, including their approval for audio recording of interviews, and necessary photography. Seeking respondents' consent was meant to set free and open environment for them to participate at their own will in order to provide true information needed. In addition, coded names were adopted for those who preferred sealing of their identity.

A pre-test on data collection was conducted prior to actual fieldwork in order to achieve quality assurance aspects on accuracy and validity of the data collection tool. Pre-testing of the data collection tool was done to check on appropriateness in data collection duration per respondent, consistent flow of questions, clarity and interrelationships of research questions and objectives, adequate capturing of all necessary variables and indicators in each objective, and any other redundancies of research questions in every objective. Any emerging issues on correctness of all data collection tools were adequately addressed before proceeding for data collection.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of data analyzed from the interviews with hydroponics farmers and key informant interviews. They are presented in terms of the study objectives which were to establish the nature of hydroponics farming in urban and peri-urban areas of Nairobi; assess role of non-state organizations in promoting hydroponics farming in urban and peri-urban areas of Nairobi; analyze the economic and environmental benefits of hydroponics farming in urban and peri-urban areas of Nairobi; and determine the constraints of hydroponics farming in urban and peri-urban areas of Nairobi.

4.2 The Nature of Hydroponics Farming in Urban and Peri-Urban Areas of Nairobi

4.2.1 Characteristics of Hydroponics Farmers

Table 4.1 presents a summary of the characteristics of hydroponics farmers in Nairobi's urban and peri-urban areas. Majority (62.5%) of the sampled hydroponics farmers were males, while the rest (37.5%) were females. The dominance of males can be attributed to the fact that hydroponics farming is capital and technologically intensive, with costly installation. According to Ogam (2016) and Njima (2016), who reported similar results, male farmers have high interests in hydroponics farming and quickly venture into new farming technology.

Table 4.1: Characteristics of Hydroponics Farmers

Characteristics	Category	Frequency	Percentage
Gender of farmer (n=40)	Male	25	62.5
	Female	15	37.5
Age of farmer (in years) (n=40)	18-30	15	37.5
	31-42	12	30.0
	43-54	9	22.5
	55+	4	10.0
Education level of farmer (n=40)	Secondary	12	30.0
	College	15	37.5
	University	13	32.5
Duration of hydroponics farming (in years) (n=40)	Less than 1	6	15.0
	1-4	24	60.0
	5-8	10	25.0

Source: Field Survey (2022)

In terms of age, there were more young farmers venturing in hydroponics farming. Those aged between 18 and 30 years old constituted 37.5% of the hydroponics farmers and those aged between 31 and 42 years old constituted 30% of the hydroponics farmers. The older hydroponics famers, aged 55 years old and above, were only 10%. The sampled hydroponics farmers had either attained secondary (30%), college (37.5%) or university (32.5%) levels of education. Previous empirical literature affirms that education enhances farmers' awareness on, and understanding of, new farming techniques. A large majority (60%) of the hydroponics farmers had practiced the farming system for between one to four years. One-quarter (25%) of them had practiced hydroponics farming for between five to eight years, while 15% had practiced the farming system for less than one year. It is deducible that hydroponics farming is still considered a new farming technology in Nairobi's urban and peri-urban areas thus depicted such variations in adoption as influenced by gender, age, education and duration of farming.

4.2.2 Hydroponics Farming Techniques and Crop Varieties

The hydroponics farmers used different hydroponics farming techniques depending on installation costs, crop varieties, and ease of operation and management, among other determinants. Nutrient Film Technique (NFT) or what majority of the farmers and respondents called "A-frame structure", was the most used by 13 of the farmers (Table 4.2). On the other hand, eight farmers used both NFT and Deep Water Culture (DWC) techniques, whilst nine of the farmers used open-plastic trough. Lastly, 10 farmers used a combination of open-trough, vertical shaft and drip irrigation.

Table 4.2 Hydroponics Farming Techniques and Crop Varieties

Technique	Frequency	Percentage	Crop varieties grown
NFT	13	32.5	Leafy vegetables (spinach, coriander, lettuce, and kale)
NFT and DWC	8	20	Leafy vegetables (spinach, lettuce, and kale)
Open-plastic trough	9	22.5	Barley fodder
Open-trough, vertical shaft, and drip irrigation	10	25	Fruit vegetables (tomatoes, pepper, capsicum), and strawberry

Source: Field Survey (2022)

The NFT (Photo 4.1) was the most preferred technique to others because of space maximization; accommodation of several crop varieties vertically and horizontally at the same time; suitability for shallow-rooted and short-cycle plants such as vegetables (lettuce, kale, and spinach); being less labour intensive; and that it could be automated for convenient recirculation and flushing off, of water and nutrient solution. However, clogging of drain pipes and nozzles could lead to plants drying out.

Photo 4.1 Kale and Spinach Production Using NFT
Source: Researcher (2022)

Farmers who used DWC technique (Photo 4.2) mentioned its ease of manual operation and growth of one particular crop (mostly leafy vegetables) in one raft in large numbers. Open-plastic trough was preferred for its suitability to grow hydroponic fodder; ease of misty irrigation; and ease of operation and management, even though plastic troughs are more expensive, costing Kshs. 2,000 each, compared to metal ones. One of the key informants explained that metal troughs encourage growth of moulds and production of aflatoxin, which are hazardous for livestock consumption in the feed.

Photo 4.2 Spinach Production Using DWC
Source: Researcher (2022)

Lastly, a combination of open-trough, vertical shaft and drip irrigation technique was preferred because of their suitability for production of fruit vegetables such as tomatoes, which require constant moisture and stem stability.

Photo 4.3 Production of Onions Using Vertical Shaft
Source: Researcher (2022)

The management of these hydroponics farming techniques tend to be general and similar in nature, as most of the responses mentioned routine crop monitoring involving observation of leaf physiology to detect any pest and disease attack or nutrient deficiency. In addition, some of the farmers stated that they feed and irrigate the crops on daily basis, as well as pruning certain crops such as kale. One of the farmers explained that:

> "I do daily checking of the crops, nutrient feeding, and irrigation throughout the growth period to prevent any loss. After every 3 or 4 days, nutrient solution is flushed out. That does not mean pouring it out, instead it is recycled with a newly prepared one, being added to prevent build-up of calcium around plant roots".

4.2.3 Hydroponics Farm Sizes

Hydroponics farmers use varying farm sizes in accordance with one's set installation capital, construction materials, inputs, choice, and preference of crops grown. About half of the farmers indicated that they used a plot of about 8x10m in hydroponics farming. Another one-quarter of the farmers used smaller plots measuring about 6x10m. On the other hand, another one-quarter of the farmers had relatively larger plots of about 8x24m. Notably, some of these farms were greenhouse-based, with some constructed using nets and greenhouse anti-UV polythene, depending on the farmer's financial capability. However, it was complex to quantify the size of hydroponic fodder farmers as the respective farmers based their responses on the number of open-plastic troughs or trays stacked, and not the area they covered.

4.2.4 Hydroponics Farming Inputs

There were two categories of hydroponics farming inputs: installation inputs and plant growth inputs. Installation inputs included Electric Conductivity Meter and PH Meter, electricity, motor, water tanks, PVC pipes, nets of preferred gauges, translucent and anti-ultra-violet ray polythene, steel rods, polythene paper, and ground wooden chips or sawdust. On the other hand, the plant growth inputs included plant net cups/holding cups, substrate (growth media), purified/distilled irrigation water, and nutrient solutions.

The common substrate used by most of the farmers were coco-peat and pumice because of their high-water retention capacity, affordability at relatively low costs, durability, and recyclability for several crop seasons. However, different crops require certain types of nutrients. The most commonly used nutrient solutions by most of the farmers were NPK-Nitrogen, Phosphorus and Potassium (Solution A); and CAN-Calcium and Ammonium Nitrate or urea solution (Solution B). One of the respondents explained that:

> "After every 3 or 4 days, nutrient solution A is flushed out and nutrient solution B is added for the plants. The flushed solution is re-circulated such that nothing is discarded till crops mature and get harvested. The flushing process occurs again after 3 or 4 days for solution B, and the whole process continues up to crop maturity".

4.2.5 Hydroponics Farming Production

Quantity of production in hydroponics farming is dependent on the production scales due to intensive stacking of crops vertically and laterally, effective application of all required nutrients, irrigation, control of pests and diseases, and sunlight intensity. However, the type of hydroponics farming technique determines the choice of crops grown and intended purposes of growing them. The following presents examples of hydroponics farming production for selected crops, using different farming techniques:

- An average farm size of 8x24m yields about 600-700kg of lettuce per harvest, after about 2 months, grown using NFT. The lettuce farmers mentioned that one can harvest their lettuce twice or thrice a week.
- The kale and spinach farmers noted that they harvest about 20-30kg of kale and spinach on an average farm-size of 6x10m or 8x10m, after three weeks, using both NFT and DWC.
- For the hydroponic fodder producers, 2kg of barley sprouted for 7 days, yielded them 15kg of fodder for two dairy cattle, and when harvested after 4 or 5 days, this could feed 200 chicken. Additionally, 3 trays of barley could produce 24-30 kg of fodder, enough to supplement chicken feed for 800 birds.
- Furthermore, farmers who use a combination of open-trough, vertical shaft, and drip irrigation outlined that their technique yielded about 460kg of fruit vegetables such as tomatoes, capsicum (red, green, and yellow varieties) and onions.

Based on the above findings on production quantities, it is arguable that different hydroponics farming techniques were applied to grow different crops. Therefore, comparison of their productivity considers the type of crops grown, variations in farm sizes, levels of operation and management of the farms and weights of each type of crops. For instance, weight of tomatoes, capsicums or onions yielded from open-trough, vertical shaft and drip irrigation system could not be equivalent to that of barely fodder sprouted in open-trough using misty irrigation or lettuce, spinach and kales produced in NFT or DWC techniques. It was not the type of hydroponics farming technology that determines production quantities rather, the degree of farm operation and management, including correctness in farm set up, installation of techniques and crop input applications.

4.3 The Role of Non-State Organizations in Promoting Hydroponics Farming in Urban and Peri-Urban Areas of Nairobi

Non-state organizations such as Granduer Africa Limited, Hydroponics Africa Limited, Joe Hydroponics, Miramar International College and KCB Group Foundation, Pan-African Agribusiness Consortium, Agro-Tunnel International Limited, Komb Green Solutions, Greenlife Veggies Hydroponics, and Vertical Gardens Hydroponics, play an important role in promoting hydroponics farming in Nairobi's urban and peri-urban areas. Interviews with farmers discerned four important roles. These are dissemination of information on hydroponics farming; training of hydroponics farmers; setting-up and installation of hydroponics farms; and facilitation of farmers' access to start-up capital, inputs and markets.

4.3.1 Dissemination of Information on Hydroponics Farming

Half of the hydroponics farmers (52.2%) stated that they get information about hydroponics farming and techniques through non-state organizations that support hydroponics farming (Figure 4.1). The other sources of information include through social media (YouTube, Facebook), used by 15% of the farmers; through mainstream media like TV, radio and newspapers (10%); through referrals from fellow farmers, friends and relatives (10%); and through internet searching and platforms (2.5%). The information was largely on farming techniques and their advantages and disadvantages, installation, inputs, and markets.

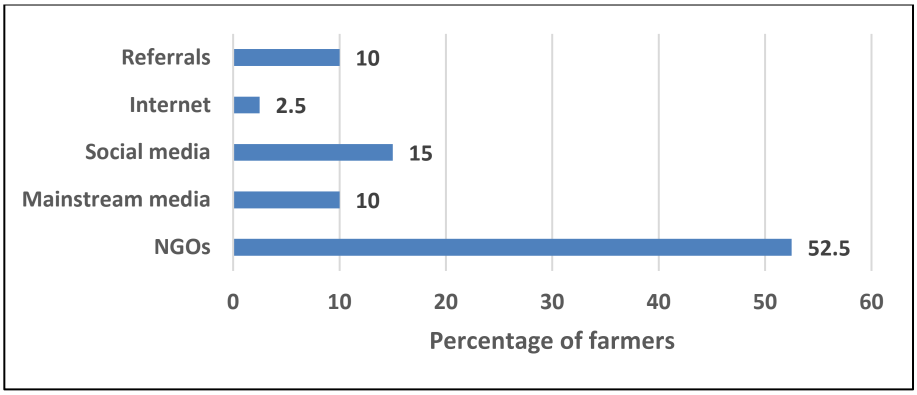

Figure 4.1 Sources of Hydroponics Farming Information
Source: Field Survey (2022)

Though least used, internet is an important source of information for some of the hydroponics farmers. Internet sources contain audio-visual files, photos, and reading materials on hydroponics farming. For example, one of the farmers remarked that:

> "I first saw about hydroponics farming posted on Facebook by a certain organization then I decided to Google about it, visited YouTube for more information, then I made an appointment and visited the organization to see it myself on the ground".

However, the hydroponics farmers are also visited by some of these non-state organizations as one of the key informants explained:

> "Once I have a record of hydroponics farmers, as a hydroponic fodder farming organization and consultant, I contact them and share knowledge of hydroponic fodder production, especially for chicken and dairy farmers. Upon mutual agreement, I have a call-center model through which we share more about other practical aspects of hydroponics farming".

The higher percentage of interviewed farmers (52.5%) that received information on hydroponics farming from non-state organizations suggests reliable and accurate information compared to those obtained from other sources such as social media or internet. This does not mean other sources were inadequate with information on hydroponics farming technology, non-state organizations offered practical or in-the site hydroponics demonstration farms for farmers who physically visited them. This was more of primary information which superseded secondary information from the rest of sources.

4.3.2 Training of Hydroponics Farmers

Following access to information on hydroponics farming, (prospective) farmers strive to gain practical training, knowledge and skills on its practice. Most of the hydroponics farmers in Nairobi's urban and peri-urban areas have been trained by one of the following non-state organizations: Granduer Africa Limited, Hydroponics Africa Limited, Joe Hydroponics, Miramar International College and KCB Group Foundation, Pan-African Agribusiness Consortium, Agro-Tunnel International Limited, Komb Green Solutions, Greenlife Veggies Hydroponics, and Vertical Gardens Hydroponics. These training are complimented by occasional workshops, seminars, and farm visits. Even though the training duration varied from one organization to the other, there was no significant divergence in the lessons learned. Generally, the trainings revolved around farming techniques; farm installation, operations and management; crop nutrients, substrate and physiology; and crop routine management practices, among others.

4.3.3 Setting-Up and Installation of Hydroponics Farms

In addition to training the farmers on hydroponics farming, non-state organizations also engage in setting-up for them hydroponics farms. Three-quarters (75%) of the sampled hydroponics farmers had their hydroponics farm systems installed by these non-state organizations, some of them at an agreed affordable cost. One quarter (25%) installed their farms on their own, having obtained adequate installation skills from training. Hydroponics system installation is very expensive, a probable reason that could have resulted to the larger percentage seeking such service from non-state organizations.

4.3.4 Facilitation of Farmers' Access to Start-Up Capital, Inputs and Markets

The network between hydroponics farmers and the non-state organizations extends to facilitating farmers' access to startup capital, inputs for production, and markets for the products. Notably, financial investment in hydroponics farming is a key determinant of other factors in crop production, a justification for 47.5% of the sampled hydroponics farmers who got loans and credit facilities through networking with relevant non-state organizations (Figure 4.2). Such funds were accessed from banks and other financial institutions in collaboration with hydroponics farming non-state organizations. One of the farmers explained that:

> "In 2017/2018, Miramar International College partnered with KCB Foundation to loan groups of trained hydroponics farmers, including ours within and around Nairobi. We were required to register our farming business, find some space and commit ourselves".

Other sources of start-up capital include own savings, used by 32.5% of the hydroponics farmers to establish simplified hydroponic farms then later expanded them for commercial production; SACCOs and cooperatives (7.5%); grants (7.5%); and farmers group contribution (5%). A study by Mugambi (2020) observed that credit institutions such as banks, merry-go-rounds, savings and credit cooperative organizations provide farmers with loans and credits to start up hydroponics farming. This is one of the avenues which non-state organizations explored to help farmers navigate strict terms and conditions associated with loans and credit facilities and repayment mechanisms of such loans.

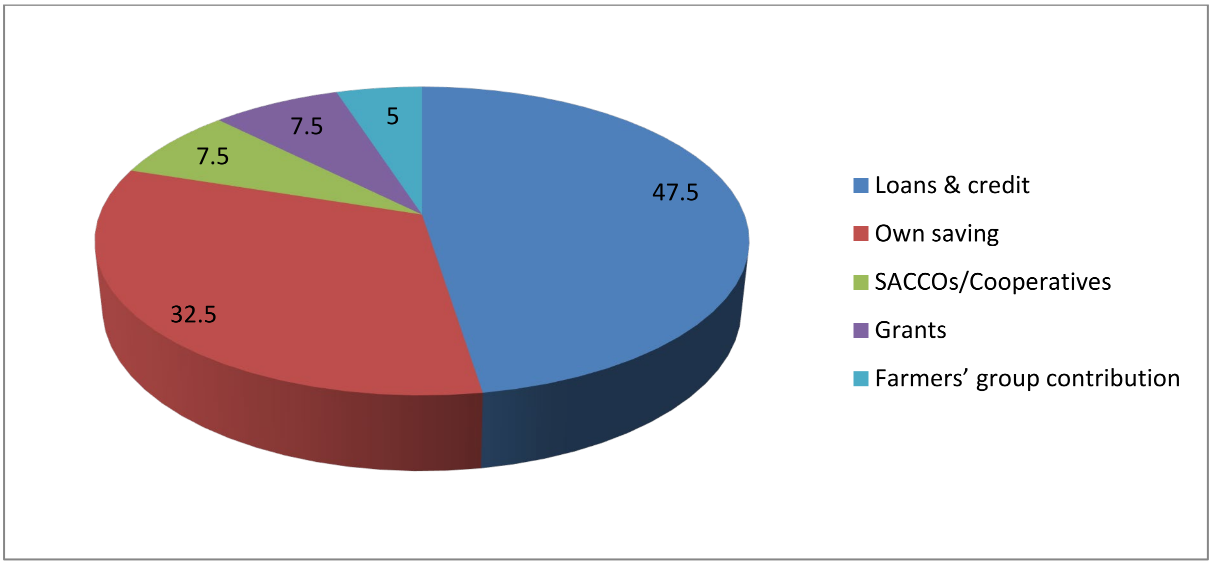

Figure 4.2 Sources of Hydroponics Farming Start-Up Capital

Source: Field Survey (2022)

The choice of crop inputs such as nutrient solutions, substrate (growth media) and electrical conductivity meter lies with the farmers. However, access to these products is manageable via relations with non-state organizations, especially for the starters.

> "Hydroponics farming organizations are aware of the sources of these things (inputs), so I order cocoa peat from the Coast through them. This helped me when starting this system, but nowadays I just order directly on my own".

> "My visit to Grandeur Africa Limited enabled me get sources of NPK and CAN nutrient solutions for my vegetables. I just simply order them. Substrate is not a big problem, pumice is readily available".

> "Obtaining seedlings or seeds becomes much easier through these hydroponics farming organizations. Some of them sell to us at subsidized costs thus reducing even time to look for them elsewhere".

In addition, these non-state organizations play a vital role in identifying market sources for the new hydroponics farmers. According to one of the key informant interviews, the non-state organizations "look for market and inform farmers about such before encouraging them to invest in installation of the farming system". Another interview conducted with Agro-Tunnel International, a hydroponics fodder farming company in Karen, Nairobi, revealed that there is ready market in Karen and other parts of the city for milk and chicken produced through hydroponics fodder production.

4.4 Economic and Environmental Benefits of Hydroponics Farming in Urban and Peri-Urban Areas of Nairobi

4.4.1 Economic Benefits

The main economic benefits of hydroponics farming were reduced production costs, generation of income and creation of employment. Although it is costly to install hydroponics farms, 35% of the hydroponics farmers mentioned that they experienced reduced production costs over time, especially in terms of frequency of expenditure on crop production inputs. According to one of the key informant interviews, 8 to 10kg of fodder sprouting within 7 days is producible at Kshs. 12.5/kg, an amount that is far much less than what could have been spent on conventional farming of barley fodder of the same kilograms. Some of the farmer's experiences include:

> "It costs me Kshs. 450 to substitute processed chicken feed with hydroponic fodder. This amount is less than about Kshs. 800 that could have taken me to feed 100 chicken yet each one of them consumes almost 140g/day of feeds".

> "We only heavily incur the cost of installation, but once the system is put in place no frequent purchase of other nutrient solution, substrate and even water. Almost everything is recycled, including nutrients".

> "This net (walling of the farm) prevents many pests and insects that may be flying around and getting to the farm. It is like that of greenhouse. The farming system is also soilless, no soil-born pests and diseases, thus no need of budgeting for pesticides".

Hydroponics farming is geared towards income generation. The hydroponics farmers earned different amounts of income from sales of their produce. Most of the farmers sold their produce to high-end hotels and restaurants in Westlands and Karen, as well as to some supermarkets, open-air markets, and schools within Nairobi. The hydroponics farmers who used NFT generated an average income of Kshs. 259,600 after three consecutive seasons of growing leafy vegetables, which were being harvested after 2-3 months.

> "I found out that iceberg lettuce is weighty. 1kg could go for Kshs. 330 at ABC Place in Westlands and in my first harvest, I got about 700kg of lettuce from 8x24m hydroponic greenhouse farm".

The hydroponics farmers who used NFT and DWC generated an average income of Kshs.149,000 after selling leafy vegetables produced after similar period as that of purely NFT farmers. Fruit vegetables grown by hydroponics farmers through open-trough, vertical shaft and drip irrigation system earned them a mean income of Kshs.160,000, after two successive growing periods of about 3 months.

Though hydroponics fodder producers emphasized on the number of trays or troughs of mature fodder, the hydroponics fodder producers earned the highest average income of Kshs. 500,000 in one season, compared to those producing food crops hydroponically. Most of the hydroponics fodder producers kept chicken and/or dairy cattle - a justification for the farmers recording a higher value of sales from chicken and milk.

> "I personally produce barley using open-plastic troughs, which do not rust. Within 7 days they are mature, but I do harvest fodder on the fourth day to feed my one, two and two and a half day old chicks, and those harvested on day seven are fed to old chicken. My customers are some hotels here in Kitengela, whom I sell to them slaughtered chicken. Every part (organ) are sold separately at a given price. A whole chick can generate over Kshs. 1,000".

> "Milk is ever in demand in this area (Limuru) and in a day after feeding two dairy cattle with hydroponic barley fodder, about 22 and 25 liters are collected. I sell the milk via our cooperative, which distributes to Kinoo, Uthiru and even to Westlands. The price of milk varies with supply, sometimes a liter goes for Kshs.170 to Kshs. 220".

Though the study did not access book keeping records on hydroponics farming expenditure and profit to scrutinize and determine net-income (profitability) and return on investment, all the 40 interviewed hydroponics farmers stated that they got profit and amount of finance they spent on setting up and installing hydroponics farms despite such amounts being highly costly. Profit was mentioned to have been earned after full crop growth cycles, that is from first to the last harvests in leafy vegetables (spinach, coriander, lettuce and kale), a single harvest for barley fodder and periodical harvests from fruit vegetables (tomatoes, capsicums, peppers and onions).

Hydroponics farming is also a source of employment, especially to the workers and farm hands. Specialized hired workers were hired for installation purposes and training. On the other hand, farm hands were performing day-to-day farm activities such as monitoring of crops. In addition, some farmers hired farm managers, as well as security guards.

4.4.2 Environmental Benefits

One-third (35%) of the farmers mentioned that hydroponics farming uses relatively less water for irrigation purposes (Figure 4.3). The water for irrigation is sourced from boreholes and also from public piped water connection (from the county governments). However, some of the farmers have 2000-liter water tanks to run about 192m^2 hydroponics greenhouse farms. On average, about 1000 liters of water is used per day (morning, midday and evening), for about one month, during dry months, to irrigate crops and prepare nutrient solution. Hydroponic fodder production saves much more water because of misty irrigation (small and pressurized water molecules) – in comparison to spray, sprinkler or drip irrigation. One of the farmers explained that 2 liters of water is enough for sprouting 4 trays of fodder within a week.

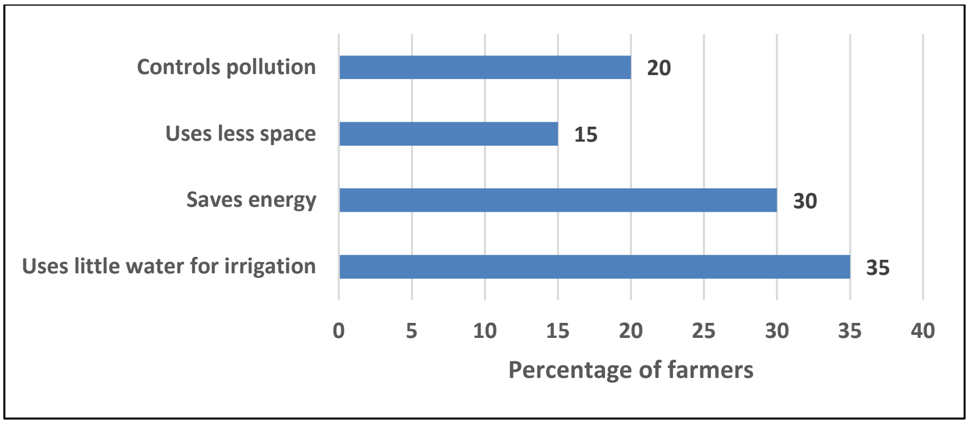

Figure 4.3 Environmental Benefits of Hydroponics Farming
Source: Field Survey (2022)

Water quality is an important element for the farmers. Regardless of water source, the farmers have to ensure that the water is clean in terms of the recommended electric conductivity (EC) and PH in order to help determine chemical compounds before preparing nutrient solutions for the plants. One of the key informants explained that:

> "Irrigation water for hydroponics farming should be clean, purified or distilled. Chemical compounds in water can raise or lower the PH of the nutrient solution. City county water contains chlorine, which needs careful measurement of PH. Saline water also has to be desalinated. Dirty water or wastewater may carry pathogens, which cause diseases to plants, hence has to be purified first".

Though energy use has been an impediment in hydroponics farming, 30% of the hydroponics farmers in urban and peri-urban areas of Nairobi noted that hydroponics farming saves energy. They explained that crops utilize sunlight, while installed electricity only runs the irrigation system and pumping of the nutrient solution. The major source of energy is electricity of whose stability varied from one area to another. Some of the farmers hinted at installing solar power for steady operation of irrigation and nutrient supply system. Even then, most of the farmers indicated that the cost of electricity was not very experience. They explained that they spend, on average, about Kshs. 400-600 per month, to prepay metered electricity tokens.

Unlike conventional production of vegetables and fodder, which require sizable piece of arable and fertile land, hydroponics farming maximizes the use of limited space. For example, a 6x10m (60m^2) plot can accommodate several vertically and horizontally layered varieties of leafy vegetables. Fifteen percent of the farmers noted that hydroponics farming utilizes less land space for crop production, and that it reduces crop growth cycle by almost half since it is soilless (land fertility is a non-issue). However, the cost of rental land for larger commercial hydroponics farming is what affects some farmers in Nairobi, a reason for some of them planning to relocate to far peri-urban areas of Nairobi.

Lastly, pollution of rivers and underground water sources is prevented by hydroponics farming. Although only 20% of the farmers noted that hydroponics farming controls pollution, there is no doubt that in hydroponics farming both irrigation water and nutrient solution are recycled right from planting to harvesting of the crops. Furthermore, no discarding of nutrient solution interferes with aquatic life in water ecosystems – compared to conventional farming.

4.5 Constraints of Hydroponics Farming in Urban and Peri-Urban Areas of Nairobi

The study results bring out four categories of constraints to hydroponics farming. These are financial constraints, operational and management constraints, physical and environmental constraints, and technical constraints (Figure 4.4). Financial constraint is a major issue to more than half (55%) of the hydroponics farmers. The financial challenges were specifically in terms of the initial cost in installing the hydroponics farm and the high costs of purchasing inputs such as nutrient solution, water tank, greenhouse, net, PVC pipes, and electric conductivity (EC) meter, among others.

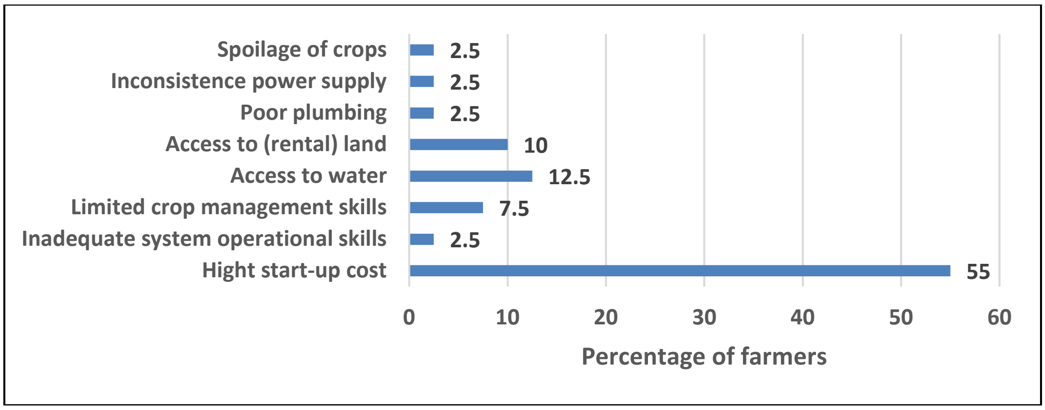

Figure 4.4 Constraints of Hydroponics Farming
Source: Field Survey (2022)

Some of the farmers reported that it costs an average of Kshs. 850,000 to set up an 8x24m greenhouse hydroponics farm. Depending on the size of the farm and the technique used, the cheapest hydroponics farm could cost between Kshs. 15,000 and 25,000. In addition, at the time of study, it cost about Kshs. 35,000 to 40,000 to acquire an electric conductivity (EC) meter used for measuring electrical conductivity of nutrient solution. Empirically, Wood et *al*. (2020) and Mugambi (2020) confirmed high startup capital as a bottleneck to establish hydroponics farms in Singapore and Kenyan urban centres, respectively. However, as earlier noted in section 4.3 (role of non-state organizations), 47.5% of interviewed hydroponics farmers emphasized their networking with such organizations as one of the strategies to mitigate challenges of initial startup costs by acquiring loans and credits from financial institutions. The rest 53.5% explored other ways such as own savings, SACCOs and cooperatives, grants and farmers' group contribution.

The operational and management constraints were mentioned by 10% of the hydroponics farmers. Specifically, these constraints were inadequate system operational skills and limited crop management skills. For example, some of the farmers could not determine whether vegetable leaf colorization is a problem of sunlight intensity, pest and disease infestation, nutrient solution deficiency, or concentration conditions. Less than one-quarter of the farmers (22.5%) had experienced physical and environmental constraints in terms of access to water and access to (rental) land for hydroponics farming. Lack of enough water reduces operation of the farms since irrigation and nutrient solution preparation became ineffective. One of farmers explained about the land constraints:

> Nairobi is already congested with high cost of less available land. We cannot enlarge this farm for intensive production. In fact, we are considering a plan to relocate to Kitengela where land could be easily affordable compared to this place.

Lastly, 7.5% of the hydroponics farming mentioned that they experienced technical constraints such as poor plumbing, inconsistent power supply, and spoilage of crops. Wrong plumbing could lead to leakage of irrigation water and nutrient solution from taps or drip pipes. Power outage sometimes hinder flow of water and nutrient solution to plants, thus causing them to dry. Improper handling of crops during routine growth monitoring and harvesting could result to some breakages or spoilage. However, some farmers still managed to sell the broken plants to adjacent livestock keepers. Issues of poor plumbing were quickly addressed to avoid long time interruption with irrigation water and nutrient flow to crops. Some of the hydroponics farmers at the time of this study were considering installing solar panels as second alternative to solve power blackouts.

4.6 Hypothesis Testing

The study's null hypothesis was: There was no difference between the type of hydroponics farming technique and income from sale of farm produce. The chi-square test was applied to test this null hypothesis by cross-tabulating two variables: (1) on the type of hydroponics farming technique; and (2) on the income after the sale of farm produce. Based on the results presented in Table 4.3, the p-value of .545 is greater than the chosen significance level (α = 0.05). As such there was no enough evidence to reject the null hypothesis. Regardless of any type of hydroponics farming technique applied, all the hydroponics farmers affirmed earning income from sale of farm produce. This was determined by factors such as crop varieties grown (marketability), production quantities, farm size variations, level of farm operation and management among others.

Table 4.3 Chi-Square Test Results

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.852[a]	1	.356		
Continuity Correction[b]	.366	1	.545		
Likelihood Ratio	.854	1	.355		
Fisher's Exact Test				.525	.273
Linear-by-Linear Association	.830	1	.362		
N of Valid Cases	40				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.55.
b. Computed only for a 2x2 table

Source: Data Analysis (2023)

CHAPTER 5
SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

5.1.1 The Nature of Hydroponics Farming

Hydroponics farming in urban and peri-urban areas of Nairobi is dominated by more males than females. This is largely because hydroponics farming is both capital and technologically intensive and expensive, drawing in men's income desire and control over resources to invest in it. Majority of the farmers are youthful, aged 42 years and below, and are more likely to be enthusiastic in venturing into new farming technologies and agribusinesses. All the hydroponics farmers had attained secondary education and above, with about one-third of them having university level of education. The experience in hydroponics farming varied, with a majority of them having practiced hydroponics farming for one to four years, although there were others who had ventured into the practice for five to eight years.

The farmers use different types of hydroponics farming techniques, namely, Nutrient Film Technique (NFT), Deep Water Culture (DWC) technique, open-plastic trough, and vertical shaft techniques. However, most of the farmers prefer NFT and open-trough techniques for ease of operation and intensification of shallow-rooted and short-cycle crops. The farm sizes varied depending on the type of hydroponics farming technique and crops grown. The crops grown included leafy vegetables (using NFT), fruit vegetables (using DWC), and barley fodder (using open-plastic trough). Subsequently, the use of inputs and production scale varied from one hydroponics farming technique to the other. Furthermore, the type of hydroponics farming technique determines the choice of crops grown and intended purposes of growing them.

5.1.2 The Role of Non-State Organizations in Promoting Hydroponics Farming

There are a number of non-state organizations that promote hydroponics farming in the urban and peri-urban areas of Nairobi. These are Granduer Africa Limited, Hydroponics Africa Limited, Joe Hydroponics, Miramar International College and KCB Group Foundation, Pan-African Agribusiness Consortium, Agro-Tunnel International Limited, Komb Green Solutions, Greenlife Veggies Hydroponics, and Vertical Gardens Hydroponics. They ensure the uptake of hydroponics farming technology, training of farmers, dissemination of information on hydroponics farming, setting-up of the farms, provision of inputs, linking farmers with markets, including facilitating farmers' access to start-up capital and inputs.

5.1.3 Economic and Environmental Benefits of Hydroponics Farming

Hydroponics farming can lead to economic and environmental benefits not only to the farmer, but also to the community and to the nation where the farming technology is practiced. Economically, several farmers identified reduced production costs, increased income from sales of produce and creation of job opportunities. Environmentally, hydroponics farming reduces the amount of irrigation water and farming space. With all the explored farms being outdoor, crops were growing using sunlight, while electricity was limitedly used to operate irrigation systems. Re-circulation of nutrients also prevented pollution of adjacent ecosystems.

5.1.4 Constraints of Hydroponics Farming

Hydroponics farmers face a number of financial, operational and management, physical and environmental, and technical constraints. The farming technology has very high (initial) start-up and installation costs. Operational and management constraints revolve around inadequate system operational skills and limited crop management skills. Physical and environmental constraints were in terms of access to water and access to (rental) land for hydroponics farming, while technical constraints constituted poor plumbing, inconsistent power supply, and spoilage of crops.

5.2 Conclusion

Despite being an old soilless farming in the developed regions, hydroponics farming in urban and peri-urban areas of Nairobi is still considered 'a new technology' which many farmers have not yet adopted. However, with the role of non-state organizations in promoting hydroponics farming, its practice will spread beyond Nairobi city urban peripheries. Though costly to install, hydroponics farming is economically and environmentally beneficial to both farmers and non-farmer residents in and around Nairobi. High income generation, job opportunities, water and energy saving, and environmental pollution control, are some of the essentially sustainable benefits cascading from hydroponics farming. Therefore, with minimization of its constraints, maximization of the related potential benefits, as well as involvement of non-state organizations in collaboration with the state actors, hydroponics farming technology would be one of the sustainable urban and peri-urban farming practices.

5.3 Recommendations

5.3.1 Policy Recommendations

1. The Ministry of Agriculture (National and County levels), urban farming policymakers and relevant knowledge institutions should facilitate state and non-state actors' partnership for promotion of urban and peri-urban hydroponics farming. This might enhance provision of certain incentives or subsidies to hydroponics farmers and also reduce tax for operation of hydroponics farming non-state organizations.
2. Hydroponics farming non-state organizations, in collaboration with financial institutions, should enhance group farming in the poor urban and peri-urban neighborhoods to maximize potential economic and environmental benefits of hydroponics farming. Examples can be drawn from Olympics secondary school in Kibra and in Korogocho A Village.

5.3.2 Research Recommendations

1. Further empirical research on diversification in hydroponics farming. For instance, cultivation of medicinal plants alongside food crops or integration of poultry with hydroponics fodder production. Diversification in hydroponics farming could be a key to increased economic resilience and market opportunities. More circular food production system is possible, for example, keeping poultry that feeds on hydroponics fodder such as barley while obtaining back dissolved solution from their remains as manure to grown other hydroponics leafy vegetables.
2. Need for practical cost-benefit analysis of varieties of crops vis-à-vis hydroponics farming techniques. Different crop varieties attract different market prices assuming all conditions of high quality including correct packaging and handling are constant. Cost-benefit analysis would provide farmers with primary knowledge on which crop variety to venture into, with regard to suitable hydroponics technique, installation costs, inputs, operation and management and available market.

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APPENDIX

INTERVIEW GUIDE FOR HYDROPONICS FARMERS

SECTION A: Preliminary Information

Date and time of interview	
Hydroponics farmer's personal characteristics	
Name	
Gender	Male [] Female []
Age	18-30 [] 31-42 [] 43-54 [] 55+ []
Education level	
Area of hydroponic farming	

SECTION B: ROLE OF NGOs IN PROMOTING HYDROPONICS FARMING

1 How did you know about hydroponics farming?

2 a) Any training on hydroponics farming? Who trainers were? Training duration?

b) Lessons gained from hydroponics farming training

3 a) Connection with any hydroponics farming organization

b) Hydroponics farming benefits obtained from such organization

SECTION C: ADOPTION AND PRACTICE OF HYDROPONICS FARMING

1 Source and approximate amount of your income

2 Do you farm as an individual, household family, company or community group?

3 a) How long have you been doing hydroponics farming?

b) Motivation to grow crops hydroponically?

4 a) Hydroponics systems used? System advantages? Crops grown?

b) Inputs? Their sources?

5 a) Management and operation of hydroponics farm?

b) Approximate area of the plot (in m, acres, hectares) under crop cultivation?

c) How long do crops take to be harvested? Approximate amount of yield per harvest?

SECTION D: ECONOMIC AND ENVIRONMENTAL BENEFITS OF URBAN HYDROPONICS FARMING

SECTION D (I): Economic Benefits

1 What do you do with the hydroponics produce?

2. If selling the produce, who are your customers?

3a) What approximate total hydroponics produce sold? At what estimate price?

b) Frequency of selling the hydroponics produce?

4 People employment in hydroponics farm? Number? Their roles?

<u>SECTION D (II): Hydroponics farming and urban environment</u>

1a) Type of irrigation water?

b) Frequency of water use for irrigation and preparation of nutrient solution? Water quantity used?

c) Irrigation water re-collection and re-use

2.a) Do you change fertilizers/nutrient solutions that plant use? Why? After how long?

b) Use of the changed nutrient solutions?

3 Electricity quantity used in hydroponic farm per month? Monthly cost?

4 Hydroponics farming products disposed after use? Disposal method?

<u>SECTION E: CONSTRAINTS OF HYDROPONICS FARMING</u>

1Approximate total start-up cost for hydroponics farming?

2 a) How did you obtain funds to start up hydroponics farming?

b) If loan/credit what were requirements? Duration to obtain it?

3. Any problem while acquiring information, skills in hydroponics farming?

4 a) Any customers' complaints on hydroponic products?

b) Other hydroponics farming problems?

c) Management of such problems?

KEY INFORMANTS' INTERVIEW GUIDE

Introduction to the research problem, confidentiality and compliance with other key research ethics including request for recording responses when necessary.

Date and time of Interview

Mode of Interview:

<u>KII Code 001</u>

Part 1: Role of non-state actors in hydroponics farming

Promotion of adoption and practice of hydroponics farming

- Information dissemination
- Means of accessing farmers
- Training of farmers
- Setting up of hydroponics farms
- Facilitation of access to start-up capital

- Input access
- Market access
- Mitigation of hydroponics challenges to farmers

<u>Part 2: Practice of Hydroponics Farming in and around Nairobi city</u>

- Most preferable crops grown and reason why?
- Common hydroponic farming technologies applied
- Setting up hydroponics farms for farmers
- Farmers' access to hydroponics facilities, seedlings/seeds and fertilizers etc.
- Cost of seedlings/seed, nutrient solution and other inputs

<u>Part 3: Economic and Urban Environmental benefits of hydroponics farming</u>

3.a) Economic benefits

1. Hydroponics farmers' income
- Quantity of produce
- Sales of produce
- Frequency of sales
- Approximate sales income
- Diversification in hydroponics farming
2. Market access for farmers' hydroponics produce
- Major Market sources
- Pricing of the produce
- Long/short term realization of return of investment (ROI) for commercial hydroponics farmers
3. Employment
- Specific employment areas in hydroponics farms and/or facilities
- Requirement for employment
- Approximate number of urban residents already absorbed by some hydroponics farms

3.b) Urban environmental benefits

1. Water use- type of waters used, access, amount and re-use
2. Energy: type, access, quantity and cost
3. Water and nutrient recycling
4. Solid waste material re-use in hydroponics

<u>Part 4: Constraints of Hydroponics Farming</u>

1. Farmers' challenges in access to startup costs
- Procedures followed in acquiring capital

- Loan interest charged

2. Access to hydroponics facilities and other inputs

- Physical access in relation to farm sites
- Affordability of the facilities and other inputs by different farmers

3. Pushbacks in knowledge and skills acquisition by the farmers
4. Marketing challenges