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Assessment Of Vertical Farming and Hydroponics as Sustainable Solutions to Urban Food Production in Cross River State, Nigeria

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Abstract

Urbanisation has led to increased pressure on food systems due to limited land, high food costs, and dependence on rural food supply. This study examined the application of vertical farming and hydroponics as sustainable solutions for food production in urban contexts. The study explored the potential benefits, challenges of adoption, global best practices, and the policy and educational implications of these technologies. Findings revealed that vertical farming and hydroponics enable efficient use of space, water conservation, year-round crop production, and reduced transportation costs. These systems can be applied in households, schools, markets, and commercial centres to improve food security and create employment opportunities. However, high capital cost, energy requirements, and lack of technical knowledge remain major barriers to adoption. Global experiences from countries such as Singapore, the Netherlands, the United States, and Japan show that government support, research, and public-private partnerships are critical for success. The study concluded that with appropriate policies, funding, and education, vertical farming and hydroponics can contribute significantly to sustainable urban food production and resilient city food systems.

Keywords: Vertical Farming, Hydroponics, Urban Agriculture, Food Security & Sustainable Development

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I. INTRODUCTION

Urbanisation is one of the most significant demographic shifts of the 21st century. According to the United Nations (2022), over 56% of the world's population currently lives in urban areas, and this number is expected to reach 68% by 2050. In Africa, and particularly in Nigeria, urbanisation is occurring at a very rapid pace. The World Bank (2023) reports that Nigeria's urban population is growing at an estimated rate of 4.3% per year due to rural-urban migration, natural population growth, and the pursuit of better economic opportunities. This rapid urban expansion has placed immense pressure on land, housing, infrastructure, and food systems in Nigerian cities.

In Cross River State, the capital city Calabar has witnessed substantial urban growth over the last two decades. The increasing demand for residential, commercial, and industrial land has significantly reduced the availability of arable land within and around the city (Okon & Bassey, 2021). Traditional agriculture, which depends on large tracts of land and fertile soil, is becoming increasingly impractical in such urban environments. At the same time, the demand for fresh, affordable, and nutritious food continues to rise as the urban population grows. This creates a serious challenge for food security and sustainable urban development.

Food insecurity in Nigerian cities is further compounded by inefficiencies in the food supply chain. The Food and Agriculture Organization [FAO] (2021) notes that urban households in low-income countries often spend more than half of their income on food, yet still struggle to access adequate nutrition. In Nigeria, most of the food consumed in cities is transported from rural areas over long distances. This results in high transportation costs, post-harvest losses, and price volatility (Adebayo & Adeola, 2020). The disruptions caused by the COVID-19 pandemic also revealed how vulnerable urban food systems are to shocks, as lockdowns and movement restrictions led to food shortages and increased hunger in many urban centers (Olaoye et al., 2022).

Given these challenges, there is a growing need to explore alternative models of food production that are suitable for urban areas. The concept of urban agriculture has been widely promoted as a strategy for improving food access, creating employment, and promoting environmental sustainability in cities (Mougeot, 2021). However, conventional urban farming is limited by the same constraints of land scarcity, poor soil quality, and limited water resources. This has led to increased interest in technology-driven agricultural systems that can produce more food using fewer resources and less space.

Among these alternatives, vertical farming and hydroponics have gained global attention as sustainable solutions for urban food production. Vertical farming involves growing crops in vertically stacked layers within controlled indoor environments. This approach maximises the use of space by producing high yields per square meter and utilizes artificial lighting, climate control, and automation to optimize plant growth (Despommier, 2020). Hydroponics is a soil-less method of cultivation in which plants are grown in a nutrient-rich water solution. The plants are supported by inert materials such as gravel, coco peat, or rockwool, and nutrients are delivered directly to the roots (Resh, 2021). When combined, vertical hydroponic systems allow for intensive food production in warehouses, rooftops, and other spaces where traditional farming is not possible.

Globally, many cities have already adopted these systems to address land constraints and ensure a stable food supply. Countries such as Singapore, the Netherlands, Japan, and the United States have invested heavily in vertical farms to produce leafy greens, herbs, and fruits year-round (Al-Kodmany, 2021). Research indicates that hydroponic systems can conserve up to 90% of water compared to conventional farming because water is recirculated within a closed system rather than being lost to evaporation or runoff (Barbosa et al., 2020). In addition, because environmental conditions are fully controlled, vertical farms can achieve 10 to 20 times higher productivity per unit area and are not affected by seasonal changes or adverse weather (Benke & Tomkins, 2021).

In Africa, some countries, including Kenya, South Africa, and Egypt have started pilot projects using hydroponics and vertical farming to improve urban food security (UNEP, 2022). However, in Nigeria, and specifically in Cross River State, the adoption of these technologies is still at a very early stage. Most discussions around agriculture in the state continue to focus on traditional, soil-based farming. There is limited research and policy attention on how vertical farming and hydroponics can be adapted to the Nigerian urban context. This gap is particularly important given the challenges of land scarcity and food insecurity in Calabar and other urban areas in the state.

The problem is further compounded by the nature of agricultural education in Nigeria. Technical and vocational education institutions still emphasise conventional farming practices and have not fully integrated modern agricultural technologies into their curriculum (Nwafor & Okoro, 2020). As a result, graduates lack the skills and knowledge needed to operate and manage innovative urban farming systems. Without deliberate policy support and educational reforms, it will be difficult to scale these technologies and realise their potential benefits.

Therefore, this study seeks to conceptually assess vertical farming and hydroponics as sustainable solutions to urban food production in Cross River State, Nigeria. Using a literature review and conceptual approach, the paper examines the principles, benefits, and challenges of these systems. It draws on global best practices, sustainability theory, and reports from agricultural and urban planning agencies to provide insights that are relevant to the Nigerian context. The goal is to establish a conceptual basis for understanding how these systems can contribute to food security, environmental sustainability, and green urban development in Cross River State.

II. CONCEPTUAL CLARIFICATION

Urbanisation is the process through which people move from rural communities into towns and cities, and through which cities expand in size, population, and economic activities. It is not just about population growth. It also involves changes in how people live, work, and use land and resources (United Nations, 2022). In most developing countries, urbanisation is happening rapidly and often without adequate planning. Nigeria is a clear example. The World Bank (2023) estimates that Nigeria's urban population is growing at more than 4% per year. People move to cities in search of employment, better schools, healthcare, and other social amenities that are often lacking in rural areas.

The effects of urbanisation are visible in every major Nigerian city. In Cross River State, Calabar has grown beyond its original boundaries. Areas that were once farmlands and forests on the outskirts of the city have now become residential estates, markets, and industrial zones. This expansion reduces the amount of land available for agriculture within and around the city (Okon & Bassey, 2021). At the same time, the demand for food, water, housing, and transportation increases sharply. City planners and policymakers are therefore faced with the challenge of feeding a growing population with fewer local resources.

One of the most pressing consequences of rapid urbanisation is pressure on the food system. Most of the food consumed in Calabar today comes from rural areas in Cross River State and neighbouring states. These foods travel long distances by road before reaching urban markets. The journey increases costs, causes spoilage, and makes prices unstable (Adebayo & Adeola, 2020). When there are fuel shortages, bad roads, or security issues, food supply to the city is disrupted. The COVID-19 lockdowns showed how fragile this system is. With movement restricted, many urban households struggled to access basic food items (Olaoye et al., 2022).

Urbanisation also changes consumption patterns. As incomes rise in cities, people tend to demand more fresh vegetables, fruits, and protein. But the capacity to produce these within the city is limited. Traditional urban agriculture, such as backyard gardens and open-space farming, cannot meet the demand because land is now expensive and scarce. In addition, urban soils are often polluted by waste, construction, and chemicals, making them unsafe for food production. Given these realities, urbanization in Cross River State creates both a problem and an opportunity. The problem is food insecurity and dependence on external supply. The opportunity is the need to rethink how food is produced in cities. This is why alternative systems like vertical farming and hydroponics are being considered. They are designed specifically for environments where land is limited but demand is high. Therefore, understanding urbanization is the first step in understanding why new models of urban food production are necessary in Calabar and other urban centers in the state.

2.2 Urban Food Production

Urban food production refers to all activities involved in growing, processing, and distributing food within cities and their immediate surroundings (Mougeot, 2021). The goal is to make food more available to urban residents while reducing dependence on long supply chains. Urban food production is not new. For decades, people in Nigerian cities have engaged in small-scale farming. Common practices include growing vegetables in backyards, rearing poultry in compounds, and cultivating crops on undeveloped plots.

The importance of urban food production has increased in recent years because of rising food prices and concerns about food security. The Food and Agriculture Organization [FAO] (2021) states that urban households in low-income countries spend a large portion of their income on food. When food is produced closer to where people live, transportation costs are reduced, and fresh produce can reach consumers faster. This also reduces post-harvest losses, which are a major problem in Nigeria's food system.

In Cross River State, urban food production is still largely informal and small-scale. Many residents grow leafy vegetables, pepper, and cassava in available spaces. Some schools and institutions also have small gardens. However, these efforts face several limitations. First, land is scarce. As Calabar expands, open spaces are quickly taken over by buildings. Second, water for irrigation is often inadequate, especially during the dry season. Third, urban soils are not always suitable due to contamination. Fourth, pests and diseases are more common in densely populated areas. Because of these challenges, there is a need to move beyond traditional methods and adopt technologies that can produce more food in less space. This is where vertical farming and hydroponics become relevant.

Urban food production in the 21st century must be able to function without large tracts of land and without depending on soil quality. It must also be able to operate year-round, regardless of weather. Urban food production also has social and economic benefits. It can create jobs for young people, provide fresh and affordable food, and improve nutrition in urban households. It can also contribute to environmental goals by reducing the distance food travels and by greening the city (FAO, 2021). For Cross River State, promoting urban food production is consistent with the state's goals of sustainable development and food security. But to achieve this, the state must embrace new approaches that fit the urban context. Vertical farming and hydroponics represent such approaches because they are designed to work in limited spaces and with efficient use of water and nutrients.

2.3 Vertical Farming

Vertical farming is the practice of growing crops in stacked layers inside a building or other enclosed structure (Despommier, 2020). The idea is simple: instead of spreading crops horizontally across a field, grow them vertically. This allows a large volume of food to be produced in a small footprint. A single room with 5 or 6 growing tiers can produce as much as several acres of farmland.

The main feature of vertical farming is environmental control. Light, temperature, humidity, and carbon dioxide levels are all regulated. Many vertical farms use LED grow lights to provide the exact light spectrum that plants need. Irrigation systems deliver water and nutrients directly to the plants. Because the environment is controlled, crops can be grown throughout the year without being affected by rain, drought, or pests (Benke & Tomkins, 2021). This is a major advantage in a place like Calabar, where rainfall is heavy for part of the year and dry for another part.

Vertical farms are suitable for crops with short growing cycles and high value per unit area. Leafy greens such as lettuce, spinach, and fluted pumpkin leaves do well. Herbs such as basil and scent leaf are also common. Fruits like strawberries and tomatoes can be grown, though they require more energy. The produce from vertical farms is usually clean, pesticide-free, and ready for market quickly because there is no need for long transport.

In Cross River State, vertical farming offers several possibilities. First, it can help address land scarcity in Calabar. Food can be produced in warehouses, on rooftops, or in unused buildings within the city. Second, it can improve food security by providing a steady supply of fresh vegetables. Third, it can create new types of jobs in areas such as farm management, engineering, and marketing. Fourth, it can reduce the environmental impact of food production by using less water and less land (Despommier, 2020). However, vertical farming also has requirements. It needs reliable electricity, technical knowledge, and initial investment in infrastructure. These are challenges that must be addressed through policy and education. Despite these challenges, vertical farming is increasingly seen as a viable option for cities that cannot expand outward. As urbanisation continues in Cross River State, vertical farming may become an important part of the local food system.

2.4 Hydroponics

Hydroponics is a method of growing plants without soil. Instead, plants are grown in a nutrient-rich water solution (Resh, 2021). The roots of the plants are either suspended in the water or supported by an inert medium such as coco peat, gravel, or rockwool. The nutrient solution contains all the essential elements that plants need to grow: nitrogen, phosphorus, potassium, and micronutrients. There are different types of hydroponic systems. In the Nutrient Film Technique, a thin film of nutrient solution flows over the roots. In Deep Water Culture, the roots are submerged in oxygenated nutrient solution. In drip systems, the solution is delivered to each plant through tubes. All these systems share one feature: water is recirculated. This makes hydroponics very water-efficient. Research shows that hydroponics can use up to 90% less water than soil-based farming because water is not lost to runoff or deep percolation (Barbosa et al., 2020).

Another advantage of hydroponics is that it does not require fertile soil. This is important in urban areas where good soil is scarce or contaminated. Hydroponic units can be set up on rooftops, in greenhouses, or inside buildings. They can also be used in areas with poor drainage or rocky ground. Because nutrients are delivered directly to the plant, growth is often faster and yields are higher compared to traditional farming.

In Cross River State, hydroponics can be used to produce vegetables and herbs for the urban market. It is particularly useful for crops that are in high demand but expensive to import. A small hydroponic unit can supply a household or a restaurant with fresh produce throughout the year. Larger units can supply markets and institutions (Al-Kodmany, 2021). Hydroponics also fits well with the concept of sustainability. By using less water and less land, it reduces pressure on natural resources. By growing food in the city, it reduces transportation and packaging. However, hydroponics requires knowledge of nutrient management, pH control, and system maintenance. Farmers and students need to be trained in these skills. There is also the cost of setting up the system and the need for reliable power to run pumps and controls.

Despite these challenges, hydroponics is a practical technology for urban food production. When combined with vertical structures, it becomes vertical hydroponics, which maximises both space and resource efficiency. For Cross River State, promoting hydroponics can be a step toward a more resilient and productive urban food system.

2.5 Sustainability

Sustainability in agriculture means producing food in a way that meets present needs without damaging the environment or depleting resources needed by future generations (WCED, 1987). The concept became popular after the 1987 Brundtland Report and has since guided policies in agriculture, energy, and urban planning. In the context of food production, sustainability has three dimensions: environmental, economic, and social. Environmentally, sustainable agriculture conserves water, protects soil, reduces chemical use, and lowers greenhouse gas emissions. Economically, it is profitable and provides livelihoods. Socially, it ensures food security and equity (FAO, 2021).

Vertical farming and hydroponics contribute to sustainability in several ways. They use significantly less water than conventional farming because water is recirculated (Barbosa et al., 2020). They use less land because crops are grown vertically. They reduce the need for pesticides because the controlled environment limits pests. They also reduce food miles because production can take place within the city, cutting transport emissions and spoilage. I the context of For Cross River State, sustainability is faced by of deforestation, flooding, and land degradation. At the same time, the population is growing and food demand is rising. Relying solely on conventional agriculture will put more pressure on land and water resources. Adopting sustainable urban food systems can help balance these pressures.

Sustainability also has an educational dimension. For new technologies to succeed, people must understand them. Technical and vocational schools in Cross River State need to include training on vertical farming and hydroponics in their curriculum. This will equip graduates with skills for modern agriculture and entrepreneurship (Federal Ministry of Education, 2020).

III. MEANING AND PRINCIPLES OF VERTICAL FARMING AND HYDROPONICS

3.1 Meaning of Vertical Farming

According to Despommier (2020), vertical farming is the practice of growing crops in vertically stacked layers within a controlled indoor environment. The main idea is to build farms upward instead of outward. This can be done in warehouses, shipping containers, greenhouses, or multi-story buildings. The concept emerged because cities are running out of farmland. As (Benke & Tomkins,

2021) explain, urban areas have limited, expensive land, so producing food vertically allows for much higher yields per square meter. Crops are arranged on racks or shelves, and each layer receives regulated light, water, and nutrients. Vertical farming is most suitable for fast-growing crops. Leafy vegetables such as lettuce, spinach, fluted pumpkin, and herbs like scent leaf and basil are commonly grown. Because the environment is controlled, these crops can be harvested multiple times a year, unlike seasonal field farming. In Cross River State, where urbanization is reducing available farmland in Calabar, vertical farming provides an alternative way to produce food within the city instead of depending entirely on rural supply (Okon & Bassey, 2021).

3.2 Principles of Vertical Farming

i. Vertical farming operates on specific principles that distinguish it from traditional agriculture.
ii. Space Optimisation: Despommier (2020) identifies space efficiency as the core principle. By stacking crops, a small floor area can produce the output of several acres. For example, a 10m x 10m room with 6 tiers has 600m² of growing area. This principle is critical for cities like Calabar where land is scarce.
iii. Environmental Control: As noted by Al-Kodmany (2021), all growing conditions in vertical farms are regulated. Temperature, humidity, CO2, and lighting are managed using sensors and automation. LED lights provide the exact wavelengths plants need. Because the system is enclosed, crops are shielded from pests, rain, and extreme weather. This allows continuous production throughout the year.
iv. Efficient Resource Use: Water and nutrients are used sparingly. (Barbosa et al., 2020) found that recirculating irrigation systems in vertical farms can reduce water use by up to 90% compared to soil farming. Fertilizers are delivered in precise doses directly to plant roots, which minimises waste and environmental pollution.
v. Proximity to Consumers: Mougeot (2021) emphasises that urban agriculture should be located close to consumers. Vertical farms sited within Calabar can supply fresh produce daily, reducing transport costs, spoilage, and carbon emissions. It also creates jobs in processing, marketing, and farm management.5. Technology and Automation: According to Benke & Tomkins (2021), vertical farming is knowledge- and technology-driven. Sensors monitor plant health, automated systems handle planting and harvesting, and data is used to improve yields. This makes it different from labour-intensive traditional farming.

3.3 Meaning of Hydroponics

Resh (2021) defines hydroponics as a soil-less method of growing plants in which nutrients are supplied through a water solution. The term comes from Greek words meaning "water" and "to work." In this system, soil is replaced by inert media such as coco peat, gravel, or rockwool that hold the plant upright. The plant roots absorb nutrients directly from the water. Because nutrients are delivered in available form, plants often grow faster than in soil. There are several hydroponic designs in use today. (Al-Kodmany, 2021) lists the most common as Nutrient Film Technique, Deep Water Culture, and Drip systems. Hydroponics is already used in Kenya, South Africa, and Egypt for urban vegetable production (UNEP, 2022), and it can be adapted for use in Cross River State.

3.4 Principles of Hydroponics

The operation of hydroponics is guided by the following principles:

1. Soil-less Growth Medium: The first principle, as stated by Resh (2021), is that plants do not require soil. They only need water, nutrients, oxygen, and physical support. This makes hydroponics ideal for urban areas with poor or contaminated soil.2. Nutrient Solution Management

According to Barbosa et al. (2020), the nutrient solution must contain all essential elements in the correct proportions. The pH is usually maintained between 5.5 and 6.5 for optimal uptake. The solution is recirculated to conserve both water and fertilizer.

3. Oxygen Supply to Roots: Resh (2021) explains that roots must receive oxygen to prevent rot. This is done using air pumps or by designing systems that allow roots to be intermittently exposed to air. Proper aeration is critical for plant health.
5. Control of Growing Conditions: As Benke & Tomkins (2021) point out, hydroponics works best when combined with environmental control. Regulated light, temperature, and humidity lead to faster growth, higher yields, and more predictable harvests

IV. APPLICATION OF VERTICAL FARMING AND HYDROPONICS IN URBAN CONTEXTS

Vertical farming and hydroponics are modern approaches to food production that are well suited for urban areas where land is limited. According to Despommier (2020), vertical farming involves growing crops in stacked layers within controlled environments. Resh (2021) also defined hydroponics as a soil-less method where plants receive nutrients through water. When combined, these systems allow for high food output in small urban spaces.

In cities, these technologies can be applied in several ways. According to Benke and Tomkins (2021), households can use small hydroponic units on rooftops and in compounds to grow vegetables for home consumption. Nwafor and Okoro (2020) noted that schools and institutions can establish demonstration farms to produce food and train students in modern agriculture. Al-Kodmany (2021) further stated that commercial farms can be set up close to markets to supply fresh produce daily and reduce transportation costs and spoilage.

One major advantage of applying these systems in urban areas is efficient use of resources. According to Barbosa et al. (2020), hydroponics uses up to 90% less water than traditional soil farming because water is recirculated. Despommier (2020) explained that vertical farming also maximises space by growing upward instead of outward, making it possible to produce more food on limited land. In addition, the FAO (2021) reported that because production occurs close to consumers, food reaches the market fresher and with less waste.

However, there are challenges to adoption. Benke and Tomkins (2021) identified the high initial cost of setting up vertical farms and hydroponic systems as a major barrier. The World Bank (2023) also pointed out that controlled environment systems require constant electricity, which is a challenge in many cities. Resh (2021) added that many urban residents lack the technical knowledge needed to manage nutrient solutions and controlled environments.

To ensure successful application, training and capacity building are essential (Nwafor & Okoro, 2020). According to UNEP (2022), governments and private organizations should collaborate to provide funding and incentives for urban farmers. The World Bank (2023) further suggested that the use of renewable energy such as solar power can help address electricity challenges.

V. POTENTIAL BENEFITS

One of the major benefits of vertical farming and hydroponics in urban areas is efficient use of space. According to Despommier (2020), vertical farming allows crops to be grown in stacked layers within buildings, which increases food production per square meter of land. This is particularly important in cities where land is scarce and expensive. By building upward instead of outward, urban areas can produce large quantities of food without clearing more land.

Another key benefit is water conservation. According to Barbosa et al. (2020), hydroponic systems use up to 90% less water than traditional soil farming because water and nutrients are recirculated in a closed system. This makes the technology suitable for cities where water supply may be limited or expensive. The reduced water use also helps to minimise environmental impact.

Vertical farming and hydroponics also support year-round food production. The FAO (2021) reported that because these systems operate in controlled environments, crops can be grown irrespective of season or weather conditions. This ensures a consistent supply of fresh vegetables in urban markets and reduces dependence on food transported from rural areas.

In addition, locating food production within cities helps to reduce transportation costs and food waste.

Al-Kodmany (2021) stated that when farms are close to consumers, produce reaches the market faster and in better condition. This improves food quality and reduces post-harvest losses that often occur during long-distance transportation. There are also social and economic benefits. According to Nwafor and Okoro (2020), the adoption of these technologies can create jobs in areas such as system installation, farm management, and marketing. It also provides opportunities for training youths and urban residents in modern agricultural skills, which can improve livelihoods in cities.

Finally, vertical farming and hydroponics contribute to environmental sustainability. Resh (2021) noted that because the growing environment is controlled, there is less need for pesticides and chemical fertilizers. The systems also conserve land and reduce pressure on forests and farmlands around urban centers.

VI. CHALLENGES OF ADOPTION

One of the most significant challenges to the adoption of vertical farming and hydroponics in urban areas is the high capital cost required for establishment. According to Benke and Tomkins (2021), vertical farming involves substantial investment in infrastructure, technology, and equipment before any production can begin. Unlike traditional farming that mainly requires land, seeds, and basic tools, vertical and hydroponic systems depend on structures, lighting, irrigation, climate control, and monitoring systems. The cost of setting up a vertical farm begins with the physical structure.

According to Despommier (2020), even a small-scale vertical farm requires a building or retrofitted facility that can support multiple growing tiers. In urban areas, real estate is expensive, and renting or purchasing warehouse space in city centers adds to the initial cost. For cities with limited vacant buildings, new construction may be necessary, which further increases capital requirements. Lighting is another major cost component. Because vertical farms operate indoors, they rely heavily on artificial lighting, specifically LED grow lights, to provide the light spectrum needed for plant growth.

Resh (2021) explained that LED systems must run for 12 to 18 hours daily to support plant photosynthesis. The cost of purchasing high-quality LED panels, as well as the electrical wiring and installation, represents a significant portion of startup expenses. For a medium-scale facility, lighting alone can account for 30% to 40% of the total capital investment.

The hydroponic system itself also requires investment. According to Barbosa et al. (2020), a functional hydroponic setup includes water tanks, pumps, pipes, nutrient reservoirs, grow trays, and inert growing media such as coco peat or rockwool. Automated systems that regulate pH, nutrient concentration, and water flow add to the cost but are necessary to ensure efficiency and reduce labor. For commercial operations, these systems must be durable and scalable, which means higher quality and higher price.

Climate control equipment is equally essential. Vertical farms must maintain specific temperature, humidity, and CO_2 levels to optimize plant growth. The World Bank (2023) noted that in tropical urban areas, cooling and ventilation systems are required to manage heat and humidity. Dehumidifiers, fans, HVAC systems, and sensors all contribute to the capital cost. Without proper climate control, crop failure is likely, making this investment unavoidable.

Another cost driver is energy. According to the World Bank (2023), electricity is needed not only for lighting but also for running pumps, climate control, and monitoring systems. In many developing countries, including Nigeria, power supply is unreliable, so investors must also budget for generators or solar power systems as backup. The cost of installing solar panels and batteries adds significantly to the initial capital outlay, even though it may reduce operating costs in the long term.The issue of high capital cost is more pronounced for small-scale urban farmers and households. Benke and Tomkins (2021) stated that most low-income urban residents cannot afford to set up even a basic hydroponic unit without external support. A simple home hydroponic kit may cost several hundred dollars, while a commercial vertical farm can run into hundreds of thousands of dollars. This creates a barrier that limits adoption to large investors, institutions, or well-funded organisations.

Access to credit is also a challenge. According to Okon and Bassey (2021), financial institutions in many developing countries are reluctant to lend for agricultural technologies they are not familiar with. Banks often view vertical farming and hydroponics as risky ventures because they are new and require specialised knowledge. High interest rates and stringent collateral requirements make it difficult for entrepreneurs to secure loans. Without affordable financing, many potential adopters are unable to raise the funds needed. The high cost also affects maintenance and replacement of equipment. Resh (2021) explained that pumps, sensors, and LED lights have a limited lifespan and must be replaced periodically. Nutrient solutions and growing media also require regular replenishment. For farmers who struggle to recover the initial investment, these recurring costs can make the system unsustainable.

Despite the benefits, the high capital requirement means that adoption is slow. The FAO (2021) reported that in many urban areas, governments and NGOs have had to intervene by providing subsidies, grants, or demonstration projects to help farmers get started. Public-private partnerships have also been suggested as a way to share the financial burden (UNEP, 2022). Without such support, vertical farming and hydroponics remain out of reach for most urban residents.

In the context of developing countries, the capital cost challenge is compounded by other factors such as inflation and import duties. Much of the equipment used in vertical and hydroponic systems is imported. According to the World Bank (2023), import taxes and currency fluctuations increase the final cost of these technologies. Local manufacturing of components is still limited, which means adopters must depend on foreign suppliers. It is important to note that while the initial cost is high, proponents argue that the investment can be recovered over time through higher yields, lower water and labor costs, and premium prices for fresh produce (Despommier, 2020). However, the payback period can be long, and many urban farmers lack the financial capacity to wait. This creates a situation where only well-funded entities can afford to adopt the technology.

VII. GLOBAL BEST PRACTICES

Several countries around the world have successfully adopted vertical farming and hydroponics as part of their urban food systems. According to Despommier (2020), these countries have developed models that combine technology, policy support, and community engagement to make urban agriculture viable. Studying these practices provides useful lessons for other cities seeking to adopt similar systems.

Singapore: Integration into Urban Planning

Singapore is widely recognized as a leader in vertical farming and hydroponics. According to the FAO (2021), the country imports over 90% of its food, which made food security a national priority. In response, the government integrated urban farming into national planning. The "30 by 30" policy aims to produce 30% of Singapore's nutritional needs locally by 2030. Best practices from Singapore include the use of high-rise hydroponic farms and rooftop gardens. Companies like Sky Greens developed vertical towers that use gravity and low energy to rotate crops for even sunlight exposure (Benke & Tomkins, 2021). The government also provides grants, training, and land leases to support urban farmers. According to Al-Kodmany (2021), locating farms near housing estates and markets reduces food miles and ensures fresh produce for residents.

Netherlands: Technology and Research-Driven Model

The Netherlands is known for its advanced greenhouse and hydroponic systems. According to Resh (2021), Dutch farms use precision hydroponics combined with data analytics to maximise yields while minimising resource use. The country produces large quantities of vegetables on very small land areas through closed-loop systems. Best practice is the strong link between research institutions and industry. Universities and agricultural centres work with farmers to test new crop varieties and nutrient solutions (Nwafor & Okoro, 2020). The government also supports energy efficiency by encouraging the use of geothermal energy and LED lighting. Barbosa et al. (2020) noted that Dutch farms recycle up to 95%

of water used in hydroponics, setting a global standard for sustainability.

United States: Commercial and Community Models

In the United States, both large commercial vertical farms and community-based projects have emerged. According to Despommier (2020), companies like Aero Farms and Plenty use fully automated vertical farms in warehouses to grow leafy greens year-round. These farms use AI and sensors to monitor plant health and optimise growing conditions. At the community level, best practices include school and neighbourhood hydroponic gardens. Al-Kodmany (2021) reported that cities like New York and Chicago have integrated urban farms into public housing and schools to improve food access and education. Public-private partnerships are common, with local governments providing space and funding while private firms provide technology and expertise.

Japan: Post-Disaster and Space-Efficient Farming

Japan adopted vertical farming after the 2011 tsunami destroyed farmland. According to the FAO (2021), the country turned to plant factories to ensure food supply in urban areas. Japanese plant factories use LED lighting, hydroponics, and strict hygiene to produce vegetables in sterile environments. A major best practice is the focus on energy efficiency and automation. World Bank (2023) stated that Japanese farms use solar power and recycled water to reduce costs. The produce is also marketed as clean and pesticide-free, which allows farmers to charge premium prices and recover investment costs.

VIII. POLICY AND EDUCATIONAL IMPLICATIONS

The adoption of vertical farming and hydroponics in urban areas has important implications for policy and education. For these technologies to succeed, governments, institutions, and communities must create an enabling environment through supportive policies and capacity building.

Policy Implications

According to UNEP (2022), government policy plays a central role in promoting urban agriculture. One key implication is the need for urban planning policies that recognize agriculture as a legitimate land use in cities. Currently, most urban master plans focus on housing, commerce, and industry, with little provision for food production (Okon & Bassey, 2021). Integrating vertical farms and hydroponic units into building codes and zoning laws can help secure space for urban agriculture.

Financial support is another policy implication

According to Benke and Tomkins (2021), the high capital cost of vertical farming makes it difficult for individuals and small businesses to adopt the technology. Governments can address this by providing grants, subsidies, and low-interest loans to urban farmers. Tax incentives for companies that invest in vertical farming can also encourage private sector participation.

Energy policy is equally important.

The World Bank (2023) noted that vertical farms require reliable electricity for lighting and climate control. Policies that promote renewable energy, such as solar power, and provide subsidized tariffs for urban farms can reduce operating costs and make the systems more viable.

Food safety and quality standards are also necessary.

Resh (2021) stated that hydroponic produce must meet health and safety guidelines to gain consumer trust. Government agencies should develop clear regulations for urban farming and provide inspection and certification services.

Educational Implications

Education is critical for the successful adoption of vertical farming and hydroponics. According to Nwafor and Okoro (2020), many people lack the technical knowledge needed to manage nutrient solutions, lighting, and controlled environments. Therefore, training programs must be developed to build local capacity. At the tertiary level, universities and agricultural institutions should include hydroponics and controlled environment agriculture in their curriculum. Practical training through demonstration farms can help students gain hands-on experience (Despommier, 2020). Research institutions should also conduct studies on crop varieties, nutrient management, and energy efficiency that are suitable for local conditions.

At the community level, extension services and NGOs can organize workshops and training for urban residents. According to the FAO (2021), public awareness campaigns can educate citizens on the benefits of urban farming and how to set up small-scale systems at home. Schools can also integrate school gardens and hydroponic projects into science subjects to teach students about food production and sustainability.

Collaboration between government, private sector, and educational institutions is essential. Al-Kodmany (2021) suggested that partnerships can help develop training manuals, provide equipment, and fund research. This will ensure that knowledge is transferred effectively and that the workforce is prepared to manage modern urban farms.

IX. SUMMARY AND CONCLUSION

Urban areas are facing increasing pressure to produce food due to population growth, limited land, and rising food prices. Traditional farming is becoming difficult in cities because of space constraints and environmental challenges. Vertical farming and hydroponics provide an alternative by allowing food to be grown in small spaces using less land and water. This study has shown that vertical farming and hydroponics can be applied in different urban settings such as households, schools, markets, and commercial centres. Vertical farming makes it possible to grow crops in stacked layers, while hydroponics allows plants to grow without soil by supplying nutrients directly through water. Together, these systems make it possible to produce fresh vegetables and other crops all year round, close to where people live.

The benefits of adopting these technologies in urban areas are significant. They help to conserve water and land, reduce the cost and waste associated with transporting food, and provide a steady supply of fresh produce. They also create jobs and offer opportunities for young people to learn modern agricultural skills. In addition, because production takes place in controlled environments, there is less need for pesticides and chemical fertilisers. Despite these benefits, there are challenges to adoption. The major challenge is the high cost of setting up vertical farms and hydroponic systems. Other challenges include the need for constant electricity, lack of technical knowledge, and limited policy support for urban agriculture.

Global experiences show that these challenges can be overcome with the right support. Countries that have succeeded in urban farming have done so through government policies, funding, research, and public awareness. Training and education are also important to help people understand and manage these systems effectively.

In conclusion, vertical farming and hydroponics offer practical solutions for food production in urban areas. They can help cities become more food secure, use resources more efficiently, and build sustainable food systems. With proper planning, investment, and education, these technologies can play a major role in meeting the food needs of growing urban populations in the future.

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