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Implication of Urban Agriculture and Vertical Farming for Future Sustainability

Anwesha Chatterjee, Sanjit Debnath and Harshata Pal

Abstract

Urban agriculture (UA) is defined as the production of agricultural goods (crop) and livestock goods within urban areas like cities and towns. In the modern days, the urbanization process has raised a question on the sustainable development and growing of urban population. UA has been claimed to contribute to urban waste recycling, efficient water use and energy conservation, reduction in air pollution and soil erosion, urban beautification, climate change adaptation and resilience, disaster prevention, and ecological and social urban sustainability. Therefore, UA contributes to the sustainability of cities in various ways—socially, economically, and environmentally. An urban farming technology that involves the large-scale agricultural production in the urban surroundings is the vertical farming (VF) or high-rise farming technology. It enables fast growth and production of the crops by maintaining the environmental conditions and nutrient solutions to crop based on hydroponics technology. Vertical farms are able to grow food year-round because they maintain consistent growing conditions regardless of the weather outside and are much less vulnerable to climate changes. This promises a steady flow of products for the consumers and a consistent income for growers. Various advantages of VF over traditional farming, such as reduced farm inputs and crop failures and restored farmland, have enabled scientists to implement VF on a large scale.

Keywords: urban agriculture, vertical farming, hydroponics, aquaponics, aeroponics

1. Urban agriculture

Urban agriculture (UA) can be defined as the growing of plants and rearing of livestock within a city (intra-urban) or on the areas surrounding the cities (peri-urban agriculture), involving input provision and processing of raw materials into edible forms followed by marketing activities [1, 2].

2. Need for urban agriculture/importance of urban agriculture

The proportion of the world's population living in cities is increasing dramatically. It is predicted that by 2030, the worldwide population of urban dwellers will be nearly 5 billion [3], and by 2050 it may reach 9 billion [4]. The increased rate of

urbanization has important economic, social, and political implications: A large number of people residing in the cities can approach toward education and employment easily; they can trust the healthcare industry and can see cultural evolution. But this rapid growth of population is often integrated with communal challenges and also climate change: cities may fail to provide the basic facilities resulting in communal riots leading to inferior and undesirable living conditions. Therefore, in order to deal with the challenges of rapid urbanization, urban agriculture is in demand nowadays.

The need or importance of urban agriculture is broadly discussed with the following *advantages* associated with it [5].

2.1 Fighting environmental challenges

Today, cities consume more than two-thirds of the world's energy and are responsible for 70% of global CO₂ emissions. Recently, UA is considered to deal with the difficult situations like climate change as it plays sufficiently in greening the metros and improving the warmer city climate while encouraging the reuse of organic wastes that reduces the urban energy footprint [2].

The World Meteorological Organization (WMO) suggested that more urban farming should take place as a response to climate change and as a way to build more resilient cities.

UA helps cities to improve the urban environment and become more resilient by [2, 6]:

- UA reduces the weakness of specific urban groups and diversifies urban food sources and income opportunities of the urban poor and forms a source of innovation and learning about new strategies/technologies for land- and water-efficient food production.
- UA helps in keeping the open areas covered with greeneries that might reduce the severity of the climatic conditions. UA also makes the microclimate worth living and also forbids the construction of buildings on risky areas, and by this not only flooding, landslides, and other disasters are reduced but also urban biodiversity and living conditions are improved. Such open green spaces also help to control storm water flows by allowing water storage and increased infiltration of excess storm water [7]. In these open green spaces in and around urban areas, food production can be combined with other services to city dwellers, such as agro-tourism or park and landscape maintenance, e.g., “productive parks.”
- UA produces fresh green foods that reduces the green-house gas emission and also uses limited energy in the process of getting food from the farm to the plate in industrially developed countries [8].
- Productive reuse of waste water in UA helps to combat the freshwater crisis and also saves rivers, canals, and other water bodies from being polluted by the waste water. On the other hand, waste water as a source of irrigation might decrease the risk of water scarcity [9]. Use of urban waste water as a source of irrigation will help to adapt to risks of drought and flood. Urban waste water can be recycled for irrigation/fertilization of horticultural crops, i.e., floriculture and fruit crops, as well as for irrigation of forest plantations that provide wood for fuel.

2.2 Food security and nutrition

UA contributes to enhance urban food security and nourishment of the poor class. Families that are involved in UA are exposed to better quality and variety of diet. They consume more herbs and greens than the others. Production of food by urban families can supply up to 20–60% of their total food consumption especially in green vegetables, medicinal and aromatic plants, eggs, and milk and meat from small animals. Involvement in UA may also cause better mitigation of diseases as it has better nutritional and medicinal properties in homegrown medicinal plants, it causes more physical exercise, and people do not have to depend on gifts and food aid which may enhance their self-esteem. UA also increases the accessibility of fresh and affordable food for other urban consumers, as most of the food produced by urban farmers is bartered or sold locally. UA also ensures food requirement during natural calamities and wars. In Sierra Leone, the residents devoted themselves in UA in order to meet their daily foods during the civil war that lasted for about 10 years. UA acts as a survival strategy for the refugees and helps them to live in a state of being worthy for honor [1, 2, 6].

2.3 Poverty alleviation

The world's urban population is expected to reach 6–9 billion by 2050. It is estimated that poverty will progress from villages to the metro cities by 2030 as 60% of the Earth's population will reside in the cities. Moreover, in most developing countries, urbanization has led to the growth of slum population which has almost doubled in the past 15 years [3]. Also this rapid urbanization in developing countries created difficulty in making sufficient employment opportunities creating very poor living conditions in the slum areas. The presence of UA can definitely meet the requirement of employment to some extent in the cities of developing countries. The effects of UA on poverty alleviation vary with the type of participants involved, the products produced, and the degree of market orientation, among other things. UA often plays an important role in the survival strategies of the urban dwellers, who might be benefited from UA in various ways: Firstly, when a household produces edible crops, their food expenses are reduced and they can do a huge amount of savings. Moreover, the surplus produce can be sold by them in order to make a profitable business [2, 6].

2.4 Proper land use

In addition to climate change and urbanization, food production is confronted with decrease in productive agricultural land. Large-scale urban food production could provide opportunities and take the pressure off agricultural land. Consequently, researchers and practitioners are aiming to separate arable land from production and produce food on a larger scale in and on buildings in high-density urban areas. Scientists visualized the “edible city” and introduced the concept of continuous productive urban landscape (CPUL), recommending the coherent introduction of interlinked productive landscapes into cities as an essential element of sustainable urban infrastructure. One major challenge of urban food production is land availability and access. Principally, there might be large resources of land that could be made accessible for agricultural purposes, but for densely built-up areas and where availability of space often limits the area of production unit, no-space or low-space technologies provide opportunities for space-confined growing [5, 10, 11].

Besides its so many advantages, there are some *disadvantages* of UA associated with potential health risks [2]:

1. Reuse of contaminated, untreated irrigation water from urban streams gives rise to potential health risks. This can be managed through complementary health risk reduction measures as explained in the 2006 WHO guidelines for safe use of excreta and waste water.
2. Insufficient or improper management of livestock leads to health risks. Proper management of animals, manure, urine, and slaughterhouse procedures will reduce the rate of the associated health risks.
3. Intensive use of fertilizers, pesticides, and fungicides in UA may lead to residues of agrochemicals in crops or in the groundwater. The risk mainly occurs in areas with commercial urban farming. In subsistence and semicommercial urban farming, this risk is limited because the producers rarely apply agrochemicals due to poverty. They use composted organic wastes as they prefer a clean product for self-consumption.

3. Vertical farming: an urban farming technology

With rapid worldwide population growth, there is scarcity of agricultural lands. It increases the demand for both more food and more land to grow food. But some entrepreneurs and farmers are beginning to find a solution to this problem, one of which can be found in the abandoned warehouses in our cities, in new buildings built on environmentally damaged lands, and even in used shipping containers from ocean transports. This solution is called vertical farming, which is an UA technology involving growing crops in controlled indoor environments, with precise light, nutrients, and temperatures.

In vertical farming, growing plants are arranged in layers that may reach several stories high. Although small-scale, residential vertical gardening (including window farms) is under practice for several years, commercial-scale vertical farms have become an important topic of discussion for the past few years in the United States. This new farming technology is growing rapidly, and entrepreneurs in many cities are taking an interest in this innovative farming system [12].

Vertical farming is gaining its importance throughout several urban cities around the world due to the beneficial role it plays in the field of agriculture. Vertical farming can reduce the transportation costs due to its adjacency to the buyer; planned production of herbs and their growing conditions can be enhanced by adjusting the temperature, humidity, lighting conditions, etc. Indoor farming in a controlled environment needs much less amount of water than outdoor farming because it involves recycling of waste water. Because of these features, vertical farming is widely implemented initially in desert and drought-stricken regions, such as some Middle Eastern countries, Africa, Israel, Japan, and the Netherlands [13].

4. Types of vertical farms

4.1 Hydroponics

It is the predominant growing system used in vertical farms, involving growing plants in nutrient solutions that are devoid of soil. The plant roots are submerged in a nutrient solution, which is frequently examined and circulated to ensure that the correct chemical composition is maintained [12].

Urban hydroponics is not a recent invention. The Hanging Gardens of Babylon and the Floating Gardens of the Aztecs were beautifying the cities for quite a long period of time. Also, fruits and vegetables were cultivated in those areas. Nowadays, modern cities use urban hydroponics for physical and psychological relaxation. It also plays an important role in managing the urban environment. In areas with arid climate, it increases humidity and lowers temperatures. It also captures dust and polluted air by the foliage of the plants. It contributes to the reduction of the overall discharge of CO₂, hence preventing global warming to some extent. Hydroponics gardens are usually constructed vertically because city space is limited. Apart from immediate improvement in the environmental quality, vertical farms on top of traditional buildings serve as large heat sinks that radiate heat and increase ambient air temperature; hydroponic systems thermoregulate buildings by trapping heat in the winter and cooling buildings in the summer. The air quality inside the house can also be improved by growing plants on interior walls. In some modern cities, for example in Bangkok, the concrete roads and railway overpasses are covered with hydroponically grown ornamentals. Also commercial centers are decorated with indoor hydroponics for an improved air quality inside [14].

4.2 Aquaponics

The hydroponic system is taken one step forward by another system called aquaponics which combines plants and fish in the same ecosystem. The nutrient-rich wastes produced by the indoor-grown fish serve as feed source of the plants present in the vertical farm. On the other hand, the plant filters and purifies the waste water which is then recycled into the fish tanks [12].

This combination of systems is cheaper and easier as mineral nutrients are not be purchased and the plants are growing totally organically and moreover no additional expenses are required to clean the fish tanks and there is no scene of pesticides harming the fish. Thus, aquaponics is not only cost-effective but also diseases in the systems can be reduced and a very suitable urban farming technology can be formed. Canadian scientist Savidov explained that possibly the organic components in the system make the trace elements readily available to the plant for proper growth and thus recirculating aquaponic system decreases root diseases in the crop with increased crop yield from aquaponics compared with conventional hydroponics. Also fruits and vegetables grown in aquaponic system qualify for organic product certification very easily since no pesticides and fertilizers are used in this system. Some scientists are planning to construct vertical farms in skyscrapers and have created the name sky farming. Such buildings may also incorporate aquaponics to ensure a good source of fresh fish [14].

4.3 Aeroponics

This innovative indoor growing technique was first developed by the National Aeronautics and Space Administration (NASA). In the 1990s, NASA started finding efficient ways to grow plants in space and coined the term “aeroponics.” Aeroponic systems are still in a growing phase in the vertical farming world, however gaining interest gradually. It is an efficient plant-growing system in vertical farms, using up to 90% less water than other efficient hydroponic systems. Plants grown in these aeroponic systems take up more minerals and vitamins, making the plants healthier and more nutritious [12].

In tropical hot and humid climate, it is difficult to grow temperate vegetables like lettuce. Geoff Wilson, an agricultural journalist and Australia’s representative of a group of 16 national organizations for an international Green Roofs

organization, has reported in an article that a new aeroponic system originated in Singapore can provide a solution to this difficulty. Traditional aeroponic method involved cold nutrient mixture that used to be sprayed onto the plant roots, thereby lowering the temperature causing wilting and ultimately death of the plant. But this type of cooling is expensive, even for rich cities like Singapore. To overcome this limitation, in the year 2004, Gregory Chow, lecturer at the Ngee Ann Polytechnic of Singapore invented the air dynaponics—a much less costly way of maintaining low root-zone temperatures for commercially successful aeraponics. This system gave positive outcomes. Researchers stated that the nutrients infused with oxygen “energized” the entire root system and improved the plant top biomass. Air dynaponics uses the cooling methods of Venturi nozzle effect in an air-powered operation that lowers the temperature of the nutrient mixture and supplies air from the dissolved oxygen. In Singapore, this method is used to produce valuable greens like butter-head lettuce, Batavia lettuce, and Romaine lettuce for moneymaking purposes [14].

4.4 Vertical farming systems can be further classified on the basis of structure that houses the system

4.4.1 Building-based vertical farms

These are the types of vertical farms constructed in abandoned buildings in urban areas. For example, Chicago’s “The Plant” vertical farm was constructed in an old pork-packing plant. Vertical farms are also constructed in new buildings. A new multistory vertical farm is built to an existing parking lot structure in downtown Jackson Hole, Wyoming. Here, vegetables are grown throughout the year in the 13,500-square-foot hydroponic greenhouse for sale to restaurants, to local grocery stores, and also directly to consumers [12].

4.4.2 Shipping-container vertical farms

These types of vertical farms are becoming popular day by day. They use 40-foot shipping containers that carry goods around the world and house vertical farms with LED lights, drip irrigation systems, and vertically stacked shelves for growing a variety of plants. It contains computer-controlled growth management systems that allow users to examine all systems from a smartphone or computer. The three leading companies producing shipping-container vertical farms are Freight Farms, CropBox, and Growtainers [12].

5. Advantages of vertical farming

Despommier mentioned a number of environmental and social advantages in his book called “The Vertical Farm: Feeding the World in the 21st Century.” The advantages are summarized below [15]:

- Vertical farming ensures production of greens all year round in nontropical countries and is better than normal farming. Despommier stated that 1 acre of vertical farm can produce products almost equal to the amount of products produced by 30 acres of normal farmland on considering the number of crops produced each season.
- Vertical farming involves reduction or abandonment of the use of herbicides and pesticides. In some cases, vertical farming uses ladybugs and other biological controls when required.

- As the crops in a vertical farm are grown under a controlled environment, they are safe from extreme weather conditions such as droughts, hail, and floods.
- Hydroponic growing techniques help in water conservation by using about 70% less water than normal agriculture.
- Indoor farming reduces or eliminates the use of tractors and other large farm equipment that are commonly used on outdoor farms, thus reducing the burning of fossil fuel. According to Despommier, large-scale vertical farming could result in a significant reduction in air pollution and in CO₂ emissions.
- Vertical farming is people friendly. Some hazards that can be avoided in vertical farming are accidents while operating heavy farming equipment and exposure to harmful chemicals.

6. Disadvantages of vertical farming

Apart from so many advantages, there are many critics of the vertical farming described by the scientists. They claimed that there are a number of problems in vertical farming. The challenges to vertical farming may be summarized as follows [13]:

- Start-up costs are high in order to purchase land in central business districts.
- The number of crops grown is sometimes less than rural farming.
- Production volumes are also not as large as conventional farming and scaling-up may add cost and complexity.
- Raising investment capitals and training a skilled workforce are also challenges in vertical farming.

7. World-wide implementation of urban agriculture/vertical farming

Scientists explored the motivations for urban gardening in Germany by screening 657 urban gardening project websites and characterized the types of gardeners, cultivation methods, and consumer behavior. The study also highlighted the “terrabioponic smart-garden system” where the plants grow in natural soil and in organic nutrient solution, which may facilitate social transition toward bio economy [16]. Also scientists from the United Kingdom reported that vertical farming system has increased the yield of lettuce per unit area as compared to traditional horizontal hydroponics [17]. Agriculture and food production activities in the cities of Mexico can contribute in reducing carbon footprint by creating green environment and better land use [18].

Case study 1: The world’s largest indoor vertical farm, AeroFarms, is located in Newark, New Jersey, which grows more than 2 million pounds of greens per year without sunlight, soil or pesticides. Instead of using a huge quantity of water to grow plants, AeroFarms system sprays nutrient-rich mist to the plants. Seeds are sown, germinated, and grown on reusable sheets of cloth and are stretched out over trays stacked vertically. LED lights are used instead of the sun, and the exposure is controlled depending upon the maturity of the plant [12].

Case study 2: Rob Laing founded Farm.One in the year 2016 in order to grow rare and hard-to-find produce to the chefs and restaurants in the middle of New York City. The first farm was set up at the Institute of Culinary Education (ICE) in downtown Manhattan, and the second farm is in Tribeca. It uses hydroponics and LED lights and aims to grow rare produce every year. The company supplies rare herbs, edible flowers and microgreens to some of the best chefs in New York [19].

Case study 3: One of the world's first commercial vertical farms named Sky Greens was built in Singapore. This vertical farm produces one ton of vegetables every other day. Large varieties of tropical vegetables like Chinese cabbage, spinach, lettuce, xia bai cai, bayam, kang kong, cai xin, gai lan, and nai bai are grown. Sky Greens uses a hydraulic system called "A Go-Gro," which consists of 6-m-tall hydraulic water-driven A-shaped towers. Each tower contains 22–26 tiers of growing troughs, and is spun around the aluminum frame at a speed of 1 mm/sec for a steady radiation of sunlight, proper air flow, and irrigation for all the edibles growing in the tower. The rotation system is powered by a unique gravity-aided water-pulley system that uses only 1 L of water per 16-hour cycle, which is collected in a rainwater-fed reservoir. The water used in powering the frames is recycled and filtered before returning to the plants. The organic wastes produced on the farm are composted and reused [19].

8. Concept of urban agriculture/vertical farming in India

India is one of the largest producers of fruits, vegetables, and many other agricultural products. In India, vertical farming has been introduced in recent times. Experts from Indian Council of Agricultural Research (ICAR) are working on the concept of "vertical farming" which can be implemented in metros like New Delhi, Mumbai, Kolkata, and Chennai [20].

8.1 Current scenario of urban agriculture/vertical farming in India

Scientists at Bidhan Chandra Krishi Viswavidyalaya in Nadia, West Bengal, had initial success on growing brinjal and tomato hydroponically on a small scale. Punjab also has succeeded in producing potato tubers through vertical farming [20].

In cities like Cuttack and Nagpur, the slum dwellers performed organic farming on terrace and plots and sold the surplus products to the local markets. In Delhi, on the fertile banks of Yamuna River, extensive farming is going on in spite of the fact that farmers do not have any legal sanction to do farming there. In Hyderabad, farmers living along the banks of Musi River use water from the river for urban farming and contributed rice and vegetables to the market [21].

In the urban areas of Tripura, to help the youth for income generation, a prototype model on "vertical farming system" was developed. The area of the structure was about 630 sq. ft. with two floors and two galleries. The ground floor contained two cages (50 sq. ft. each) at both corners that accommodated 100 layer chicks. The central space (140 sq. ft) housed 200 bird broiler/layer chicks per batch. Eight goats were kept on the first floor (140 sq. ft.) area. There were also 12 rabbits kept in hanging cages (4 sq. ft. each). Proper drainage facility was provided to collect wastes with storage facility where it was decomposed and used for manuring the pots. Three *Azolla* tanks were constructed above the rabbit cages which were the source of nutrient to the goat as well as the birds. Ten benches (30 cm each) were kept on both sides of the structure which contained 160 pots for growing small fodder, vegetables, and spices. A water tank of 400 L capacity was also provided on top of the structure for storing water for animals and poultry and also providing irrigation to each pot through drip irrigation system [22].

Ideafarms is an Indian design-in-tech company which produces vertical farm products, and the produce is of high quality and organic and the supply is huge. A Bengaluru-based start-up company named Greenopia is selling kits with self-watering pots, enriched soil, and better quality seeds. A Mumbai-based start-up firm U-Farm Technologies is using hydroponic gardening technique to build vertical farm for an individual apartment or for a supermarket [20].

Vertical farming is definitely a solution to critical problems in Indian farming like lack of supply of farm produce, overuse of pesticides and fertilizers, and even unemployment. But there are some challenges: The initial huge cost of infrastructure for implementing vertical farming in India is difficult. Vertical farming in India has to face other challenges like public awareness, technical knowledge, and high cost of managing and maintaining the vertical farm systems [20].

9. Conclusion

Urban farming, both vertical farming or farming on vacant open spaces, can be a favorable way for ensuring food security in India and around the world in the future. Although countries like Europe, the USA, and Singapore have already implemented vertical farming and are dealing with big projects for future concerns, India still has a long way to go as it is restricted to only few self-interest-driven projects. Institutional support, awareness of the benefits associated with urban agriculture, and financial and technological support from the government can only attract the city dwellers and help them to move forward with the concept of urban agriculture in India. Progressive growth of urban agriculture can act as an urban regeneration tool for the cities by providing social interaction and increasing job opportunities and environmental benefits to the urban areas across the globe. Thus, to combat the challenges associated with rapid increase in population, the topic of “urban agriculture” is being closely monitored by scientists, city planners, and the sustainable agricultural community for a better future.

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