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Safayet, Mastura; Arefin, Md. Faqrul; Hasan, Md. Musleh Uddin

Article

Present practice and future prospect of rooftop farming in Dhaka city: A step towards urban sustainability

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Present practice and future prospect of rooftop farming in Dhaka city: A step towards urban sustainability☆

Mastura Safayet*, Md. Faqrul Arefin, Md. Musleh Uddin Hasan

Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET), Bangladesh

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ABSTRACT

Dhaka, the capital of Bangladesh is one of the most populated megacity in the world and the population growth in this city is extremely high. To support growing food demand of increasing population, food supply should be secure and sustainable. On the other hand, with the pace of urbanization built-up areas are increasing; hence supply of roof space is also increasing. Rooftop farming can provide solution to increased food demand and also can promote a sustainable and livable city. Local fresh and safe food can be ensured through roof gardens in Dhaka city. The aim of the study is to explore the present practice and challenges of rooftop farming that was encountered by practitioners. Mirpur and Mohammadpur areas have been selected as study areas. Two practitioners are interviewed and 60 non-practitioners are surveyed. Results show that rooftop farming can support environment by improving air quality, reducing carbon in the atmosphere and can benefit society by reducing storm water management cost. One of the significant findings from the non-practitioner survey is that maximum people are willing to practice rooftop farming and want to provide at least 50% of roof space for rooftop farming. Finally some recommendations have been suggested to improve rooftop farming practice and encourage more people to practice rooftop farming in future.

1. Introduction

Today in this urban planet, 54 percentage of the world's population are living in urban areas and the share is expected to increase to 66 percentages by 2050 (United Nations, 2014). Rapid urbanization and urban growth is placing massive demand on urban food supply systems. Moreover, many cities in the world are facing problems like rapid decrease in green space and increase in heat island effects. Urban agriculture or farming is promoted as a potential solution to these problems (Smit, Nasr & Ratta, 2001). As the food is produced locally, there is no need to travel far to get fresh foods which reduces use of fossil and consequently has a positive impact on the environment (Sprouting Good Urban Farming Sydney, 2014). Rooftop farming can reduce the temperature of roofs and the surrounding air that contribute to overall cooling a local climate (RIES, 2014) and can help reduce urban heat island effect (Hui, 2011). Roof farms can also absorb carbon emissions and noise (Dubbeling, 2014; Hui, 2011). Rain water is captured and absorbed by the plants and overflowing impact on infrastructure is reduced (RIES, 2014). Rooftops filled with vegetation can be a great place to relax. This kind of farming can easily offer employment to people (Sprouting Good Urban Farming Sydney, 2014). Farming in rooftops helps to increase biodiversity and provide habitat for a variety of insects and birds (Higher Ground Farm n.d.).

Farming on the rooftop of the buildings in urban areas is usually done by using green roof, hydroponics, organic, aeroponics or container gardens (Asad & Roy 2014). The first benefit of this practice is increased local supply of fresh food. In Singapore, while

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* Corresponding author.
E-mail addresses: masturabuet510@gmail.com (M. Safayet), fahim1015027@gmail.com (Md. F. Arefin), musleh_uddin@urp.buet.ac.bd (Md. M.U. Hasan).

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current local vegetable production can meet only 5% of Singapore's present-day needs, if rooftop farming is implemented across public housing estates, the share would increase to 35.5% and Singapore's carbon footprint would decrease by 9052 tons of emissions annually (Astee & Kishnani 2010). In Bologna, Italy, if all suitable flat roof space is used for urban agriculture, rooftop gardens in the city would supply around 12,500 tons of vegetables annually which would meet 77% of residents' needs for vegetables and an estimated 624 tons of CO_2 would be captured each year (Science for Environment Policy, 2015). Lufa Farms, Montreal produces over 25 varieties of vegetables and production is adequate to supply the needs of over 1000 people (Carrot City, 2014a). The farm of Brooklyn Navy Yard grows more than 50,000 pounds of organic produce annually. The Gary Comer Youth Center of Chicago grows 450 kg of food per year (Clarke, 2015). Rooftop urban farming also offers many environmental and social benefits to high density urban cities like Hong Kong (Hui, 2011). By utilizing rooftops for urban farming, it is possible to attain social, economic and environmental sustainability for the buildings in urban cities. Because it can contribute to the development of urban food systems by increasing local food production, meet the nutrition demand of the people by access to nutritious food, mitigation of air pollution, increasing storm water retention capacity, improvement of public health, enhancement of the aesthetic value of the urban environment and enhancement of community functions (Bay Localize, 2007).

In Dhaka, one of the world's fastest growing mega cities, open and cultivable land has been converting to built-up area indiscriminately and thus agricultural land has been decreased at an alarming rate (Islam & Ahmed 2011). Implementing rooftop farming can be a possible solution to reduce the food supply problems, make urban living more self-sufficient and make fresh vegetables more accessible to urban individuals. It is estimated that 10,000 ha space of Dhaka city can be brought under rooftop farming and the residents of the city can taste fresh vegetables as well as over 10 percent of the demand can be fulfilled through rooftop farming (Wardard, 2014). A survey shows that most of the roofs of Dhaka city are suitable for gardening and do not require major improvement work, sometimes only need some modifications (Islam, 2004).

This study aims at exploring the existing practice and associated challenges of rooftop farming. What makes this study unique is the identification of benefits from urban sustainability perspective and calculation of the monetary value of economic and environmental benefits of rooftop farming in Dhaka.

2. Urban sustainability and rooftop farming

A sustainable city is the city which meets the needs of the present without sacrificing the ability of future generations to meet their own needs (The Science Museum, 2004). The international community is already started to address the issue of urban sustainability. Urban sustainability is the idea that a city can be organized without excessive dependence on the surrounding countryside and be able to power itself with renewable sources of energy. The purpose is to create the least possible ecological footprint and to produce the minimum quantity of pollution possible, to efficient use of land, compost used materials, recycle it or convert waste-to-energy and to make the city's complete contribution to climate change minimal (The Crystal n.d.). Urban sustainability can be achieved through the sustainability of social, economic and environmental issues. Along with other initiatives and activities, urban rooftop farming, therefore, has an important role in contributing towards the future sustainability of cities. Hui (2011) and others have listed out social, economic and environmental sustainability to be achieved by urban agriculture and rooftop farming. In summary, social sustainability can be achieved by active community participation and cohesion in community green space and gardens on the rooftop; by community cohesion while sharing individual experiences, collecting fresh food; by creating local employment; by creating common amenity space for exercise and recreation and by producing common aesthetic benefits. Economic sustainability through rooftop farming means the increase in local food production and sale, increase in food security and property value, improvement of roof durability, reduction in building cooling load and energy costs, increase availability of biofuels etc. Environmental sustainability can be achieved through reduction in carbon emission food transportation, reduction of wastes by generating less packaging, recycling of organic wastes by composting, mitigation of urban heat island, increase in biodiversity, improvement of air quality urban storm water management, capacity of sound insulation and noise absorption etc. (Hui, 2011).

3. Review of rooftop farming methods throughout the world

There are fascinating projects and initiatives on rooftop gardens throughout the world. In Singapore, inorganic hydroponics is considered the more appropriate farming option, compared with conventional soil culture, in the government housing buildings as it has higher yield, lower labor requirement and needs only lightweight systems, which can be easily assembled over an existing roof (Astee & Kishnani 2010). The fiber glass containers and raised beds set up are used for the roof farming in cities of Hong Kong (Hui, 2011). Rooftop gardeners grow lettuce, black cabbage, chicory, tomato, aubergine, chili pepper, melon and watermelon, either in plastic pipes, recycled pallets filled with compost or on polystyrene panels floating in tanks, also made from recycled pallets in Bologna, Italy (Science for Environment Policy, 2015). In Montreal, Lufa farmers utilize sustainable hydroponics methods, which poses less environmental impact, to produce foods (Carrot City, 2014a). The farm at the Brooklyn Navy Yard practices 100% organic farming techniques (Clarke, 2015). In the rooftop of Gymnase Vignoles of France organic gardening is practiced (Carrot City, 2014b). In recent years, some people in Taiwan are trying to develop effective growing methods for promoting rooftop farming (Hui, 2011).

4. Challenges and incentives to rooftop farming – a review of literature

Though there are numerous benefits of rooftop farming, rooftop gardeners are facing several challenges, too. Slope of the roof, load bearing capacity of the building and roof etc. are important considerations. So, it is important to look at the structural

composition of the building and retrofit them accordingly or design of new building should consider it from the very beginning (Hui, 2011). Roof weight can increase by as much as 30–950 kg per square meter for roof gardens depending on depth of soil, when saturated by heavy rain. Most roofs need strengthening to take such weight (Dixon n.d.). Keeping the soils healthy and productive may also be challenging as rooftop structural soils are different from ground-bed soils (Green, 2011).

High winds and high temperatures are often a problem; windbreaks and heat-tolerant crops have to be deployed in the rooftop environment. Pesticide use in densely populated areas can be a problem and many rooftop gardeners go with organic farming for this reason (Tiller, 2008). Sometime, maintenance may be costly (Dixon n.d.). Many of the city residents do not have training in agriculture. Starting gardening without proper training may lead to frustrating outcomes, which might result in unwillingness of the people in initiating new projects (Islam, 2004).

However, recently some policy and field supports are being offered to the practitioners. The Milan Urban Food Policy Pact, resulting from Expo 2015with theme “Feeding the Planet, Energy for Life”, has been a boost to support innovative projects in cities (Milan’s Food Policy, 2015). Tokyo is the first city to mandate building vegetation that must constitute 20% of all new construction. Recently, urban agriculture and food security have attracted considerable interest in many cities of Canada. The green roof by law passed in 2009 states that all new buildings over six stories tall and with more than 2000 m^2 of floor space must have minimum 20 percent rooftop greenery (Torstar News Service, 2015).

Portland’s Eco-roof Incentive Program offers to pay for $5 per square foot of rooftop green space created. Austin recently passed a rooftop greenery density bonus, which can give a density bonus of up to eight square feet for every square foot of rooftop greenery installed (Plant Connection Inc., 2016). In Nepal, currently a limited number of households are practicing rooftop gardening with the support of NGOS, municipalities and the Ministry of Agriculture Development. Kathmandu Metropolitan Council (KMC) has decided to provide support to 500 households in order to expand the rooftop gardening program with aims to enhance local food production and household waste management (Nepal Forum for Environmental Journalism n.d.).

5. Study methods

5.1. Study area

To perform this research, a study area was needed that has a combination of high density of built-up area and existence of rooftop farming practitioner. In 2013, Department of Agriculture Extension (DAE), Bangladesh launched “Integrated Quality Horticulture Development Project” enlisting 68 people from different areas of Dhaka city and to train them for practicing rooftop gardening. For the purpose of the study, this database has been used to select practitioners as no other database has been found to avail the total number of practitioners in Dhaka city (corporation). Mirpur and Mohammadpur areas have been chosen as from these two areas highest number of enlisted practitioners were found. All the building where practitioners in Mirpur and Mohammadpur did their farming, were four to six storey high. Among them two third were male practitioners and more than half had formal jobs outside their homes. All practitioners who took part in that program followed the traditional farming technique. Therefore selecting a large number of practitioners may depict similar results repeatedly. Hence, one practitioner had been selected from each areas- one female practitioners from Mirpur, whose profession was housekeeping and one male practitioner from Mohammadpur, who was a government employee. Again, 30 non-practitioners from each area were surveyed to understand their familiarity with and views on rooftop farming. Among 60 non-practitioners surveyed from two study areas number of land lord and tenants were equal, so was the case for males and females.

To the best of authors’ knowledge there is no exact data on building storeys in Dhaka. (There is an incomplete database for Detailed Area Plan, DAP, areas in Dhaka). So, number of people living ‘pucca’ houses – made of brick, reinforced cement concrete structures – can be used as a proxy variable in this regard. It can be hypothesized that most of the ‘pucca’ houses are suitable for rooftop gardening. As per population census 2011, all the urban areas, i.e. Dhaka City Corporation (DCC) and municipalities, in Dhaka district 59.1% households live in ‘pucca’ houses (BBS, 2011). (It should be mentioned here that now DCC is divided into Dhaka North City Corporation, DNCC, and Dhaka South City Corporation, DSCC). 36 ‘thanas’ (police stations) are entirely or partially covered by DCC. Among these thanas lowest 39.2% households live in ‘pucca’ houses in Darus-Salam thana and highest 96.5% live in ‘pucca’ houses in Paltan thana. 12 thanas have population living below the urban average (59.1%), while rest 24 have higher than average. From the studied thanas, Mirpur has 60.7% population in this category, while for Mohammadpur the share is 67.6% as per population census 2011. On an average, in Dhaka district, 45.6% households live in ‘pucca’ houses. For many other districts in Bangladesh the share is similar. Thus it can be argued that the characteristics of the building structures studied in this research is representatives Dhaka city and other parts of the country.

5.2. Data collection

Two practitioners were interviewed to explore their motivation, present condition, benefits and problems faced and other experiences. Non-practitioners were asked about their perception towards rooftop farming, willingness to do it, etc. Value of the land price per katha and building/ apartment per square feet have been collected from the study by Seraj (2012).

5.3. Calculation of soft benefits of rooftop farming

Monetary values of the soft benefits of rooftop farming have been calculated from five perspectives- Property Value Increase; Food production; Storm water Retention; Air Quality Improvement; Carbon Sequestration. As no such work has been found for the

Table 1
General Information of Two Practitioners' of Mirpur and Mohammadpur Areas.

Practitioner	Shahnaz Rahman Nahid	Khorshed Ahmed
Type of Building	Privately Owned	Privately Owned
Tenure Type	Building Owner	Building Owner
Number of Storeys	5	4
Plot Area	4 katha/ 2880 square feet /267.66 m^2	4.25 katha/ 3060 square feet/ 284.39 m^2
Roof Area of the Building	260.45 m^2 (2802 square feet) approx.	130.0643 m^2 (1400 square feet) approx.
Gardening Area	250.84 m^2 (2700 square feet) approx.	111.4836 m^2 (1200 square feet) approx.
Starting Time of Gardening	2011	2004
Satisfaction Level	High	High

valuation of roof garden benefits in Bangladesh, the methodologies and concerned standard values for the calculation of these benefits are derived from Tomalty and Komorowski (2010). All the values are calculated in Bangladeshi Taka at first and then is converted into US Dollar, when necessary (1 US dollar = Tk. 78.71, based on the rate of February, 2016).

6. Cases of two roof gardeners

6.1. General Information of practitioners

Mrs. Shahnaz Rahman Nahid started roof gardening in 2011. The initial cost was only Tk. 1000 (USD 12.70). At first, the garden started with some guava trees. Many flower plants were also planted at that time. After one year, the fruits and vegetable plants replaced flower plants. She consulted with the project director of DAE and many others. Under the project of "Integrated Quality Horticulture Development Project" of DAE on rooftop gardening, she received training in 2013 and later on was awarded by them as a successful practitioner.

Another practitioner, Mr. Khorshed Ahmed initiated the rooftop garden in 2004. As he is an agriculturist by profession, he started gardening to explore the possibilities. The initial cost was only Tk. 2000 (USD 25.41). At the beginning of the garden, ornamental and flower trees were planted. But after two years, the practitioner started planting vegetable to have fresh and nutritious foods close to his hand. The following is a summary of the two practitioners' general information: (Table 1).

6.2. Methods for cultivation

Conventional soil culture method has been used for gardening in both cases. Many tubs and drums are available in the garden to cultivate vegetables, fruits, flowers and other types of plants. Cabbage and Cauliflower are cultivated in the garden in the bedding method.

6.3. Existing plants and production

Though Mrs. Nahid (Mirpur area) started with mainly flowers and guava trees, now almost 3/4th roof area of the garden is covered with vegetables including Tomato, Brinjal, Bean, Lady's Finger, Chili, Capsicum, Cabbage, Gourd, Spinach etc. and some fruit trees such as Guava, Wood Apple, Sweetsop, Lemon etc (Fig. 1).

Fig. 1. Overview of the Garden in Mirpur.
Field Survey, 2016

In the winter, mainly Tomato, Brinjal, Bean, Cabbage etc. are grown in the garden. Among them, Tomato has the most production (15–20 kg per year). Other vegetables in winter include- Brinjal (4–5 kg), Bean (2–3 kg), Cabbage (10–12 in number). There are Chili and Guava plants in the garden which give yields all the year round. Five lemon plants are also there in the garden, of them three plants are Kagoji Lemon and two are Elachi Lemon. Three types of spinach are cultured in the garden, each of which give production of 5–6 kg per year. Others plants which give little production now include Malta, Anar, Jamrul, Sweetsop, Wood Apple, Mango tree etc. Before two years, more than 3 kg of Capsicum was produced but now the production is not good enough. There was Pumpkin plant in the garden but it never gave any production. Moreover, Gourd has grown in the second year of the garden (6 in number) but now for the height of the neighboring building sunlight cannot pass to the plant, so it cannot grow up.

The garden owned by Mr. Ahmed (Mohammadpur) is covered with variety of vegetables, fruits, flowers, medicinal and ornamental plants. Vegetable species in the garden includes- Cabbage, Cauliflower, Broccoli, Tomato, Brinjal, Onion, Cucumber, Chili, Capsicum, Lettuce, different types of Spinach etc. Fruit species which are grown in the garden includes- Guava, Orange, Malta, Mango, Banana, Star fruit, Amloki, Pomegranate, Wood Apple, Amloki, Lemon etc. Some other plants include Drasina, Eupholia, Alovera, Rose and other types of flower plants. Under the DAE project Mr. Ahmed got Guava, Mango, Star fruit, and Pomegranate plants (Fig. 2).

Fig. 2. Overview of the Garden in Mohammadpur.
Field Survey, 2016

In the winter, mainly Tomato, Brinjal, Broccoli, Cabbage, Cauliflower etc. are grown. Cabbage (25–26 in number) and Cauliflower (20–25 in number) have the highest yield every year. Broccoli has given its first production this year and the amount is quite good (15–16 in number). Tomato and Brinjal also bring good production in the winter (10–15 kg tomato and 15–20 kg Brinjal).

There are two types of lemon plants in the garden which are cultivated over the year. One is Kagoji Lemon and another is Batabi Lemon. From the Chili plants, the practitioner gets 2–4 chilies every day. Guava plants also give production over the year. The Star fruit plant gives yield three times per year. Every time it gives 8–10 fruits. Aspara plant – mainly used in the soup – is also available in the garden. Considerable amount of cucumber and onion are grown in the garden over the year. Moreover, there was Pumpkin plant in the garden but it did not give any production. Three types of spinach are cultured in the garden which gives overall 10–12 kg yield per year. Some plants that give fruits seasonally include Malta, Orange, Mango, Amloki, Pomegranate, Banana etc.

6.4. Maintenance

Mrs. Nahid and her family maintain the garden. So there is no major maintenance cost for hiring extra gardener. Pesticides were used for two years at first but now no pesticide is used as no problem of pests is found in the plants.

Mr. Ahmed maintains his garden fully by himself. Sometimes the guard of the building helps him to maintain the garden by giving water to the plants and cleaning the garden. To save the roof from getting damped, the practitioner places drums and tubs over the brick. Pesticides are sometimes used in the garden to save plants from the attack of the insects but the use is very little.

Both practitioners use mostly compost fertilizer in the garden which is brought from nearby dairy farm. Sometimes organic fertilizer is used in little amount.

7. Benefits from rooftop gardening

7.1. Social benefits

In Dhaka, people are very anxious about the quality food and fruits bought from the market. To resist fruits from rotting and show them fresh and intact, formalin and other chemicals are indiscriminately used by sellers and suppliers. But rooftop gardeners

are free from such worries, at least for the items they produce. Supply of fresh, chemical free vegetables and fruits from a safe source is a great relief for the practitioners and their family. Besides, working in the garden gives them immense pleasure. Sometimes vegetables and fruits are shared among the tenants which creates a social bonding. Besides, roof spaces are also utilized for a better purpose, other than as a stack yard.

An important benefit, stated by both practitioners, is increased interaction with neighbors. Both Mrs. Nahid and Mr. Ahmed are happy for not only having some supply of fresh foods, but also for the utilization of their knowledge and training with neighbors. Non-practicing neighbors visit them to appreciate their garden and seek suggestions from them. It also increases the community bonding among them. In fact, it has been found from non-practitioners' survey that all of the female non-practitioners in Mirpur know, Mrs. Nahid and more than half of them visited her garden. Both of them are regarded as the champion of roof gardening in their community. Moreover, in Mrs. Nahid's words, it has also increased her sense of security outside her premise. She feels that now if she in any trouble in the road or anywhere in the community, people will come forward to help her as they know her well.

7.2. Economic and environmental benefits - monetary values of soft benefits

The rooftop garden areas of the practitioner in Mirpur is approximately 2700 square feet (250.84 m^2) and in Mohammadpur is approximately 1200 square feet (111.4836 m^2). The soft benefits obtain from the roof gardens of the buildings are calculated below:

7.2.1. Property value

The formula which has been used in this study to calculate property value is,

$$b = 0.07 * v \text{ (Tomalty \& Komorowski 2010)}$$

In this formula, 'b' denotes value of benefit and 'v' presents value of roof garden host property.

In determining v, present value of both land price and building/ apartment price is needed. On an average, the present land price per katha in Mirpur area is approximately Tk. 5,000,000 and the building/ apartment price per square feet is Tk. 5500 (Seraj, 2012). As the plot of the building is approximately 4 katha, the area of the building is approximately 2700 square feet and the building is of 5 storied, so the total price of the land is Tk. 20,000,000 and the building is (Tk. 2700*5500*5) = Tk. 74,250,000. Thus, value of the roof garden host property is approximately Tk. 94,250,000.

$$Therefore,\ value\ of\ benefit,\ b = 0.07 * 94,250,000 = Tk.\ 6,597,500\ i.e.\ US\$\ 83820.$$

Again, on an average, the present land price per katha in Mohammadpur area is approximately 8,000,000 and the building/ apartment price per square feet is Tk. 7,000 (Seraj, 2012). As the plot of the building is approximately 4.25 katha, the area of the building is approximately 2800 square feet and the building is of 4 storeys, so the total price of the land is Tk. 3,40,00,000 and the building is (Tk. 2800*7,000*4)= Tk. 78,400,000. Thus, value of the roof garden host property is approximately Tk. 112,400,000.

$$Hence,\ value\ of\ benefit,\ b = 0.07 * 11,24,00,000 = Tk.\ 78,68,000\ i.e.\ US\$\ 99962.$$

7.2.2. Food production

The value of the food production benefit can be estimated using the following formula:

$$b = P * g * a \text{ (Tomalty \& Komorowski 2010)}$$

In the above mentioned formula, 'b' represents annual value of benefit and 'a' represents roof garden area in square meter. The duration of growing season (g) of fruits, vegetables and other plants is 12 months as in Bangladesh crops are grown all over the year. For mixed fruit and vegetables (low case scenario), productivity (P) is Tk. 158 or $2 per square meter per month and for lettuces, herbs and flowers (high case scenario), productivity (P) is Tk. 1580 or $20 per square meter per month (Tomalty & Komorowski 2010).

Hence, for this study, the food production value from rooftop farming of the practitioner of Mirpur area is estimated to be between Tk. 473,846.79 and Tk. 4738,467.936 i.e. US$ 6020 and US$ 60202. As the garden mostly produces mixed fruits and vegetables, so the total value of production is likely to be at the lower end of this range (around Tk. 473,846.79 i.e. US$ 6020). Again, the food production value from rooftop farming of the practitioner of Mohammadpur area is estimated to be between Tk. 210,596.98 and Tk. 2,105,969.80 i.e. US$ 2676 and US$ 26756. As the garden produces fruits, vegetables and also lettuces, flowers, so the total value of production is likely to be at the middle of this range (around Tk. 1,158,283.39 i.e. US$ 14,716).

7.2.3. Storm water retention

The value of the storm water retention benefit can be estimated using the following equation:

$$b = (R + E) * C * a \text{ (Tomalty \& Komorowski 2010)}$$

In this formula, 'b' indicates annual value of benefit and 'a' indicates roof garden area in square meter. The value of erosion mitigation, E is worth $13.66/$m^3$ i.e. Tk. 1075/m^3 (Tomalty & Komorowski 2010). The lowest value for storm water retention services is $20.13/$m^3$ (R) for a retention pond and the highest value is $1059.44/$m^3$ (R) for a retention basin (Cunningham 2001). An average retention capacity of 42.7 L/m^2_{roof} (C) as used by Carter and Keeler (2008) has been used for the purpose of the calculation.

Therefore, in this study, the storm water management benefit from rooftop farming of the practitioner of Mirpur area is

estimated to range between Tk. 28,430.84 and Tk. 904,652.59 i.e. US$ 361 and US$ 11494 and the practitioner of Mohammadpur area is estimated to range between Tk. 12,635.82 and Tk. 402,064.73 i.e. US$ 161 and US$ 5108. As these two buildings are located in a very dense urban environment with very high land values, low cost storm water management solutions cannot be not an option. For this reason, the values of the benefits are likely to be at the upper end of the range in these cases (around Tk. 904,652.59 i.e. US$ 11494 and around Tk. 402,064.73 i.e. US$ 5108).

7.2.4. Air quality

For the purpose of calculation of air quality benefit, following formula has been used in this study:

$$b = (g/12months) * [H_{sg} * a_{sg} + H_{tg} * a_{tg} + H_d * a_d] \text{ (Tomalty \& Komorowski 2010)}$$

In the above formula, b is the value of benefit; g is the growing season in months; H_{sg}, H_{tg} and H_d represent the health benefit for short grass pollution absorption, for tall herbaceous plant pollution absorption and for deciduous plant pollution absorption in $/m^2*year respectively and a_{sg}, a_{tg} and a_d represent the roof garden area covered by short grass, by tall herbaceous plant and deciduous plants in m^2 respectively.

The duration of growing season (g) of fruits, vegetables and other plants is 12 months as in Bangladesh crops are grown all over the year. Value of annual pollutant removal health benefit for different types of rooftop vegetation has been used 0.0521 US$/m^2 for short grass, 0.0673 US$/m^2 for tall herbaceous plants and 0.0839 US$/m^2 for deciduous trees (Tomalty & Komorowski 2010).

Thus, in this study, the air quality benefit from rooftop farming for the practitioner of Mirpur area is estimated to be worth between Tk. 1018.51 and Tk. 1634.81 i.e. US$ 12.94 and US$ 20.77 and for the practitioner of Mohammadpur area is estimated to be worth between Tk. 452.78 and Tk. 726.56 i.e. US$ 5.75 and US$ 9.23. As both roofs are semi-extensive, with mixed grassy and leafy vegetation and fruits, the value of the benefits are likely to tend towards the middle of the range (around Tk. 1326.66 i.e. US$ 16.85 and around Tk. 589.67 i.e. US$ 7.5).

7.2.5. Carbon sequestration

To calculate carbon sequestration, following equation has been used-

$$b = S_d * a_d + S_g * a_g + S_f * a_f \text{ (Tomalty \& Komorowski 2010)}$$

In this formula, b means the value of benefit in $/year; S_d, S_g and S_f denote the value of carbon sequestration by deciduous plants, by grasses and by productive agriculture in $/ha*year respectively and a_d, a_g and a_f represent the area of roof garden covered by deciduous plants (ha), covered by grasses and covered by productive crops in hectare respectively.

The value of carbon sequestration by deciduous plants, by grasses and by productive agriculture have been found to be worth $39.11/ha, $28.46/ha and $28.59/ha respectively (Tomalty & Komorowski 2010).

Hence, for this study, the carbon sequestration benefit from rooftop farming of the practitioner of Mirpur area is estimated to be worth between Tk. 56.2 and Tk. 77.14 i.e. US$ 0.72 and US$ 1 and the practitioner of Mohammadpur area is estimated to be worth between Tk. 24.973 and Tk. 34.319 i.e. US$ 0.35 and US$ 0.5. As both roofs are semi-extensive, with mixed grassy and leafy vegetation and fruits, the value of the benefits are likely to lie in the middle of the range (around Tk. 66.67 i.e. US$ 0.9 and around Tk. 29.646 i.e. US$ 0.4).

Though the air quality and carbon sequestration benefits are very insignificant for individual roof gardens, both of these benefits would be more meaningful if calculated for numerous roof gardens covering a large portion of a city.

8. Problems faced by the practitioners and non-practitioners

Birds and vegetable have an ambivalent relationship. Though many birds are important predators of garden pests, it has been found that sometimes birds create disturbance by eating the small vegetable and fruit plants.

The leaves of the plants make the roof unclean so it is necessary to clean the roof in a regular basis.

Another problem is to find good quality plants. Most of the times, they get plants from nearby nursery. But sometimes they get deceived and bought low quality plants and thus they do not get desirable production.

Only one time help has been done from DAE project in 2013. There is no further help and follow up from government or any other organizations for improving their rooftop farming. Tenants usually do not take part in improvement of the garden. Moreover, if practitioner wants to expand the garden, skilled gardener would be required.

Another issue that has been found in case of Mrs. Nahid that shadow of neighboring building hampers production in her garden. So, absence of height and (building) density zoning would be a more potential problem when number of such practitioners would increase.

From non-practitioners point of view, one non-practitioner from Mohammadpur objected that now-a-days open spaces and playfields for children are very rare in Dhaka city. Children have the option to play at the roof. But the roof garden restricts the use of roof for children to play games. So the children become more dependent on technology.

Besides half of the non-practitioners, who were tenants in the area, observed that motivating their land lords to allow them use the rooftop for gardening would not be an easy task. They also urged for formulation of policy for rooftop use both by tenants and owners.

9. Opportunities for rooftop farming in Dhaka

9.1. Meeting a portion of household demand for vegetables and fruits

From the primary survey of non-practitioner, household vegetable and fruit demand have been identified. Generally people eat all kinds of vegetables but preference may vary and it would affect the quantity demand of vegetables. Vegetable demand also varies depending upon seasons. From the survey of non-practitioners, it has been identified that 43.48% people in Mirpur consume 85–105 kg vegetables annually while maximum people of Mohammadpur (33.70%) consume 65–85 kg vegetables yearly. It has been identified that 43.48% people of Mirpur, who consume 85–105 kg vegetable, spend Tk. 20,000–25,000 i.e. US$ 254- US$ 317.6 and 33.70% people of Mohammadpur, who consume 65–85 kg vegetable, spend Tk. 15,000–20,000 i.e. US$ 190.6- US$ 254. Again People, who consume highest in Mirpur (7.61%) and Mohammadpur (9.78%), also spend Tk. 25,000–30,000 i.e. US$ 317.6- US$ 381.1 annually.

Fruit is also an important source of nutrition. As fruit price is higher than vegetable, sometime people cannot afford to buy even if they want to consume. The maximum people of Mirpur (45.65%) consume 20–25 kg fruits annually while the same amount of fruit is consumed by 41.30% people of Mohammadpur. However, they have to spend Tk. 12,000–16,000 i.e. US$ 152.5- US$ 203.3 to consume these amounts of fruits. Again 39.13% people in Mohammadpur, 33.70% people in Mirpur and 32.26% people in Uttara buy 15–20 kg fruits and they spend Tk. 8000–12,000 i.e. US$ 101.6- US$ 152.5. If rooftop farming can be implemented properly, it can support the growing demand for food especially for vegetables and fruits and possibly will save a decent share of household expenditures on food.

9.2. Scope and facilities of rooftop farming

To implement rooftop farming, some pre-conditions have to be fulfilled. First of all, vacant roof space should be available which are not in use for any other purposes. From the non-practitioner respondents, it has been explored that 84.78% and 82.61% people's roof spaces are available for farming in Mirpur and Mohammadpur respectively. Among them 88.46% are willing to practice rooftop farming in Mirpur while the figure is 68.42% for Mohammadpur. Again, 80% land lords, having building coverage i.e. roof size below 1500 square feet or above 4500 square feet, are willing to provide half of the roof area (i.e. 50%), while land lords having roof in between 1500 and 4500 square feet are willing to provide even the roof for farming. It has been found that if the roof is too small, gardening will make any other use of the roof really difficult. While, if the roof is much bigger rooftop (i.e. greater than 4500 square feet) opportunity cost of gardening is high, as smaller meeting or community place, physical exercise or indoor games corners etc cannot be arranged. Hence land owners in these cases are not willing to allow more than 50% of the rooftop.

9.3. Willingness to bear the cost

When it is about cost bearing for farming, people are willing to bear minimum or moderate cost. Maximum non-practitioners (in Mirpur 55.07% and in Mohammadpur 48.48%) are willing to spend Tk. 5000–10,000 i.e. US$ 63.5- US$ 127 to implement rooftop farming.

10. Threats to rooftop farming in Dhaka

During non-practitioners survey it had been explored why people were not practicing rooftop farming. Most of them answered that they did not have sufficient leisure or free time to implement and look after the garden. 33.3% people told that they are busy with their personal and official works and do not have enough time to spend on gardening or farming. Lack of technological knowledge is also a constraint for not practicing. There is very few opportunities for acquire technological and farming knowledge.

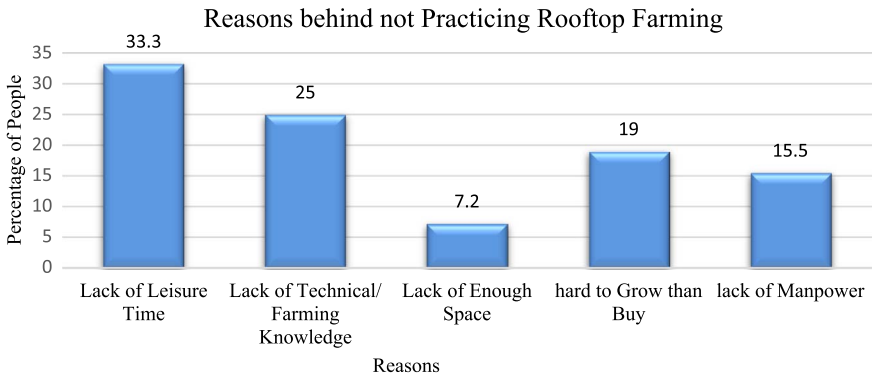

Fig. 3. Reasons behind not willing to Practice Rooftop Farming.
Field Survey, 2016

There is no government or private initiative to train people and serve proper farming facilities. So 25% people said that they are not willing to practice as they do not have proper farming knowledge.

There is also a tendency to buy food items from near market places rather than growing them. 19% people think that it is easier to buy necessary products from nearby market or kutcha bazar than growing on their rooftop as it requires time, labor and money. So they think they can have what they want by spending some money. Lack of manpower is also a limitation. If people want to implement farming on their rooftop, they need some assistance but in present condition there is lack of experienced and competent labor for taking care of farming. 15.5% people think that it is a problem to them of having no manpower. Only 7.2% people answered that they do not have enough space because their roof is used by other purposes (Fig. 3).

11. Recommendations

- There is no proper initiatives and incentives from government or any other organizations to boost up and flourish the practice of rooftop farming in Dhaka city. As mentioned earlier, there are policy incentive practices in Tokyo, Austin and Portland. Similarly, several policy incentives can be introduced for Dhaka city as well. However, in current building codes like Bangladesh National Building Code (BNBC 2006), there has no provision for including facilities for rooftop farming when any building is designed. Thus, the provision can be made in BNBC and can be enacted to make rooftop farming mandatory in all new construction. In addition, FAR (Floor Area Ratio) or density bonus can be provided to the people who will practice rooftop farming. This will further encourage real estate sector to consider rooftop farming in the designing building. Moreover, municipality should provide fund or incentive for those who are currently practicing and those who will practice in future as by storm water retention due to rooftop farming, municipality can save a significant amount of money. Also, if government provides incentives regarding the price of plants and necessary equipment, it may encourage people to initiate rooftop farming.
- There is a lack of information about rooftop farming among the Dhaka city dwellers. The people are not fully aware of the benefits that can be tapped from rooftop farming. This is mainly due to the fact that there are no organized efforts on it from government, community and NGO side. Again, most of the people do not have proper technical or farming knowledge on rooftop farming. Proper training and awareness program should be initiated by Government to spread the knowledge of rooftop farming. DAE should be worked in more efficient way and should be supportive to make provision of rooftop farming training in a regular basis through support from NGOs or community organizations.
- Though most of the roofs of Dhaka city are suitable for gardening, some modifications are always necessary to make it more suitable for rooftop farming. This always includes an extra cost. However, if the design of a building considers rooftop farming from the inception phase so that it can bear the load of the plants, soil etc., this further modification and extra cost committed to that will not be needed. It should also be planned that what plants to be grown and which space of the roof can bear how much of the weight, the size of the drums or tubs etc. There should also be provision to provide necessary facilities like water taps in different location on the roof, designated space for plantation, facility of netting to protect plants and fruits from birds etc. All these necessary measures should be considered during the design phase of the buildings.
- One of the most prominent challenges to rooftop farming in Dhaka is roof dampness. For saving the roof from any harmful condition, drums, containers and tubs can be placed over the bricks. If there are bed systems for vegetables and fruits in the roof, then the roof will be saved from future damage.

12. Conclusion

As population of Dhaka city is growing higher and higher, demand for food and expenditure on food are also increasing. But the resource is scarce as agricultural land is converting to residential, commercial or industrial land uses. Thus it reduces the possibility to grow more and different agricultural food products. Again food contamination such as harmful chemical usage to ripe fruits, hazardous and inorganic fertilizer and pesticide usage to increase production etc. is increasing at an alarming rate. In this circumstances, to solve these problems and find a way out, initiation of rooftop farming can be a possible and potential solution. Rooftop farming can help to meet food demand by supplying fresh and hygienic food products, reducing household expenditure for buying vegetable and fruit, saving cost for municipality by storm water retention, creating healthy atmosphere by improving air quality and absorbing carbon from air and lessening the impact of climate change. But without government provision this is not possible to initiate at a large scale. If government and other responsible organizations step forward to encourage and flourish the practice of rooftop farming, a sustainable city can be built by ensuring food supply and urban greenery. This study basically concentrates on the practice of rooftop farming in Dhaka city and associated challenges through the intense study of two cases. But other cities can also practice and may get similar benefit. Other countries that have scarcity of cultivable land like Bangladesh can also practice rooftop farming to increase greenery and fresh food supply by following the farming method. With the help and guidance of this study, any further research like calculation of benefits of rooftop farming in local, regional and national contexts, standardize the constant factors of monetary valuation, create a replicable model of rooftop farming is possible.

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