POTENTIAL OF URBAN ROOFTOP AGRICULTURE AS A CLIMATE CHANGE ADAPTATION TOOL THROUGH EFFICIENT WATER MANGEMENT

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CERTIFICATE OF APPROVAL

The thesis titled "**POTENTIAL OF URBAN ROOFTOP AGRICULTURE AS A CLIMATE CHANGE ADAPTATION TOOL THROUGH EFFICIENT WATER MANAGEMENT"** Submitted by Musammat Shahinara Begum, Roll No. 0413284002F, Session: April 2013, has been accepted as satisfactory in partial fulfilment of the requirement for the degree of Doctor of Philosophy (Ph.D.) on 8 January 2022.

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This is to certify that this work entitled "**Potential of Urban Rooftop Agriculture as a Climate Change Adaptation Tool Through Efficient Water Management**" has been done by me under the supervision of Dr. Sujit Kumar Bala, Professor, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), Dhaka. I do hereby declare that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma from any other institution.

Signature of the candidate

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DEDICATED

TO MY BELOVED FAMILY

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ABSTRACT

Urban cities are facing the challenges of microclimatic changes with substantially warmer environments than adjacent rural areas and making cities uncomfortable embracing challenges like ecological imbalances, fresh food unavailability, water insecurity, insufficient agricultural land, increased climate change risks, reduced green spaces and many other. Resilient cities through green approaches are the global demand to eliminate the climate change impacts. The gradual growth of urban rooftop agriculture (URTA) is an increasing trend among private residents towards the green cities and URTA differs substantially from traditional agriculture in terms of built-up urban environment. So, URTA needed a science-based study to achieve economically, socially and ecologically viable urban agriculture with indicative guidelines to popularize it.

For this purpose, this study was carried out two experimental plots with agriculture on roof of the buildings in Dhaka. The area covered with agriculture was 70% of the roof top area where selected crops were tomato, brinjal, chili, bottle gourd and leafy vegetables. The modern drip method was considered as an irrigation technique. The water productivity of those crops was compared to the traditional irrigation approach. So, groundwater and grey and rain water were considered as irrigation source. ET_0 of those crops were estimated using the CROPWAT 8.0 model. The microclimatic parameters like air temperature, near roof surface temperature, indoor temperature and relative humidity and carbon dioxide concentration from different locations of the experimental agricultural plot and from nearby bare roofs were recorded. Five private rooftop gardens with green area coverage of 40%, 50%, 60%, 80%, and 85% and nearby 5 bare roofs were also selected and measured the temperature in the roofs and rooms below the roofs for estimating cooling effect of rooftop agriculture. Questionnaire surveys were done for 200 private rooftop gardens for understanding the social dynamics of the existing private rooftop gardens.

The results showed that the temperature in the rooftops and top floor rooms under rooftops were found to be reduced from 1.2°C to 5.5 °C and 1.38 to 3.07°C respectively. The cooling load was found to be decreased from 3.62% to 23.73%, and energy saving increased significantly from 5.87% to 55.63% for agricultural roofs compared to bare roofs. Excess irrigation water use by the traditional method was around 30% to 75% of compared to the drip irrigation method. It was found that drip irrigation using rain and grey-water could save up to 80% potable water through increased yield by about 31.87% to 33.33% compared to hand irrigation by hose pipe or other devices. Based on the experimental results of the study, a climate and water smart rooftop agricultural conceptual model (CWSRAM) has been proposed for further wide application of the urban rooftop agriculture to arrest urban heat island and micro climatic parameters as a tool of climate change adaptation technology. This conceptual model included the need for capacity development of different actors in national rooftop agricultural systems and the provision of appropriate incentives to involve the private sector in strengthening rooftop agriculture as commercial thinking.

It could be concluded that the urban rooftop agriculture is highly environment and economic friendly to compensate warming up of urban cities through cooling effect as well as supplying fresh vegetables to the dining tables. The city corporations, govt. agencies need to support the rooftop agriculture initiatives through policy supports and addition of change in building code. Findings of the study can be useful for urban planners, city dwellers, and researchers for their respective uses. The CWSRAM can serve as a guiding tool to achieve the resilient urban cities towards the sustainability.

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ABBREVIATIONS AND ACRONYMS

URTA	Urban rooftop agriculture
AR	Agricultural Roof
AT	Air Temperature
BMD	Bangladesh Meteorological Department
BR	Bare Roof
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
CDD	Cooling Degree Day
ETc	Evapotranspiration of Crops
DI	Drip Irrigation
DMA	Dhaka Metropolitan Area
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GR	Green Roof
IPCC	Intergovernmental Panel on Climate Change
OLI	Operational Land Imager
LST	Land Surface Temperature
RH	Relative Humidity
RST	Roof Surface Temperature
SAU	Sher-e-Bangla Agricultural University
TIR	Thermal infrared
TIRS	Thermal Infrared Sensor (TIRS)
UNFCC	United Nations Framework Convention on Climate Change
UHI	Urban Heat Island
URTA	Urban Rooftop Agriculture
UNFCC	United Nations Framework Convention on Climate Change
NDVI	Normalize Difference Vegetation Index
ULCC	Urban land cover changes

Chapter 1
INTRODUCTION

1.1 Background

An urban heat island (UHI) phenomenon has been created in urban city areas with substantial warmer temperature than adjacent rural areas causing huge thermal discomfort to all living entities [1]. As a result, urban city is facing the challenges of fresh food, water security, health threats and clean city to achieve Sustainable Development Goals (SDGs) 2, 6 and 11 [2]. Dhaka is a mega city with 17 million people and poised to be the 6th largest city of the world by 2030 with a population of about 27 million [3]. Global warming will have additional impacts upon Dhaka city increasing severe UHI conditions creating more heat stress impacting urban life quality and all concerned activities [4] [5]. There are several studies carried out in Bangladesh to examine the cooling effect by green roofs of Dhaka city and found the potential to decrease of temperature of about 1.8 to 5.4 degrees Celsius. [6]]7] [8]. Green roofs reduce 10-50% energy and peak electricity use up to 23% during the summer as well as reduces the air-conditioning applications [9]. It has been found that each 0.5^{o}C reduction of indoor air temperature is capable of 8% reduction of electricity consumption [10]. A study in Toronto city also found that with a green roof, an entire typical residential building experienced 25% cooling effect, while for the floor below the green roof had the 60% cooling effect [11]. Another study also found that green roofs of industrial buildings save from 1/100th to 1/10th amount of total annual energy consumption [12]. A greenery vegetation activity like Urban Rooftop Agriculture (URTA) is turning out to be a very effective green adaptation tool to cool down UHI for resilient urban cities to global warming [13] [14]. Moreover, URTA helps increasing social community, environmental quality and economic conditions of city dwellers and can provide people with more access to fresh vegetables for a healthier food supply [15] [17].

1.2 The Rationale of the Study

Among Water functions as a key element in any greening action and activity as well as the most important factor for promoting URTA [18]. Scarcity of water in urban areas is rapidly increasing due to urbanizing and population growth as well as increasing demand and pressure for water resources, more than any other resource or commodity and it will be increased by 55% by 2050 [19] [20]. Efficient water use and management are today's major concerns to properly manage the water resources, gains an economic advantage and reduces environmental burdens [21]. In URTA, usually irrigation is carried out using local traditional tools like mugs, hose pipes, etc. where huge fresh potable water is lost [22]. More than 90% rooftop gardeners in Dhaka city and about 82% rooftop gardeners in Chittagong city use traditional irrigation from own water source [23]. Therefore, an effective, efficient and economic viable method is highly important for utilization of the scarce water particularly during the dry season. Rooftop drip irrigation reduces fire risks, increase evaporative cooling instead of a destructive splattering and due to slowly release moisture into the soil [24]. A study found that the drip irrigation increased water use efficiency by 60-200%, saved water by 20-60%, reduced fertilization requirement by 20-33% through fertigation, produced better quality crop and increased yield by 7-25% as compared with conventional irrigation [25]. Another study also finds that the distribution efficiency, design discharge uniformity, application efficiency and water application uniformity of drip irrigation system is 94-96%, 77-81%, 85 -88% and more than 80% respectively [26]. It also finds that drip irrigation achieves up to 95 percent irrigation efficiency [27]. The several studies also find that drip irrigation saves water, minimizes irrigation cost, reduces all losses except transpiration, increases yield and water productivity [28] [30]. The performance of drip irrigation is usually defined in terms of its efficiency and its uniformity of water application which leads to sustainable agricultural production [31].

In Dhaka city, a gradual growth of URTA is happening through private rooftop gardens. The owners of the garden do it out of hobby or recreational purposes or out of love to nature only without considering the efficient water management techniques and productivity. But, URTA needs to be established based on a set of science-based findings and conceptual models which should address climate change mitigation and adaptation, food security, water productivity as well as crop productivity [32] [35]. At present, conceptual climate and water smart model for URTA is not formulated for an urban city. The criteria of climate smart water saving URTA model needs to be derived from a micro level drip irrigation experiment under URTA and from the survey of existing rooftop gardens.

Several authors endorsed that increasing the green vegetation is one of the most effective strategies to mitigate the UHI effects [36] - [41]. But there are some knowledge gaps on cooling effect of the types of crops and the percentage of roof area cover-age of URTA which will reduce urban heat island effects through the efficient water management. That's why in light of the above discussion original contribution of this study will be addressed the urban irrigation development as well as establish a conceptual 'Climate and Water Smart Rooftop Agriculture' Model to UHI reduction and energy saving of livelihoods. Water resource management of URTA will be encompassed based on a holistic benefit of drip irrigation that will goes beyond fresh food production and global warming reduction as well as popularization of URTA to everyone, to every apartment and to every building. In light of the above discussion, this study has been proposed to achieve the following aims and objectives.

1.3 Objectives and Outcomes

The specific aim of the current study is to develop a Conceptual 'Climate and Water Smart Rooftop Agriculture' Model which would utilize inclusive exploration of URTA to address UHI as well as urban microclimatic changes by increasing cooler environment for urban dwellers through URTA with efficient water management practices. To accomplish the main objective, the following specific objectives will be achieved by this study:

i) To assess spatio-temporal trend in land surface temperature (LST) using remotely sensed data;
ii) To assess the environmental and social dynamics of urban rooftop agriculture and their impacts on microclimate change;
iii) To evaluate the performance of a water saving irrigation technology in an urban rooftop agriculture;
iv) To develop a Conceptual Climate and Water Smart Rooftop Agriculture Model.

The possible outcome of this study will be understanding most hotpot zone through GIS based maps of spatial and temporal trend in land surface temperature in Dhaka City for five areas will be found which will demonstrate the gradual increase of thermal regime of Dhaka city. Indoor and outdoor thermal dynamics under experimental green roofs and blank roofs will be found showing changes temperature and exposing the huge reduction of urban heat and energy consumption and potential applicability of climate change adaptation. The performance of drip irrigation technology will also be found which increase crop water productivity of selected vegetables with application and distribution uniformity of water as well as soil moisture dynamics under urban roof's weather conditions. Finally, a Conceptual Climate and Water Smart Rooftop Agriculture Model will be the final outcome of the study that will help city dwellers, developers as well as city planners and decision makers to take adaptive planning to reduce increasing urban heat to a great extent.

1.4 Outline of the Thesis

This thesis contains ten chapters.

Chapter 1 describes the background and rationale of the study. It also mentions the objectives of the study;

Chapter 2 describes the literature review on urbanization and microclimate change, urban warming and formation of urban heat island (UHI), variation of land surface temperature (LST), adaptation to urban warming, green approaches for reducing urban heat island, cooling effect of green approaches, social perspectives of green approaches, green approaches in urban Bangladesh, green roofs and urban water management, summary;

Chapter 3 and Chapter 4 describes the study area & data and the methodologies respectively;

Chapters 5 to Chapter 8 details the results and discussions found in this study;

Finally, **Chapter 9** draws the conclusions, recommendation and limitations of the study.

Chapter 2
LITERATURE REVIEW

4.1 Urbanization and Micro Climate Change

Urbanization is one of the most influential and visible humans caused forces on Earth particularly in developing countries. The rapid urbanization process plays a key role to change its microclimate where the heating would have a further impact upon the urban life quality [42]. In 1957, 30% of the global population lived in urban areas, in 2018, it reached 55% and an estimated 68% is projected to live in cities by 2050 [43]. Urbanization has played an important role in the development and modernization of underdeveloped and developing regions, and increasing attention has been paid to cities and urbanization from scientists and policy makers over the last several decades to global environmental changes [44]. The extent and rate of, whether greenhouse gas-induced warming, deforestation, desertification, or loss in biodiversity, are driven largely by the rapid growth of the Earth's human population. That's why Cities are the first to involvement effects from climate change. On the other hand, temperature rising, heat waves, extreme precipitation events, water logging are causing economic losses, social insecurity and affecting health and human well-being in the urban areas. Urban areas are the major sources of human caused carbon dioxide emissions from the burning of fossil fuels for heating and cooling; from industrial processes; transportation of people and goods, more than 90% of anthropogenic carbon emissions are generated in cities [Figure 2.2]. In the urban areas, less built-up areas and developed built-up areas are differenced by air temperature, humidity, wind speed and direction, and amount of precipitation [45]. These changes originate in large part from the altering of the natural topography through the construction of non-natural structures and surfaces. Urbanization deeply affected the environment and climate all over the world and has increased the climate change impacts [Figure 2.1]. The urban climate is clear by specific climate conditions which differ from surrounding rural areas, and have higher temperatures than surrounding rural areas and weaker winds. A microclimate is a local atmospheric region where the climate differs from the surrounding rural areas. The term micro-climatic area represents the areas as small as a few square meters or as large as many square kilometers [46]. On the opposite hand, close bodies of water which can cool the local atmosphere, or in severely urban regions where brick, concrete, and asphalt absorb the solar power, heat up, and reradiate that warmth to the ambient air; the resulting urban heat island may be a sort of microclimate [47]. However, urban microclimate depends on the type and size, geographical location, population size, and density, and height of buildings, street widths, and location, the subdivision of the building masses, etc. according to the city [Figure 2.1]. That's why urban development leads to surface modification, land cover change as well as at the structure and content of the atmosphere. Because unplanned urbanization creates a more impermeable environment which decreases the vegetation cover and increases in urban heat island effect (UHI) and increases carbon dioxide levels in the atmosphere which eventually leads to climatic changes [Figure 2.1, IPCC annual report 6]

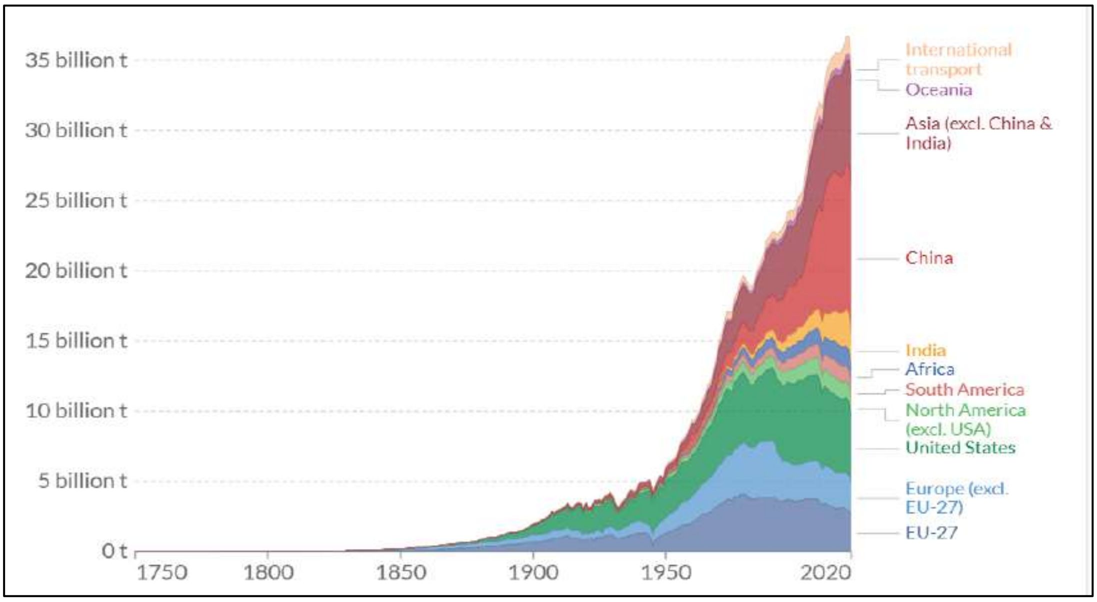


Figure 2. 1 Emissions produced by different economic sectors
(Source: Global Carbon Project. http://mitigation2014.org/report/figures/summary-for-policymakers-figures/)

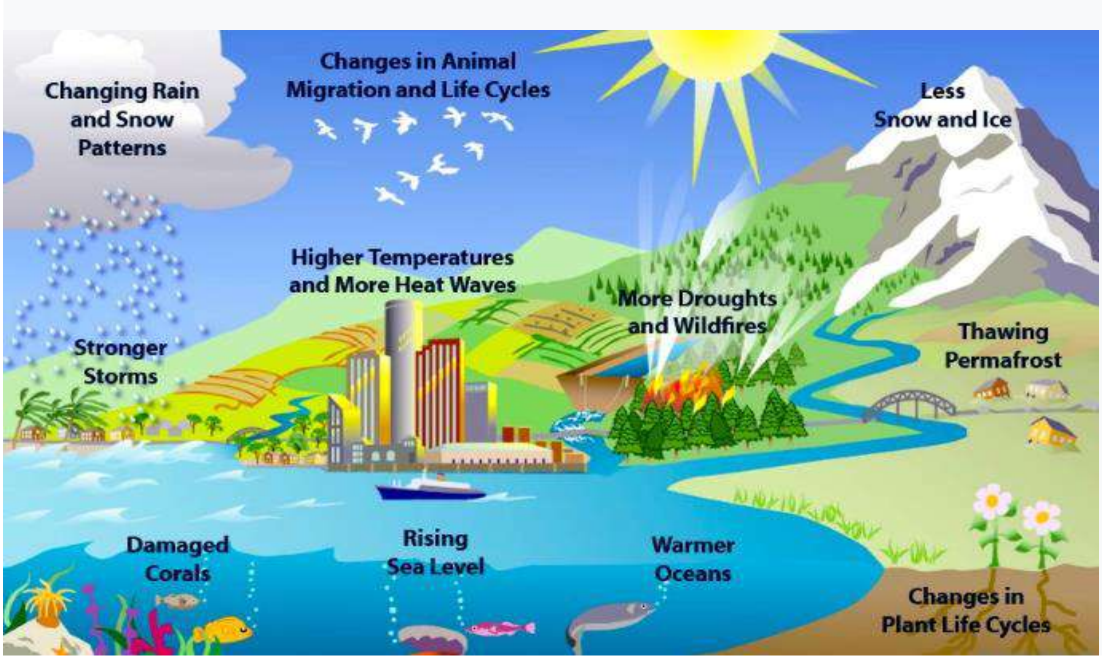


Figure 2. 2 Emissions produced by different economic sectors

Microclimates are concerned with the atmospheric layer that extends from the surface of the earth to a height where the effects of the features of the underlying surface can no longer be distinguished from the local climate [48]. It measures the most parameters of a microclimate during a house: temperature, humidity, and level of CO_2 (that is, freshness and to a point the purity of air). The microclimate can also be thought of, in the dimension of time, as a sequence of atmospheric changes that occur within a small region [49]. The urban microclimate is determined by the local temperature (LST and Air temperature), humidity, solar irradiation, and diffuse reflection, surface temperature of building and ground, the respective long-wave radiation exchange, and the sky condition are shown in Figure 2.1[50]. In this research work, three of the microclimatic parameters such as temperature, relative humidity, carbon-di-oxide are considered as variables because these are directly connected with building energy performance and thermal comfort.

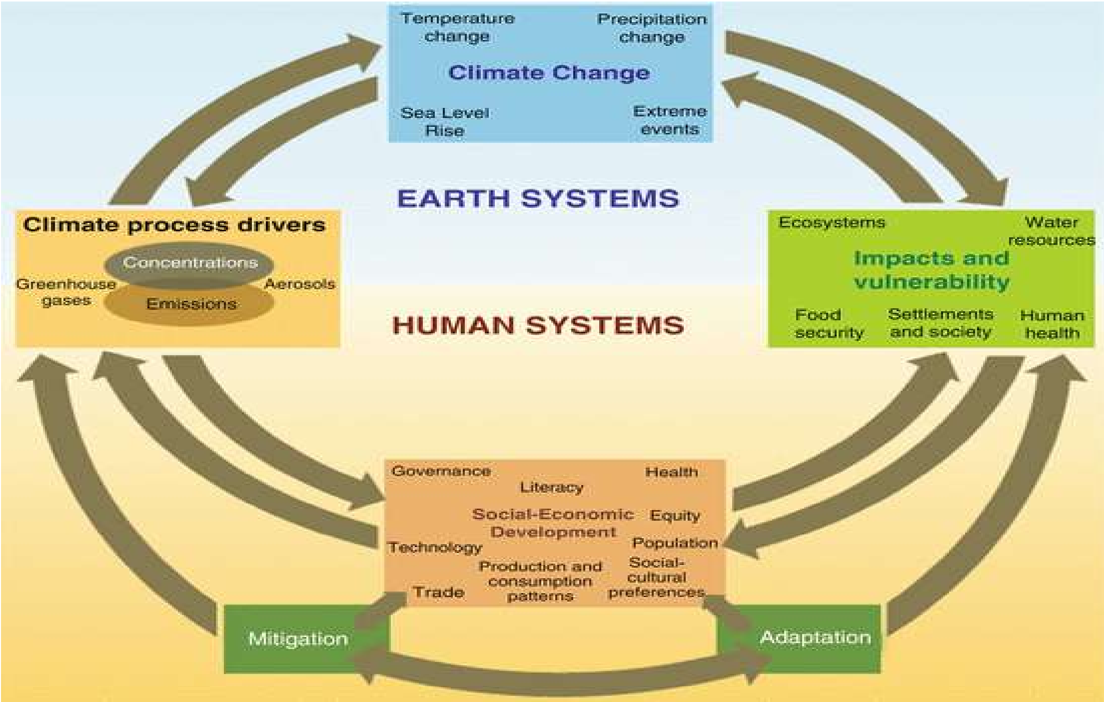


Figure 2. 3 Representativeoverview of the urbanization and climate change (Source: M. H. Bazrkar, N. Zamani, S. Eslamian, A. Eslamian, and Z. Dehghan, "Urbanization and Climate Change," in Handbook of Climate Change Adaptation, W. Leal Filho, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015, pp. 619)

2.2 Urban Warming and Formation of UHI

In a phase of global warming, the urban warming effect is likely to be amplified and as a result increase human discomfort, especially during summer. The local warming, caused by the urban heat island effect, significantly increases temperatures as well as economic losses in addition to global warming. Urban warming occurs from human-caused climate change, and it would be probably comparable to about half of the warming caused by climate change by the year 2050 [51] [52]. The rapid urbanization process plays a key role in the urban heat island (UHI) as well as global warming which will have additional impacts upon urban life quality [53]. Natural landscapes of urban areas are transformed into modern land use and land covers such as buildings, roads and, other impervious surfaces, making urban landscapes fragmented and complex and affecting the habitability of cities [54]. The urban heat island warming could double the economic losses expected from human-caused climate change as well as human activities creates 1.1°C of warming since the late 19th century [IPCC, 2021, Figure 2.3]. On average globally, urban heat island warming will probably be equivalent to about half the warming caused by climate change by the year 2050 [55]. Daily minimum temperature readings at related urban and rural sites frequently show that the urban site is 6° to 11° C (10° to 20° F) warmer than the rural site [56]. Two primary processes influence the formation of this “Warmer”. During summer, urban masonry and asphalt absorb, store, and reradiate more solar energy per unit area than do the vegetation and soil typical of rural areas [57].

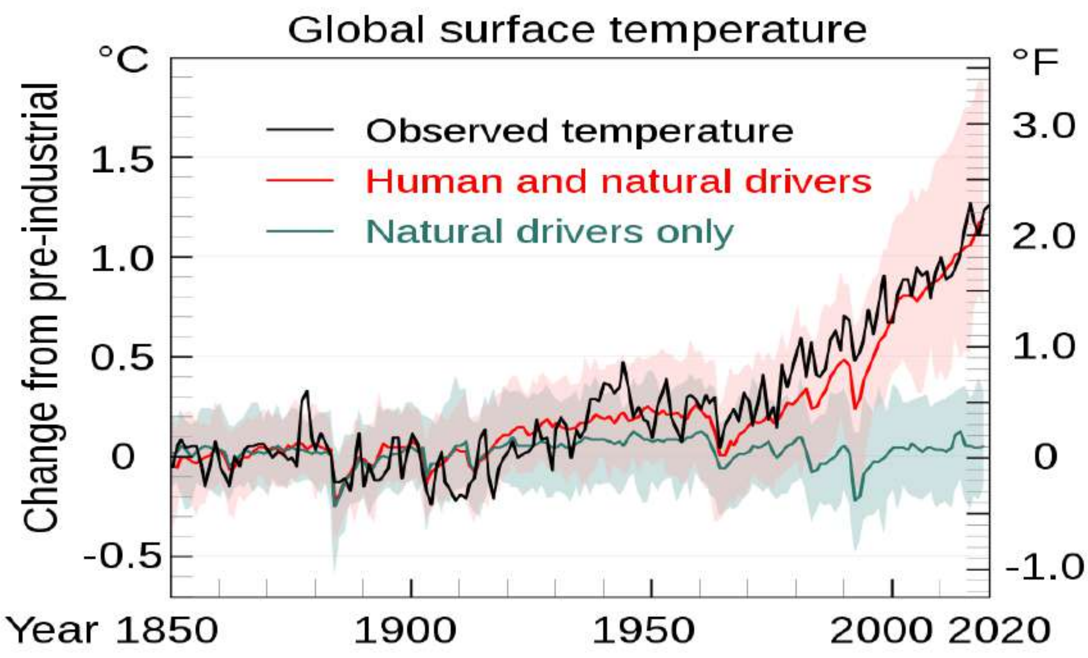


Figure 2. 4 Global surface temperature changes over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to CMIP6 climate model simulations of the temperature response to both human and natural drivers (red), and to only natural drivers (solar and volcanic activity, green). Solid colored lines show the multi-model average, and colored shades show the range ("very likely") of simulations. Source: IPCC AR6.

Furthermore, less of this energy uses for evaporation in urban areas, which characteristically exhibit greater precipitation runoff from streets and buildings [58]. At night, radioactive losses from urban building and street materials keep the city’s air warmer than that of rural areas. Human activities, both cultural and economic, have distinctive effects on this warmer as well as effects on urban climate [59]. Moreover, the weather conditions that are occasionally arisen allow the accumulation of pollutants over an urban area. For this reason, air temperature is increasing with strongly inhibits atmospheric mixing, and can cause acute distress in the population and even, under extremely severe conditions, and also loss of life [60]. As a result, global climate change is increasing through industrialization and urbanization. Currently, the most crucial problem that urban areas have been suffering from the surface temperatures are rising caused by the loss of vegetation and the increase of impermeable non-transpiring, non-evaporating, hard land surfaces areas [Figure 2.5] [61].

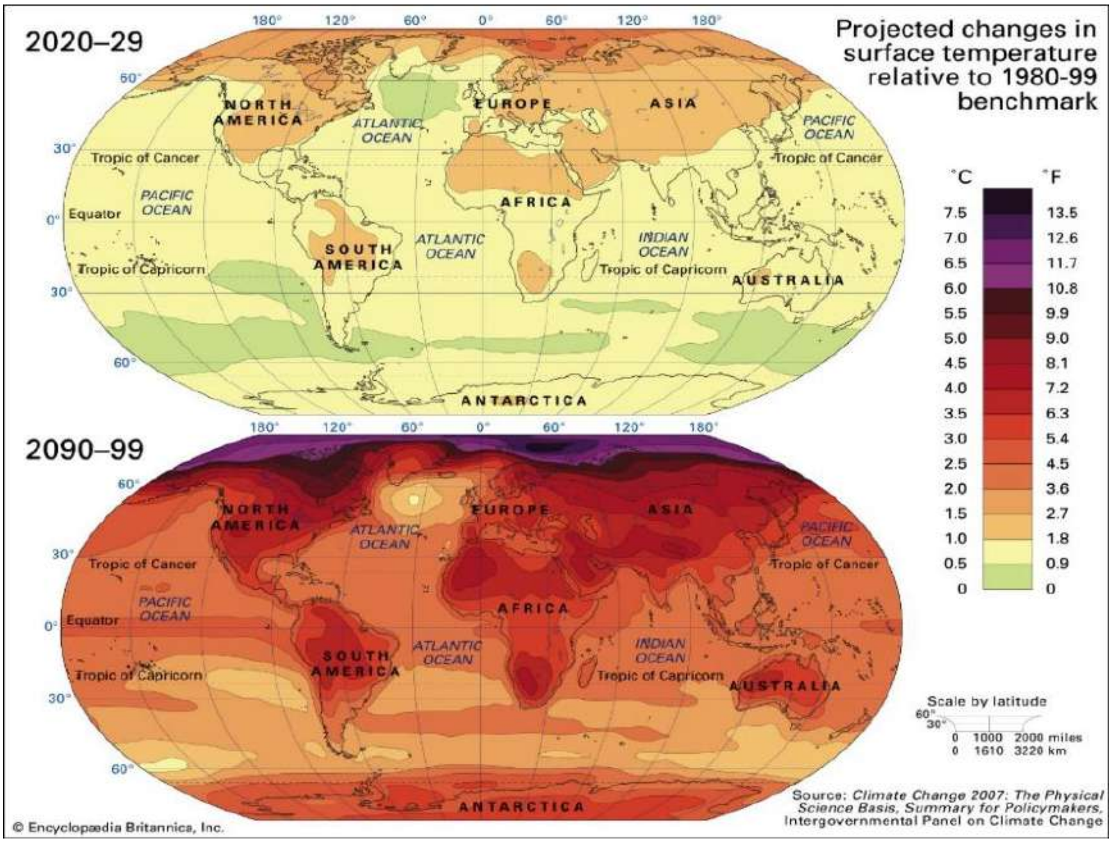


Figure 2. 5 Projected change in surface temperature in 2020-2029 and 2090 -99 relative to 1980-99

Source: IPCC AR5 report (http://mitigation2014.org/report/figures/summary-for-policymakers-figures/)

Climatic impact of urbanization on a regional level describes the urban heat islands (UHI) due to greenery and shade effect of vegetation through evapotranspiration and that’s why UHI displays discrepancy in ambient temperature inside the city and its surrounding areas producing and storing more heat than the surrounding rural areas [Figure 2.6 (a)].On the other hand, UHIs are the results of the unintentional modification of climate, which can lead to severe environmental and social consequences [Figure 2.6 (b)] [62].

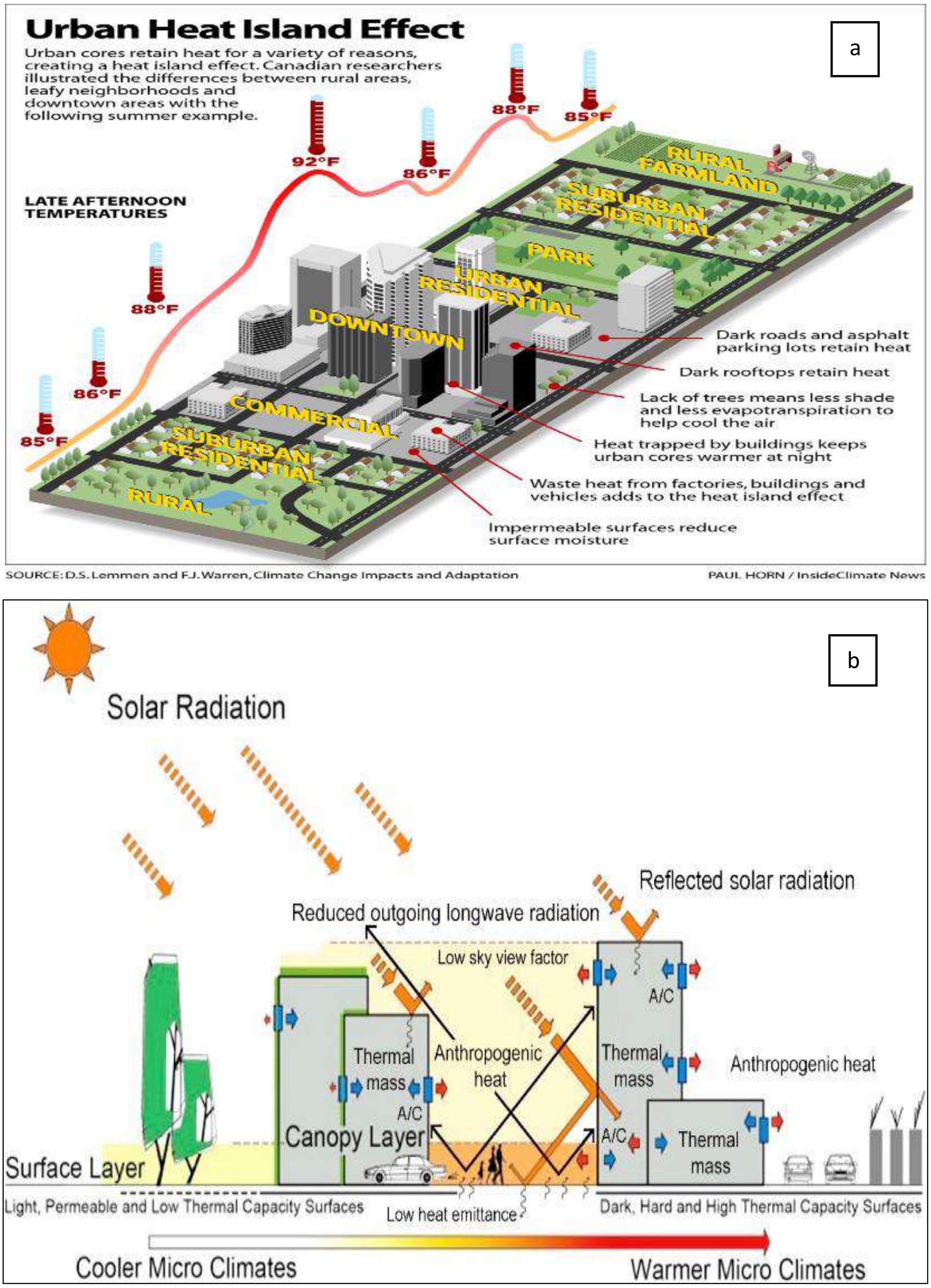


Figure 2.6 Urban Heat Island (UHI) Effect in Highly Developed Areas. (Source: Sharifi, E., & Lehmann, S. (2014). Comparative analysis of surface urban heat island effect in central Sydney, p. 25, and Osmond P, Sharifi E. Guide to urban cooling strategies. Low Carbon Living CRC. 2017 Jul.)

The UHI is more closely related to the type and amount of urban development than population or the actual size of the city [63]. Urban surface temperatures tend to increase the UHI and it also contain several hot spots inside with higher temperatures and UHI is created through the diversity of land surface, including natural factors and human factors [64]. However, with the development of urbanization, urban built-up areas, namely, impervious surfaces, including roads and buildings, instead of green lands and water bodies, are rapidly sprawling, and, thus, the city is suffering from the UHI effect [65]. Paved roofs absorbing the heat blacktop absorbs the sun as well as land surface temperature increases with reflect of much solar radiation and get hotter than lighter colored surfaces [66].

2.3 Variation of Land Surface Temperature (LST)

LST is an indicator for UHI and a general climate variable, which refers to the temperature measured in the air close (1 m) to the earth's surface in an open area [59]. The LST of a place is the indicator of its climate change and radiation exchange with the atmosphere [67]. LST is the term of how hot the "surface" of the world would feel to the touch during a particular location [68]. The LST or skin temperature refers to the temperature of the top surface in bare soil conditions and to the effective emitting temperature of vegetation "canopies" as determined from a view of the top of a canopy. LST could even be a basic determinant of terrestrial thermal behavior because it controls the effective radiating temperature of the surface [69]. LST assisted by the thermal infrared bands of remote sensing data of space-borne sensors, which analyze the connection between urban thermal patterns, spatial structure, and urban surface characteristics may be a major application of remote sensing in urban climate studies because it helps land use and occupation planning [70]. LST information on regional and global scales is obtained by thermal infrared (TIR) remote sensing; it's a singular approach as sensors during this spectral region detect the energy that is emitted directly from the land surface [71]. The urban thermal environment is governed by the distribution of land surface temperature (LST). Many studies have been also supported satellite image applied remote sensing (RS) and geographical information system (GIS) to examine the impact of urban growth on surface temperatures. Urban land development raised the surface radiant temperature by 13.01 K used landscape metrics to look at the connection between LULC pattern and LST and regarded landscape ecology as an efficient tool to quantify the LULC and LST patterns [72]. The LULC areas and landscape metrics can provide useful information for assessing and monitoring urban thermal environments in a neighborhood, but they can't compute the LST in each area urban thermal environment is governed by the distribution of LST [73]. The LULC areas and landscape metrics also provide useful information for assessing and monitoring urban thermal environments in a neighborhood, but they can't compute the LST in each area. Urban land cover changes (ULCC) due to urbanization are mainly caused by the removal of vegetation cover, which affects the microclimate change [74]. When the surfaces of different materials receive the same amount of solar radiation, the resulting temperature differs of that different surfaces, due to differences in their heating capacity [75]. In the urban areas' surface cover, the surface temperature is higher than in vegetated and water-covered areas. LST may be a controlling factor for many of the physical, chemical, and biological processes in the world, and maybe considered as a measure of global climate change [76]. For the urban environment, LST may be a crucial parameter for the monitoring of the energy exchange between the land surface and thus the atmosphere in terms of the sensible and heat of transformation fluxes [77] [78] which are important when discussing the thermal effects of the cities on the regional cli-mate. An understanding of LST is vital for urban climatology, global environmental change, and human-environment interactions [79]. Understanding the linkage between LST and concrete sur-face characteristics is vital for designing effective measures to mitigate the amplitude of SUHI [80]. Furthermore, effective and sustainable urban management increasingly demands innovative concepts and techniques to obtain up-to-date and area-wide information on the characteristics and development of the urban system in support of smart urbanization policies and measures [81]. The geographical and ecological patterns tend to be spatial variables of LST and its impact factors are often characterized by local changes [82]. The LST in Dhaka City has been increased substantially within the city area [83]. Most of the prevailing research has been accomplished based upon the LST changes or land cover (LC) changes in DMA [84] [85] for the period of 1989 - 2009. The LSTs were retrieved to know the variation of temperature from rural areas to urban areas [86] [87]. Another study found that agricultural land had been decreased from 67.38% to 62.20% between 1976 and 2014 having an annual rate of 0.56% between 2001 and 2008. The increase of the urban areas was found from 11% to 34.4% between 1960 and 2005 in Dhaka city. It has also been found that the warming has been mostly connected to Dhaka city due to urbanization having a global phenomenon [88]. The knowledge generated by this study will be an aid to assess and mitigate the socio-economic impacts of the increased thermal changes in the UHI of the DMA.

2.4 Adaptation to Urban Warming

In a phase of global warming, the urban warming effect is likely to be amplified especially increases in human discomfort during the summer period. The local warming, caused by the urban heat island, significantly increases temperatures as well as economic losses in addition to global warming [88]. That's why urban microclimate is changing as well as global warming is increasing in the urban areas [89] [90]. Adaptation is a response to global warming or urban warming as well as climate change. On the opposite hand, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities or natural systems, and human intervention is facilitated to the expected climate [91]. Adaptation actions are also considered the actions where the central aim is to take care of the essence and integrity of a system or transformational adaptation (actions that change the elemental attributes of a system in response to global climate change and its impacts). The need for adaptation varies from place to place, relying on the sensitivity and vulnerability to environmental impacts [92].

Building roofs are directly attached to these phenomena since high overheating on both walls and roof surfaces can negatively affect all these aspects [93] [94]. During the dry season, urban masonry and asphalt captivate, store, and re-radiate more solar energy per unit area than the vegetation and soil types of rural areas [95] [96]. Furthermore, less of this energy can be used for evaporation in urban areas, which characteristically exhibit greater precipitation runoff from streets and buildings [97] [98]. However, in arid environments, cities with large amounts of greenspace may actually be cooler than the surrounding dry areas. The locality in any city, the relative balance of controls depends on the nature of the urban environment, human activity, and meteorological conditions. Green adaptation improves the ecosystem services in an urban area which contribute to human wellbeing through production of fruits, grains and seeds; carbon sequestration; microclimate regulation; noise abatement; air, water and pollutant filtration; pollination; and recreation [99]. Integration of urban green spaces with other urban infrastructure can be effective adaptive responses to, extreme heat events. Importantly, for developing countries, green adaptation responses present affordable options, utilize ecosystems for multifunctional purposes, and involve multiple stakeholders [100]. Dhaka is the capital city of Bangladesh and is experiencing extensive agricultural land use change led by rapid urbanization. Mostly, lands are converted to built-up areas with urban expansion, poses severe impacts on wetlands, rivers, parks, agriculture land, forest. There is an urgent need to assess the states of these ecosystems and to implement measures to stop further deterioration and to maintain or improve ecosystem services for human wellbeing. It has been found that each 0.5^{o}C reduction of indoor air temperature allows an 8% reduction of electricity consumption [101] [102]. Air temperatures under green roofs are cooler than normal roofs at least by 3°C to 4°C and a building with a green roof experienced a 25% cooling effect, while the floor below the green roof had a 60% cooling effect [103] [104]. The roof gardens have the potential to act as insulation for the roof because of heat exchange with the outside environment [105]. Figure 2.7 represents that greenery vegetation activities is a very effective green adaptation tool to cool down UHI for achieving resilient urban cities in the face of global warming [106] [107]. In the context of global climate change, cities have a crucial role to play in building re-salient communities. Green roofs are complex interactions between natural systems and human activities, and it is an interdisciplinary research approach [108]. Conversely, most of the existing researches are based on the green version approaches such as parks, gardens, green roofs, green façades/walls, porous pavement, and green and blue belts in the context of urban development and to divert potential impacts of global climate change for the city center [109].

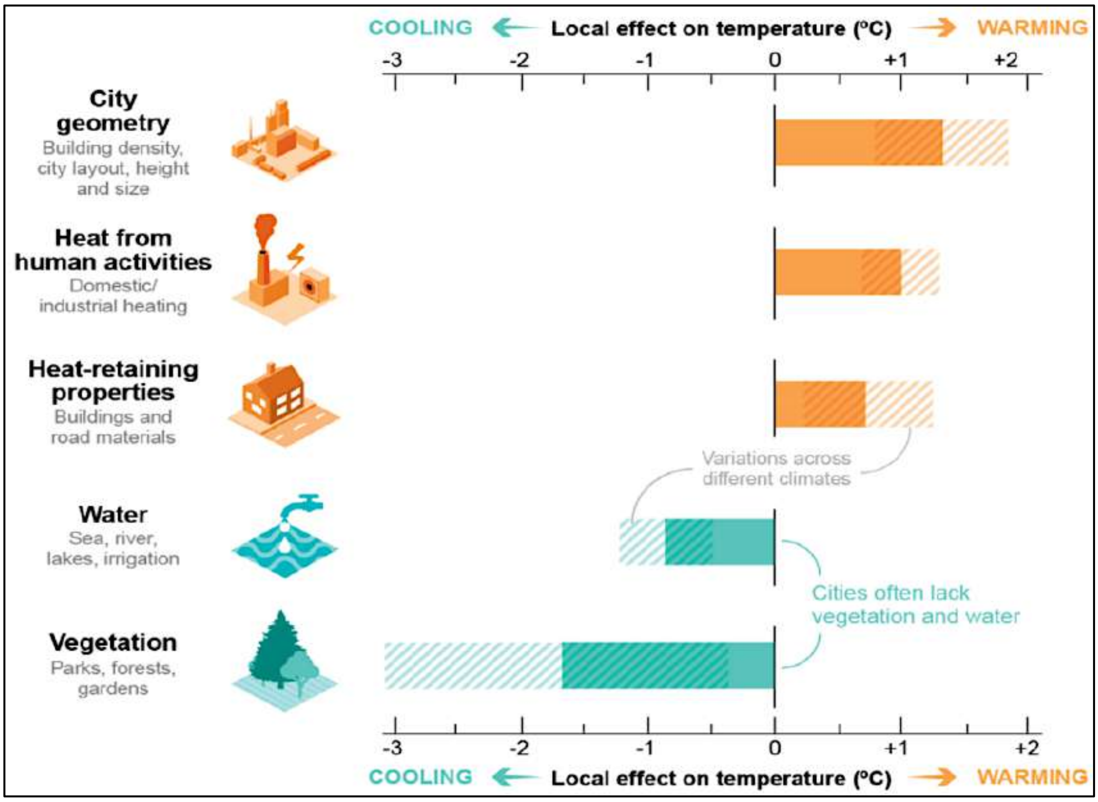


Figure 2. 7 Factors of heat releasing and natural cooling influences. (Source: sixth assessment report, IPCC, 2021)

Global warming will have additional impacts upon Dhaka city for the increase of severe UHI conditions, creating more heat stress, by affecting urban life quality and all concerned activities [110]. As a result, urban Dhaka city is fronting the challenges of UHI effect, fresh food, and water security [111] [112]. That's why the megacity Dhaka needs urgent sustainable green approach to minimize the urban warming in such way that every population feel comfort in their life.

2.5 Green Approaches for Reducing Urban Heat Island

Green approaches are the nature-based solutions (NBS) for urban environments restoration and recuperation which is a sustainable apparatus for urban heat island (UHI) effects mitigation [113]. Above section describes the causes the UHI phenomenon such as the anthropogenic heat, huge thermal mass of building and paved materials, low evapotranspiration, low wind condition and air pollution which are highly and urgently required to adaptation or mitigation to UHI. Due to urbanization, green roof or rooftop agriculture is the best green approaches to reducing the effect of

UHI for urban city [114]. A green roof contains growing medium and vegetation layer as its outermost surface which are recognized as an excellent heat removing the medium from the air through evapotranspiration of the plants, which results in a discount of the temperatures of the roof surface and the surrounding air which is shown Figure 2.8 [115].

Figure 2.8: Components of green roof for new construction building. (source: Http://dx.doi.org/10.13140/RG.2.2.10839.32163)

On the other hand, a green roof is a combination of different layers comprising of a waterproofing membrane, growing medium, and thus the vegetation layer itself. Green roofs help to improve the environmental quality, economic conditions of city dwellers and provide fresh vegetables to the city dwellers [116] [117]. The green roof is a passive cooling technique. Generally, it has three general categories: intensive, semi-intensive, and extensive which are also subdivided by semi-intensive and semi-extensive [Figure-8]. Intensive green roofs have a deep growing medium, which allows the utilization of trees and shrubs, extensive green roofs have a thin growing medium and require minimal maintenance, and in general, do not require irrigation and, are generally less costly to install than intensive green roofs [5] [118] [. The plants that have 2-20 cm root zone depth and are also able to store water and reduces water losses are suitable for extensive green roofs cultivation [119]. Grass-herbaceous plants, wild shrubs-coppices, coppices, and shrubs and coppices that's are required a deeper growing medium, i.e., 12–100 cm is cultivated in the semi-intensive green roofs [120]. Agricultural roof or green roof reduces ambient temperature as well as cooling load potential for comfort conditioning of buildings during summers [121]. Green roofs contribute not only to reducing urban heat island effects but also reducing the thermal loads and cooling load on the building's in densely built areas. Green roof strategy has been proved to possess positive effects on buildings by reducing the strain on the roof surface, improving thermal comfort inside the building, reducing noise transmission into the building, reducing the urban heat island effect by reducing 'hot' surfaces facing the sky, reducing stormwater run-off, re-oxygenating the air and removing airborne toxins, recycling nutrients and providing a habitat for living organisms [122] [6]. It often also includes rooftop agriculture contains a root barrier layer, drainage layer, and, where the climate necessitates, an irrigation system. Nowadays, in the country of Germany, more than 10% of roofs are constructed with green roofs, and it was started at end of the 19th century [123]. Nowadays, green roofs are also widespread in others countries, for instance, Singapore, New York, Canada, France, Switzerland, and Portland's government organized a couple of incentive programs to encourage the installation of green roofs on buildings. Especially, Toronto in Canada, to satisfy the urban environmental challenges through structure of sustainable green roofs.

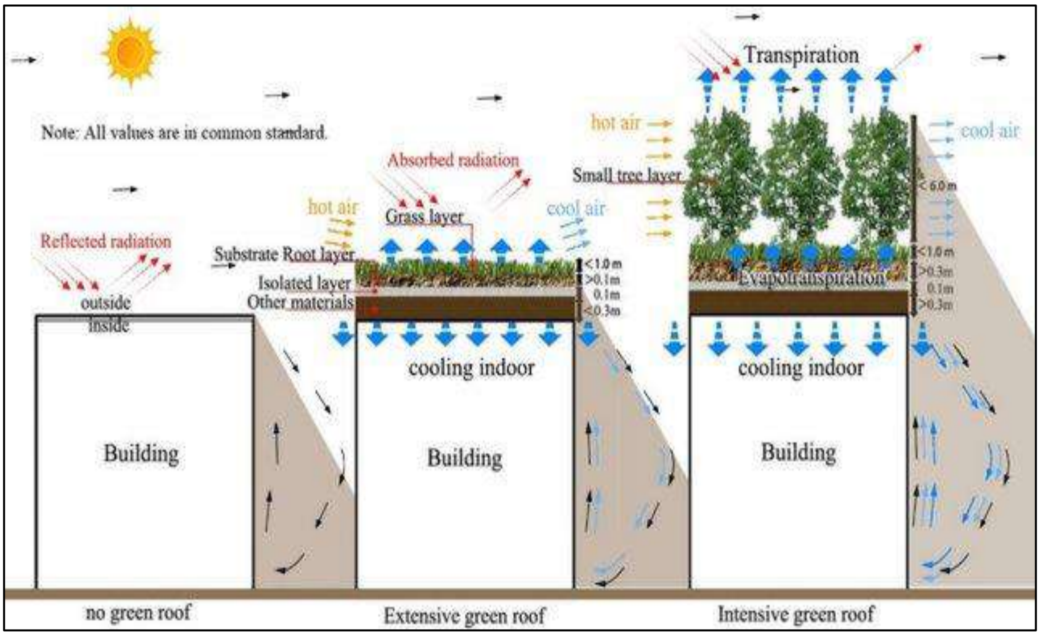


Figure 2.9: A schematic structure of an extensive green roof and an intensive green roof, and the cooling mechanism in the daytime. (Source: http://dx.doi.org/10.3390/ijerph16020179)

So, Green roofs offer improved aesthetic environments in both work and home settings, stormwater management, UHI mitigation, reduction in carbon dioxide, economic benefits, habitat restoration, and conserving energy [124]. On the other hand, Green roofs also improve the building LEED (leadership in energy and environmental design) ratings where building owners are benefitted from the green roofs [125]. LEED is the most widely used green building rating system in the world which provides a framework for healthy, highly efficient, and cost saving which helps to identify and rate sustainable designs [126]. Therefore, the Selection of plants and rooftop agriculture is also a essential components in resulting earns highest sensitivity LEED ratings [127].
On the other hand, women carry out the burden activities in the green roofs and also provide better carrying of green roofs through fulfilling household fresh food deficits, improvements in household agricultural productivity, food security, improves children's well-being, especially in the form of investments in children's health and education, and nutrition security [128]. Therefore, prevent of dangerous and uncomfortable urban heat island effects, cooling the ambient temperature and also energy the indispensable need for planted surfaces in the urban areas.

2.6 Cooling Effect of Green Approaches

Until early 1951, Bangladesh was mostly a rural country and only 4% of the population lived in urban centers [129]. But at current, the rate of urban population growth is estimated at 2.8% and for this Bangladesh's urban population will be reached at 79 million or 42% of the population by 2035 (BBS, 2018) [130]. The subsequent shift to urban areas has resulted in rising urbanization, decreasing arable land and quality of foods, weather extremes due to climate change, and increasing global greenhouse gas emissions [131]. The climate of Bangladesh, based on the widely used classification according to monsoon climate based on the temperature profile [132]. However, given the time of persistence of the warm humid season, which is the longest of the season, the climate can be termed as warm humid. In a phase of global warming, the urban warming effect is likely to be amplified especially increases in human discomfort during the summer period. Local warming creates the UHI, significantly increases temperatures as well as economic losses in addition to global warming [133]. The economic development and the improvement of living standards and energy consumption of electricity etc. are increasing in the urban cities, planning as crucial factors for climate change [134] [135]. The amount of consumed energy is increasing in urban areas due to the factors such as economic and population growth, and energy demand for modified and newly created services [136] [137]. A large amount of overall consumed energy in urban buildings is mostly due to using of air conditions. Therefore, finding a way to reduce energy consumption with respect to cooling load can significantly reduce the heat burden directly, because of greenhouse emissions indirectly. For colder days (25°C or 77°F), a 1°C increase in daily temperature leads to an increase of 14.5% consumption of electricity [138] [139]. Urban warming could lead to double the economic losses expected from human-caused climate change, and it would be probably comparable to about half of the warming caused by climate change by the year 2050 [140] [141]. The daily difference of minimum temperature in urban and rural sites are 6° C to 11° C (10° F to 20° F) [142] [143]. However, outdoor and indoor warm air comforts in the assembled environment are crucial factors impacting urban warming, building energy consumption, and occupant welfare. Building roofs are directly attached to these phenomena since high overheating on both walls and roof surfaces can negatively affect all these aspects [144] [145]. Two primary processes are responsible for influencing the formation of this warmer and thermal comfort. During the dry season, urban masonry and asphalt captivate, store, and reradiate more solar energy per unit area than the vegetation and soil types of rural areas [146] [147]. At night, the city's air becomes warmer than that of rural areas and human, cultural and economic activities have distinctive effects on warming impacting urban climate [148]. It has been found that each 0.5^{o}C reduction of indoor air temperature allows an 8% reduction of electricity consumption [149] [150]. Air temperatures in the GRs are cooler than normal roofs at least by 3°C to 4°C and the residential building with a green roof experienced a 25% cooling effect, while the floor below the GR had a 60% cooling effect [151] [152]. RA is the insulation for the roof because of heat exchange with the outside environment [153]. GR reduce a huge amount of heat absorption in summer and thus, less energy is required to keep the indoor air cool inside. [154] [155]. However, greenery vegetation activities like rooftop agriculture are turning out to be a very effective green adaptation tool to cool down UHI for achieving resilient urban cities in the face of global warming [156] [157]. In the context of global climate change, cities have a crucial role to play in building resilient communities. Rooftop agriculture is complex interactions between natural systems and human activities. RA is an interdisciplinary research approach and helps to improve the environmental quality, economic conditions of city dwellers and has the potential to provide fresh vegetables to people for a healthier food supply [158] [159]. Though GR produces and distributes food locally for marketing, it also reduces carbon footprints for transportation and stress on the environment through energy and resource-efficient buildings and savings from amplified building importance, higher rental rates, and reduced assessment costs [160].

2.7 Social Perspectives of Green Approaches

Due to the increasing population in Dhaka city, fruits and vegetables purchased in the city are often mixed with chemicals, which are hazardous for health. The value of urban rooftop agriculture is one of the most important questions is what the impact might be on Dhaka cities if urban farmers were better supported through policy, capacity development, and infrastructure, and the source of fresh vegetables [161]. Rooftop gardens could satisfy up to 75% of the demand for vegetables by the citizens of Bologna, Italy, according to the rooftop area identified as suitable for this purpose [162]. Towards the goal of achieving food self-sufficiency in Cleveland, the use of 62% of the roofs of commercial and industrial buildings could increase urban self-sufficiency by 1.5 times [163]. City dwellers can achieve 100 % autonomy with regards to meeting their fresh vegetable requirements or maybe self-sufficiency in food in cities and low-income communities can earn monetary value from their cultivation processes throughout the year [164]. That is why RA is not only realistically mental freshness and climate change adaptation tool of city dwellers but also make the cities self-sufficiency [165]. In terms of fresh vegetables as well as self-dependent of women dwellers and increase the contribution of women in all decision making both family and society which are strongly related to Sustainable development goal (SDG) 1, 6.1 and 11 [166]. RA will besides prevent women from acquiring higher-paying occupations as well as low-income trap imprisoning unskilled women [167]. Rooftop Agriculture may be the potential to enable women’s empowerment to tear down the barriers of inequitable gender relations when women’s participation comes out of choice rather than need and also can promote a sustainable and livable city [168]. The appropriateness of a field for performing urban rooftop agriculture is determined by its social, economic, and environmental characteristics. A major feature of urban agriculture is that it is characterized by the socio-economic profiles of the involved actors where urban rooftop agriculture activities are adjusted to the collective and individual needs [169]. Hence, economically sensitive social groups and people in times of domination, perceive and perform urban agriculture for livelihood; whereas, wealthy social groups perceive and perform urban rooftop agriculture for recreational, leisure, and for greening their surroundings [170]. URTA enhances species biodiversity and increases the potential of recycling by reducing the volumes of organic food waste through compost. Urban agriculture also reduces food miles by providing food locally [171]. Thus, RA is a way to survive the competition in the real estate market and climate change particularly in developed countries, beyond policy recommendations to improve urban sustainability, the environmental awareness of citizens in the local food sector [172] [173].

2.8 Green Roofs and Urban Water Management

As urbanization increases globally and the natural environment becomes increasingly fragmented, URTA as well as home gardens with different crops have a relevant role in the urban green space and can provide considerable biodiversity benefits [174]. URTA and green spaces require water which functions as a key element in any greening action and activity as well as the most important factor for promoting URTA [175]. Water forms over 90% of the plant body on a green or fresh weight basis. The total amount of water made available by the hydrologic cycle is enough to provide the world’s current population with adequate freshwater [176]. The scarcity of water in urban areas is rapidly increasing due to urbanizing and population growth efficient water use and management are today’s major concerns to properly manage the water resources [177]. The sources of water for irrigation can include surface water sources, groundwater sources, municipal, water supplies, grey-water sources, and other agricultural and industrial process wastewaters [178]. Surface water sources include 'flowing' water supplies and 'standing' or stored water supplies like ponds, reservoirs, lakes, greywater, and rainwater, etc. [179]. Greywater is domestic wastewater, other than that containing human excreta, such as sink drainage, washing machine discharge, or bath water [180]. The quality of agricultural or industrial process wastewaters often limits their use to surface or sprinkler irrigation methods, and in their suitability for fruit and vegetable crop irrigation [181]. The use of irrigation water in urban rooftop agriculture is a very important and crucial issue both in terms of competition with other uses and in terms of groundwater level depletion. Swift population density increasing, suburbanization, and economic development lead to growing pressure on water resources in urban areas [182]. With water demand exceeding water supplies, the water shortage has become more prominent in many cities in both the developed and developing world [183]. In the Mediterranean countries, the competition can be exacerbated especially during the summer months and the situation will be deteriorated in the future by climate change, increasing urbanization, and population growth [184]. Cities are made up mainly of extended sealed surfaces (e.g., streets, roofs, and car parks) and are more and more frequently affected by risks of floods and landslides due to difficulties in stormwater management 25 liters of water per capita a day [185]. A water scarcity figure is a global environmental challenge, which is not the time or location-specific [186]. Dhaka is the largest and fastest-growing urban center in Bangladesh where 36% country's urban population lives in this city. On average, per capita, water usage is 310 liters per day and 509 liters per day in the more developed areas where 78% water comes from ground water and as a result, the groundwater table is rapidly declining (3m/yr) due to a large-scale abstraction [187-188]. Moreover, groundwater depletion is driving up the cost of extraction and reducing the operational lifespan of pumps. Urban water problems are different in the developed and developing parts of the world, but all cities share the same goal of managing our precious water resources in a sustainable way. On the other hand, urban rooftop agriculture has become increasingly popular across the world and also the Dhaka city that includes a variety of activities: community gardens and fruit orchard, home gardens and veggie patches, urban forest, public open spaces, reserves, urban forest and recreational landscaping. Urban rooftop agriculture differs from traditional agriculture as it is integrated into densely populated areas with limited land for food production with artificial growing medium. Irrigation is an essential component of rooftop agricultural management where the production of fresh foods, vegetables, and agricultural goods, within and around cities, with a motivation of personal consumption or income generation water plays a vital role [189].

Rooftop agriculture utilizes a significant amount of water for growing foods and crops with the traditional method, which is usually expensive than agricultural water supplies [190]. On the other hand, reducing outdoor use of scheme water for agriculture activities is a major component of many strategies to reduce urban water use and ensure reliable indoor water supply [191]. Almost 40% of the scheme water is consumed for agricultural irrigation activities in urban and regional areas and in the summer season, agricultural irrigation is normally restricted with demand management practices [192].

As a result, urban rooftop agricultural activities are not always supplied with efficient irrigation, especially when they use traditional equipment for requires irrigation, hence affecting the continuity of food production and other agricultural activities [190]. Therefore, sustainable irrigation management calls for a better understanding of water requirements to lessen environmental risks and increase water use efficiency.

In this context, rain and gray water is an alternative source of irrigation and both ground and harvested water can utilize through a smart water-saving irrigation system that could have multiple benefits from helping water authorities in augmenting water supply and ensuring cheap and reliable irrigation for urban agricultural activities [193]

The goal of a water-saving irrigation system is to use water in the most profitable way at sustainable production levels to help landscape maintenance, reduce the effect of inadequate rainfall, etc. provides the best residential or commercial landscaping needs [194]. Effective use of irrigation water is a key issue for agricultural development in regions where water is a limiting factor for crop production [195]. Although efforts to increase crop production have been focused on the field of irrigation, the world is continually challenged to increase production using an ever-decreasing amount of water [196]. Thus, increasing water use efficiency has been an urgent issue in such a region where water demand has been an increasing concern [197]. The efficient application of irrigation water the adequate soil moisture, is available for crop consumptive use without an excessive runoff, deep percolation, or conveyance losses must be the goal of all irrigators [198]. Irrigation systems have been under pressure to produce more with lower supplies of water and various innovative practices can gain an economic advantage while also reducing environmental burdens such as water abstraction, energy use, pollutants, etc. [199]. There are quite a few forms of urban rooftop irrigation, the simplest is hand watering, which is simply pouring water over a plant and the soil surrounding it using a bucket, mugs, hose pipes, etc. or watering can by using human labor called traditional methods where huge fresh potable water is lost. More than 90% of rooftop gardeners in Dhaka city use traditional irrigation from their own water source [200].

Substantial Effective management of water under irrigated agriculture is crucial to ensure food production and security. Several suggestions have been made to optimize the use of water for crop production [201]. One of them is that water should be applied to crops when they need it most, that is when the shortage of water could lead to a significant reduction in yield. This approach is called regulated, pre-planned or deficit irrigation (DI). DI is a means of reducing crop water use while minimizing adverse effects on crop yield [202]. Drip irrigation is a set of modern solutions of applying water based on a common principle of very low application rates which is called "thirsty", irrigation methods. It helps to use water economically without wastage and reduces fire risks, increases evaporative cooling instead of a destructive splattering, and slowly releases moisture into the soil [203]. The drip irrigation method allows water to drip slowly to the roots of plants through narrow tubes equipped with emitters and conserves water and efficiently irrigates vegetables and perennial gardens on the rooftop [204]. Early drip systems were simple and used holes or micro tubing instead of sophisticated emitters as well as the development of drip irrigation sent through technical options to be used for massive irrigation fields in the developed countries, though drip systems started from kitchen garden [205]. Drip irrigation increased water use efficiency by 60-200%, saved water by 20-60%, reduced fertilization requirement by 20-33%, increased yield by 7-25% as compared with conventional irrigation [206]. The distribution efficiency, design discharge uniformity, application efficiency, and water application uniformity of drip irrigation system is 94-96%, 77-81%, 85 -88%, and more than 80% respectively, and average achieves up to 95 percent irrigation efficiency [207]. The performance of drip irrigation is usually defined in terms of its efficiency and its uniformity of water application which leads to sustainable agricultural production [208] [209].

The water-saving potential of drip irrigation is an irrigation technique that doubles the crop yield per unit of water in many applications [210]. Water use reductions with drip irrigation of 30-60% and typical yield increases of 20-50% for a variety of crops [211]. Wastewater application, especially for turf and landscape plants, offers great potential. Profitability and economic aspects have not been determined conclusively and will depend greatly on local conditions and constraints, especially the availability and cost of water [212]. Low-cost drip systems achieve more than 50% water savings compared to surface irrigation systems and increase the yield of vegetables. It is the conjunction of good water and nutrient management if higher water and crop productivity are to be realized than surface irrigation systems [213]. Another study revealed that 62.44% higher yield in case of drip irrigation as compared to traditional irrigation and net seasonal income is also highest as US$ 4333 in case of drip irrigation from others irrigation [214].

Low-cost drip systems save 50% irrigation water compared to surface irrigation systems and influenced the yield of vegetables significantly [215]. It is the super media of proper water and nutrient management if higher water and crop productivity are to be realized than surface irrigation systems [216]. Drip irrigation is one of the most efficient methods of vegetable crop production and improves water and nitrogen use efficiency compared to other irrigation methods [217]. It decreases the field evapotranspiration (ET) and consumptive water footprint (WF). It saves time, money and finite resource i.e. groundwater, however, the availability of drip irrigation facilities which is highly inadequate in the urban area [218]. Drip irrigation is important because of the accuracy in which the water is applied and it is most suited to the URTA is the best way of increased crop water productivity [219].

Water productivity is generally defined as crop yield per cubic meter of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas [220]. Water productivity is the ratio of the actual crop yield over the volume of water that is beneficially consumed by the crop. This concept can also be applied in a wider sense, by placing monetary units (e.g. in dollars per cubic meter of water), social attributes (jobs, food security, etc.), or environmental attributes (carbon sequestration, biodiversity, etc.) [221]. Economic valuations of water resources provide a method to compare economic water productivity values across scales, but also across production systems such as crops, energy, fisheries, and livestock [222]. Water-use efficiency is often used in the agricultural sector to measure the efficiency of crops to produce biomass and/or harvestable yield [223] while it is generally defined as the ratio between the water used and the water is withdrawn for the water sector as a whole. The different attributes given by the water and agriculture sectors in the use of this term are often a cause for confusion. However, water and irrigation water productivity may be increased by skipping irrigation and improve crop water and economic productivity on local and international scales [224]. WP reduced water requirement by 20 and 35% during maturity and seed filling. DI during reproductive stages reduced economic water productivity by 6.7–35% while revenue was reduced by 18.5–47.7% [225]. In order to adopt DI, information on the responses of crops to water deficit at various stages is required without a significant reduction in the yield [226].

On the other hand, URTA is the major part of the Leadership in Energy and Environmental Design (LEED) certification system where efficient surface water uses play a key role in getting more ratings to a building. It delivers independent authentication of a building or neighborhood's green features, allowing for the design, construction, operations, and maintenance of resource-efficient, high-performing, healthy, cost-effective buildings [227]. It makes a building with more productive places, and reduced stress on the environment by encouraging energy. It increases the building value and decreased utility costs [228]. Smart drip irrigation with green water, URTA can increase the building values and serves as an excellent adaptation tool to micro-climate change. Therefore, dwellers of Dhaka or any other city need a framework or model to implement URTA in a proper focus that climate and water-smart rooftop agriculture.

Water management for rooftop agricultural production is a critical component that needs to adapt in the face of both climate and socioeconomic pressures in the coming decades. That's why changes in water use through URTA are combined effects of (i) changes in water availability, (ii) changes in water demand for agriculture, as well as from competing sectors including urban development and industrialization, and (iii) changes in water management [229]. In traditional agriculture practices, farmers use more amount of water as their thinking for optimum production com-pare to plant requirements. To increase water use efficiency, farmers needed to integrate water captures approaches into a farmer's strategy [230].

On the other hand, better management of rainfed water or the use of supplementary irrigation at an appropriate scale can achieve significant long-term positive impacts on groundwater. With changing global climatic patterns coupled with the declining per capita availability of groundwater resources, sustainable water management in agriculture is a great challenge in Dhaka [231]. However, sustainable water management in urban areas helps to transform and reorient the agricultural production system to effectively support the development and ensure food security in a changing climate [232]. Sustainable green water management has three simultaneous goals and interlinking objectives: increased productivity and incomes, adapting and building enhanced resilience, and reducing emissions associated with agriculture [233].

2.9 Green Approaches in Urban Bangladesh

A green approach is an inclusive approach of safeguarding economic and social progress considering the environment such as energy-saving, pollution, modernize green products, reduction of UHI effect, recycling the waste, efficient use of resources, and environmental management [234]. Green invention and effective supply chains for green development are crucial factors for cutting carbon in urban areas. Buildings account for 40% of total global energy consumption where 33% is the raw materials of the building, and 50% is for electricity consumption [235]. Commercial and residential buildings devour nearly 40% of the primary energy and nearly 65% of the electricity [236]. Bangladesh is one of the vulnerable countries in the world due to climate change like UHI, cyclones, excessive rain, floods, droughts, river erosion are hampering the life of people and the economy almost every year. In this situation, a green approach is essential for the country in order to mitigate the micro-climate climate change impacts and reduce the negative effects of natural disasters for ensuring the sustainable livelihood of people [237]. The government of Bangladesh (GOB) is already concerned about green approaches and also, its development. Various ministries, divisions, and regulatory boards including Bangladesh Bank (BB) formulate several acts, regulations, and policy initiatives in the aspect of green development of Bangladesh. However, preservation of ecosystems and biodiversity are the foundations of a sustainable growing economy, and the government green policy initiatives ensure general synchronization due to the development of rooftop agriculture in the urban areas [238]. These initiatives create the city dweller's more positive reactions and also caring responses to the green approach in Bangladesh [239] [Figure 10]. The government taxation rebate initiatives in the city corporation in Dhaka create a positive influence on building owners' initiatives to the green roof as well as rooftop agriculture. Government green creativities endorse the projects to provide funding in a low carbon economy [240]. Green enterprises reduce the subtraction of carbon emissions and pollute the country. The major challenges for the implementation of green approach related projects are: lack of legal and governing framework, available supporting, and provisions of financial foundations and financial institutions appears that initial cost risks are complicated in green projects rather than development or others conformist projects [241] [242].

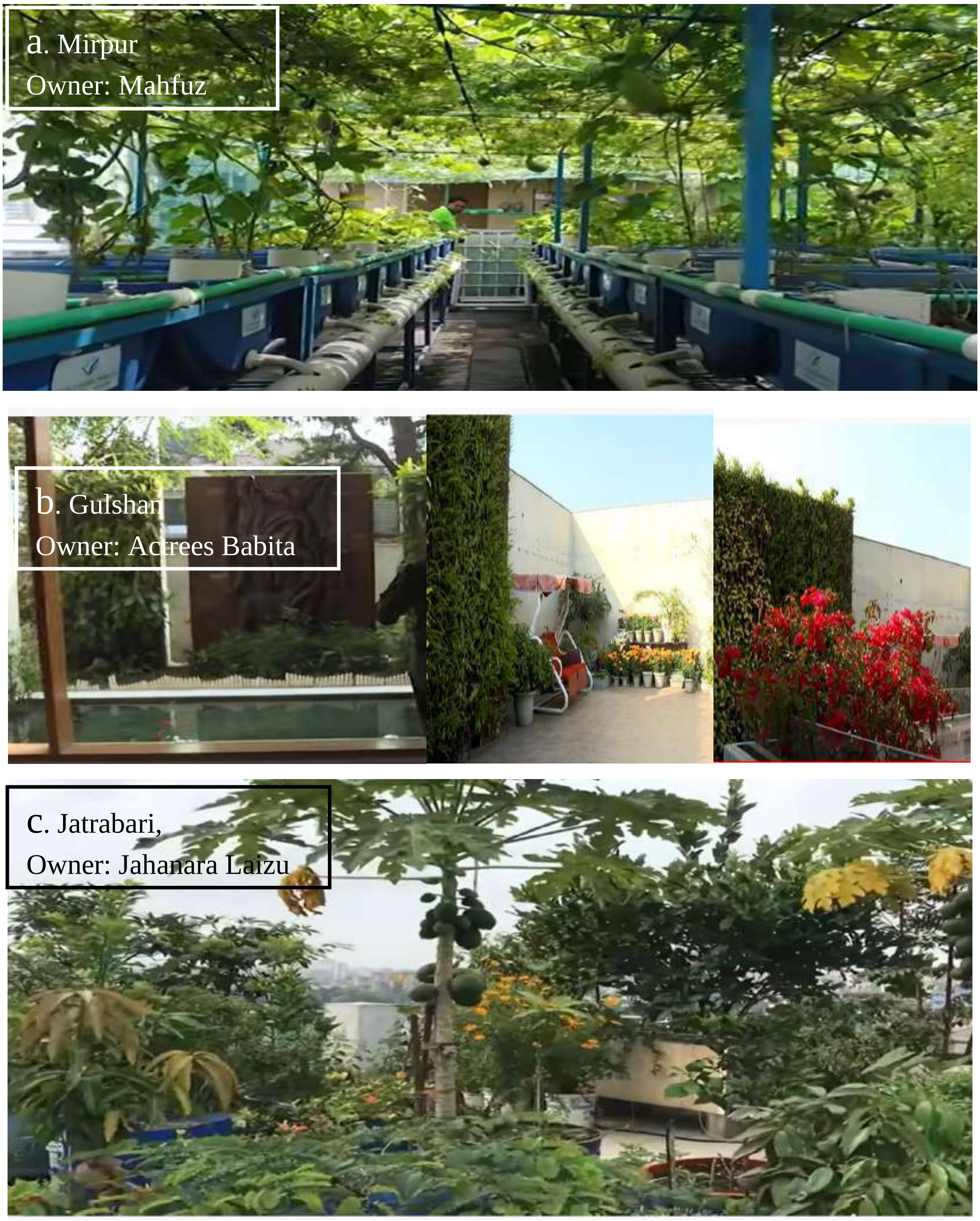


Figure 2.10: Different type of green roofs in Dhaka. (a) Rooftop agriculture with aquaculture; (b) Vertical agriculture; (c) Rooftop firming with fruits and vegetables. (source: https://youtu.be/b8cGfm45V98, Ridoye Mati O Manosh, Chanel I, Bangladesh]

Conversely, Shaikh Shiraz, Managing Director "Ridoye Mati O Manosh" and AFM Jamal Uddin, Professor, Sher-e-Bangla Agricultural University with 90-minute schooling focuses the rooftop agriculture to the City Dwellers which inspires the general people and this type of program is suitable more than politicians in the agriculture of this country [243] .The different private group also works together for human wellbeing and the environmental multiple challenges to address when evaluating eco-friendly cities. The eventual solution, and "multi-criteria evaluation of environmental concerns" system is the ecological opportunity with the multi-criteria appraisal of green and open spaces [244]. However, an urban framework generates a clear connection between expressive comfort and green-lively teenager pleasant involvements provides a new perception for sustainable youngster-friendly green space in the urban areas with different policy guidance [245].

2.10 Summary

Above detailed literature review was done to assess urbanization and its effects on global warming as well as micro-climate changes scenario at the existing urban condition. This chapter concluded that urban city needed to nature-based solution to adapt urban heat island effect in the urban areas. In this case, URTA is the nature based best solution to reduce the urban warming. That is why, URTA needs to be established based on a set of science-based findings and conceptual models which should address climate adaptation, food security, water productivity as well as popularization of URTA to everyone, to every apartment, and to every building. But, the conceptual climate and water-smart model for URTA is not formulated for an urban city. That's why the criteria of the climate and water-smart URTA model have been created from the result or finding of the selected objectives of this study. Firstly, spatio-temporal trends of land Surface temperature in the Dhaka Metropolitan area based on LANDSAT Products from 1988-2018 were analyzed to identify the most hots-pot zone of the urban areas and their vegetation variation conditions. Secondly, micro-climatic parameters dynamics were assessed based on roof area coverages by plants or agriculture. Thirdly the irrigation water requirements of selected crops (Tomato, Bottle Gourd, Brinjal, and Chili, from November 2018 to May 2019 and November 2019 to March 2020) were quantified through drip irrigation and traditional irrigation approach with the source of potable water and green water to explore sustainable water use for agriculture under future climate change scenarios with the increase of water productivity through the efficient water management practice. All microclimatic parameters such as temperature, Relative humidity, carbon dioxide was collected from experimental agricultural roofs and BRs during the period of November 2018 to May 2019. This study is to provide a widespread assessment of the prospective of URTA using the primary data over the experimental plot and existing URTA in the Dhaka Metropolitan

Area (DMA). The criteria of the climate and water smart URTA model was consider from the findings of this study and also from the questionnaire survey of existing rooftop gardens to popularization of green approach such as URTA to everyone, to every apartment, and to every building to minimize the UHI effect and also carbon cutting from carbon emissions.

Chapter 3

STUDY AREA AND EXPERIMENTAL SETUP

3.1 Location and present climate of the study area

Dhaka City as Dhaka Metropolitan Area (DMA) is located almost in the geographical center of Bangladesh at 23˚43'0"N and 90˚24'0"E (Figure 1). Dhaka city is the capital of Bangladesh. It is rapidly growing in terms of population and extent. In 2016, the population of the greater Dhaka area was 18.237 million. The city has been transformed into a mega city of about 19.56 million people. Now it is the hub of the industrial, commercial, cultural, educational, and political activities of the country [246] [247]. The city is rich with colorful history and cultural tradition. Dhaka is famous for her big numbers of mosques and ancient muslin already revived very recently. This profile captures the unplanned and spontaneous urbanization of Dhaka, which has been resulted in unplanned and disorganized spatial expansion and transformation of the city. The unbalanced urban primacy is the result of a high concentration of administrative activities, jobs, and services in the city [248]. Such a dramatic urbanization process inevitably has brought an UHI effect on the entire city due to the increasing built-up density and the loss of urban green spaces. For the research purposes, study areas were categorized into two types: developed and growing developing areas. For this study, Motijheel, Gulshan, and Uttara was selected as developed area and Demra, Pallabi for developing areas within the DMA. The developed area was considered based on land use, and land cover categories of the specific areas, like Motijheel was considered as developed area, and Pallabi was considered as growing developing areas. Conversely, Motijheel represented the prime commercial area of the Dhaka district. Head offices of a variety of commercial establishments exist in Motijheel. On the other hand, Pallabi Thana is bounded by natural almost geographical settings. Uttara thanas are on the north, Mirpur model and Shah Ali thanas are on the south, Biman Bandar, cantonment and Kafrule thanas are on the east and Savar Upazila is on the west. Pallabi is a developing area with residential facilities like markets and shopping centers mostly in a planned way. A large portion of land is yet to come under developmental activities. So, Pallabi was considered as a growing and developing area [249]. Such a dramatic urbanization process inevitably brings urban heat island effect of the whole city because of the increasing built-up density and loss of urban green spaces. Due to fast urbanization, it's facing the loss of natural vegetation, loss of open spaces, and a general decline within the spatial extent and connectivity of wetlands and wildlife habitat. The city of Dhaka is rapidly growing in terms of both population and extent. It is becoming the center of the country's industrial, commercial, cultural, educational, and political activities [250]. That's why Dhaka is growing as a warmer city compare to the rural areas. In this regard, the study was conducted within the DMA [Figure 3.1].

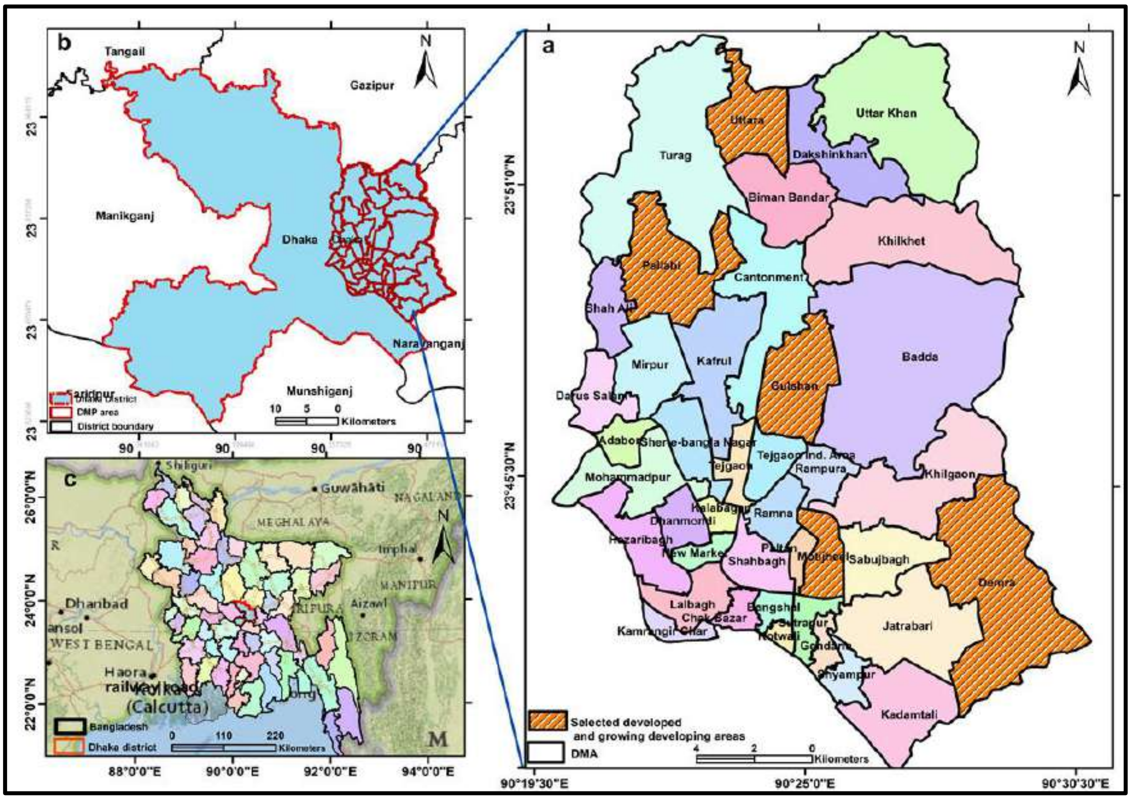


Figure 3.1: (a) Study Area (Dhaka Metropolitan Area with Developed and Growing Developing Area); (b) Dhaka District; (c) Bangladesh with Base Map.

3.2 Experimental plot setup of the study

3.2.1 Experimental plot design

The city of Dhaka is rapidly growing in terms of both population and extent. It is becoming the center of the country's industrial, commercial, cultural, educational and political activities. That is why Dhaka is becoming a warmer city compared to the rural areas. In this regard, the present study was conducted through URTA as an adaptation tool within the DMA from November 2018 to May 2019. The experimental plot of agricultural roof (AR) was designed on the roof of the Department of Agriculture, Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh, to cultivate the selected crops (Tomato, Brinjal, Chili, and Bottle Gourd and leafy vegetables) (Figure 3.2). The height of the institutional building roof was about 50 ft (about 15 m). The experimental plot was established for the first-year of the experiment on the roof of an institution (Sher-e-Bangla Agricultural University, Sher-e- Bangla Nagar, Dhaka, Bangladesh), and for the second-year experiment on the roof of a government residential quarter, (Bangladesh Agricultural Development Corporation (BADC) officer's' quarter, 22, Manik Mia Avenue, Sech Bhaban, Dhaka). The experimental plot was 18 m in length and 12 m in width. The area of the experimental plot was 216 m^2, 18-m long and 12-m wide, which is physically significant for such experiments. Thus, a completely randomized design (CRD) was used for designing experimental plots of AR in such a way that at least 70% of the roof area was covered with the selected crops (Tomatoes - 16%, Brinjals -15% Chilies -13%, Bottle Gourds - 25% and Recreational room - 2.3%) (Figure 3.5). Similarly, 216 m^2 bare roof (BR) was also selected near the experimental AR. Two rooms were covered with the experimental AR below it and two rooms below the BR, which were also considered in this study. Bottle Gourd was cultivated around the experimental plot using fencing panels. Below the fencing panel, leafy vegetables such as Spinach, Red Spinach and Water Spinach were cultivated in 8 wooden frames where the area of each wooden frame was 2.23 m2. Plant center to center spacing of those crops was maintained as per the Bangladesh Agricultural Research Institute's (BARI) recommended guidelines.

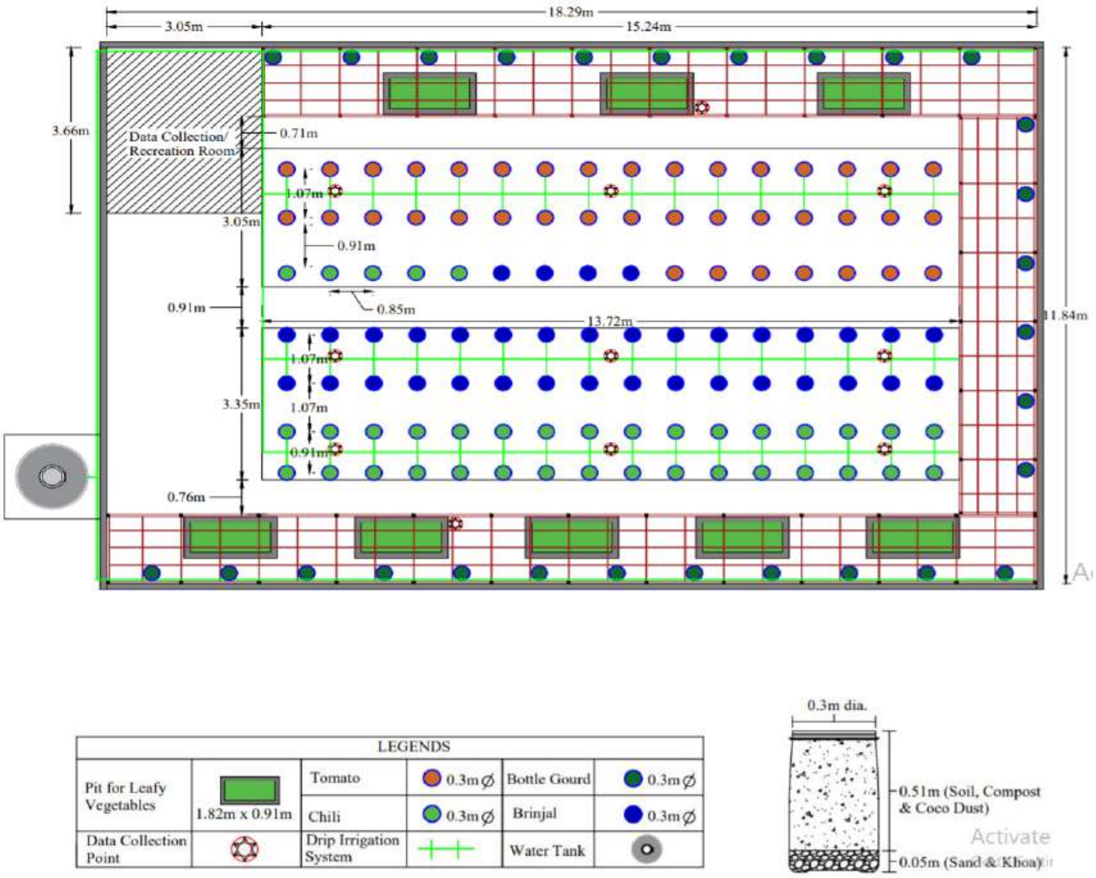


Figure 3. 2 The Design layout of the experimental plot.

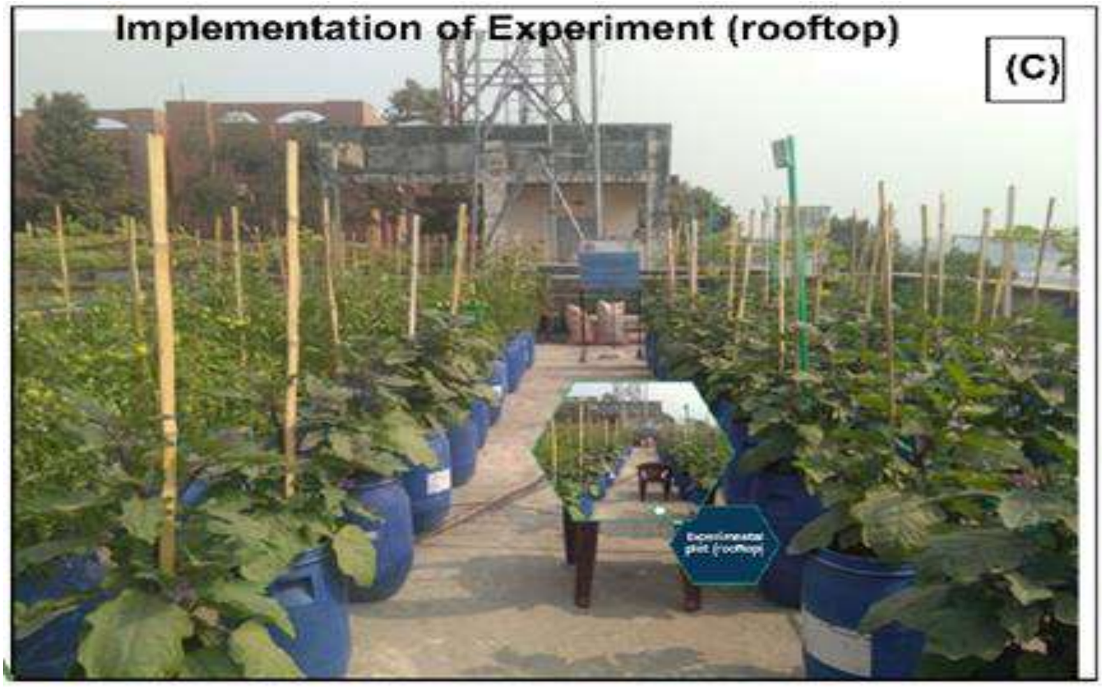


Figure 3.3: (a) Dhaka Metropolitan area with base map and location of expr; (b) Experimental plot (rooftop); (c) Implementation scenario of Experiment (URTA).

3.2.2 Irrigation System Setup in the Experimental plot

A demonstrative drip irrigation (DI) system was used to deliver the irrigation water to the plants from the portable water storage source with a manual operating valve system and from the green water storage source with a 1 hp Single Phase, Self-Priming Monoblock pumping system [Figure 3.4]. Five lateral pipes (12.7 mm diameter) were designed from the submain pipe (25.4 mm diameter) of the groundwater source [Figure 3.4] and two lateral pipes were utilized with a sub-main pipe connected to the rain and grey water storage source (1500 liters), lifting this with a 1Hp motor from the main grey water storage on the roof. Emitter pipes (6 mm diameter) were connected with a 4 mm diameter connecting pipe to the lateral pipe with a T-joint and the tiny plastic nubs or emitters were set at the end of the emitter pipe to allow water to drip out at a regulated pace without clogging, into the soil at the plants' roots. The traditional irrigation approach was also applied for cultivation of these crops to compare the water productivity with the drip irrigation system. In the case of potable water source for irrigation, a total 8 rows of drip irrigation containing 128 container, and 2 rows (24 containers) using the traditional irrigation method (mug and pipe) were used with 3 replications in 152 plastic drums [Figure 3.3]. Two rows for Tomato, two rows for

Brinjal, two rows for Chilies, and two rows for Bottle gourd were used for cultivation, where each row contained 18 containers except for Bottle Gourd with 10 containers. At the middle of the experimental plot, 1.5 m was used as free space for easy movement and for carrying the plants. Thus, the vegetative area of each plant could cover the roof area to reduce the roof surface temperature. On the other hand, in the green water source (rainwater and greywater) experiment, a similar common setup was designed, and Tomatoes, and Brinjals were cultivated and irrigation were maintained based on the first experimental result, considered only for yield comparison of these crops.

Figure 3.4: Drip Irrigation Setup with Potable Water Supply in the Experimental Plot.

3.2.3 Soil Preparation and Soil properties of the Experimental Plot

In this research the soil was prepared with organic matter such as cocoa dust and vermicompost at a proportion of soil: cocoa dust: vermicompost of 2:1:1. Furadan, dye-ammonium phosphate (DAP), calcium carbonate, and powder from eggshell membrane and bones were also added during the soil preparation [Figure 3.5]. Conversely, physical and chemical properties of soil such as soil texture, bulk density (weight basis), field capacity (weight basis), pH, micro and macronutrients were also tested in the Soil Research and Development Institute (SRDI), Dhaka, before preparation of soil [Table 3.1].

Table 3. 1 Physical and chemical characteristics of growing medium (Soil).

Item Name	Value in (%)
Moisture content of soil before adding water	19.80%
Moisture content of wet soil or field capacity of soil	33.58%
Soil texture	Silt loam (sand-9%, silt-78% and clay-13%)
pH of soil	Strongly acidic (5.5)
Organic matter	Low (1.40%)
Total Nitrogen (N)	Very low (0.070%)
Potassium (K)	1.32 meq/100 g soil (very high)
Calcium (Ca)	7.32 meq/100 g soil (very high)
Magnesium (Mg)	7.00 meq/100 g soil (very high)
Phosphorus (P)	78.93 µg/g (ppm) (very high)
Sulphur (S)	143.89 µg/g (ppm) (very high)
Boron (B)	0.77 µg/g (ppm) (very high)
Copper©	2.28 µg/g (ppm) (very high)
Iron (I)	45.16µg/g (ppm)
Manganese (Mn)	13.29 µg/g (ppm) (very high)
Zink (Z)	4.47 µg/g (ppm) (very high)
Bulk density of prepared soil	1.04 gm/cm^3

Figure 3. 5 (a) Soil mixer with vermicompost (soil:vermi compost=2:1) (b) Savin 85 SP (100 gm) (c) Furadon (d) Bone’s powder and (e) Dye-ammonium phosphate (DAP).

3.2.4 Green Water Harvesting for irrigation in the experimental plot

In this study, a rainwater collection system or rainwater catchment system was achieved by a 4-inch UPVc pipe with 1.78 m3 concrete structure, pumps, tanks, and filtration systems [Figure 2b]. The simplest rainwater harvesting systems were used in these studies, which are non-pressurized wet systems. In this system, the storage structure or tanks are located underground and under the building. On the other hand, sinks, hand basins, washing machines, showers, and recyclable bath water were used as greywater which provides a constant source of irrigation in residential buildings. Greywater was collected from these selected sources via a separate dedicated 4-inch UPVC pipe. The outlet of the collecting pipe was connected to the underground concrete structure storage tank which is also used as a storage container for rainwater [Figure 3.6].

Figure 3.6 Drip Irrigation Setup with Grey and Rainwater Supply in the experimental plot.

The water passes into the tank into the pre-filtering double-layer plastic net in such a way that any hitches were left in the net. The pre-filter removes any mop and large particulates from the greywater preventing it from entering the tank chamber. The overflow ball valve was also set into the storage structure, and automatically topped up the system, providing full continuity of water supply, and water and particulates passed to the drainage line via the overflow pipe's outlet. The tank contains a pump that is used to pump water to the roof header tank. Prior to entering the header tank, the water passes through an activated carbon filter, which removes discolorations, particulates, and excess bromine. Subsequently, the source of water for drip irrigation is pumped from the underground green water storage tanks to roof tanks to serve the irrigation system, using a 1 hp pump. Lateral pipes ware connected to the riser tank and a sub lateral pipe was also used with the main pipe which contained an emitter to deliver water to the plants [Figure 3.6].

3.3 Present Strengths of Existing Rooftop Garden in the study area

Dhaka is the most densely inhabited city of Bangladesh and is considered by its demanding urban life with lively and multipurpose source of economy. The climate of Dhaka is hot, wet and humid. tropical climate. Dhaka city also going the lack of open spaces and greenery that are essential for socialization and healthy life for its inhabitants. Air and water pollution are increasing in Dhaka due to traffic congestion and industrial waste are serious problems affecting public health and the quality of life in the city. Water bodies and wetlands around Dhaka are facing obliteration as these are being filled up to construct multi-storied buildings and other real estate developments. Nowadays, Dhaka city dwellers are practicing the rooftop agriculture on their own building roofs to fulfill their hobby and also fresh foody supply for their family as well as improve food security in Dhaka city. Most of Dhaka's rooftops are flat and superlative for rooftop agriculture. Flat owners' households are practicing gardening with ornamental plants either in roofs or balconies with gardens. most of the flat roofs are isolated, with no relation to the adjacent one. Building owners rarely use roofs as space for gardens. The socioeconomic impacts of URTA also surveyed from open-ended questionnaire surveys of 200 existing rooftop gardens. The survey was conducted within the DMA, and rooftop gardens were selected randomly in the specific area. It was done by survey through oral interviews of the building/rooftop garden owner to gather more in-depth information, opinions and preferences. The role of food production, priorities of involvement of women, choices of multiple crops, promotion or popularization, growth and trends and economic strengths or values of URTA, etc., were considered in the study to clarify the social changing aspects of URTA. On the other hand, 5 existing rooftop gardens or ARs with an area coverage of 40, 50, 60, 80 and 85% by agriculture and 5 nearby BRs were selected through a survey of 200 existing private rooftop gardens within the DMA.

3.4 Design of Water and Climate smart URTA conceptual model

3.4.1 Objectives of Water and Climate smart URTA conceptual model

Dhaka is facing the challenges of having fresh food, water security, healthy lives and a cleaner city to achieve Sustainable Development Goals (SDGs) 2, 5, 6 and 11 [251] [252]. On the contrary, rooftop gardens/agriculture have very high social gratitude (85%) and is commonly experienced in Dhaka, and it has good economic prospects [253]. Today, urban city dwellers especially owners of the building are becoming interested in rooftop gardening and irrigated chemical-free organic vegetables and fruits [253][254]. They do it out of a hobby or recreational purposes or out of love to nature only without considering efficient water management techniques as well as water productivity [255]. Though climate change has become a serious concern of government, urban adaptation issues still receive limited attention through a holistic approach in the urban contexts. That's why urban rooftop agriculture is a good adaptation technology applying smart irrigation which we can address climate change at a local level and prepare urban populations to deal with the challenges it brings. Therefore, climate and water-smart rooftop agricultural model (CWSRAM) is the major concern of micro-climate change and also water savings approach in the Dhaka areas which is all about the interdependencies between yields and impacts on water and also microclimatic parameters. That's why the main objectives of CWSRAM have been addressed to improve the following real-world problem:

(i) To reduce the effect of UHI and related others microclimatic parameters (Temperature, RH, CO2, CDD, and energy savings).

(ii) To reduce the pressure on potable water and increase water saving through grey and rain water use in the URTA.

(iii) To increase economic feasibility and empowerment of women and elder city dwellers

3.4.2 Description of Conceptual Model of URTA

The conceptual model of URTA is an appreciated vehicle or transporter for so long as concepts to planners/city dwellers/manipulators/users. A physical concept of CWSRA model generated by real information/data about URTA and refined to the specific requirements of the urban dwellers. So conceptual modeling of URTA would help to reduce the formation thinking time of RTA in the early stages of the design process. On the other hand, this conceptual model is the way of representing a rooftop agricultural system's concept that helps to city dwellers understand or simulate the subject of that model. That's why conceptual model plays an important role all over the scheme development life cycle of URTA. Figure 3.7 below depicts the role of the conceptual model in a typical system development scenario.

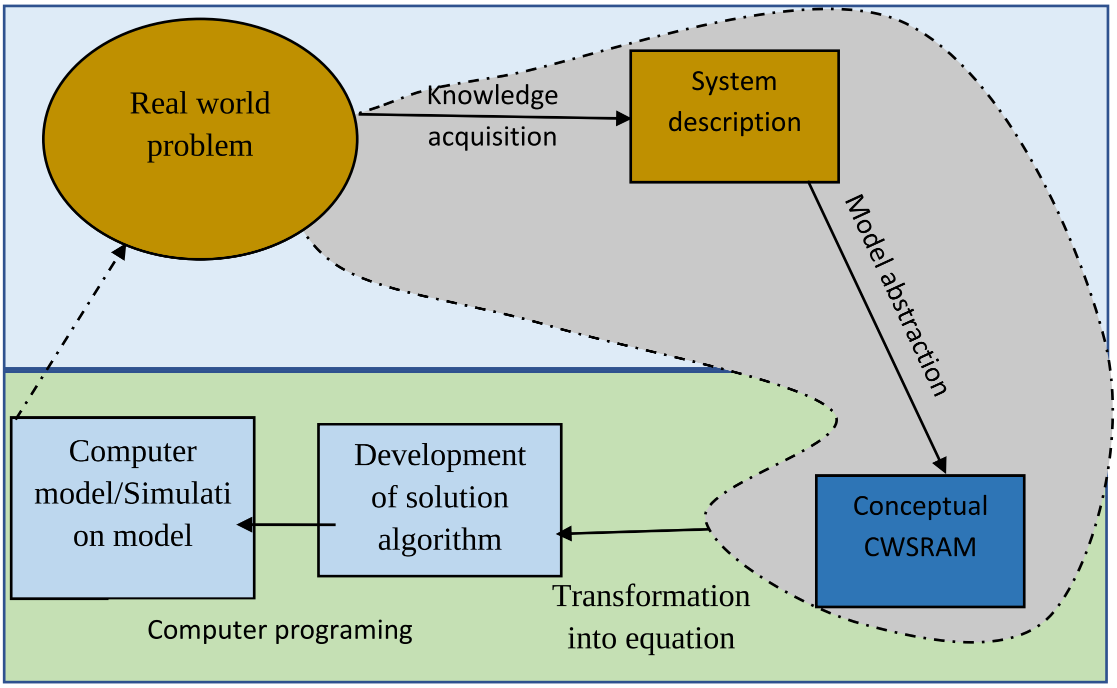


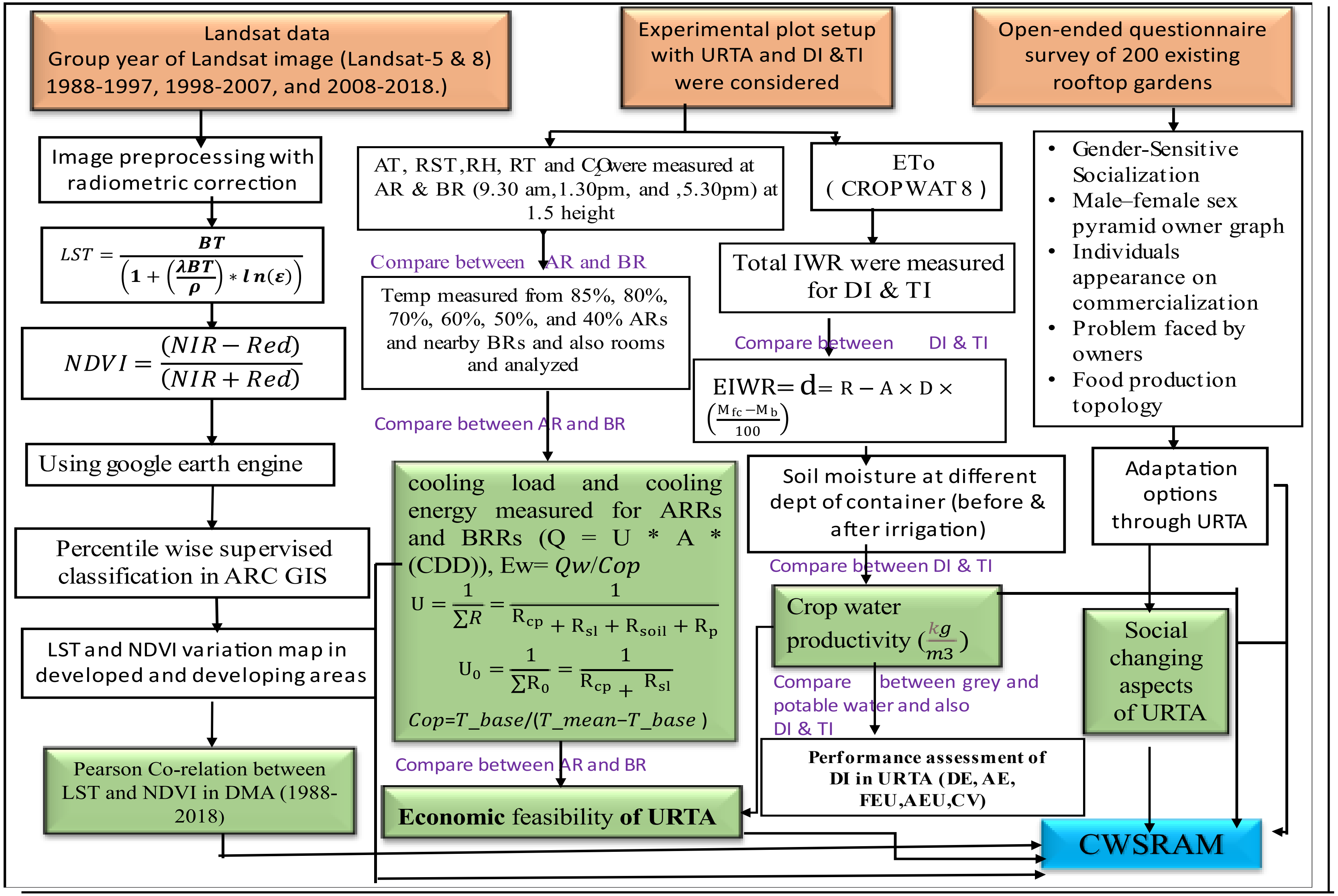
Figure 3.7 Conceptual Model's (CWSRAM) Diagram

So, the CWSRAM is the way to realize the importance of URTA and make adjustments the roofs to achieve maximum benefits from the system of RTA.

Chapter 4
MATERIALS AND METHODS

4.1 Introduction

The local warming, instigated by the urban heat island (UHI), significantly increases temperatures as well as economic losses in addition to global warming. The rapid urbanization process plays a key role in the formation of UHI as well as global warming. Natural landscapes of rural areas are transformed into modern land use and land covers like buildings, markets, roads, and other impervious surfaces, making urban landscapes fragmented and sophisticated and raising the urban temperature affecting the lives of urban dwellers. That's why climate change in urban areas is likely to have a substantial impact on quality of life, the water cycle, fluctuating rainfall forms affecting the availability and quality of both surface and groundwater, agricultural production, and related ecosystems. Extreme weather conditions such as high temperatures, in height wind pressures, and irregularity of rainfall have a great deal of influence on agricultural activities. Dhaka is a mega city that is about to become the sixth largest city in the world and increasing the severe UHI conditions in Dhaka by creating heat stress. To address this problem, this study has been conducted within the DMA to find the potential of URTA as a climate change adaptation tool through efficient water management technique. Finally, this study has developed a CWSRAM for the future guideline of URTA to city dwellers under the present warming situation as well as changing global climate in the urban areas. This chapter described the methodology which represents the i) identified the most hotpot zone and relation between LST and vegetation index through calculation of land surface temperature (LST) applying Landsat images in the developed and developing areas of the study area; ii) Observed the variation of micro-climatic parameter's between experimental AR and BR and finally cooling degree day (CDD), cooling load and Energy savings were found from the climatic parameters variation and social aspects of URTA ; iii) observed the drip irrigation performance compare to traditional irrigation in the urban rooftop agriculture as well as water saving performance and crop water productivity under these irrigation approaches, finally, iv) developed a conceptual model of climate and water smart urban rooftop agriculture (WCSRAM) for sustainable climate change adaptation and food security for city dwellers. The overall flow chart of methodology is given bellow.



$$LST = \frac{BT}{\left(1 + \left(\frac{\lambda BT}{\rho}\right) * ln(\varepsilon)\right)}$$

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

$$EIWR = d = R - A \times D \times \left(\frac{M_{fc} - M_b}{100}\right)$$

$$U = \frac{1}{\Sigma R} = \frac{1}{R_{cp} + R_{sl} + R_{soil} + R_p}$$

$$U_0 = \frac{1}{\Sigma R_0} = \frac{1}{R_{cp} + R_{sl}}$$

Figure 4.1 Overall flow chart of methodology of the study.

The flow chart represents the outline of methodology of the study where CWSRAM has been developed. Firstly, from the Landsat data, spatial and temporal variation of LST and NDVI in DMA were calculated during the period of 1988-2018. A supervised classification has been applied to develop the LST and NDVI mapping of DMP area. A regression trend has been developed based on LST and NDVI, LST and DBT. The experimental plot has prepared in the roof of SAU and BADC officers Quarter. Temperature, Relative humidity, CO2 data were measure in the AR and nearby BR and also selected roof (40%, 50%, 60%, 70%, 80%, and 85%) from the questionnaire survey. Cooling load and energy savings have been calculated by AR compare to the BR. On the other hand, crop water productivity of Bottle Gourd, Tomato, Brinjal, Chili were also calculated by the drip irrigation and traditional irrigation from the irrigation source of potable water and grey water. Social aspects of URTA were also analyzed from the open-ended questionnaire survey. Finally, a CWRAM has been developed from these findings of the study adaptation options of URTA. All primary and secondary data and data analysis have been described below.

4.2 Description of dataset

4.2.1 Landsat data

Landsat 5 TM and Landsat 8 OLI/TIRS were acquired for the summer months like March, April, and May from 1988 to 2018 for deriving LST trends. The images received from the USGS website (http://www.earthexplorer.usgs.gov) and cloud-free images or images with minimal cloudiness (less than 5%) were considered. All bands of the satellite imagery of the DMA (band 2 - 8 and 10 - 11) were clipped to the study area boundary. Before vegetation and LST variation mapping, these satellite images were subjected to a group of preprocessing procedures. The pre-processing included radiometric calibration and atmospheric correction (dark-object subtraction). Then, the pictures were further resampled with pixel sizes of 30 m by 30 m for all bands, including the thermal band. The ultimate urban landscape was divided into different group classifications. During this process, with the Google Earth Engine, images with high spatial resolution and other auxiliary data were calculated to spot the land use types. Alongside the LST data, Landsat image of the clear sky days were used for the accurate estimation of the LST averages for the month of March, April, and May. Additionally, the standard assurance data sets were used, and only good data quality pixels were selected, which have a mean error for emissivity ≤ 0.01 and for LST ≤ 1 K [256].

Table 4.1 Information about Landsat images used in the study.

Year Range	**Sensor Type**	**Number of Images**	**Acquisition Months**	**Path/rows**	**Spatial Resolution**
1988-1997	TM	106	March, April & May	137/44	30m
1998-2007	TM	90	March, April & May	137/44	30m
2008-2018	TM and OLI/TIRS	117	March, April & May	137/43 and 137/44	30m

4.2.2 Climatic data (BMD station data)

Daily climate data such as maximum temperature, minimum temperature, relative humidity, sunshine hours, and wind speed have been collected from Bangladesh Meteorological Department (BMD), Dhaka from 2008-2017 [Table 4.2, Table 4.3, Table 4.4, Table 4.5 and Table 4.6]. Besides, hourly dry bulb temperature (DBT) has also been collected for the month of March, April, and May during 1988-2018 (Annexture-1). Self-determining five climatic data have been used to run the CROPWAT 8.0 model for estimating the reference evapotranspiration (ET_0) for starting the irrigation. The hourly DBT data have been used for regression analysis of LST and DBT.

Table 4.2. Monthly & Yearly Maximum Temperature in °C from 2008-2017

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Spt.	Oct.	Nov.	Dec.
2008	29	30.6	34.6	36.9	36.7	35.4	34	36	34.8	34.8	32.3	29
2009	28.1	33.9	36	39.6	37.8	36.5	35.7	34.3	35.3	35.8	33.9	29
2010	29	31.2	37.3	37.9	36.9	35.8	35.1	35.1	34	35.7	33.2	29.7
2011	27.8	31	34.5	35.8	35.3	36	35.4	35	36.2	34.5	32.4	30
2012	28.5	33	37.3	37.1	36.2	36.7	34.3	34.5	36.5	34.4	32.4	28.5
2013	28.1	32.4	36	37	37.1	36.4	34.6	35	35.7	35.2	32.1	30.5
2014	28.5	30.4	38	40.2	38	37	35.8	34.4	34.8	36	33.8	29.2
2015	29.9	32.2	36.4	35.5	36.4	36.5	35.5	34.7	36.5	35.5	32.9	30.3
2016	27.6	34	34.8	39	37	36	34.6	36.1	34.7	36	34.5	31
2017	30.2	32	33.6	36.5	37	36.1	35.8	34.2	36	36.5	33.2	29.4

Table 4.3. Monthly & Yearly Minimum Temperature in °C from 2008-2017

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Spt.	Oct.	Nov.	Dec.
2008	10.5	10.8	16.5	19.6	20.3	22.5	24.6	23.6	24.4	18	16.3	13
2009	11.1	12.2	15.8	20.4	21.6	22.6	24.4	24.3	24.5	20.6	15.2	11.4
2010	9.6	12	18.4	20.8	21.3	23.2	25.3	25	24.8	21.5	16.6	11
2011	8.2	13	16	20.2	21.3	23.2	23.9	24.5	23.7	22	17.2	11
2012	10.5	12.2	18.3	19	20.5	23.2	25.2	24.4	24.9	20.3	14.8	9.6
2013	7.2	14	16.7	19.8	20	22	24.5	24.5	24.2	20.1	16	11.8
2014	10.3	11.6	16	18.9	21.1	23.2	24	24.3	24.2	19.5	15.4	12.3
2015	11.4	12.8	15	19.5	20.1	23.2	23.6	23.8	24	20.3	17.5	11.5
2016	10	13.3	19.5	18.2	21.3	22.8	24.5	24	25.3	22.8	17.6	14.9
2017	11.3	14.2	16	20	21	22.8	24.8	25.2	24	19.1	17.1	14.2

Table 4.4 Monthly & Yearly Average Relative humidity in % from 2008-2017

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2008	69	61	67	64	70	80	83	81	81	77	69	79
2009	72	55	53	66	72	74	80	82	81	73	66	69
2010	71	56	59	67	71	79	77	78	79	74	68	66
2011	69	54	57	64	76	80	79	82	77	73	67	73
2012	66	52	57	69	70	77	79	78	79	71	68	77
2013	65	55	55	63	78	76	77	80	81	78	66	72
2014	72	62	52	56	68	78	77	82	76	72	66	77
2015	70	63	52	68	71	77	81	79	78	73	69	68
2016	68	63	59	72	74	75	82	77	82	74	73	72
2017	62	57	67	72	73	80	83	83	82	79	67	76

Table 4.5 Monthly & Yearly Average Hours from 2008-2017

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	4.7	6.6	5.9	8.5	7.7	4.2	3.1	4	4.4	5.8	7.9	3.9
2009	5.7	8.7	7.3	8.3	6.8	5.9	4.7	3.9	4.1	6.2	6.7	4.8
2010	5.7	6.7	8.3	7.3	6.7	3.7	4.9	4.4	3.8	5.8	6.2	6.2
2011	4.9	7.5	7	6.8	5.5	3.5	4.1	2.5	5.1	6.1	6	4.4
2012	4.6	7.1	7.6	7.1	6.2	2.9	3.9	3.8	4	6	5.6	3
2013	4.5	7	7.9	6.5	3.6	4.8	4.4	3.3	3.6	4.5	7	4.1
2014	4.2	6.3	8.6	8.6	6.7	3.3	3.9	3.2	4.8	5.8	5.2	2.8
2015	4.4	5.4	8.5	6.4	6.4	4.7	2.5	3.4	4.2	6.1	6.2	4.6
2016	5.1	6.2	7.1	7.4	5.8	5.5	3.4	4.8	4	5.3	5.6	5.2
2017	6.2	7.3	6.1	6.1	6.8	4.2	3	3.4	3.8	4.9	5.6	4.4

Table 4.6 Monthly Prevailing Wind Speed in Knots of Dhaka

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2008	3.6	3.2	3.8	3.4	3.4	3.3	3.4	2.8	2.8	9.6	2.5	3.3
2009	3.3	4.1	4	4.1	3.8	3.1	4.3	2.8	4.2	2.3	2.8	2.4
2010	2.9	3.3	3.8	4.1	3.7	3	2.4	2.2	2.6	2	2.9	2.4
2011	2.2	2.4	3.8	2.4	3	2.7	2.4	2.4	2.6	2	2.3	2.1
2012	2.4	3	2.5	2.6	2.5	3	2.7	2.5	2.2	2	2.2	2.3
2013	2.3	2.2	2.6	2.8	3.2	2.3	2.7	2.7	2.2	2.9	2.1	2.3
2014	2.5	2.5	2.4	2.2	2.8	2.1	2.4	2.4	2.1	2.1	2.1	2.2
2015	2.2	2.4	2.2	2.5	2.3	2.6	2.4	2.7	3	1.9	2.5	2.1
2016	2.7	2.6	2.3	3	3.6	2.4	2.3	2.8	2.1	2	2.5	2
2017	2.2	2.3	2.5	3.1	2.5	2.4	2	2.2	2.2	3.3	2.4	2

4.2.3 Open-ended questionnaire survey data

The questionnaire survey was conducted within the DMA, and rooftop gardens were selected randomly in the specific area. The 200 rooftop gardens were randomly visited among the 30 wards of the study area. Azimpur, Maghbazar, Malibagh, Motijheel, Jatrabari, Bangsal, Dhanmondi, Mohammadpur, Shamoli, Lalmatia, Farmgate, Agargoan, Mirpur 10, Mirpur 11, Shewrapara, Shahbagh, Khilgoan, Mirpur 13, Mirpur 14, Mirpur1, Mirpur 2, Kallanpur, Uttara, Modeltown, Khilkhet, Badda, Rampura, Mohakhali and Gulsion 1 and Gulsion 2 have included for questionare survey. It was done by oral interviews of the building/rooftop garden owner to gather more in-depth information, opinions and preferences. The role of food production, priorities of involvement of women, choices of multiple crops, promotion or popularization, growth and trends and economic strengths or values of URTA, etc., were considered in the study to clarify the social dynamics of URTA. On the other hand, profile of garden initiative (year of establishment, size, design, number of members); type of garden (ownerships, organization form, management); technical knowledge of gardeners (cultivation method, irrigation system, growing medium, interest of gardener, motivation behind the activities; key stakeholders indispensable for founding and developing an initiative; resources needed; sustainability habits related to the activities. Much attention was paid to the present trends of existing rooftop garden's, technical knowledge of gardeners, the space, design, ownerships, cultivation method, irrigation system, growing medium, interest of gardener, problem identify during cultivation, production, contribution of family members, view of gardeners (benefits of gardens) installation costs, roof weight limitations, appropriate management practices such as energy savings and storm water management, water proofing and urban communities.

4.2 Questionnaire survey of rooftop gardener

On the other hand, some major approaches have also been considered during questionnaire to the owners of the garden for sustainable URTA for urban areas. The approaches identified vary widely in complexity, as well as in the type and nature of information essential for city dweller's practice on RTA. Most have already been used for assessments of crop water productivity, adaptation, or mitigation of micro-climate effects in rooftop agriculture. The participatory approach to prioritize research aims around climate change and ground water-saving, for instance. However, quantitative information from a wide variety of sources, including data derived from the experimental plot were analyzed and used as input to the process. Table 4.7 shows that different indicators of URTA. Area coverage with different percentages was the main focal point indicators based on climatic parameters (temperature, relative humidity, CO_2 concentration, CDD, and energy-saving trends) and the owner's opinions on responses to rooftop agricultural principles. Demand for fresh food was simulated based on changes in income, population, and prices. The impact of the commercial demand was assumed by finding the product prices that are related to the market prices, equating supply for all commodities. Techno-socio-economic Paths and inter-connection with communities, especially leadership within the URTA's groups and their suggestion on the agricultural system and impacts of RTA were also evaluated at the global and national level. The types of approaches and their priority are described in Table 4.7.

Table 4.7. Different types of approaches and their intercession and prioritization in URTA

Approaches	**Social (S) (mental recreation hobby)**	**Adaptation and Mitigation (AM)**	**Fresh food production**	**Water pressure reduce**	**Gender empowerment and global economy**	**Government policy**
1. Micro-climate change adaptation to enhance fresh food security	*	***	**	**	*	***
2. Adaptation Possibilities in Relation to the Sustainable Development Goals	*	***	**	**	**	***
3. Vulnerabilities and barriers of key rooftop agriculture Sectors to Climate Change	*	***	**	**	*	***
4. Mainstream adaptation into cultivation activities	**	**	***	***	***	**
5. Regular management practices to improve crop water	*	**	***	***	***	**

Approaches	Social (S) (mental recreation hobby)	Adaptation and Mitigation (AM)	Fresh food production	Water pressure reduce	Gender empowerment and global economy	Government policy
productivity and efficiency						
6. Farming systems consistent with climate-smart agriculture	*	***	***	***	***	***
7. Micro-climate change impacts on freshwater resources and water-dependent services	**	**	***	***	***	***
8. City dwellers community resilience to climate change and RTA	***	***	***	***	*	*
9. Impact of large-scale governmental Soil and Water Conservation on smart container use in the RTA	***	**	***	***	***	***
10. Improving food security by using suitable place for different types of plant RTA	**	***	***	***	***	***
11. The Role of sustainable roof area and soil use management to achieve effective water Use	*	***	***	***	*	***
12. Managing rain and grey water	-	**	**	***	***	***
13. Flexible water storage and adaptation to climate change	*	***	*	***	*	*
14. Realizing the potential of low-cost drip irrigation in promoting food production and income	*	*	***	***	**	***
15. Cropping Season variation with high impact of micro-climate change	*	***	**	**	***	**

Note: Relevance: *** highly relevance; ** relevance; * slightly or highly context-specific

4.2.4 Temperature, Relative humidity (RH) and Carbon-dioxide (CO_2) concentration data

The air temperature (AT), near roof surface temperature (RST), relative humidity (RH) and carbon dioxide (CO_2) data were collected from the middle part of the experimental AR plot and from four middle locations of the east, west, south and north edges of the experimental AR plot. Temperature-RH- CO_2 measuring data loggers (HUATO, S653) was used to measure temperature, RH and CO_2 concentration (Figure 4.8). Glass thermometer was also used measure the air temperature at the same heigh to justify the reading of temperature. It was done 5 days per week from November 2018 to May 2019 from the experimental AR and nearby BR at 9:00 am, 1:30 pm and 5:30 pm. A digital compact infrared thermometer (Figure 4.9) with a 4-h interval was also used for the measurement of roof surface temperature.

Figure 4.8 Temperature-RH-CO_2 measuring data loggers (HUATO, S653)

Figure 4.9 A digital compact infrared thermometer

4.2.5 Field capacity and soil moisture data in the growing medium

In this study, before sending the soil to the laboratory, the field capacity of the soil was measured. Firstly, a known quantity of soil container was taken and then saturated until the free water drained by the several holes at bottom of the drum or container [Figure 4.10]. Saturated the soil in the container and covered the top of the pot to avoid evaporation by 24 hours so that excess water of soil was removed. In this system, all micropores of soil were filled up by water. When the gravitational water was seized then wet soil was collected using a 53 mm diameter steel core sampler. The samples were weighed immediately in the field, kept in a sealed polythene bag, and transported to the laboratory where they were oven-dried at 105°C for about 48 h until constant weight. After drying, the soil was again weighed and therefore the mass of water determined on the idea of pre and post readings. The dry weight fraction of each sample was calculated using the following equation [257].

$$\theta_w = \frac{W_w - W_d}{W_d} \times 100 \quad (4.1)$$

Where θw = Soil water content on a dry mass basis [%], Ww = Weight of the wet soil (gm), Wd= Dry weight of the soil (gm). Then the moisture contents of the soils collected from the chosen fields at different depths were determined. To convert the dry weight soil moisture fraction into volumetric moisture content, the dry weight fraction (θw) was multiplied by its respective bulk density bρ and divided by the specific weight of water ρw as follows;

$$\theta = \frac{b_\rho \times \theta_w}{\rho_w} \quad (4.2)$$

Subsequently dry soil sample was also sent to the laboratory to measure the moisture content of dry soil which indicates permanent wilting point of crops.

Figure 4.10 Measurement of field capacity of soil in the experimental

On the other hand, the moisture and temperature measurement data logger (HUATO-SS00) were used to measure the soil moisture before and after irrigation and this was carried out for 2 days/week (Figure 4.11 and Figure 4.12) within the experimental period (December 2018 to May 2019). Soil moisture and temperature were measured in the container at a depth range of 45 cm 30 cm and 15 cm, respectively from the surface of the soil container, so that the right amount of irrigation was applied to maintain the soil's available moisture has shown in Table 4.8 [258]. The average root depths of the selected crops were measured after the ripening stage to select the third season's container size.

Figure 4.11 Soil moisture and temperature measurement data logger (HUATO-SS00)

Figure 4.12 Soil moisture and temperature measurement scenario at different depth of soil in the container.

Table 4.8 The average moisture content data of soil at different depths in the container during, before and after irrigation (from the top of the container).

Crop's Name	The Moisture Content before Irrigation (%)				The Moisture Content after Irrigation (%)			
	5 cm	15 cm	30 cm	45 cm	Top	15 cm	30 cm	45 cm
Bottle Gourd	26.3	23	20	19.9	30.8	25.3	22.5	20.32
BARI Tomato 3	28.2	20	21	20	31.34	26.4	24	22
BARI Hybrid Brinjal	26.4	22	20	19	31.5	26.8	21	19
Bogra local chili	26.7	22	21	21	33	28.5	25	22

4.2.6 Irrigation water requirement data

The irrigation water requirements were calculated from actual daily climatic data taken from the experimental plot using a temperature-humidity measurement data logger [HUATO, S653]. The crop water requirement of the reference crops was determined by using the CROPWAT 8 model and the soil available moisture content. One day earlier, micro-climatic parameters were used to determine the daily crop water requirement. Daily temperature, humidity, and sunshine hours were considered as primary data and wind speed was considered as a 10 years average value taken from the Bangladesh Meteorological Department (BMD).

Evapotranspiration (ETo) using the CROPWAT 8.0 model was calculated (ETc) for the selected crops by the following formula [259] [260]:

$$\mathrm{ET_c} = \mathrm{ET_0} \times \mathrm{K_c} \tag{4.3}$$

where K_c = crop coefficient of selected crops. K_{ct}, $K_{cb,}$ K_{cb}, and K_{cc} are the crop efficient values of Tomato, Bottle gourd, Brinjal, and Chili, respectively [Table 4] proposed by the Bangladesh Agricultural Research Institute (BARI). ET_0 = reference evapotranspiration (mm day-1), The reference evapotranspiration (ET_0) was calculated using the following Penman-Monteith equation through the CROPWAT 8.0 model [Table 4.10] [261].

$$\mathrm{ET_o} = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma \frac{900}{\mathrm{T} + 273} \mathrm{U_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\mathrm{U_2})} \tag{4.4}$$

where R_n , G, T, $U_{2,}$ e_s, and e_a represent the net radiation of the surface (MJ m-2 day-1), the soil heat flux density (MJ m-2 day-1), air temperature at 2 m height (°C), the wind speed at 2 m height (m s-1), the saturation vapor pressure (kPa) and the actual vapor pressure (kPa), respectively; D, and γ represent the slope vapor pressure curve (kPa °C-1), and psychrometric constant (kPa °C-1), respectively. The daily volume of applied water was estimated from the crop water requirement which was measured by total daily rainfall subtracted from daily crop evapotranspiration (ETc) before the day of irrigation [Table 4.9]. When rainfall exceeded the ET =c value, irrigation was postponed and the surpassing amount of water was considered in the calculation of the succeeding irrigation volumes [Table 4.10].

Table 4.9 Kc values of BARI bottlegourd-3, BARI Tomato-3, BARI Brinjal-8 and Bogra Local Chili.

Stage	K_{Cb}	K_{Cbr}	K_{Ct}	K_{Cch}
Initial stage	0.7	0.42	0.46	0.3
Vegetative	1.5	0.8	0.83	0.6
Flowering stage	1.7	1.3	1.08	0.95
Ripening stage	1.4	0.93	0.86	0.8

Note: K_{Cb}, K_{Cbr}, K_{Ct}, and K_{Cch} represent the crop co-efficient of Bottle Gourd, Brinjal, Tomato and Chili, respectively.

Table 4.10 Rainfall (mm) and Evapotranspiration (ETo) in mm/day of the experimental plot's location.

Month	Rainfall (mm)	Eto (mm/day)
November	20	3.71
December	10	2.58
January	-	3.01
February	45	3.61
March	45	4.83
April	215	5.89
May	295	6.49

4.3 Estimation of Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI)

4.3.1 Image Pre-Processing

Landsat 5 TM and Landsat 8 OLI/TIRS were acquired for the summer months like March, April, and May from 1988 to 2018 for deriving LST trends. The images received from the USGS website (http://www.earthexplorer.usgs.gov) and cloud-free images or images with minimal cloudiness (less than 5%) were considered. All bands of the satellite imagery of the DMA (band 2-8 and 10-11) were clipped to the study area boundary. Before land cover (LU) classification mapping and LST trend, these satellite images were subjected to a group of preprocessing procedures. The pre-processing included radiometric calibration and atmospheric correction (dark-object subtraction). Then, the pictures were further resampled with pixel sizes of 30 m by 30 m for all bands, including the thermal band. The ultimate urban landscape was divided into different group classifications. During this process, with the Google Earth Engine, images with high spatial resolution and other auxiliary data were calculated to spot the land use types. Overall, the entire accuracy of the land use classification was achieved over 86.6% [262]. Alongside the LST data, Landsat image of the clear sky days were used for the accurate estimation of the LST averages for the month of March, April, and

May. To make sure the reliability of the monthly LST values, a minimum threshold of twelve clear sky days per month was set. Additionally, the standard assurance data sets were used, and only good data quality pixels were selected, which have a mean error for emissivity ≤ 0.01 and for LST≤ 1 K [263].

vegetation index (NDVI). Google Earth Engine and ArcGIS version 10.6 were used for image processing. Microsoft Excel was used for conducting the statistical analysis using the multi-buffering method. Pre-processing was done for the Landsat images to remove the biases [264]. Usually, it was not necessary to conduct a geometric correction for Landsat level 1 products, as they were registered through a systematic process [265]. The main correction was radiometric and eliminates errors that affect the brightness values of the pixels [266]. These errors were mainly due to detection errors in the sensor system and environmental attenuation errors. The original image sizes were larger than the study area, so after pre-processing, they were edited using a shapefile of the DMA.

In this study, the supervised classification was used to estimate the land cover categories and to generate the LST trends maps of the different percentiles of LSTs over time using the emissivity and effective at-sensor brightness temperature. All equations were considered from USGS website. The additional input parameters such as atmospheric water vapor content and near surface air temperature from ground-based observations were also required to calculate the LST. They were usually unavailable [267]. All the digital numbers (DN values) of thermal bands were converted into spectral radiance using Google Earth Engine. A three-step process was followed to derive the LST from Landsat image in both developed and growing developed areas [38]. The trend of different percentile of LST over time like 50^{th}, 75th, and 90th percentile for the whole DMAs was estimated by different year LST groups. The thermal infrared observations are easily contaminated by cloudiness, leading to many gaps during the LST estimation [268]. So, it is indispensable to observe the LST trend in the different locations of urban areas for further adaptation of the microclimatic changes or to mitigate the UHI. To mitigate global warming, LST is a very cohesive factor that increases UHI. The final step of retrieving the LST or the emissivity-corrected land surface temperature was computed using the emissivity and effective at-sensor brightness temperature, where images were further used to derive LST using Equation (4.5) [269]:

$$LST = \frac{BT}{(1+\left(\frac{\lambda BT}{\rho}\right)*l(\varepsilon))} \quad (4.5)$$

Where LST is in ˚C, BT is the at sensor brightness temperature (˚C), λ is the average wavelength of the specific band, ε is the emissivity and ρ = h c / σ, σ = Boltzmann constant (1.38 × 10−23 J/K), h is Planck's constant (6.626 × 10−34 J/s), c is the velocity of light (2.998 × 108 m/s).

4.3.2 Calculation of Brightness Temperature

The Equation for calculating the brightness temperature Eq. (4.6) is that the same for Landsat TM, ETM+ and OLI/TIRS [270].

$$BT = \frac{K_2}{ln\left(\frac{K_1}{L}+1\right)} - 273.15 \quad (4.6)$$

Where BT is the effective satellite temperature (brightness temperature) in °C, K_1 is that the band-specific conversion constant, and K_2 is another calibration constant in Kelvin. Therefore, values of K_1 and K_2 are constant for OLI/TIRS, but the values of bias and gain values could also be different for various satellite images.

4.3.3 Calculation of Top of Atmospheric (TOA) Spectral Radiance

Pixel values represent the Digital Number (DN). Radiance depends on the illumination (both its intensity and direction) and on the orientation and position of the target. The top-of-atmosphere (TOA) Earth radiation budget (ERB) may be a key property of the climate system that describes the balance between what proportion of solar power the world absorbs and the way much terrestrial thermal infrared it emits. The DN values were converted to TOA Spectral radiance and calculated using the subsequent Equation (4.7):

$$\mathrm{TOA(L)} = \mathrm{M_L} * \mathrm{Q_{cal}} + \mathrm{A_L} \quad (4.7)$$

Here, ML represents the band-specific multiplicative rescaling factor from the metadata, Q_{cal} is the Quantized and calibrated standard product pixel values, correspond to band 10, AL is the band-specific additive rescaling factor from the metadata, the pixel values of satellite images (DN) were converted to Kelvin and further to Celsius.

4.3.4 Estimation of Emissivity

Surface emissivity is important for calculation of land surface temperature by remote sensing. There have been several studies on emissivity. Among these, we adopted the frequently used method of the estimation of emissivity using simplified normalized difference vegetation index (NDVI) thresholds derived from the spectral reflectance in the red and near-infrared bands. It is assumed that the surface is flat and homogeneous. The conditional Equation (4.8) for estimation of emissivity [271] is as follows:

$$\text{Emissivity} = \varepsilon v\lambda PV + \varepsilon s\lambda\,(1 - Pv) + C\lambda \quad (4.8)$$

Where εv and εs are the vegetation and soil emissivity.

In this study, values of vegetation and soil emissivity 0.98 and 0.92, respectively; C represents the surface roughness taken as a constant value of 0.005 (C = 0 for flat surfaces and homogenous), λ represents wavelength (μm), Pv is the fraction of vegetation or proportion of vegetation (Pv) is calculated by the following equation (4.9).

$$Pv = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4.9)$$

4.3.5 Estimation of Normalized Difference Vegetation Index (NDVI)

In this study, NDVI was used to expression the vegetation land cover changes in urban area specifically, in the more developed and growing developing areas within the study area and differences in the spatial resolution of the images, which are within 30 m. GIS tools were then applied to the data using visual analysis, reference data, as well as local knowledge to split and recode these covers. It was done to closely reflect their true classes. Conversely, assessment of NDVI for a specified pixel always results in a number that ranges from minus one (-1) to plus one (+1). The Normalized Difference Vegetation Index (NDVI) is calculated by the ensuing equation (6). Three main types were identified: low vegetation, medium vegetation, and high vegetation. In this study, NDVI values have been selected less than zero to 0.05 for low vegetation and others (less vegetation, no vegetation, built-up areas, and waterbody), 0.05 to 0.2 for medium vegetation, and 0.2 to 1 for high vegetation. The supervised classification of NDVI were re-classed because sometimes urban landfill were merged with other classes, which were not possible to separate them due to their similar spectral properties. So, re-classification was used to improve the accuracy of the classification by the physical field survey method. In this study, classification accuracy refers to communication between the remotely sensed data and reference physical information of those pixel values. In order to assess the accuracy of land cover maps extracted from Landsat data, a total of 20 stratified random pixels were generated for the year 2018.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

(4.10)

NDVI is calculated for Landsat 5 TM and Landsat 8 OLI & TIRS with the following prescription:

NDVI for Landsat 8 OLI & TIRS = (Band 5 – Band 4) / (Band 5 + Band 4) and for Landsat 5 TM, NDVI = (Band 4 - Band 3) / (Band 4 + Band 3). NDVI will be computed temporally to understand the change of land cover during the study period and for the proportion of vegetation (Pv). That is why Pv is highly related to the NDVI and emissivity (ε).

4.4 Estimation of Environmental changing aspects of urban rooftop agriculture (URTA)

4.4.1 Analysis of air temperature, roof-surface temperature, CO_2 concentration, and room temperature in the agricultural roof (AR) and bare roof (BR)

The temperature was measured near the roof surface, 1 m, 1.5 m and 2 m above from roof surface for both AR and BR for the same height. However, all data (except at 2 m) were collected from below the shaded of the canopy layer of plants so that direct solar radiation could be avoided. The temperature was also measured from the selected five existing ARs and top floor room at 1.5-m height above the roof surface. At the same time, temperatures were measured from the middle of the top floor room of the selected 6 BRs near the experimental AR. RH and CO_2 data were collected only at 1.5-m height above the roof surface for the URTA roof and comparatively to the adjacent BRs in this study. All data were collected at 1.5 m above the roof surface because the average minimum height and branch density of those selected crops varied from 0.9 m to 1.5 m due to human comfort breathing at this height in Bangladesh context. The ambient temperature data from the top floor room under the experimental AR and the BR were also collected for comparing the thermal variation among them. Daily mean air temperature trend, Percentiles of daily mean air temperature trend of ARs and BRs, Temperature differences histogram for different area coverage ARs and BRs, box and whisker plots for spatio-temporal variation of roof surface temperature for experimental ARs and BRs etc. were analyzed to make a comparison of the temperature effect between ARs and BRs. On the other hand, descriptive statistics of air temperature at different positions of ARs and BRs, and relative humidity trend in experimental AR and BR, were also analyzed to find the environmental benefits of URTA. Linear regression analysis of average CO_2 concentration was also considered for AR and BR.

4.4.2 Temperature Trend Measurement of Soil in the Container and Air Under URTA

The temperature trend in the container was also measured in the ARs at the lower, middle and upper portion of the container. At the same time, the temperature in the land was measured for the same height of the lower middle, and upper portion of the container for comparing the trend of temperature and find out the cause of roof cooling by URTA. Temperatures were measured at 0.8 m, 1 m, 1.5 m and 2 m from the roof surface to find out the temperature trend in URTA during the whole experiment period for 9:30 am, 1:30 pm and 5:30 pm daily.

4.4.3 Cooling Degree Day (CDD) calculation

The degree-day approach was directly proportional to a difference between the mean daily temperature of ambient air and indoor temperature. The higher the CDD, the higher was the energy requirement for cooling. Considering the average outside temperature of Dhaka during the summer season, the base temperature for cooling comfort in the room (T_{base}) was 20 °C [260]. In this study, the principles of CDD were used to study the energy consumption of URTA-containing buildings in Dhaka. About 40–85% area coverage scenarios were explained and calculated for the trend of energy consumption. We determined the corresponding energy and cost savings in those selected URTA locations across Dhaka. The CDDs were calculated for six URTA roofs based on roof area coverage by plants. However, the optimal area coverage and plant density worked as an insulation thickness. A function of CDD and the pay back period of the URTA, as well as insulation costs and other costs, were analyzed, which addressed the comparison between URTA roofs and roofs without URTA. The following equation was used for the calculation of the CDD. If $T_{max} < T_{base}$, CDD = 0; If the average value of the minimum and maximum temperature below the base temperature, then the corresponding values of the daily and monthly CDD was calculated by the following formulas (Equations (4.11) and (4.12)):

$$\text{If, } (T_{max} + T_{min})/2 < T_{base}, \text{ then CDD} = (T_{max} + T_{base})/4 \quad (4.11)$$

$$\text{If, } T_{min} > T_{base}, \text{ then CDD} = (T_{max} + T_{min})/2 - T_{base} \quad (4.12)$$

where T_{max}, T_{min}, T_{base} and CDD are the maximum temperature, minimum temperature, base temperature and cooling degree day, respectively.

4.4.4 Overall heat transfer coefficient calculation

The overall heat transfer coefficient, U, may change because of variations in inflow conditions and fluid properties. For steady-state conditions, the rate of heat flow per unit area through a compound element, such as in the AR, was estimated by the following Equation (9) and heat flow through the BR was calculated by the following Equation (4.13, 4.14):

$$U = \frac{1}{\sum R} = \frac{1}{\text{Rcp} + \text{Rsl} + \text{Rsoil} + \text{Rp}} \quad (4.13)$$

$$U = \frac{1}{R_{cp} + R_{sl}} \quad (4.14)$$

where $\sum R$ (m^2K/W) is the total resistance (the sum of individual resistances), R_0 is the thermal resistance of BR, R_s is the thermal resistance of soil with 40% moisture content, R_{cp} is the thermal resistance of cement plaster, R_{sl} is the thermal resistance of slab and R_p is the thermal resistance of small plants. R-value of different layers of an AR is given in Table 4.11.

Table 4. 11 R-values of different layers of the agricultural roof (AR).

Particulars	Thickness	$\sum R$ (m^2K/W)	Source
Vegetation (small plants)		0.35	[261]
Soil with 40% moisture	400 mm	0.25	[262]
Soil with 40% moisture	100 mm	0.05	[263]

Cement plaster	50 mm	0.10	[264]
RCC slab	152 mm	0.108	[264]

4.4.5 Cooling Load and Energy saving Calculation:

The total cooling load on a room or building consists of internal loads. The external loads contain heat transfer by conduction through the building walls, roofs, floors, doors, etc., heat transfer by radiation through fenestration such as windows and sky-lights. The load due to heat transfer through the envelope is named as the external load, while all other loads are called indoor loads. In the case of an internal load of a building, the cooling load is required, especially for internal heat-generating sources such as occupants, lights or appliances. The proportion of external versus internal load varies with building type, site climate and building design. Since the surrounding conditions are highly variable on any given day, the cooling load of an outside-loaded building varies extensively. Apparently, from the energy production and economics points of view, the system design approach for an externally loaded building is a very important issue. Peak load calculations evaluate the utmost load to size and choose the refrigeration equipment. The energy analysis program compares the entire energy use during a certain period with various alternatives so as to work out the optimum one. In this study, Cooling Load Temperature Differential (CLTD) through the roof (URTA roof and BR) was derived and used tabulated data to simplify the calculation process. The basic conduction equation for warmth gain is:

$$\mathbf{Q = U\ A\ \Delta T} \quad (4.15)$$

where Q (W/m2) is the rate of heat flow per unit area through a compound element and $\triangle T$ (K) is the temperature difference. For steady-state conditions, the rate of heat per unit area between each surface is the same. The heat gain is converted to cooling load using the space transfer functions (sol-air temperature) for the rooms with light, medium and heavy thermal characteristics [Figure 4.13]. The equation is modified as [272]:

$$Q = U * A * (CDD) \quad (4.16)$$

Where Q = cooling load (W/m^2) is the rate of heat flow per unit area through a compound element; U = Coefficient of heat transfer of roof or wall or glass, W/ m^2K; A = area of roof in m^2 (Table 4.2); CDD = cooling degree day temperature difference (k). In this study, in case of overall heat transfer co-efficient (U) calculation, area covered by plants and soil is considered from the survey of existing roofs and experimental roofs (Table-4.12).

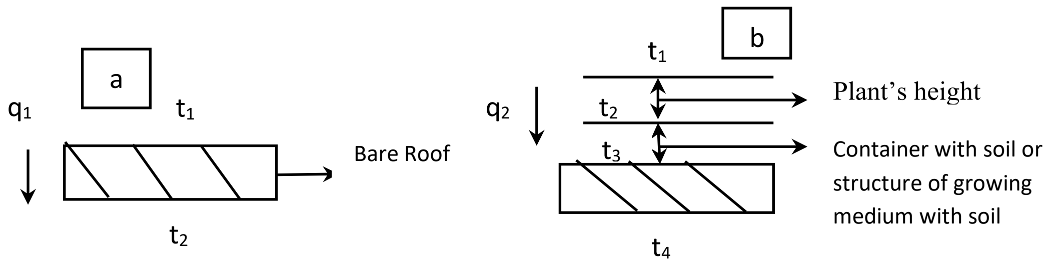


Figure 4. 13 Diagram of URTA experiment set-up. (a) bare roof (b) Typical roof with soil layer and plants.

Table 4. 12 Area considered for calculation of cooling load of the selected agricultural roofs (AR)

Details of Roof	% of the Area Covered by Soil with Plants	% of the Area Covered by Plants	% of the Bared Area
40% coverage	40%	40%	20%
50% coverage	30%	60%	10%
60% coverage	30%	30%	40%
70% coverage	30%	40%	30%
80% coverage	30%	40%	30%
85% coverage	30%	40%	30%

Note: The % of the area covered by soil with plants, % of the area covered by plants and % of the bare area were considered within the details of roof; e.g., 40% coverage roof represented that 60% of the area of the total roof was bare and 40% of the area was covered by URTA. Within the URTA-covered area, again, 40% of the area was covered with soil with plants, 40% of the area was covered with plants and 20% of the area was bare (all values in the table are measured values).

Here, the area covered by soil with plants represent the total area of roof covered by soil with the container or growing medium of plants, and only plants represent the area covered by a leaf of plants that were free from the container or growing medium. Surface temperatures were also measured on the AR under the plants (t_2) and over the plant (t_1) cover and room below the roof's temperature (t_3). On the other hand, at the BR surface, temperatures measured on the roof surface (t_1) and the room below the roof's temperature (t_2) were used in the calculation of U. Total amount of energy consumption for air conditioning is calculated by the following equation:

$$Ew=\frac{Q_w}{C_{op}} \quad (4.17)$$

where Q (W/m2) is the cooling load or heat transmission through the roof (W/m2), and

Cop is the co-efficient of performance of air conditioning system and is the ratio of useful heating or cooling provided to work required. In this study, Cop is calculated by the following Equations [272]

$$\text{Cop} = \frac{T_{base}}{T_{base} - T_{mean}} \qquad (4.18)$$

Where, T_{base} is the preferred human comfort temperature as 20 °C, and T_{mean} is the daily average value of room temperature.

Finally, Daily average energy saving (%) have been calculated with the different area coverage roofs by AR compare to adjacent BR during the month of March 2019 to May 2019. Different percentile of daily average energy saving (%) with respect to in the different area coverage AR have also been analyzed within those periods. Percentiles of cooling load and energy savings of different ARs represent the significant difference between the cooling load of different ARs reflects how benefit the greater area coverage comparison to other roofs and also compare to the BRs.

4.5 Estimation of irrigation water productivity in the urban rooftop agriculture (URTA) with the source of potable water and grey and rain water

4.5.1 Analysis of Irrigation Water Quality of Harvesting Greywater and Rainwater

The irrigation water quality of harvesting green water (grey and rainwater) was tested in the laboratory of the Bangladesh Agricultural Development Corporation (BADC) during the whole period of the second-year winter experiment (November 2019 to March 2020) every 15 days alternately. A total of 13 parameters (pH, Electric Conductivity (µs/cm), Total Dissolved Solids (mg/L), Arsenic (ppb), Iron (mg/L), Chloride (mg/L), Sodium (meq/L), Total Alkalinity (mg/L), Total Hardness (mg/L), Nitrate-Nitrogen (mg/L), Phosphate (mg/L) and Sulfate, (mg/L)) were measured in the laboratory [Table 4.13].

Table 4.13 Irrigation water quality of grey and rainwater

Sample Collecting Date	pH		EC (µs/cm)		TDS (mg/l)		As(mg/l)		Cl(mg/l)		Na (meq/l)	
	Tested value	Acceptable limit	Tested	Acceptable limit	Tested	Acceptable limit	Tested	Acceptable limit	Tested	Acceptable limit	Tested	Acceptable limit

1	2	3	4	5	6	7	8	9	10	11	12	13
7-Oct-19	7.9		826		413		0		0.01		1.00	
17-Oct-19	7.8		658		311		0		0		1.98	
14-Nov-19	7.4		912		457		0		0		3.72	
30-Nov-19	7.4		914		470		0		0		1.30	
15-Jan-20	7.7	6.5 to 8.5	736	2250 µs/cm	368	2000 mg/l	0	100 ppb	0	5.0 mg/l	1.00	600 mg/L
2-Feb-20	7.4		823		413		0		0		1.20	
17-Feb-20	7.9		826		398		0		0		1.00	
3-Mar-20	7.6		738		420		0		0		1.40	
20 March 2020	7.2		826		311		0		0		1.20	

Sample Collecting Date	**Total Alkalinity (mg/l)**		**Total Hardness (mg/l**		**NO3−_N (mg/l)**		**PO4 (mg/l)**		**SO4 (mg/l)**	
	Tested value	**Acceptable limit**	**Tested value**	**Acceptable limit**	**Tested**	**Acceptable limit**	**Tested**	**Acceptable limit**	**Tested**	**Acceptable limit**
15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
7-Oct-19	280		200		0		1.87		52	
17-Oct-19	260		185		0		2.3		70	
14-Nov-19	340		264		6		0.8		50	
30-Nov-19	320		136		4		0.6		95	
15-Jan-20	300	1000 mg/l	220	120 mg/l	3	23 mg/l	0.2	10 (mg/l)	60	1000(mg/l)
2-Feb-20	240		105		4		0.6		90	
17-Feb-20	320		230		3		0.4		80	
3-Mar-20	280		180		5		0.6		60	
20 March 2020	270		153		4		0.8		90	

4.5.2 Analysis Irrigation water requirement in the URTA

In case of drip irrigation, the irrigation water requirements of Tomato, Bottle Gourd, Brinjal, and Chili were calculated using the CROPWAT 8 model and the soil available moisture content at the different growth stage. One day earlier, micro-climatic parameters were used to determine the daily crop water requirement.

On the other hand, due to high roof surface temperature, air temperature and excess irrigation was also estimated by the moisture content variation of soil in the container. According to available soil moisture content, 70% moisture absorbs at 50% rootzone depth and the remaining 30% absorbs at the remaining 50% rootzone depth. However, in URTA total depth of container is the total rootzone depth and root is counted along with the soil in the container. This is why irrigation was not enough when regarding crop water requirement (ETc calculated by CROPWAT model). The change in the moisture at root zone was determined from the measurement of soil moisture in the container with a soil moisture measurement data logger. Total seasonal irrigation water use was determined by adding excess water to remaining available soil moisture in the soil up to 50% rootzone depth at each stage. That is why irrigation was carried out at the initial and vegetative stage every 10 days after and at the stage of flowering and ripening, irrigation was carried out every alternate 5 days and total depth of irrigation was maintained by the following formula [293]:

$$\mathrm{d} = \mathrm{R} - \mathrm{A} \times \mathrm{D} \times \left(\frac{\mathrm{M_{fc}} - \mathrm{M_b}}{100}\right) \tag{4.19}$$

where d, R, $\mathrm{M_{fc}}$ indicate the net amount of applied irrigation (mm), rainfall (mm), and the field capacity of the soil, respectively. $\mathrm{M_b}$ is the moisture content of soil before adding water, D is the depth of the soil in the container (mm) and A is the bulk density of the soil (g/cm3) in the container which was calculated by the following formula, A=M/V, where M is the weight of soil before adding water and v is the total volume of soil in the container. In this study bulk density of prepared soil is determined using the weight of the soil mixture in the container is 35000gm and the total volume of the container is 33343.87 cm3 (volume of the cylindrical container, $V = h\pi r^2$, h is the height in cm and area is πr^2 in cm3. However, in this study, the bulk density of prepared soil for URTA=35000gm/33343.87cm^3=1.04 gm/cm^3 is found in the prepared soil in the 1st year experiment and 2nd year experiment was found by 0.81 gm/cm^3. The bulk density was less in the 2nd year experiment compare to the 1st year experiment due to added more organic matter such as coconut and dry wastage of different vegetables and fruits. Conversely, container depth was considered as the root zone depth of the plans to measure the volume of soil in the container. The rainfall was also collected in the rain gauge and was measured in mm (container area divided (m^2) by the rainfall (in the litter) = rainfall in mm).

The total supplied irrigation water of those crops was also calculated for the traditional irrigation method by volumetric method is shown in Table 4.14.

Table 4. 14 Growth stages and irrigation water requirement (IWR) in mm.

Stage	**IWR (mm) for Rooftop Agriculture**											
	BARI Tomato-3			**BARI Bottle Gourd-3**			**BARI Brinjal-8**			**Local Chili**		
	DI	**TI (Pipe)**	**TI (Container)**	**DI**	**TI (Pipe)**	**TI (Container)**	**DI**	**TI (Pipe)**	**TI (Container)**	**DI**	**TI (Pipe)**	**TI (Container)**
Initial	76	145	95	94	185	140	68	100	120	63	121	106
Vegetative	125	350	180	245	578	220	153	200	450	125	285	161
Flowering	236	520	320	336	965	600	471	600	860	416	1020	641
Ripening	290	1000	750	419	2680	1500	361	600	1000	186	450	241
Total	726	2015	1345	1093	4408	2460	1053	1500	2430	790	1875	1148
Total IWR for land according to BARI	350–425 mm			320–350 mm			361 mm			290–340 mm		

Finally, after the cropping season the rootzone depth of each type of crop was measured to find the maximum rootzone depth and total length of the roots of those selected crops in the container. The soil around the roots was carefully removed from the selected crops after the first experimental setup of RTA and then roots were washed and measured on millimeter paper in order to determine the root depth in the container [Figure-4.14]. The average root depths were measured after the ripening stage of those crops. Thus, the container size was selected in the experimental setup according to the root depth of those selected crops.

Figure 4. 14 Measurement soil moisture and Root depth after ripening stage

4.5.3 Performance measurement of irrigation in URTA

Irrigation performance depends on various segments of the total irrigation water applied, how much water gets to the crop and how it is distributed among the plants by each emitter over the entire experimental roof. However, the irrigation performance was measured based on the applied water in the respective container or plant per unit time. Conversely, in this research a uniformly distributed irrigation strategy was carried out on a CRD with 2 replications for both drip and traditional irrigation approach as follows.

4.5.3.1 Distribution Efficiency

The distribution efficiency for URTA represents how uniformly irrigation water can be distributed through a drip irrigation system into the field or container as well as how uniformly moisture content was found to be in the soil. Distribution efficiency was

$$CV = 100 * \left[\frac{SD}{Q_{avg}}\right] \quad (4.23)$$

measured through the average soil moisture content of each emitter. This was done by measurement of discharge of

each emitter which by daily crop water requirement. In this study, the following statistical approach was used for obtaining irrigation uniformity [273]:

$$Ed = 1 - \frac{\Delta M_a}{M_m} \times 100 \quad (4.20)$$

where Ed = distribution efficiency (%) or uniformity coefficient, M_m = mean moisture content (%) and ΔM_a = average absolute soil moisture deviance of each emitter in the container from the mean moisture content.

4.5.3.2 Application Efficiency

The application efficiency was measured through the required available moisture content of soil and average soil moisture content of emitter after applied irrigation and expressed as [274]

$$E_a = \frac{M_{rsm}}{M_{asm}} \times 100 \quad (4.21)$$

where E_a = application efficiency, %, M_{rms} = minimum required soil moisture content of crops (%), and M_{asm} = average soil moisture after irrigation (%).

4.5.3.3 Field Emission Uniformity (*EU_f*)

The EU_f is the ratio of the average emitter discharge from the lowest 1/4th of the emitter to the average discharge of all the emitters in the drip system. The EUf was calculated through measuring the percentage of the average emitter discharge from the lowest 1/4th of the emitter and the average discharge of all the emitters. EUf is expressed by the following equation [275].

$$EU_f = \frac{q_n}{q_a} \times 100 \quad (4.22)$$

where EU_f = the field test emission uniformity, percent, q_n= average of the lowest 1/4th of the field data emitter discharge, l/h q_a = average or design emitter discharge rate l/h, and q_a = average or design emitter. The field evaluation of uniformity is useful for improving the operation and management of the existing system. The discharge of the emitter was measured by selecting the first point, 1/3rd, 2/3rd point and last emitter on the corresponding laterals in the experimental plot setup (URTA).

4.5.3.4 Absolute Emission Uniformity

The absolute emission uniformity was calculated by the following equation [276]:

$$EU_a = 100 * \left[\frac{Q_{min}}{Q_{avg}} + \frac{Q_{avg}}{Q_x}\right] \times \frac{1}{2} \quad (4.24)$$

where EU_a, Q_x, Q_{min}, Q_{avg} represent the absolute emission uniformity, average of the highest 1/8th of emitter discharge (l/h), minimum emitter discharge rate (l/h), and average or design emitter discharge rate (l/h), respectively. Data was collected from the six lateral lines and four emitters on each lateral were selected and then emitters' discharge and soil moisture of each plant were measured along with the emitter flow rate at two adjacent emitters at each collection container, by collecting the discharge for one minute in a move up cylindrical container; then the average emitter discharge for each of the sixteenth locations were calculated.

4.5.3.5 Co-Efficient of Variance (CV)

The coefficient of variation represents the ratio of the standard deviation of emitter discharge to the mean discharge of the emitter, and is a useful statistic for comparing the degree of variation from one data series to another. The coefficient of variation was calculated by the following equation [277]:

$$CV = 100 * \left[\frac{SD}{Q_{avg}}\right] \quad (4.25)$$

where CV, SD and Q_{avg} represent the coefficient of variation of emitter discharges, standard deviation of selected emitter discharges and average discharge in the same emitters (L/h), respectively.

4.5.3.6 Irrigation Water Productivity

Water is an increasingly scarce resource in many urban areas and so it is important to assess the productivity of urban rooftop irrigation in terms of this scarce resource. That is why such an assessment is made from a variety of viewpoints regarding the sustainable and efficient use of water. Improving water productivity through water-efficient technologies is an important step towards putting water to more economically and environmentally beneficial uses. Water productivity in terms of actual evapotranspiration (ETc) and the volume of water applied is most common during the cropping period. In this study the water productivity of the selected crops was determined by the following formula [278] [279]:

$$\text{Crop Water productivity}\left[\frac{\text{Kg}}{\text{mm}}\right] = \frac{\text{Yield of harvested crop(kg)}}{\text{ETc(mm)}} \quad (4.26)$$

$$\text{Irrigation Water productivity } \left[\frac{\text{Kg}}{\text{m3}}\right] \frac{\text{Yield of harvested crop(kg)}}{\text{Total volume of water applied(m3)}} \quad (4.27)$$

The total harvested yield of the cultivated crops with the drip irrigation (potable water and grey water) and traditional irrigation was converted to the unit yield (kg/plants) and total supplied water was also measured to analyze the irrigation water productivity (Table 4.15). Actually, the values of ETc and the volume of irrigation water are heavily influenced by the microclimate of the experimental field. In case of traditional irrigation, the crop water productivity and irrigation water productivity in URTA considered all losses such as watering in the plant's container, leaves and also roofs surface. The greatest potential for water savings is also tied to the specific crops requiring the most irrigation within URTA. The total life period of those crops was considered according to Bangladesh Agricultural Research Institute (BARI) recommendation guide book. The yield and benefit (in BDT) scenario of the selected crops using the experimental rooftop agriculture is shown in Figure 4.15 and Table 4.15.

Table 4. 15 Average yield and irrigation water requirements of BARI Tomato-3, BARI Bottlegourd-3, BARI Brinjal-8 and Bogra Red Chili.

Exp. Status		**Name of Crops**	**Source of Water**	**Drip Irrigation**		**Traditional Method**		
				Average Yield/Plant (kg)	**Total Irrigation water Used (mm)**	**Average Yield/Plant (kg)**	**Total Irrigation Water Used /Plant (mm) by Container**	**Total Irrigation Water Used (mm) by Pipe and Pipe with Shower**
1st_year experiment	Winter season	BARI Tomato-3	Ground water	2.35	726	1.92	1345	2015
		BARI Bringle-8		2.1	1053	1.8	1500	2430
		BARI Bottle Gourd-3		6.5	1093	3.5	2460	4408
		Bogra Red Chili		0.65	790	0.4	1148	1875
	Summer season	BARI Tomato-4		0.85	511	0.7	721	946
		BARI Bottle Gourd-4		4.8	1013	4.5	1246	1579
2nd_year experiment	Winter season	BARI Tomato-3	Green water (grey and rain water)	2.4	612	1.8	1024.64	1434

Figure 4. 15 The yield scenario of (**a**) BARI Tomato-3, (**b**) BARI Bottlegourd-3, (**c**) BARI Brinjal-8, and (**d**) Bogra Local Chili in the experimental URTA.

4.6 Economic Analysis of URA

4.6.1 Benefit from the experimental URTA

Potential environmental benefits of green roofs require quantitative appraisals to estimate the financial benefit. However, information on such benefits is not corporate and mostly subjective with normal assumption. The assessment presented in this section takes into account numerous accessible sources that justify the economic rewards of urban rooftop agriculture (URA). In this study URA is implemented with 70% area coverage (on experimental green roofs) with the selected crops such as Tomato, Brinjal, Chili, Bottle Gourd and leafy vegetables. However, the cost and benefit include two levels: (a) direct effects incurred by the operators of the systems, i.e., investment costs, operation costs, and profits generated from yields; and (b) societal effects on local community, such as market impacts (households' savings in food expenses, local jobs creation) and environmental impacts (Green roof enhanced air quality, green roof habitat creation, and mitigation of heat island effect and energy saving) are considered for economic analysis. The Yield cash flow quantifies the economic value of the outputs of rooftops' productive use, i.e., of food harvested or energy generated. In the food production scenarios for the selected crops, two seasons (summer and winter) were considered in this analysis. The values of food supply chains (long and short) in the URTA system, where crops were distributed from gardeners to vendors or consumers, were also calculated at the average local market selling price. Planting pots or growing mediums of existing URTA (typically consisting of shallow, free-standing blue plastic drums, wooden boxes, bottles, tins, drums, jutes and plastic bags) were also categorized. Bottle gourd, Tomato and Brinjal were cultivated in two seasons (winter and summer, from November 2018 to May 2019). After completing the winter season, the maximum root zone depth and area were measured, and the container size was selected in the next summer season and winter season based on the first-year winter season findings. Similarly, the vegetative area and yield of those crops were also calculated and compared between these two setups.

The weight of each Tomato, Brinjal, Chili and Bottle Gourd was measured by a digital weighing machine, and then the total weight of those selected crops was calculated later. For the second-year experiment, the Bean was grown in those experiments using the same size of the plastic drum that was used during the first-year experiment of Bottle gourd. Several leafy vegetables were considered for this study, including the Spinach, Red Spinach, Water Spinach and Green Spinach, for vertical cultivation as well as for bed cultivation of those vegetables since they were under the fencing panel of Bottle gourd and Bean. The potential crop yields of selected crops in the experimental AR were calculated, and an average sell price in BDT/m2 from the yearly production was estimated for two seasons to assess the economic benefit and recognize the commercial value of URTA [Table 4.16].

Table 4. 16 Annual fresh food production benefit of experimental URTA (summer and winter season).

Name of crops	Winter season (December-February)		Summer season (March-May)		Total yield (kg)	Total value in BDT@local market price
	Yield/plant (kg)	Total yield (kg)	Yield/plant (kg)	Total yield (kg)		
Tomatoo	2.1	88.2	1	42	130.2	3906
Bringal	1.44	60.48	0.91	38.22	98.7	2961
Chilli	0.48	20.16	0.48	20.16	40.32	3225.6
Bottle gourd	5.5	71.5	8.4	109.2	180.7	5421
Bean	2.5	30	-	-	30	1200
Water spinach	18	36	18	36	72	1440
Green spinach	10	20	10	20	40	800
Red spinach	12	24	12	24	48	960
Spinach	15	30	15	30	60	1200
					Total	21113.6
					Benefit (BDT)/m2/year	138.90

4.6.2 Economic Evaluation of URTA

Economic evaluation is the process of systematic identification, measurement and valuation of the inputs and outcomes of the activities, and the subsequent comparative analysis of these inputs and outputs. An economic evaluation is crucial to enumerate the potential costs and benefits of a proposed strategy or initiative and, ultimately, its feasibility. It also allows the comparison of alternatives, hence, providing a systematic process for decision-making and trade-offs. The test of net present value (NPV), Profitability index (PI) or Cost-Benefit ratio (BCR), Internal Rate of Return (IRR) and the payback period, i.e., the period of time required before total revenues equal or surpass total costs for the first time are a standard method which have been used for economic analysis of URA. Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time and internal rate of return (IRR) is a calculation used to estimate the profitability of potential investments or discount rate at which NPV is zero [270]. At the case of NPV > 0; consider the preferred condition of a project. In this study, the roof option with the highest NPV, highest IRR and PI>o indicates the preferred option of URTA. NPV comes to the rescue for financial decision making, provided the investments, estimates, and projections are accurate to a high degree. However, Life cycle cost (LCC) is considered during the analysis which is the cost that is associated with the project from the beginning of the project to the end of its useful life [280].

So, Environmental and social benefits of URTAs require quantitative appraisals to estimate the financial benefits. However, information on such benefits is not yet commercialized and are mostly individually based on regular conventions. The assessment presented here took into account several accessible sources that justify the economic rewards of URTA. In this study, URTA was implemented with 70% area coverage (on experimental Ars) with the selected crops, as mentioned above. The cost and benefit included two levels: (a) direct effects incurred by the operators of the systems, i.e., investment costs, operation costs and profits generated from yields; and (b) societal effects on the local community, such as market impacts (household savings in food expenses, local jobs creation) and environmental impacts (AR-enhanced air quality, AR habitat creation and mitigation of UHI effect and energy savings) were considered for economic analysis (Table 4.17). In this study, NPV and IRR were considered for evaluating the feasibility of URTA. However, Life Cycle Cost (LCC) was considered during the analysis, which was the cost that was associated with the rooftop agricultural firm from the beginning of the project/firm to the end of its useful life, which was considered as 30 years. In this study, NPV is calculated by the following formula [281]

$$NPV = -C_i + \sum_{t=1}^{n} \frac{F_t}{(1+r)^t} \tag{4.28}$$

Where,

F_t = net cash inflow-outflows during a single period;
r = discount rate or return that be earned in alternative investments;
C_i = initial investment cost of all setups of URTA;
t = number of years within the time periods of first instalment of URTA, generally computed yearly for which the economic evaluation is desired (15 years for this study).

Though, if the present value of future cash flows from a likely project using the internal rate as the discount rate, which is subtracted out from the original investment, the net present value would be zero. IRR will be bigger than the discount rate of return (r) for the accepted project. In this research, the discount rate was considered as 12% for calculating NPV based on the Bangladesh government project plan implementation guideline. The payback period means the period of time that a project requires for recovering the money invested in it as well as the life span of the URTA system including all installed material. The payback period is calculated by the following formula [282]:

$$\text{Payback Period} = \frac{\text{Investement}}{\text{Net annual cash Inflow}} \tag{4.29}$$

Table 4. 17 Sources for net present value (NPV) computation parameters.

Variable	Value	Source
The installation cost of URTA system including (i) installation of irrigation system and fencing panels, (ii) containers and other concrete structures, (iii) electrical equipment (light, fan, Wi-Fi connection) soil, conduct, varmicompost and equipment needed)	BDT 1460 per square meter	Local practitioners
Annual operations and maintenance cost	BDT 120 per square meter for 150 m	Local practitioners of Bangladesh
Annual irrigation cost (source: Groundwater)	BDT 15/m^3 for domestic use preposes	Dhaka Water Supply and Sewerage Authority (DWASA), Bangladesh
Annual irrigation cost (source: Rainwater and grey water)	---	---
Total cost for the starting year	---	---
Annual fresh food production benefit (summer and winter season, shown in table)	BDT 138.90/m^2	Local practitioners of Bangladesh
Annual Energy consumption benefit	BDT 184.45/m^2	Local practitioners of Dhaka Power Distribution Company Ltd. (DPDC) in Bangladesh energy consumption tariff
AR-enhanced air quality advantage	BDT 2/m^2	[283] [284]
Job creation advantage	BDT 138.90/m^2	Local practitioners of Bangladesh
Mitigation of heat island effect	BDT 67.17/m^2	[285] [286]

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The total irrigation cost has been calculated from the total water requirement (mm) of the selected vegetables and figured the amount of cost based on the tariff of Dhaka Water Supply and Sewerage Authority (DWASA), Bangladesh, from the total amount of water. The cost of yearly energy savings was computed through the multiplication of the simulated energy savings in kWh/m^2, the total area of the roof, and the energy consumption tariff in Bangladesh. The net cash flows were computed yearly and were assumed to be constant over the investment lifetime. Labour requirements were also considered in the study on the economic evaluation of URTA

4.6.3 Evaluation of property value under rooftop agriculture

URTA predominantly is consuming energy efficient usage, water conserving, the use of recyclable materials that contribute to the environmental, social and economics. So, building with URTA is needed to assess importance of RTA or rating the Building. Therefore, green building assessment tools would help the development of green building assessment to compare to a normal traditional building. In this study rating of URTA has calculated according to Leadership in Energy and Environmental Design (LEED) which was developed by United States Green Building Council (USGBC). This rating system is a way to enhance and promoting the sustainable built environment with buildings about the issues in environments and sustainability for the future generations [287]. The founding result of this experimental roof and the materials that are used to cultivation of different crops on rooftop are helped to calculating the rating of building. Built indoor and outdoor environment quality, energy efficiency, water use efficiency, resources & materials, sustainable site & management, heat island effect are considered for rating by LEED rating system of URTA (Table 4.18).

Table 4. 18 LEED rating point earn through URTA [288]

Description of the items	**LEED available points**
Available total points	110
Energy and atmosphere	2
Water use efficiency	4
Resources & materials,	
Sustainable site & management	2
Heat island effect	1
Storm water design (quantity control)	2
Low-emitting materials	3
Indoor Air Quality Assessment	2
Thermal Comfort	1
Location and transportation	2
Building life-cycle impact reduction	2
Total points	25
Points earn by URTA	**21.12%**

4.7 Conceptual Modeling of Climate and Water Smart Urban Rooftop Agriculture:

4.7.1 Participatory approach:

Opinion and individual activities of owners of rooftop gardens as a step of requirements on systems for develop a conceptual CWSRAM. This conceptual model was developed based on integrated management of bare roof. The methodological approach complicated a participatory approach and analysis, extracting current operations management challenges facing the city dwellers in terms of increased productivity demands as well as increased compliance requirements from society. The survey focused on extracting the different specific requirements on bare roof management including individual requirements on productive management of bare roofs in relation to current and future activities in the urban areas. The questionnaire survey identified the necessary indicators or components which considered the maintenance of planning tools for sustainable URTA. The city dweller's opinion which was the basis for developing an initial description of the struggles and problems that users are currently faced with, both from an external and an internal point of view. A high degree of interaction between the interviewer and owner of the gardeners was pursued.

4.7.2 Findings approaches from the experimental URTA

The findings approaches have also been used to develop the conceptual CWSRAM. The findings result such as microclimatic changes, Energy savings, efficient use of potable water, benefits of grey and rain water etc. was used as the requirements of conceptual modelling. A wide range of interconnected assessments has been used for prioritization. Area coverage with different percentages was the main focal point in the model's indicators based on climatic parameters (temperature, relative humidity, CO2 concentration, CDD, and energy-saving trends) and the owner's opinions on responses to rooftop agricultural principles. Demand for fresh food was simulated based on changes in income, population, and prices. The impact of the commercial demand was assumed by finding the product prices that are related to the market prices, equating supply for all commodities. Fresh food availability, green water use, and maximum roof area use for agriculture and impacts of the CWSRTA model also estimated the benefits of RTA and gender empowerment. Techno-socio-economic Paths and inter-connection with communities, especially leadership within the RTA's groups and their suggestion on the agricultural system and impacts of RTA were also evaluated at the global and national level. The indicators relevant to the input of the CWSRTA model and highlighted the need for a better understanding of the differences in key outputs from these models given ostensibly the same or very similar input data. Although the CWSRTA model was considered the forming policy decisions by government, largely on the basis the national and global basis.

Chapter 5

ANALYSIS OF SPATIO-TEMPORAL VARIATION OF LAND SURFACE TEMPERATURE IN DHAKA METROPOLITAN AREA

5.1 Introduction

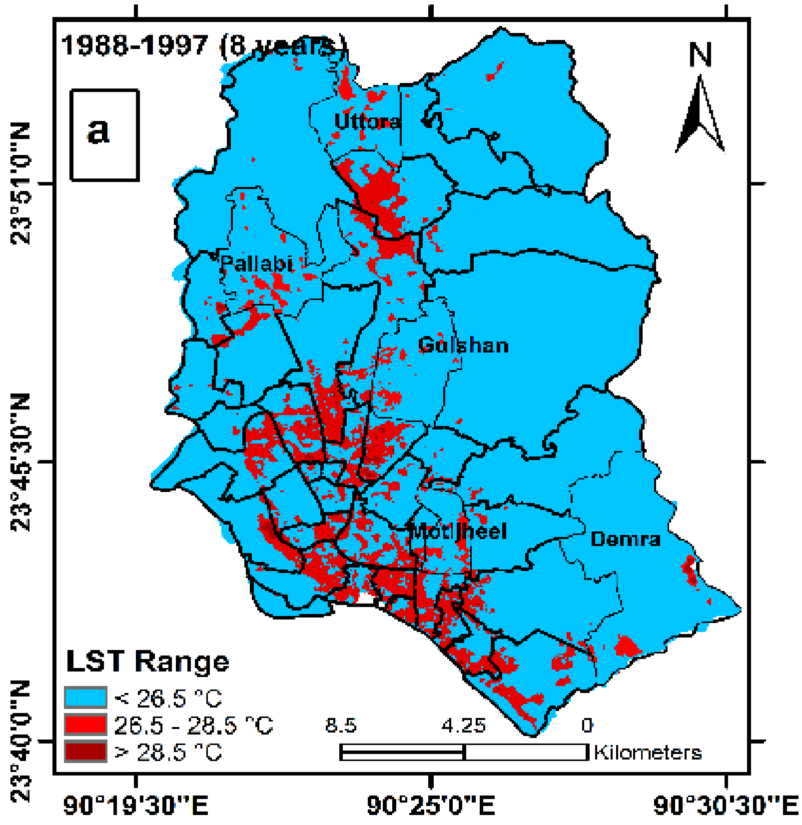
The rapid urbanization process plays a key role within the formation of urban heat islands (UHI), where the heating will have a further impact upon urban life quality [289]. A UHI phenomenon has been created in urban city areas with substantially warmer temperatures than adjacent rural areas causing huge thermal discomfort to all or any living entities within the city [290]. Natural landscapes of rural areas are transformed into modern land use and land covers like buildings, markets, roads, and other impervious surfaces, making urban landscapes fragmented and sophisticated and raising the urban temperature affecting the lifetime of urban dwellers. Urban land cover changes (ULCC), thanks to urbanization, are mainly caused by the removal of natural vegetation cover, which affects the microclimate change of the town [291]. Within the urban areas, the surface cover and, therefore, the surface temperature is above within the vegetated and water¬ covered areas. In 1990, only 15% of the world's population lived in cities, while within the 20th century, this picture has been completely changed, with about half the population of the planet is estimated to measure in cities [292]. LST may be a controlling factor for many of the physical, chemical, and biological processes on the world and may be considered as a measuring indicator of global climate change [293]. For the urban environment, LST may be a crucial parameter for the monitoring of the energy exchange between the land surface and thus the atmosphere in terms of the sensible and heat of transformation fluxes.

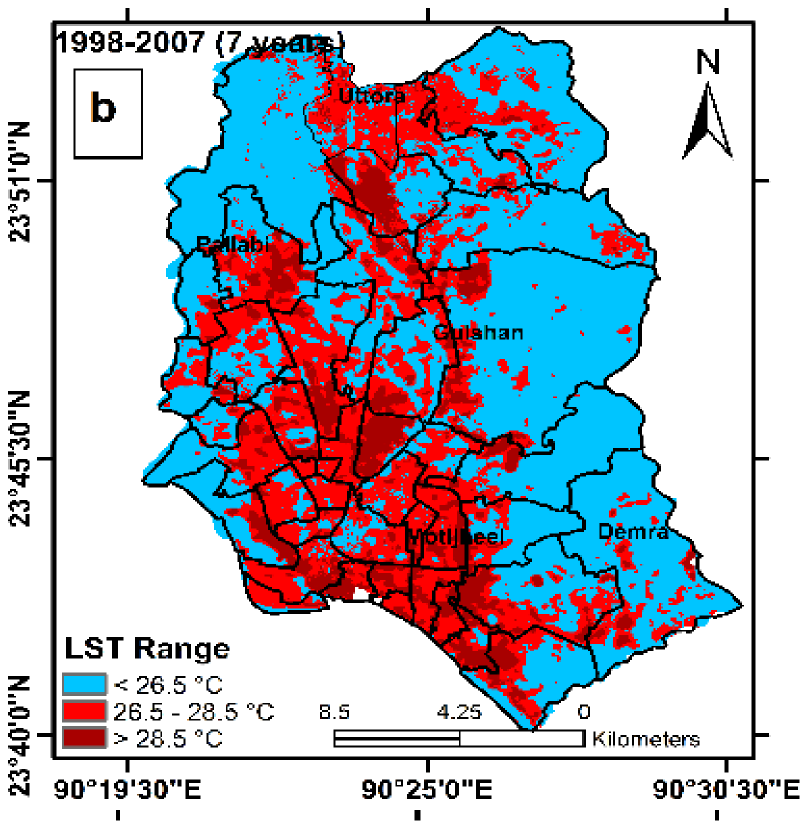
The Dhaka Metropolitan Area in Bangladesh is such a tropical metropolitan area that is undergoing rapid urbanization, becoming a hotter city. LST in Dhaka City has been increased within the city area [294]. However, most of the prevailing research has been accompanied the land surface temperatures (LST) changes or land cover (LC) changes in Dhaka Metropolitan Area (DMA) period of 1989 - 2009 were analyzed, and surface temperature is retrieved to know the variation of temperature from rural areas to urban areas [295] [296]. However, there are no studies on the variation of LST and land cover changes trend in the developed and growing developing areas during the summer season like in the month of March to observe the most hotspot areas in DMA, Bangladesh. In this respect, Landsat 5 TM and Landsat 8 OLI/TIRS, between 1988 to 2018, to demonstrate the trend of LST according to different percentiles such as 75th, 90th, and others and LULC changes trend within the different developed and undeveloped areas. Therefore, this chapter presents the spatial and temporal trends patterns of LST; to address area coverage by different percentiles of temperature, including the major influencing factors and surface processes of the thermal environment, and to assess the land cover changes and their impacts on climate change during the period of 1988-2018. However, this chapter described the thermal environment using remote sensing data over the time in the selected locations of DMA by (1) determining trends in the frequency of extreme temperature indices; (2) analyzing the spatial patterns of extreme temperature-related indices; and (3) assessing the statistical significance of the trends in indices of extreme temperature through parametric and non-parametric tests.

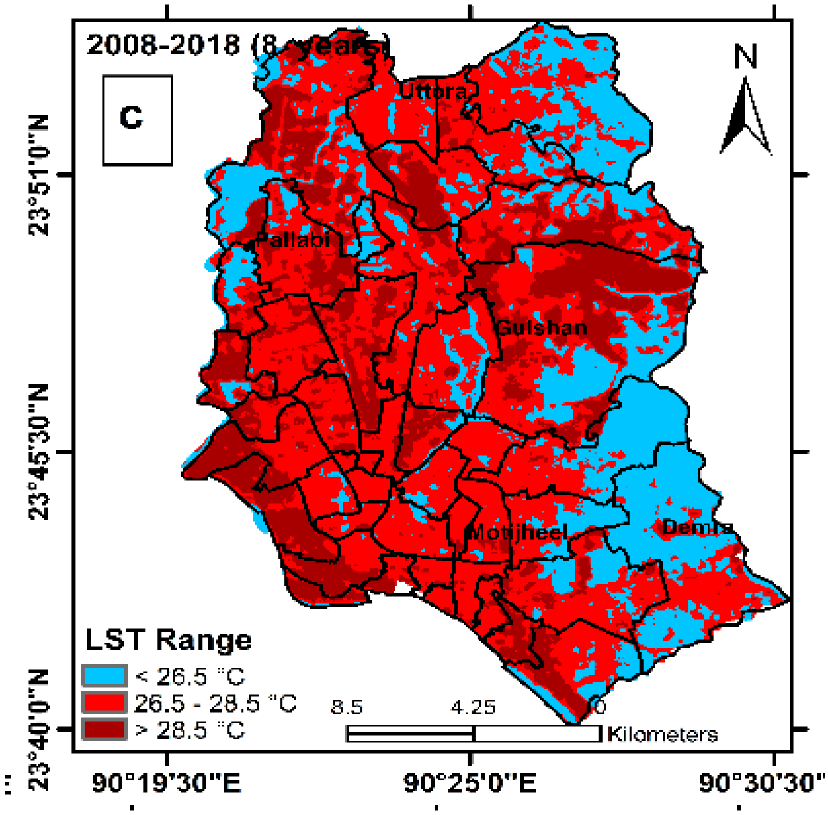
5.2 Spatial variation of different percentile of land surface temperature (LST) and vegetation

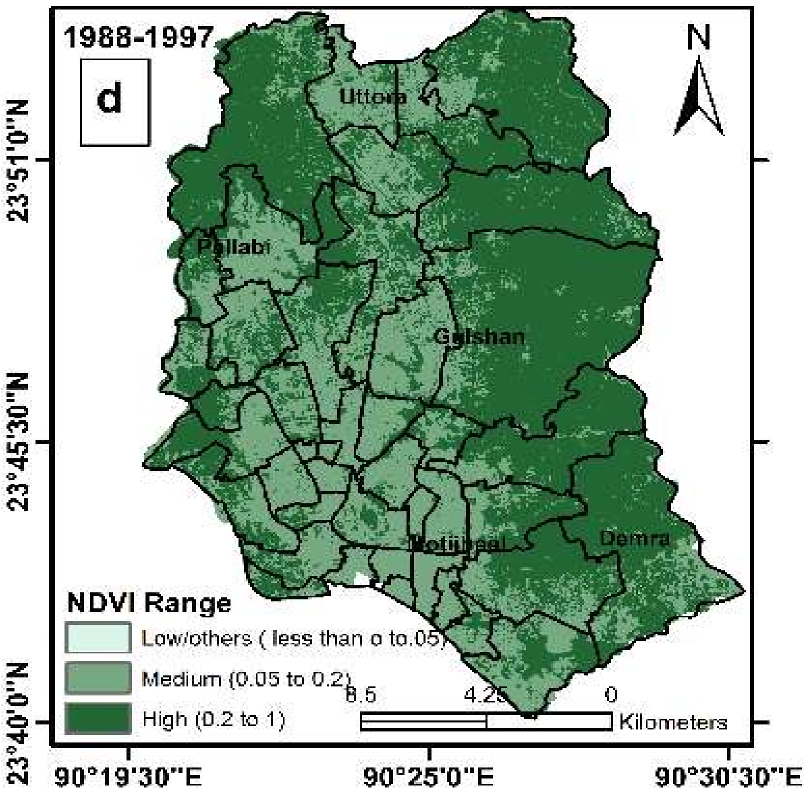
The LSTs of the study area, are calculated from the Landsat images as discussed in the methodology. The common cloud cover for the selected months (March to May) for some places, values are considered as blank. As a result, some values did not maintain the regular trend of LST. The maximum, minimum, and other statistical values of LST can be calculated using the Zonal statistics in ArcGIS. On the other hand, the land cover with vegetation have been grouped considering the NDVI values. The classification results are mostly reliable, though over-estimation of urban land cover with vegetation. Considering more on the accuracy, remotely sensed data are referenced in the practical information of 120 random pixels values of 2018. On the other hand, the maximum satellite image of March is cloud-free. That is why the month of March is considered for dry month, which is graphically represented by Figure 5.1. This phenomenon can be best explained by the fact that vegetation can decrease the amount of heat stored in the soil or land surface through the process of transpiration [297].

The LST and NDVI variation maps of DMA in Figure 5.1 and Figure 5.2 (a, b, c, d, e, and f) for the month of march and LST variation for the month of April and May are shown in Figure 5.3 and Figure (a, b, c, d, e, and f) is derived for the year group 1988-1997, 1998-2007, and 2008-2018. The studied showed that the average LST of the group of 2008-2018 is all along higher than the group of 1988-1997 and 1998-2007. It is observed that, in the year group of 1988-1997, 1998-2007, and 2008- 2018, LST values (min and max) in March in DMA showed ranges between 19.86 °C to 28.11 °C, 22.14 °C to 31.19 °C, and 24.49 °C to 31.95 °C, respectively. LST values in April in DMA showed ranges between 23.50 °C to 29.58 °C, 23.04 °C to 29.80 °C, and 24.64 °C to 30.59 °C respectively. LST values in May in DMA showed ranges between 22.02 °C to 26.66 °C, 19.96 °C to 29.94 °C, and 23.05 °C to 30.42 °C, respectively. Similarly, it was observed that the average NDVI value for the year group 1988-1997, 1998-2007, and 2008- 2018 was -0.239 to 0.501, -0.256 to 0.458, and -0.239 to 0.501, respectively. This study also observed that the highest vegetation category for 1988 to 1997 was found 74% to 95% of the total land area, medium range of vegetation was 2.44% to 25.49% of the total area, while low vegetation category was 1.47% to 3.26% of the total area. On other hand, in 2014, the highest low vegetation category was found in the developed areas of Motijheel, Uttara, and Gulshan by 68.51%, 76.55%, and 56.60% respectively of total land area. Therefore, it is strongly established that vegetation coverage in the urban areas is decreasing being replaced by built up areas. For the last 30 years, it decreased by 28.88% - 95% of the total area. This trend is true mainly for built up areas. It has been increasing for both growing developing and developed areas for the more populated city. So, LST has a strong positive relation to the vegetation index and highest vegetation category was found in the lower range of LST in Figure 5.1 (d, e, and f).


1988-1997 (8 years)
a
N
Uttora
Pallabi
Gulshan
Motijheel
Demra
LST Range
< 26.5 °C
26.5 - 28.5 °C
> 28.5 °C
8.5
4.25
0
Kilometers
23°51'0"N
23°45'30"N
23°40'0"N
90°19'30"E
90°25'0"E
90°30'30"E


1998-2007 (7 years)
b
N
Uttora
Pallabi
Gulshan
Motijheel
Demra
LST Range
< 26.5 °C
26.5 - 28.5 °C
> 28.5 °C
8.5
4.25
0
Kilometers
23°51'0"N
23°45'30"N
23°40'0"N
90°19'30"E
90°25'0"E
90°30'30"E


2008-2018 (8 years)
c
N
Uttora
Pallabi
Gulshan
Motijheel
Demra
LST Range
< 26.5 °C
26.5 - 28.5 °C
> 28.5 °C
8.5
4.25
0
Kilometers
23°51'0"N
23°45'30"N
23°40'0"N
90°19'30"E
90°25'0"E
90°30'30"


1988-1997
d
N
Uttora
Pallabi
Gulshan
Motijheel
Demra
NDVI Range
Low/others (less than o to.05)
Medium (0.05 to 0.2)
High (0.2 to 1)
8.5
4.25
0
Kilometers
23°51'0"N
23°45'30"N
23°40'0"N
90°19'30"E
90°25'0"E
90°30'30"E

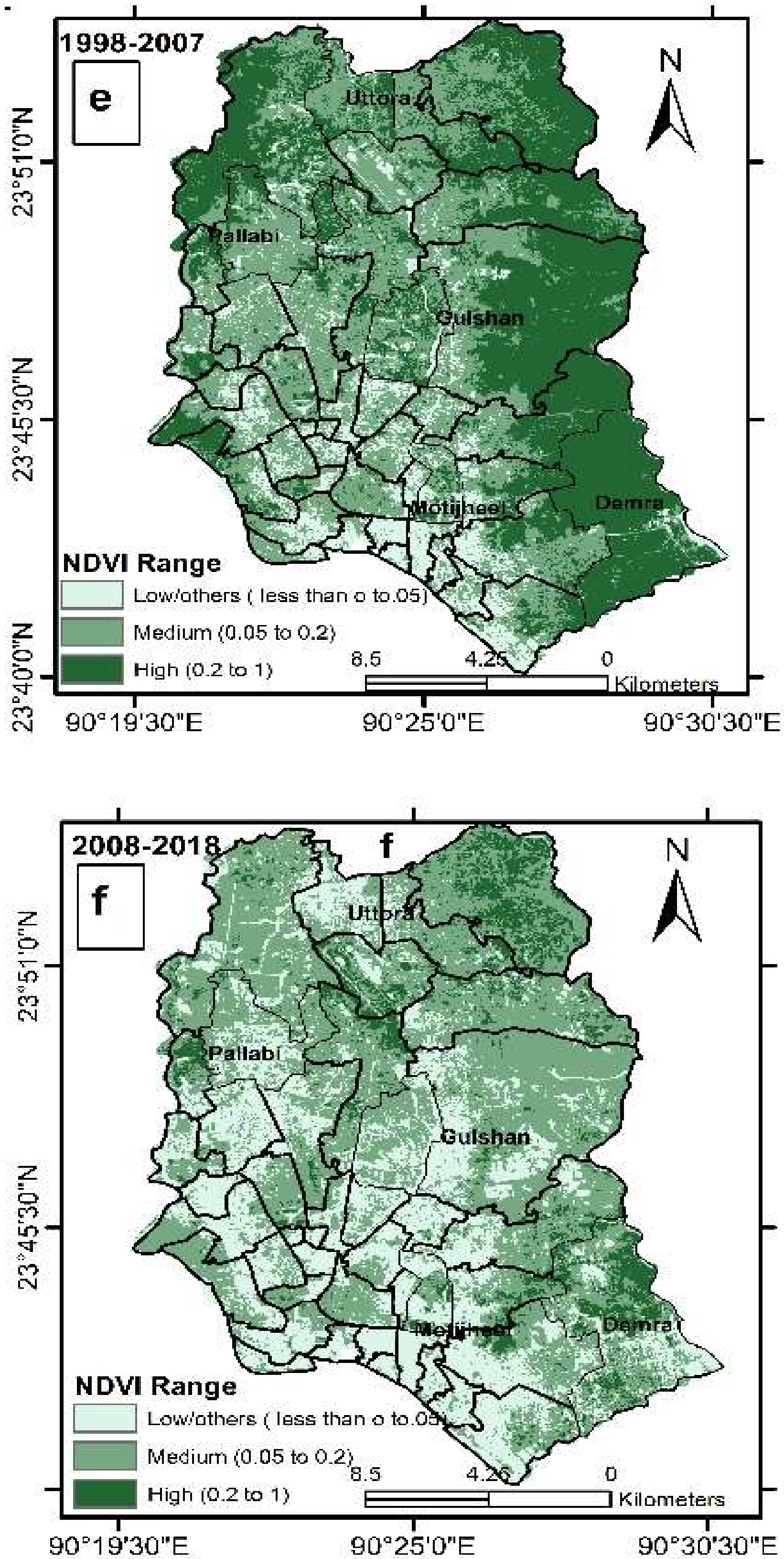


Figure 5. 1 Land Surface Temperature (LST) variation maps (a, b, c) and Normalize Difference of Vegetation Index (NDVI) trend maps (d, e, f) for developed (Motijheel, Gulshan, Uttara) and growing developing area (Pallabi and Demra) from 1988-2018 in March

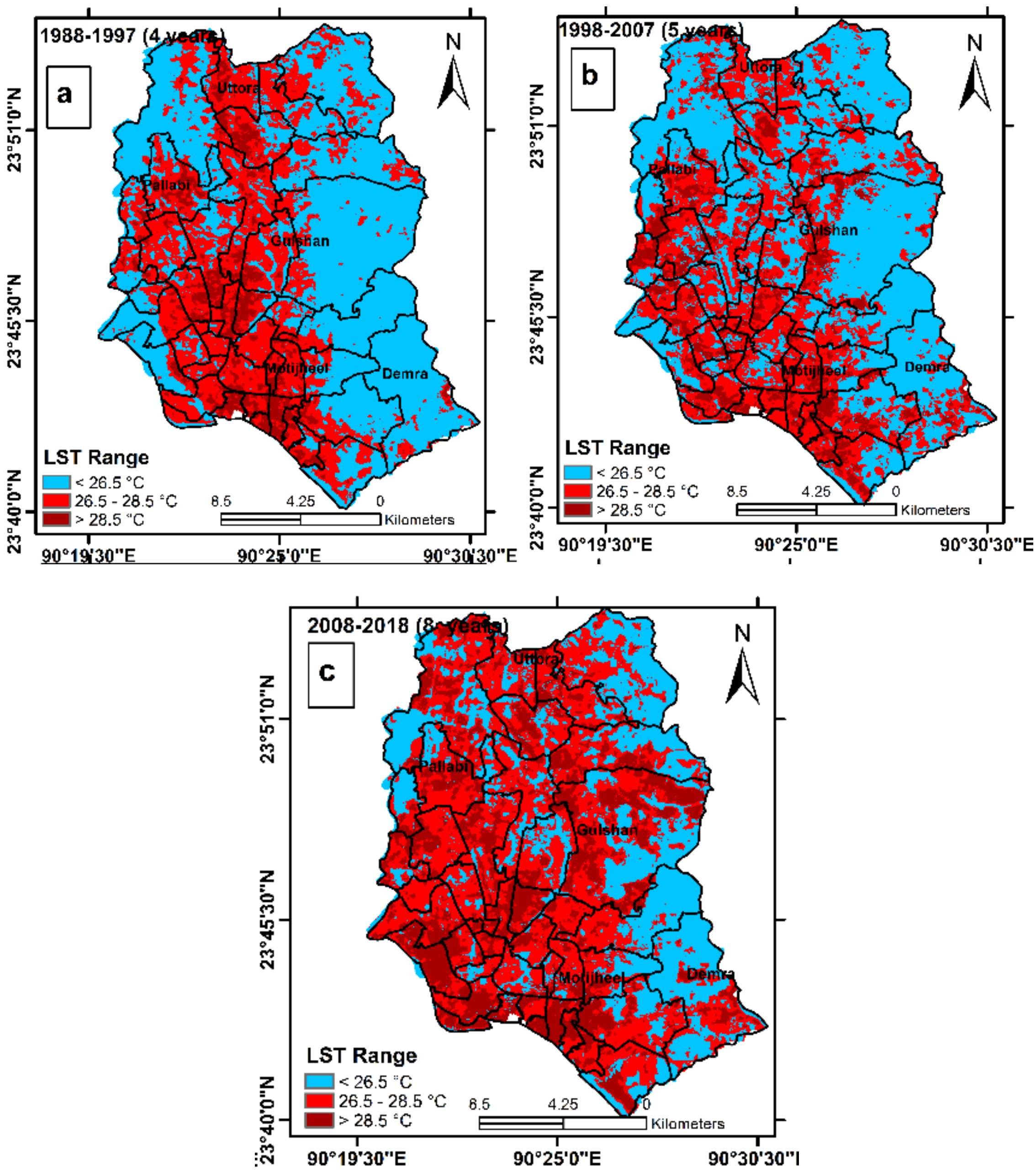


Figure 5. 2 Land Surface Temperature (LST) variation maps for the month of April (a, b, c) in DMA.

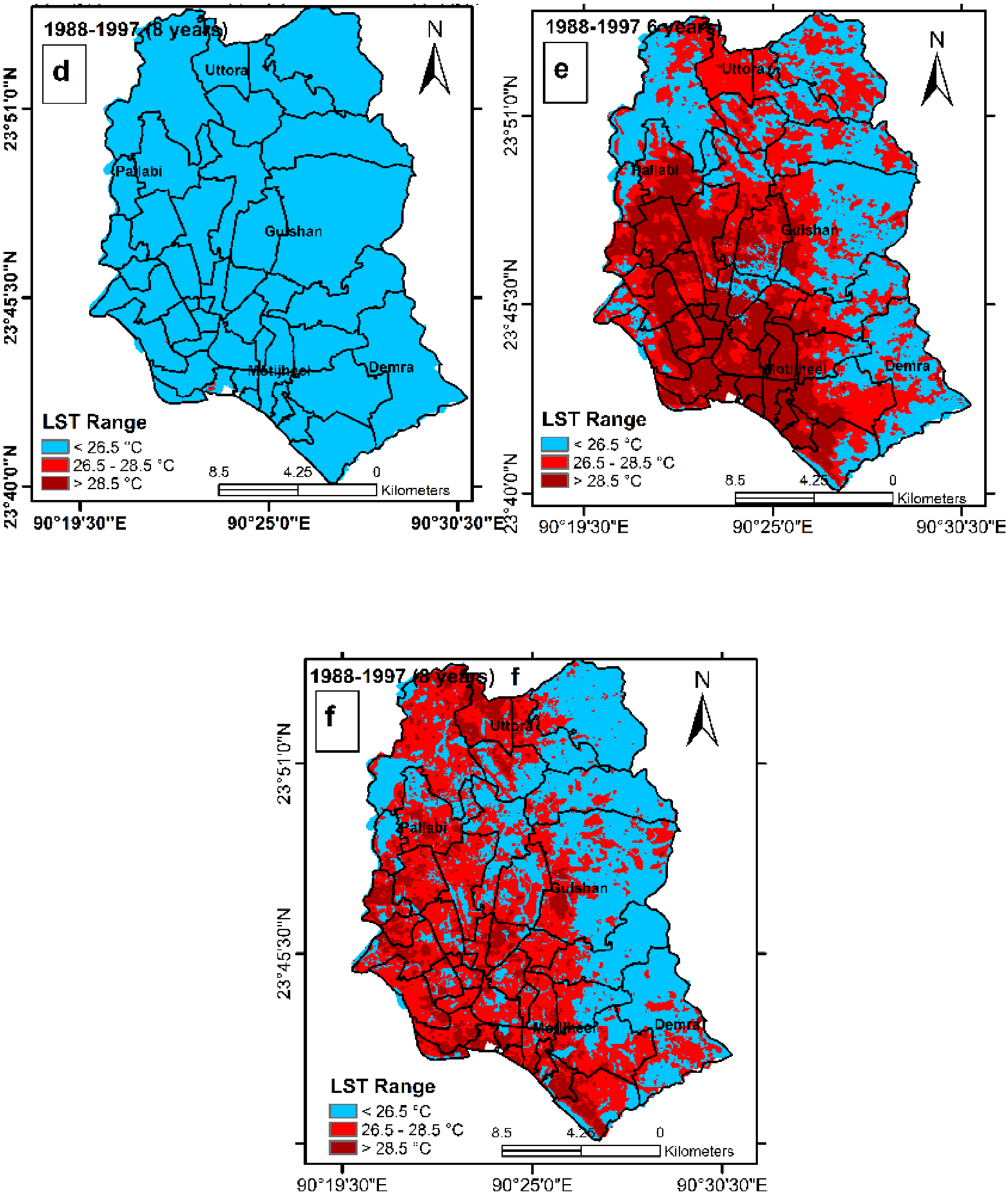


Figure 5.3 Land Surface Temperature (LST) variation maps for the month of May (d, e, f) in DMA.

Moreover, this study also graphically analyzed the LST trend in the developed and developing areas [Figure 5.3]. The trends of LSTs and NDVI for the more developed and growing developing areas such as Motijheel, Gulshan, Uttara and Demra, and Pallabi for the month of March to May within the year group of 1988-1997, 1998-2007, 2008-2018 are also analyzed. Figure 5.3 (a, b, c, d, e, and f) displayed the spatial distribution of the LST trend map and Figure 5.4 NDVI trend map for the month of March that is presented for the urban pixels of the developed area of Motijheel, Gulshan, Uttara and the growing, developing area of Pallabi and Demra of the selected year groups. The LST varied in the developed area from mini-mum 21.14°C to maximum 30.96 °C, from minimum 21.56°C to maximum 31.30°C, and from minimum 21.70°C to maximum 32.12 °C for the year groups of 1988-1997, 1998-2007, and 2008-2018 respectively in the month of May. Similarly, they were found from 22.90°C to 30.78°C, from 23.02°C to 31.31°C, and from 26.96°C to 30.44°C in April. In March, LST trend was found from 19.35°C to 38.50°C, from 21.45°C to 31.34°C and from 23.51°C to 30.75°C respectively for those year groups. It was also detected that the maximum highest trend of LST was found 27.17°C to 30.39°C, from 26.96°C to 30.14°C, and from 24.94°C to 30.96 °C for 1988, 1998, 2008, and 2018 in May, respectively [Table 5.1]. The maximum average temperature value of the developed area is found 37.93°C and the highest difference in the LST trend was found 2.97°C between the developed areas.

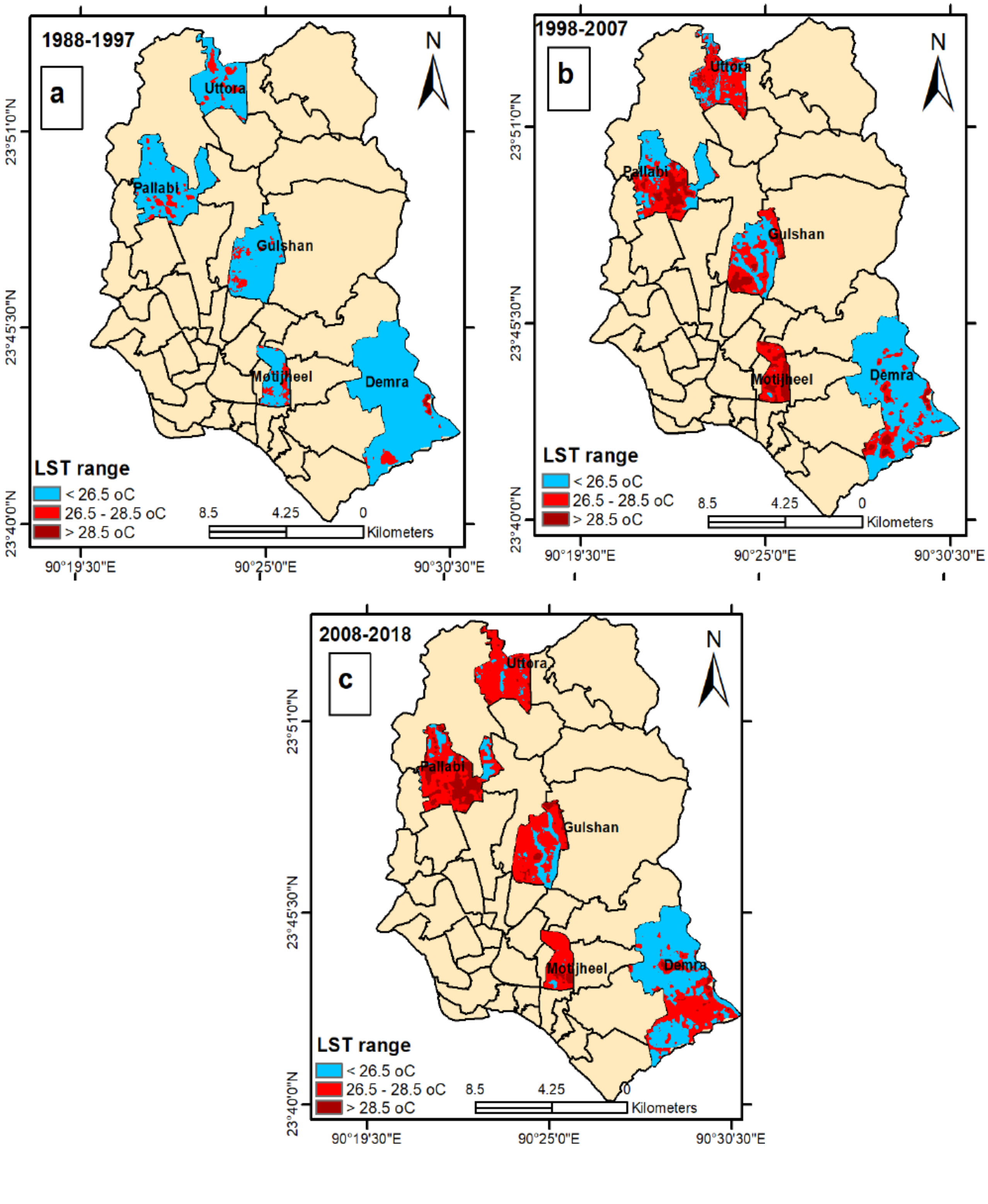


Figure 5. 4 Land Surface Temperature (LST) trend maps (a, b, c) for developed (Motijheel, Gulshan, Uttara) areas in March from 1988-2018.

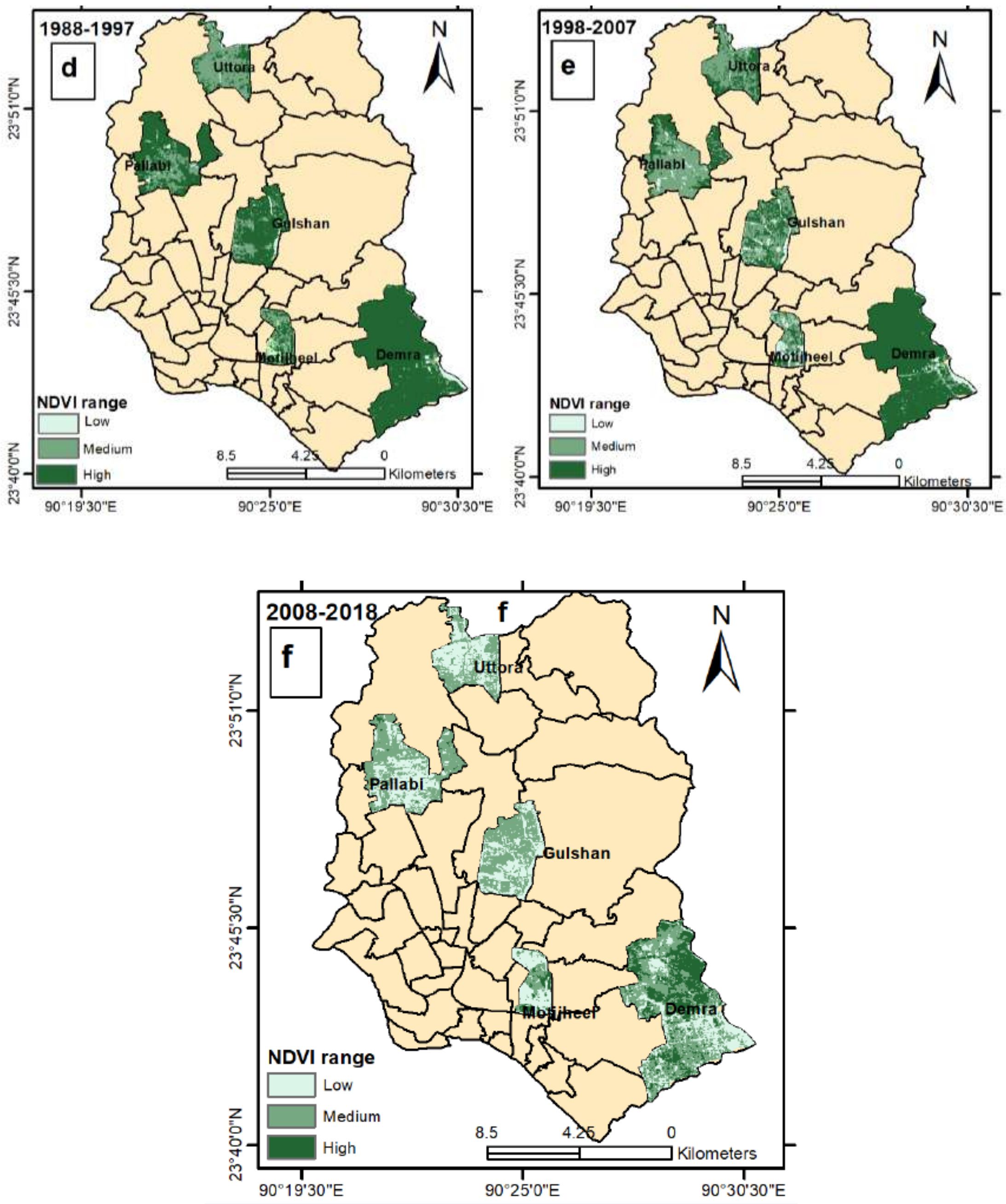


Figure 5. 4 Normalize Difference of Vegetation Index (NDVI) trend maps for developed (Motijheel, Gulshan, Uttara) and developing area (Pallabi and Demra) from 1988-2018.

Table 5. 1 The trend of Minimum, Maximum, and Mean LST of the selected developed and growing developing area for the year group of 1988-1997, 1998-2007, and 2008-2018

Thana	**Year group 1988-1997**			**Year group 1998-2007**			**Year group 2008-2018**		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
MARCH									
Gulshan	21.99	28.18	23.77	21.45	30.80	26.13	23.51	30.75	27.13
Motijheel	21.86	37.93	29.90	25.11	31.21	28.16	25.36	29.70	27.53
Uttara	20.17	27.49	23.83	22.73	31.34	27.04	25.28	30.41	27.84
Pallabi	21.11	28.51	22.67	18.95	31.35	25.15	24.22	31.43	27.82
Demra	21.73	29.77	23.45	20.51	34.50	27.50	22.64	32.20	27.42
APRIL									
Gulshan	22.90	30.51	26.71	23.02	30.90	26.96	26.62	30.44	27.06
Motijheel	24.90	30.09	27.50	25.02	31.31	28.17	28.03	30.04	27.70
Uttara	23.66	30.57	27.12	24.30	29.66	26.98	26.75	30.41	27.85
Pallabi	22.47	32.80	27.64	22.21	33.32	27.77	27.67	31.43	27.83
Demra	21.60	32.71	27.16	22.59	35.31	28.95	27.98	32.54	27.64
MAY									
Gulshan	21.14	30.14	25.48	21.90	31.30	26.60	22.14	31.71	26.93
Motijheel	23.12	30.39	26.29	23.40	31.10	27.25	23.52	31.30	27.41
Uttara	21.43	30.96	25.74	21.56	30.96	26.26	21.70	30.98	26.34
Pallabi	21.59	30.65	25.56	22.10	32.12	27.11	22.80	32.12	27.46
Demra	21.50	30.10	25.46	22.20	32.20	27.20	22.42	32.92	27.67

The trend of LST for the growing, developing areas for March was found by 16.82°Cto 29.77°C, 18.0 °C to 34.50°C and 25.15°C to 32.20°C while for April was found from 21.60°C to 32.80°C, 22.21°C to 35.31°C and 27.67°C to 32.54°C and for May they were found from 21.50°C to 30.65°C, 22.20°C to 32.20°C and 22.80°C to 32.92°C for 1988-1997, 1998- 2007- and 2008-2018-year groups respectively. In the growing, developing areas such as Demra, Pallabi for the year group 2008-2018 LST is increased from 32.24 % -43.97% in March, from 5.30% -7.78% in April, and from 4.27% -5.59% in May compared to the year group of 1988-1997. For that rea-son, March is more sensitive to changing LST in the growing, developing areas. Conversely, in the developed areas, it is increased by 1.17% -16% in the year group of 2008-2018 compared to the year group of 1988-1997 where March is also more sensitive month for LST change. Therefore, the change of the LST in an urban area is rapid, and the change of urban temperature over the last 30 years (during the period 1988 to 2018) has a positive trend and is very stronger in the more developed areas compare to less developed areas. This study revealed that the maximum LST trend for the whole area went up by 2.48 °C, 1.01 °C, and 3.76 °C in the months of March, April, and May from 1988 to 2018. Increases in the range values can be related to the time of images were captured, meaning that different times of the year affected the results during the same period. Particularly, the trends of the urban pixels during month of March are high, because of urban surface materials with higher radiant temperatures [298] [299]. A large expansion of the built-up area is clearly reflected by an increased LST in the city center. LST in the developed areas is greater than growing developed areas by 2.97 °C. The study observed that the maximum LST change rate close to from 1.1 °C to 3.76°C within the last 30 years in the urban areas.

5.3 Spatial trend of area coverage by different percentile of LST groups and different NDVI ranges for the developed and growing developing areas

The land area cover patterns by different temperature groups based on the 50th, 75th, and 90th percentile also show a similar gradient to the temperature values in Figure 5.5 (a, and b). Furthermore, vegetation coverage mapping of the study area would provide information on the identification and estimation of trends of vegetation index changing over the past 30 years. The area changing scenarios of vegetation in these time frames for the months of March of the selected areas are also presented in Table 5.2 The land cover patterns with vegetation, which were identified by 3 categories used for the year 1988 -2018, as well as land cover changes along the time, are listed in Table 5.2 by vegetation, built up area, and water bodies with others.

Along the time scale (1988-1997,1998-2007, 2008-2018), in the month of March the per-centage of areas covered by temperature ranges below 26.5°C was found by 88.51%, 58.43%, 25.31% respectively, for the range of 26.5°C to 28.5 °C was found by 11.18%, 31.25%, and 51.89% respectively and greater than 28.5°C was found by 31%, 10.32% and 22.80% respectively, which correspond to 50^{th}, 75^{th} and 90^{th} percentiles, respectively. It has evident that in the months of March during 1988-97, land area covered by temperature range of 75^{th} percentile) and 90^{th} percentile was related to rapidly increasing areas during the month of March and the area coverage with the temperature range 50^{th} percentile decreased by 71% where in 2008-2018, it was going to 22.80%. Similarly, area coverage for the range of 75th percentile was found that land area coverage increased by 78.45% and at the year group of 2008-2018, the area coverage increased 98.66% by the range of 90th percentile compared to the year group 1988 to1997. It is also observed that in the month of March, higher areas are also covered by that group of temperature compared to the month of April and May. It is exposed that during the month of April, in 2008–2018-year group, the temperature range of 50th percentile is increased by 63.63% compared to the year group 1988-1997 which is lower than March.

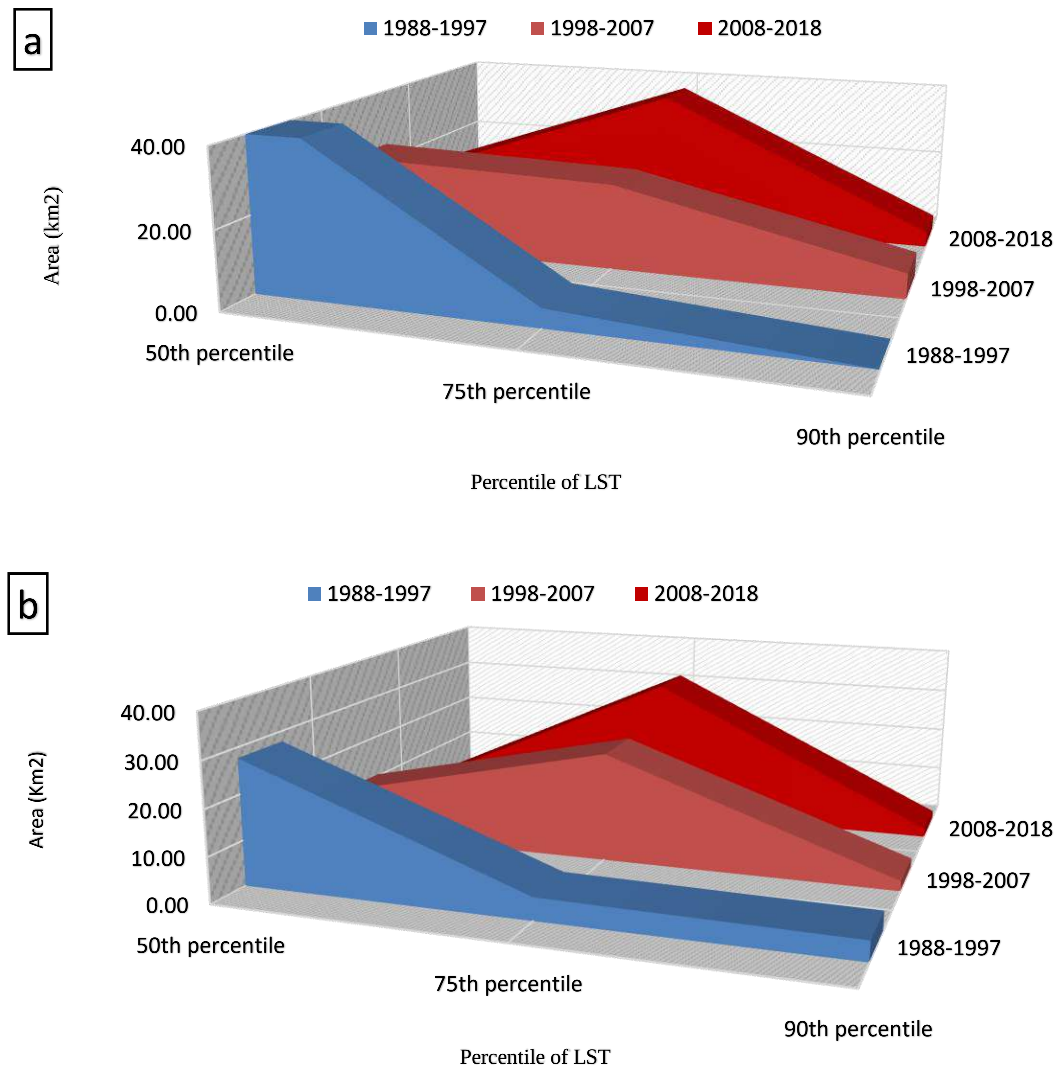


Figure 5. 5 The Urban land surface area covers by different percentile of LST groups for the corresponding month of March in the developing area (a) and developed (b) area.

Figure 5.5 symbolizes the area covered with the different percentile of selected areas in the DMA. From Figure 5.5, it is clearly understandable that the more developed urban areas show higher percentile groups of LST values compare with growing developing areas. One of the reasons for having high temperature values for developed areas is that the bares lands are in places where there is on-going development taking place. As a result, the vegetation cover is reducing in the developed and growing developing areas [Table-5.2]. Therefore, the background climate change is weaker than surface warming in urban areas. This implies that in the months of March 50^{th} percentile group of LST coverage areas is decreasing at the rate of 67%- 96%, the 75^{th} percentile group of LST coverage areas is increasing at the rate of 63%- 74%, and the 90^{th} percentile group of LST coverage areas is increasing at the rate of 5%- 28.54%. Similarly, in the month of May, more hotspots areas are covered by the group of 90th percentile. On the other hand, in 2014 -2018, vegetation coverage area with high NDVI (0.2 to1) was decreased by 13.50%, 35.15%, 25.96%, 6.76%, and 31.70% in Motijheel, Gulshan, Uttara, Demra, and Pallabi respectively in comparison to 1988 -1997, while medium range of NDVI (0.05 to 0.2) or build up areas has been increased by 21.74%, 36.15%, 31.59%, 8.1% and 31.7% [Table-5.2]. It is a well-known fact that more greenery areas lead to more cooling effects. So, it is to be confirmed that vegetation coverage such as urban rooftop agriculture (URTA), gardens, forests, parks, and grasslands are well established tools for reducing urban thermal environment enhancing urban cooling through evapotranspiration and shading effect by green activities.

Table 5. 2 Vegetation classification and area coverage by different categories of vegetation for the corresponding month of March from 1988 to 2018 in Motijheel, Gulshan, Uttara, Demra, and Pallabi.

Location	**Types of land coverage**	**Area coverage (% of the total area)**		
		1988-1997	**1998-2007**	**2008-2018**
Motijheel	Low vegetation/water body /others	16.37	12.18	2.61
	Medium vegetation/build up area	48.39	61.35	68.51
	High vegetation	39.43	22.28	28.88
Uttara	Low vegetation/water body /others	8.26	3.57	0.18
	Medium vegetation/build up area	34.80	59.52	76.22
	High vegetation	56.94	36.91	23.59
Pallabi	Low vegetation/water body /others	4.52	1.43	0.42
	Medium vegetation/build up area	24.93	44.30	57.69
	High vegetation	73.64	51.18	41.89
Gulshan	Low vegetation/water body /others	11.24	3.77	2.94
	Medium vegetation/build up area	21.57	51.01	57.76
	High vegetation	74.66	37.75	39.30
Demra	Low vegetation/water body /others	2.91	2.34	.85
	Medium vegetation/build up area	2.98	5.81	12.82
	High vegetation	94.68	91.22	86.33

The study exposed that the urban LST and vegetation changes in the three periods examined in this study did not occur evenly in all directions. New developments were observed along with the urban areas as well as in the areas that had already been replaced by built up areas. The rapid change of vegetation decreases and LST increase in the more developed areas of DMA means that it has not been possible for the metropolitan government to provide basic urban comforts for the population. It has led to a comprehensive range of environmental problems. In more developed areas, landfills have contributed to soil effluence, resulting in reduced vegetation and increases clumsy urbanization. The creation of landfill sites have intensified the extent of inundation in the developed area compared to growing developing areas in DMA.

5.4 The Temporal Trend of different percentile groups of LST

The yearly deviation of different percentiles of temperature has been analyzed with the time series data. The monthly variation of temperature has been analyzed based on the average maximum and minimum temperature of the last 30 years from 1988 - 2018. Figure 5.5 (a, b, and c) show the average monthly mean LST trend of DMA. The study perceived that average high LST is found in March during the period of 1988 -2018. The lowest average mean LST trend has been found in the month of April. A higher monthly average temperature has been observed in the month of May for the DMA.

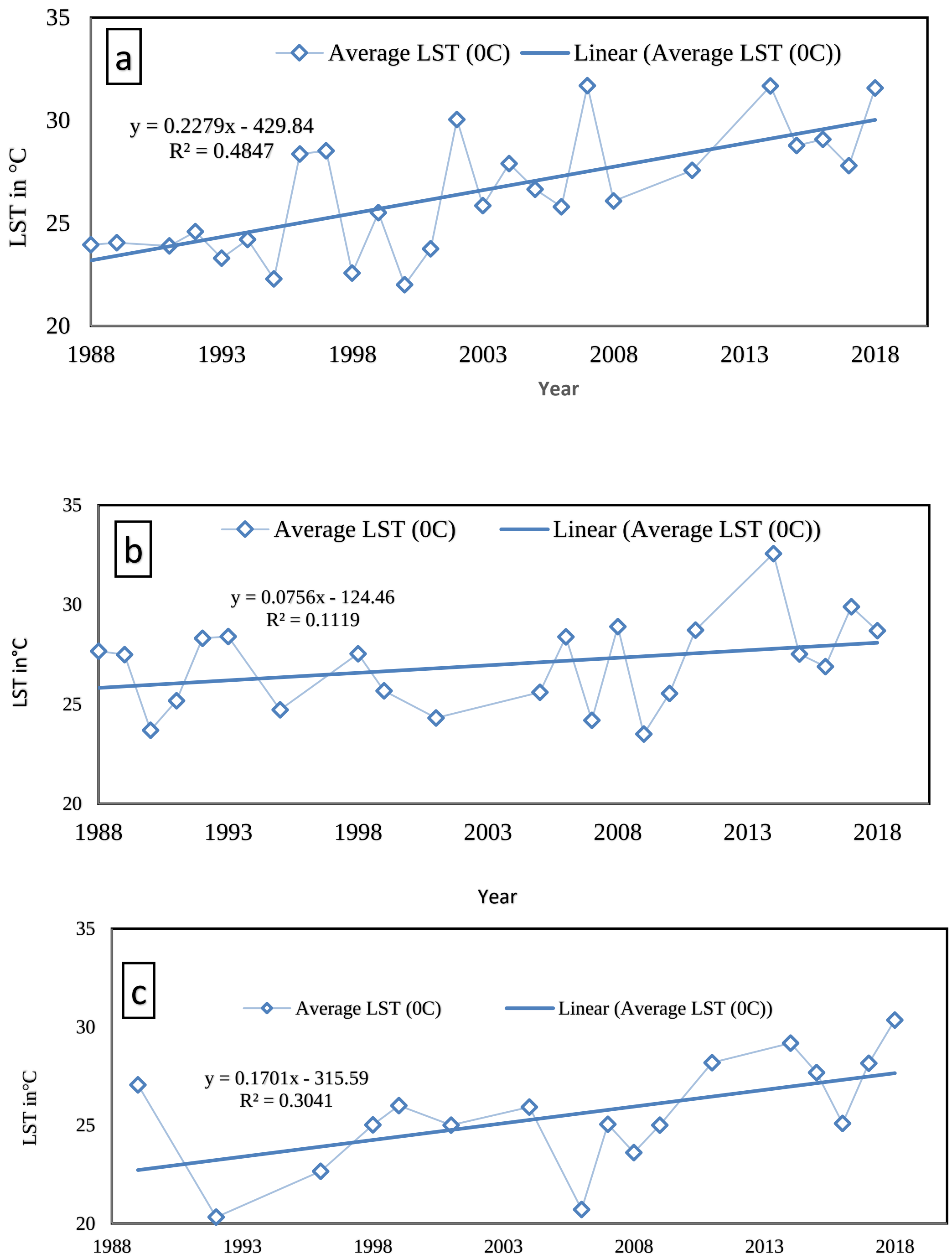
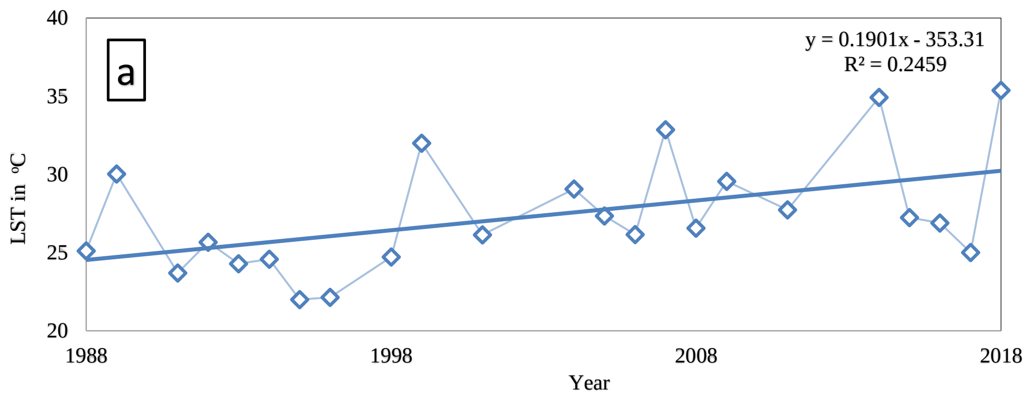
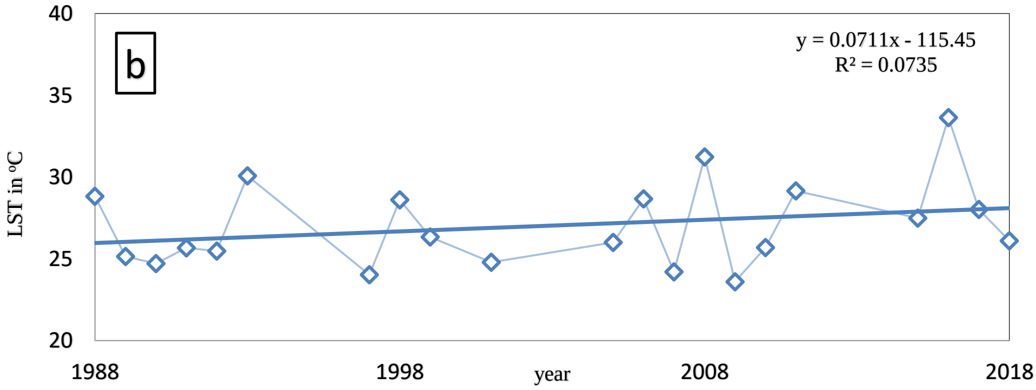


Figure 5.6 Temporal variation of mean LST of DMA in March (a), April (b) and May (c).

An increase in temperature was not found significantly within the period of 1988 -2018. In addition to the increase of LST induced by variations in the surface area cover condition, the general climatic warming environment represents an important background for analyzing the temporal variations. To deepen the understanding of the temporal variations, the mean value of LST data was derived from performing a near about similar trend analysis, as shown in Figure 5. The changed pattern distribution of mean LST in the month of March to May is significant, and the change trending in the month of March is more significant in comparison to the month of April and May. The mean value of LST has an increasing trend in urban areas. In DMA, the mean LST value was found at 24.1°C, but due to urbanization, in the year 2018, the mean value of LST in the same month was found at 29.8°C. Similarly, in the month of April and May from 1988 to 2018, the mean LST was found to increase by 4.9°C and 5.3°C in the DMA. The magnitude of the change in mean LST in the month of May is generally higher than the other month of the year. Figures 5.6 (a, b, c, d, e, and f) and 5.7 (a, b, c, d, e, and f) also show the mean LST trends both in developed (Gulshan and Motijheel) and growing developing areas (Demra and Pallabi) located around the boundary of DMA and show a strong warming effect with the higher values.





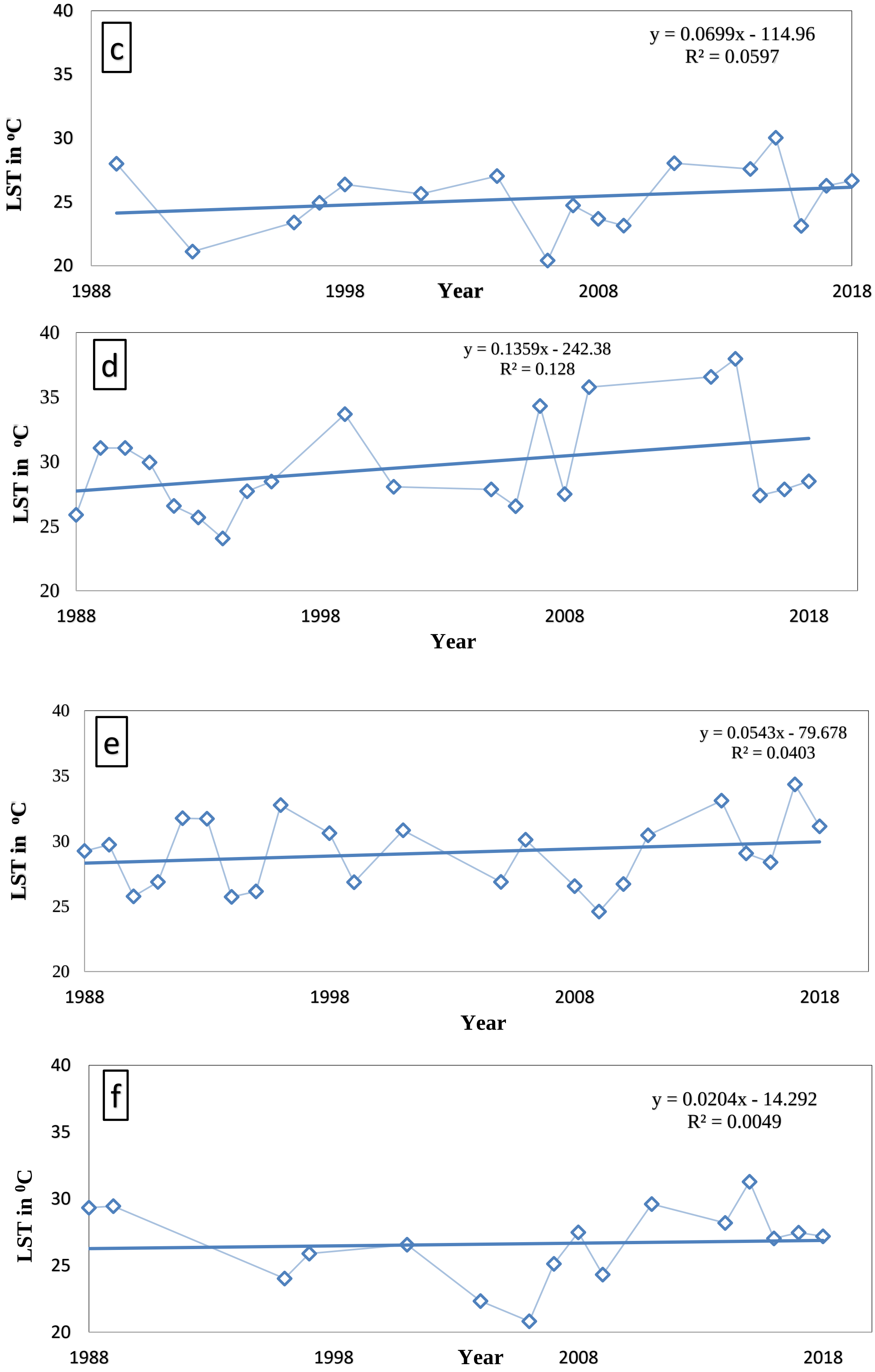


Figure 5. 7 Temporal variation of of monthly mean LST in the developed areas during March, April, and May (Gulshan- a, b, and c; Motijheel-d, e, and f).

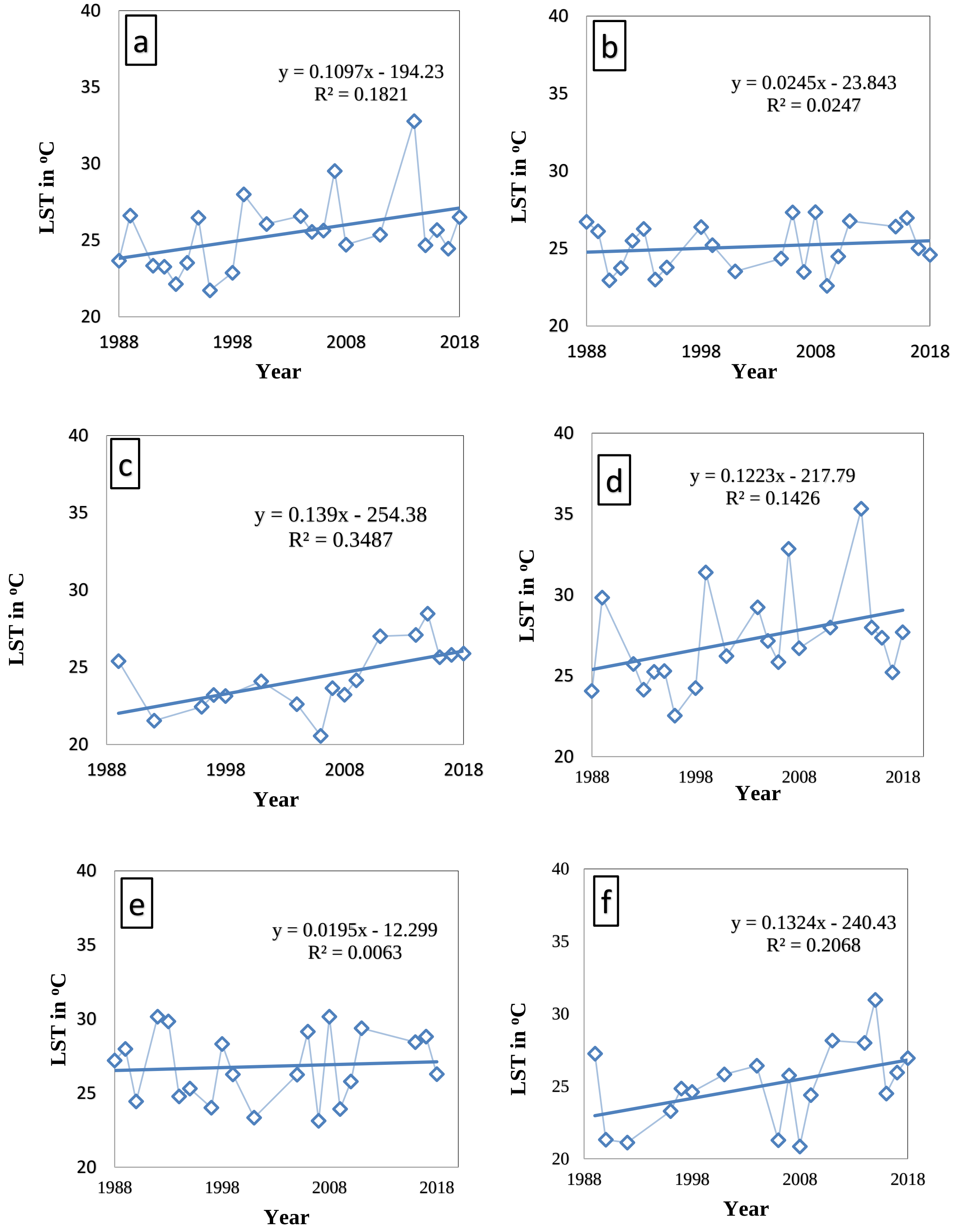


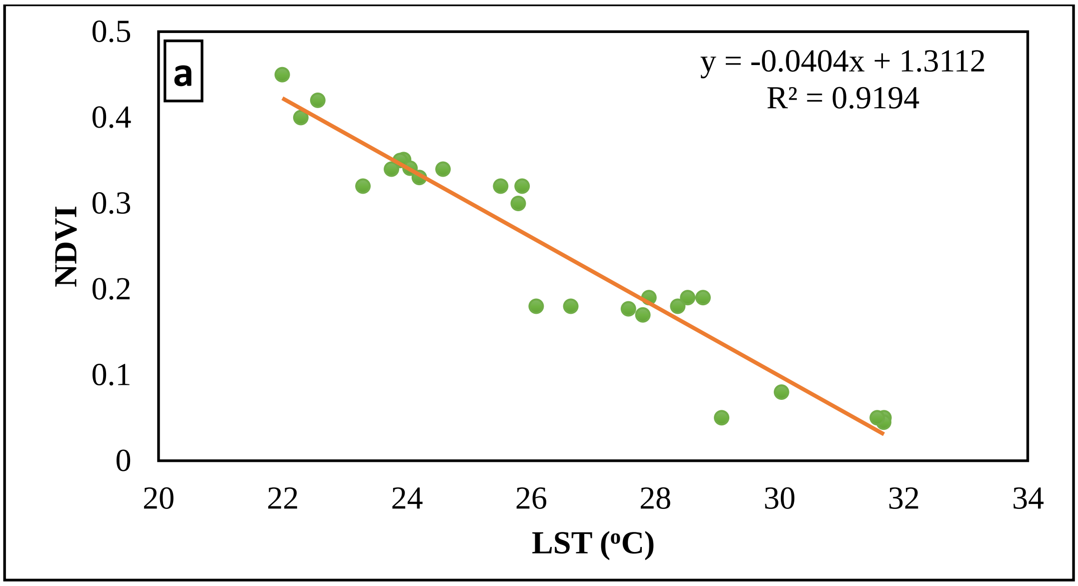
Figure 5. 8 Temporal trends of monthly mean LST in the developing areas during March, April, and May (Demra -a, b, and c, Pallabi - d, e, and f).

From analysis and observations of the Figure 5.7 and 5.8, it is found that the mean LST of each year has an increasing trend, and the warming effect is more pronounced at the month of March (R^2= 0.128 to .2459) in higher built-up areas in DMA such as Motijheel and Gulshan while the warming effect is significantly weaker (R^2=0.0049 to 0.0587) at the month of May. On the other hand, LST is higher at the month of May (R^2 = 0.2068 to 0.3487) in the growing, developing areas such as Demra and Pallabi. Analysis of the trends using the average temporal values of LST of the developing and developed areas from 1988 to 2018 of those selected areas showed that the most developed and growing developing areas have a positive trend of LST in the month of March to May.

Less significant variation was found for the months of April in both areas. The average value of LST in more developed areas has been increased by 6.3°C, 3.10°C, and 5.3°C for the months of March, April, and May over the last 30 years. Similarly, the average value of LST in the growing developed areas has been increased by 6.1°C, 3.1°C, and 3.2°C for the months of March, April, and May respectively for the last 30 years. So, a change of LST is more sensitive in the more developed areas compare to growing developing areas. Therefore, changes of different ranges of LST both in developed and growing developing areas are frequently covered by built up areas are directly related to the expansion of built-up areas. However, due to the warming effect of climate change, from the above discussion, it is clear that LST is the major issue and factor of climate change as well as global warming. This phenomenon is more reflected in the city center of urban areas, especially the more developed area's region.

5.5 Relationship of LST with vegetation (NDVI) and DBT in DMA

Finally, LST and NDBI, LST and DBT relationship during the study period (1988-2018) were developed and found a direct relationship between them within the period in March. In NDBI & LST correlation a strong negative relationship has been existed in March i.e., R^2 = 0.9194, and LST & DBT correlation also a strong positive relationship 0.8163 (Figure 5.9). The negative relationship found between NDBI and LST indicates that LST is increasing with decreasing the NDVI. On the other hand, the positive relationship found between DBT and LST indicates that LST is increasing with increasing the DBT. The Figure 5.9 (a) also indicates that the massive area of vegetation to a populated area could contribute significantly to the urban heat island effects of the DMA by increasing LST. The areas with high temperature also have a tendency to possess lower NDVI values. This aspect has also been corroborated through the analysis of the correlation be-tween LST and NDVI. Therefore, the correlation between NDVI and LST from the visual interpretation of NDVI and LST contrasts is crystal clear. Within the LST images, the LST values of low-vegetated areas (built-up, barren, dried riverbeds) are above those obtained for areas concerning waterbodies, vegetation, and agricultural land. It has also been showed that the peaks of the LST are found usually in the built-up areas, while the troughs are found in the waterbodies and vegetation areas and the peaks of NDVI has found in vegetated areas. Thus, NDVI and LST show a transparent negative correlation. In other words, the NDVI values are diminutive (or even adverse) where LST is high and vice-versa. The connection between LST and concrete land covers was investigated with an identical correlation. The very best LST was found in Motijheel which is above Demra by 37.932°C where vegetation is lower. It is a contrast for early developing and densely built-up areas. In Demra, the medium vegetation range area is increased by 13.74% compared with the developed areas, like Motijheel. A vegetation coverage area is decreased by 6.74% within the growing, developing areas compare with developed areas in 1988-2019. So, the studies used the typical satellite images at two or three different dates within the same month. All available clear-sky images within several years were studied for the selected areas to avoid the cloud contamination and the less accuracy. It is obvious that the urban vegetation landscape plays a vital role in reducing the UHI effect in the city centers. Urban planners to come forward to increase the urban green spaces through planning as mitigation tools to reduce urban heating in Dhaka City.



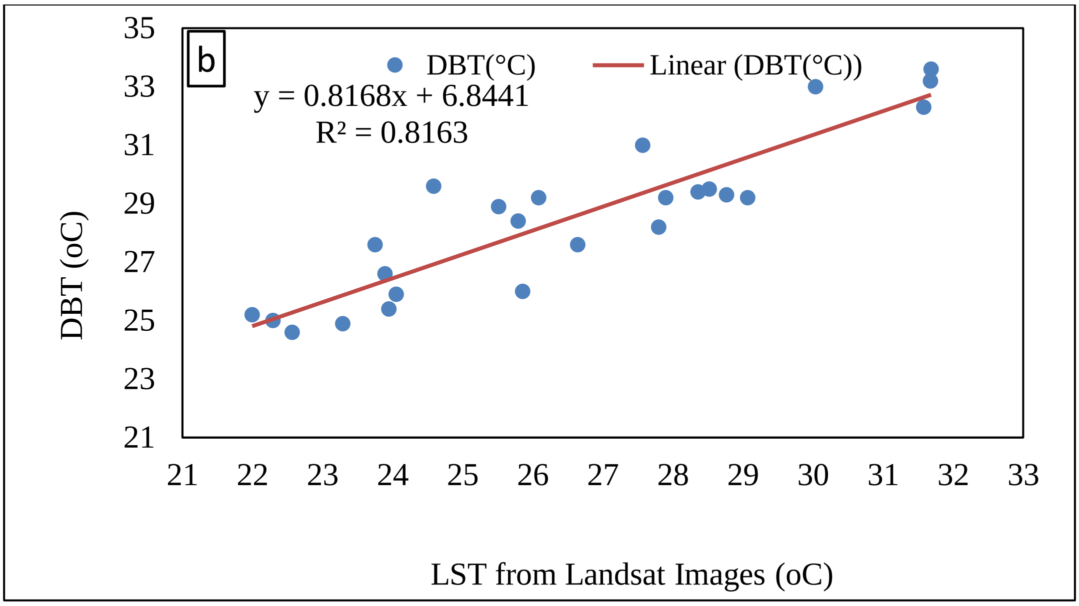


Figure 5. 9 Pearson Co-relation between (a) LST and NDVI; (b) LST and DBT in DMA (1988-2018).

5.6 Future direction of the Research

This study has analyzed the land surface temperature and urbanization trend of the Dhaka Metropolitan Area and its impacts on the creation of UHI exhausting remote sensing and GIS tools. Several studies have been conducted by urban planners and researchers in the GIS and remote sensing fields; there is still a lack of collaboration among the period of 1988-2018 among these variables with different percentile categories based on different year's group frame categories. The analysis of results indicated a significant relationship that becomes stronger through time, indicating that urbanization has had a great impact on surface warming. The urban warmer has been largely driven by population growth and economic development of the specific area. Integrated use of Arc GIS, RS, and socio-economic data would thus be effectively used to understand the spatial and temporal dynamics of LST and LULC changes. They produced maps of LST and LULC that will contribute to both the development of sustainable urban land use planning decisions and also for predicting possible future changes in growth configurations. The findings should be also useful to urban planners and building designers that they can form proposals to mitigate the temperature rise and improve the health of the city. However, most optical satellite images contain cloud cover, which is hard to avoid and to reduce the effect of thin cloud and other atmospheric conditions which can reduce the significant range of masking the cloud otherwise, remote-sensing techniques are efficient to reduce the time for analysis of urban expansion, the impact of urbanization on LST or urban heat island.

5.7 Summary

Based on the monthly Landsat LST and NDVI data covering the period from 1988 to 2018, this study provided new perceptions into the dynamics of the hotspot zone and vegetation cover changes over the Dhaka Metropolitan areas by analyzing the spatio-temporal variability of LST and vegetation cover. This study analyzed the land surface temperature and urbanization trend of the DMA and its impacts on the creation of UHI exhausting remote sensing and GIS tools. The results of this study clearly indicated a significant warming variation with NDVI changing for the most developed or the most built-up areas that are facing increased UHI aggravating climate warming. It is certain that the warming trend would further deteriorate the urban ecosystem and modify the major hydro-ecological processes over the study area. An increased vegetation activity is capable to deter the current heated local environment from the urban areas eliminating climate change impacts. The spatial and temporal trends of vegetation and their effects on LST changes as per percentiles of 50^{th}, 75^{th}, and 90^{th} led to conclusions that hot spot zones are assembled in the most developed areas where vegetation coverage is lower than the growing and developing areas. LST in the developed areas is more sensitive to climate changes than the growing, developing areas, and adaptation approaches or vegetation increases are needed to overcome LST increases in hotspot regions. It is imperative to carry out analysis of urban heating impacts using multi-source satellite images/radar data for curbing of future UHI effect of DMA. These results are supposed to provide valuable information for urban planners and researchers to take up appropriate green actions like roof top agriculture to mitigate the UHI effects. It will pave the way of achieving sustainable urban cities. Furthermore, with these findings, the planners can predict the possible changes in urban growth configurations. In general, these findings provide the importance of vegetation to adapt UHI effect in the urban city. So, greening the rooftop with agriculture is the largest adaptation tool to reduce the UHI effect in the urban areas. That’s why in the next chapter, the environmental and social dynamics of urban rooftop agriculture and their impacts on microclimate change were discussed.

Chapter 6

ENVIRONMENTAL AND SOCIAL DYNAMICS OF URBAN ROOFTOP AGRICULTURE AND THEIR IMPACTS ON MICROCLIMATE CHANGE

6.1 Introduction

In Chapter 5, it was observed that a significant warming trend is present in the most developed or most buildup areas in the urban areas as well as most developed areas in the city are facing urban heat island or climate warming. The result also indicate that the hot spot zones were assembled in the most developed areas where vegetation coverage is lower than the growing, developing areas and the cold spots zones were located in the less growing developing areas; However, as an inclusive analysis, the result chapter 5 finds that increase vegetation is to categorize the measurable involvement of climate change on the current local environment of urban areas from other factors. Moreover, URTA helps to improve the environmental quality, economic conditions of city dwellers, and can provide fresh vegetables to people for a healthier food supply [300] [301]. Though URTA produces and distributes food locally for marketing, it reduces carbon footprints and stress on the environment by in-spiring energy and resource-efficient buildings and savings from amplified building importance, higher rental rates, and reduced assessment costs [302] [303]. Global warming will have additional impacts upon Dhaka city by increasing severe UHI conditions, by creating more heat stress, by affecting urban life quality and all concerned activities [304]. As a result, urban Dhaka city is facing the challenges of fresh food, water security, health threats, and cleaner city to achieve Sustainable Development Goals (SDGs) 2, 6, and 11 [292]. However, there are some knowledge gaps on the cooling effect of the types of crops, the percentage of the crop area coverage of URTA as well as the decrease in the global warming and increase the fresh food production by URTA in the urban areas. URTA needs popularization to everyone, to every apartment, and to every building in the crucial time of warmer environment of Dhaka city, especially during the summer season. Therefore, in this chapter, Firstly, the primary data, collected from experimental roofs contain with and without URTA, from November 2018 to May 2019, to demonstrate the energy-saving trend based on cooling degree days (CDD), according to different area coverage by URTA within the experimental plot and others five URTA plot containing different areas coverage with different plants. To address this, the objectives of this chapter are to: (1) assess the dynamics of microclimatic parameters of agricultural roofs and BRs during the cooling period in Dhaka city to mitigate the UHI effect, (2) quantify the role of URTA on energy saving through different area coverage of roofs and (3) summarize the benefits and social impacts of URTA. The detail descriptions of the data and the methodology were presented in Chapter 3 and Chapter 4, respectively.

6.2 Environmental Dynamics of Urban Rooftop Agriculture (URTA)

6.2.1 Thermal Changing Features on Agricultural Roof s (ARs) and Bare Roofs (BRs)

Changing air temperature aspects were observed from different locations of the experimental AR (70% of roof area covered by agriculture with cultivation of Tomato, Chili, Brinjal, Bottle Gourd, Spinach, Red Spinach, Green Spinach) and from the nearby BR during the whole experimental period. The average temperatures of different times of a single day are shown in Figure 6.1. However, it has been detected that the temperature reached its maximum range during the month of May at 1.30 pm, for both AR and BR (Table 6.1) plots, in comparison to 9.30 pm and 5.30 pm. According to the descriptive statistics, the trend of the air temperature of the BR was always higher than the AR throughout the day.

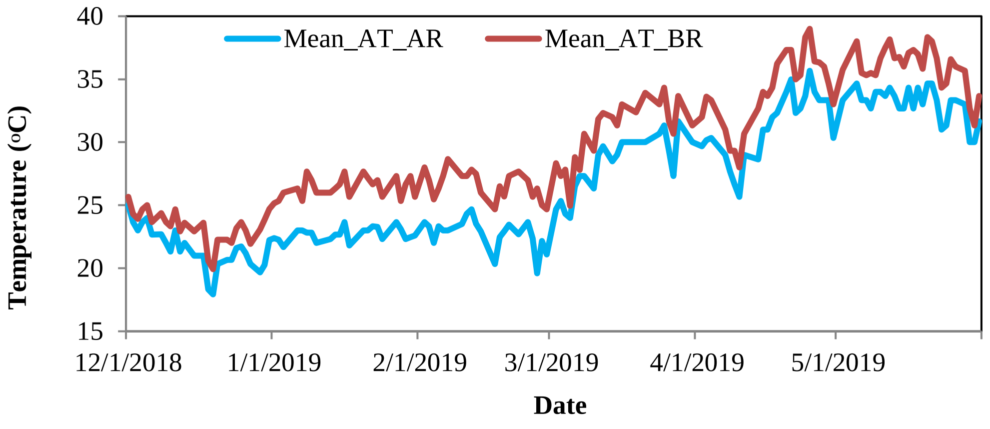


Figure 6. 1 Daily mean air temperature trend in the experimental agricultural roof (AR) and bare roof (BR) from December 2018 to May 2019.

According to Table 6.1, the comparison of the mean temperature between the AR and the BR showed that the AR, with 70% of its area covered by plants, was 2.61 °C, 3.41 °C and 2.66 °C cooler than the BR at 9:30 am, 1:30 pm and 5:30 pm, respectively. The maximum temperature differences between ARs and BRs were found by 2 °C (9:30 am), 5 °C (1:30 pm) and 4 °C (5:30 pm) higher compared to the AR (experimental roof). Consequently, the minimum temperature differences of the BRs were 1 °C (9:30 am), 2 °C (1:30 am) and 2 °C (5:30 pm) higher compared to the ARs. In the case of rainy days, the temperature differences of both roofs became very minimal. So, rain periods were avoided for temperature data analysis.

Table 6. 1 Descriptive statistics of air temperature (AT) of the experimental agricultural roof (AR) and BR from December 2018 to May 2019 (Total number of days = 142). Descriptive Statistics of Air Temperature in °C

Roof Type Time	Descriptive Statistics of Air Temperature in °C					
	Range	**Mean**	**Max**	**Min**	**Std. Deviation**	**Variance**
AR_9.30 am	20.00	23.53	34.00	14.00	5.94	35.33
BR_9.30 am	20.20	26.14	36.00	15.80	5.70	32.52
AR_1.30 pm	20.00	29.71	38.00	18.00	4.98	24.79
BR_1.30 pm	23.00	33.13	43.00	20.00	5.21	27.16
AR_5.30 pm	17.00	27.01	35.00	18.00	4.55	20.71
BR_5.30 pm	20.20	29.67	39.00	18.80	4.98	24.80

In this study, percentiles were used to understand the values of thermal variation in ARs and BRs, as well as to clearly recognize the advantage of URTA due to reduction in temperatures. From Table 6.2, it is clearly seen that the different percentile ranges of ARs were always higher than that of BRs. This means that of the 5, 10, 25, 50, 75, 90 and 95 percent temperature values, ARs had a range that was always less than BRs at the same temperature range.

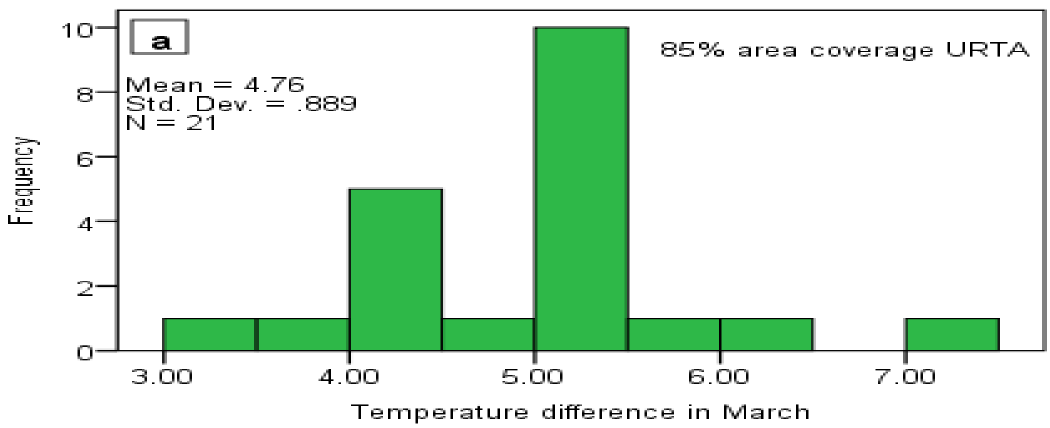
Similarly, the air temperature difference histogram, recorded from the five selected roofs (85, 80, 60, 50 and 40% roof area covered by agriculture) and the nearby BRs at 1:30 pm and 1.52 m above the roof surface, is shown in Figure 6.2. The histogram represents the mean value, standard deviation and normal distribution of the temperature difference frequencies of the different area covered roofs during the month of March. From the temperature differences analysis, it was exposed that during the month of March, the maximum frequencies of temperature differences were 5.5 °C, 4.5

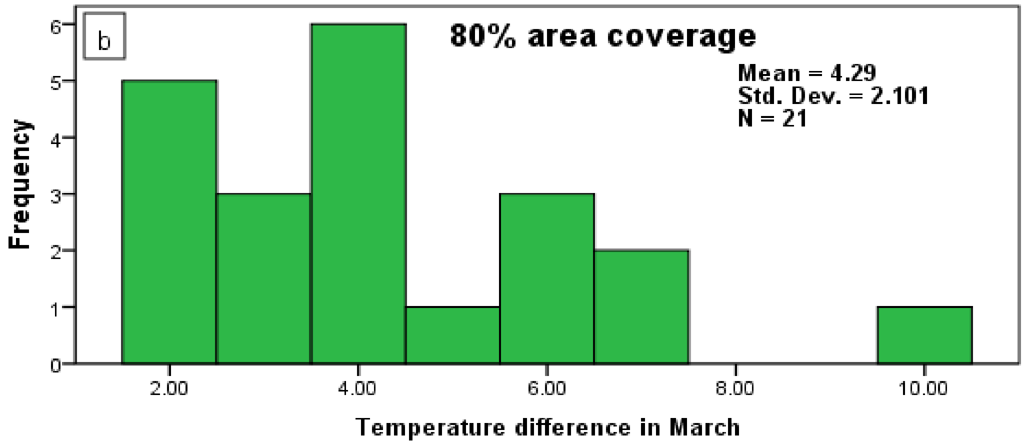
°C, 3.5 °C, 2.3 °C, 1.2 °C and 0.45 °C in 85, 80, 60, 50 and 40% roof area covered by agriculture, respectively (Figure 6.2). The mean temperature differences in April and May of those selected ARs and BRs were found to be 4.76 °C, 4.29 °C, 3.37 °C, 2.19 °C, 1.18 °C and 0.41 °C, and 4.41 °C, 3.51 °C, 3.42 °C, 1.85 °C, 1.00 °C and 0 °C in 85, 80, 60, 50 and 40% covered roof area by agriculture, respectively.

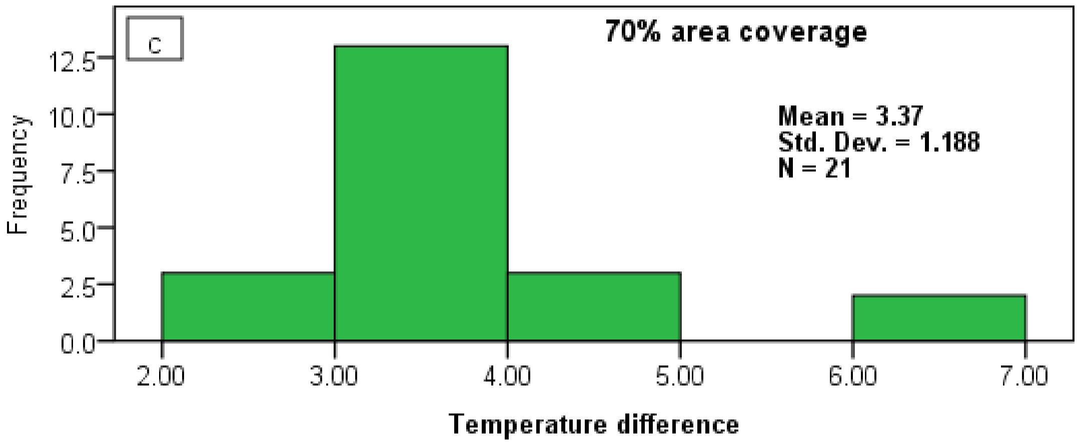
Table 6. 2 Weighted average percentiles of air temperature (AT) in the experimental AR and BR at 9.30 am, 1.30 pm and 5.30 pm from December 2018 to May 2019.

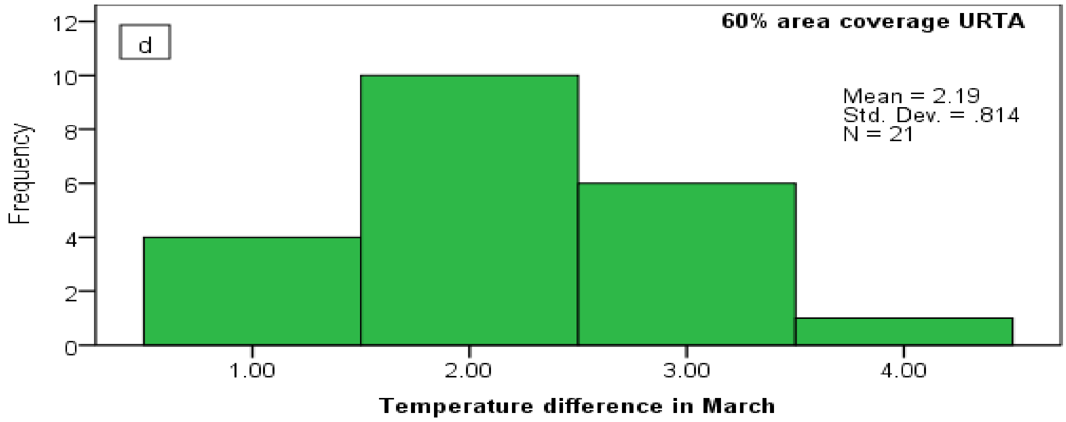
Air Temperature	Percentiles						
	5	10	25	50	75	90	95
AT_AR_9.30 am	15	17	18	22	29.25	32	32
AT_BR_9.30 am	18	19.86	21	24.75	32	34	35
AT_AR_1.30 pm	22.46	23.43	26	28.25	35	36	37
AT_BR_1.30 pm	25.24	26.93	29	32.5	38	40	41
AT_AR_5.30 pm	21	22	23	26	31	34	34
AT_BR_5.30 pm	22	23	26	30		36	37.24

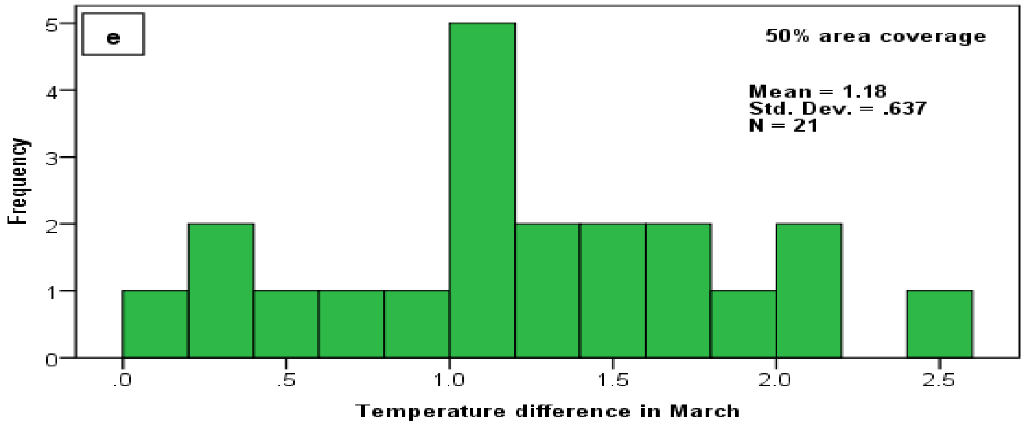
The minimum and maximum temperature differences in March were recorded as 3 °C and 6 °C, 2.10 °C and 7.20 °C, 2 °C and 6.5 °C, 1 °C and 3 °C, 0.1 °C and 1.8 °C and −1 °C and 1 °C of ARs and BRs, respectively. A 95% confidence interval for the mean was also calculated from the observed temperature differences between ARs and BRs through SPSS. It was revealed that the lower and upper bound of the 95% confidence interval for a mean temperature difference of those ARs and BRs were 4.55 °C and 5.08 °C, 3.90 °C and 5.32 °C, 2.83 °C and 3.91 °C, 1.79 °C and 2.26 °C, 0.85 °C and 1.18 °C and −0.36 °C and 0.27 °C, respectively. So, it is experiential that 50 and 40% covered roof area by URTA obtained a lower temperature reduction, recording a maximum of 1.8 °C and 1 °C and a minimum of 0.1 °C and −0.1 °C at 1:30 pm during the month of March to May, respectively.




b
80% area coverage
Mean = 4.29
Std. Dev. = 2.101
N = 21
Frequency
Temperature difference in March


c
70% area coverage
Mean = 3.37
Std. Dev. = 1.188
N = 21
Frequency
Temperature difference


d
60% area coverage URTA
Mean = 2.19
Std. Dev. = .814
N = 21
Frequency
Temperature difference in March



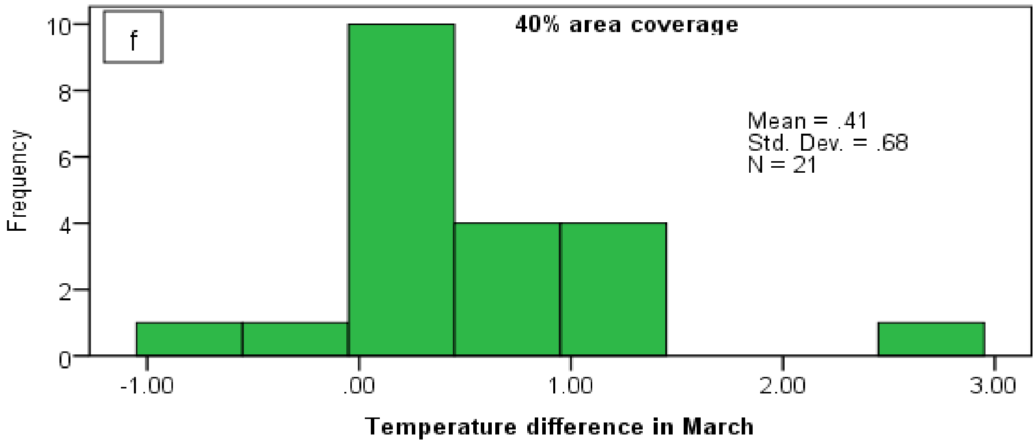


Figure 6. 2 Temperature differences histogram between (a) 85%, (b) 80%, (c) 70%, (d) 60%, 50%, and 40% area covered ARs and nearby BRs in the month of March 2019

Table 6. 3 Descriptive Statistics of room temperature difference between different AR & BR at 1.30 pm

Temperature difference between ARR and BRR	Number of days (March to May)	Mean	Maximum	Minimum	Std. Deviation
85% ARR_BRR	72	3.0778	4.50	1.00	.87854
80% ARR_BRR	72	2.4514	4.50	.50	1.55869
70% ARR_BRR	72	1.8347	4.00	.50	1.34703
60% ARR_BRR	72	1.3819	3.00	.20	.75650

On the contrary, the 85, 80, 70 and 60% URTA were equally and highly effective on-air temperature reduction compared to 50 and 40% roof area covered URTA roofs and BRs at the hottest time over the day during the summer season. On the other hand, the room temperature of those selected AR's bellow the room and near by the rooms below the BR's were also analyzed and found that up to 60% area of roof coverage by agriculture, the mean temperature difference of those room was found by 3.03°C, 2.45°C, 1.83°C, and 1.38°C between 85%, 80%, 70%, and 60% AR and nearby BR [Table 6.3]. However, the most noticeable difference is shown by the 85% roof area covered AR, which maintained its temperature variances and standard deviation as 0.34 °C and 0.58 °C compared to the other selected roofs. Thus, the temperature difference both roof and room should vary on the percentage of area covered by rooftop agriculture persists during the day at 1:30 pm.

6.2.2 Near Roof Surface Thermal Dynamics in AR and BR

The potential ranges of exterior roof surface temperature reduction were calculated for the experimental AR and BR. The winter and summer season variation of the near roof surface for the AR and the BR is presented as a Box-and-Whisker plot in Figure 6.3. This box-and-whisker plot shows the lowest value, highest value, median of surface temperature and performance on the roofs. From Figure 6, it is shown that the variability of the roof surface temperature was higher in the BRs for the month of December 2018 to May 2019 (both winter and summer seasons) than ARs.

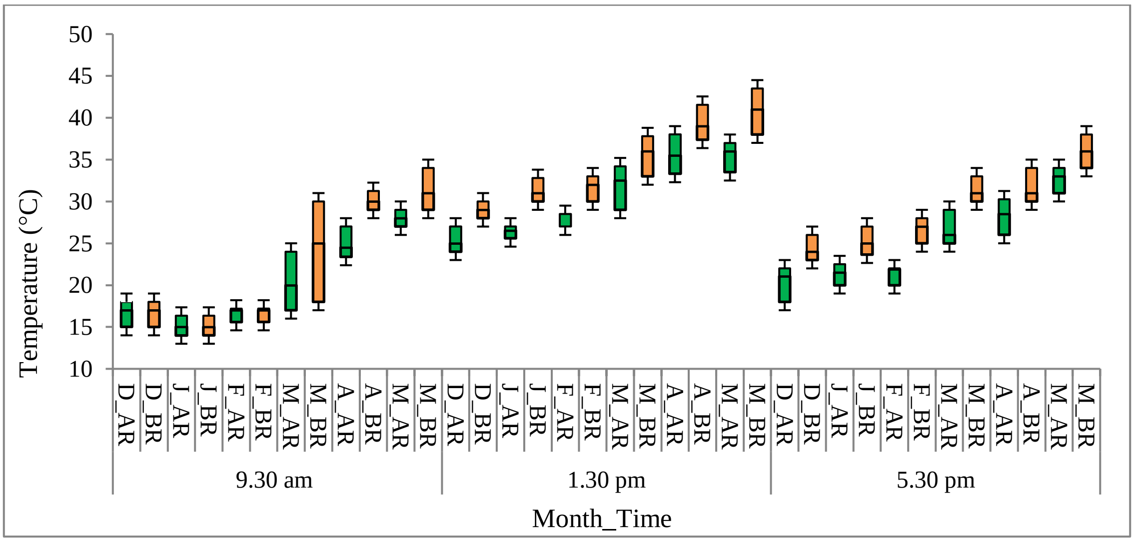


Figure 6. 3 Box and whisker plots for spatiotemporal variation of roof surface temperature in the experimental agricultural roof (AR) and bare roof (BR) at 9:30 am 1:30 pm and 5:30 pm from December 2018 to May 2020.

It has been observed that roof surface temperature in both roofs significantly varied at 1:30 pm and 5:30 pm comparatively with 9:30 am due to the shadow-shading effect or the higher leaf density of plants on the building roof surface. The maximum difference was 12 °C during the month of May, and the average difference was found to be 6 °C on a specific day. It was also observed from one sample t-test that there was no significant temperature difference during the months from December to February at 9:30 am. However, from March to May, the temperature significantly differed by 3–12 °C at 9.30 am. Similarly, at 1.30 pm and 5.30 pm, the temperature reduction was 4 to 12 °C. It was also reviewed that on semi-intensive green roofs, the roof surface temperature reduction was found to be 7 to 14 °C [305]. The results showed that the URTA roof was very effective in peripheral surface temperature reduction and thereby provided thermal shading to the building. The degree of surface temperature reduction by the URTA in-creased with the increased solar intensity, as a higher reduction was observed during the daytime at 1:30 pm.

6.2.3 Air Temperature Inclines in AR Relative to Distance from Roof Surface

Table 6.4 represents the temperature gradient at the north–south, middle and east–west side of the AR at 1.25 m above the roof surface from January to April 2019 daily at 9:30 am and 1:30 pm. The mean temperature incline, measured below the canopy shading at near roof surface 1 m, 2 m, 1.25 m and 2 m above the roof surface, varied within a confined average range of 0.74 °C to 2.32 °C and 1.15 °C to 3.37 °C on the AR during March at 9.30 am and 1.30 pm, respectively. On the BR, the air temperature in-cline at different heights varied within the range of 0.50 °C to 1.1 °C and 1 °C to 1.7 °C at 9:30 am and 1:30 pm, respectively, in March. It was also clearly observed that the temperature gradient was lower below the fencing panel at the north and south sides of the experimental roof compared to other locations, such as the middle, east and west side of the experimental AR where the fencing panel was 1.5 m above the roof surface. Leafy vegetables cultivated under the fencing panel worked as an additional input for lowering the heating effect. The canopy density and height of plants resulted in the temperature change at different heights during the day. It was an upward trend both at 9:30 am and at 1:30 pm in the case of the BR. However, for the experimental AR, the temperature variation was upward at 9:30 am, whereas, at 1:30 pm, the temperature variance moved downward. So, this impact was limited to affect the temperature changes at a different height. On the other hand, solar intensity was low in the morning compared to noon (1:30 pm), and air warming in the morning differed at different heights with little effect. It is notable that the maximum variances occurred on the near-surface at 1.2 m height compared to at 2 m height from the roof surface.

Table 6. 4 Descriptive statistics of air temperature at different sides of the AR and BR.

Place_Time	Mean	Maximum	Minimum	Std. Deviation
AT_°C_North_AR_9:30 am	22.54	33.50	13.00	6.98
AT_°C_South_AR_9:30 am	22.47	33.00	13.00	6.38
AT_°C_Middle_AR_9:30 am	22.95	34.00	12.00	7.32
AT_°C_East_AR_9:30 am	23.90	34.50	13.30	7.20
AT_°C_West_AR_9:30 am	23.55	34.30	13.00	7.04
AT_°C_BR_9:30 am	25.35	36.00	15.00	7.20
AT_°C_North_AR_1:30 pm	29.88	37.00	23.00	4.30
AT_°C_South_AR_1:30 pm	29.84	36.50	23.00	3.88
AT_°C_Middle_AR_1:30 pm	30.28	38.00	23.00	4.52
AT_°C_East_AR_1:30 pm	30.61	39.00	23.00	4.39
AT_°C_West_AR_1:30 pm	31.24	39.00	24.00	4.35
AT_°C_BR_1:30 pm	34.60	43.00	29.00	3.99

6.2.4 Relative Humidity variation of AR and BRs

In order to assess the effect of rooftop agriculture upon microclimate changes, the average mean, minimum, maximum, standard deviation and variance of the relative humidity (RH) were analyzed from December 2018 to May 2019, collected daily at 9:30 am, 1:30 pm and 5:30 pm. The variation of RH in the AR and BR are shown in Figure 6.5 a, b, and c. The mean, minimum, maximum, and standard deviation (SD) of RH were observed as 88.83, 30.67, 56.92 and 11.44 for AR and 25.33, 78.67, 49.29 and 10.64% for BR, respectively. Minimum 5% and maximum 10% variations were found between the AR and BR, which indicates that rooftop agriculture is proficient in increasing the RH in the air layer compared to the BR, and it influenced the microclimate of the surrounding air by its evapotranspiration. So, Figure 6.5a–c demonstrates that the relative humidity changes in the AR were always higher than the BR, which played a significant role in the thermal behavior of the roof in the daytime at 1:30 pm. As humidity itself was a climatic variable, it also influenced other climatic variables. On the other hand, RH were also different by 1.5-3.5 % at east and west side compare to middle part of experimental roof [Figure 6.4]. Thus, URTA would have positive impacts on the thermal comfort of the people living in urban cities through the reduction of air temperature. So, it is highly recommended to include URTA in the building code of Bangladesh to mitigate the UHI effect. It is applicable for all regions of the globe to reduce global microclimatic change during warmer seasons.

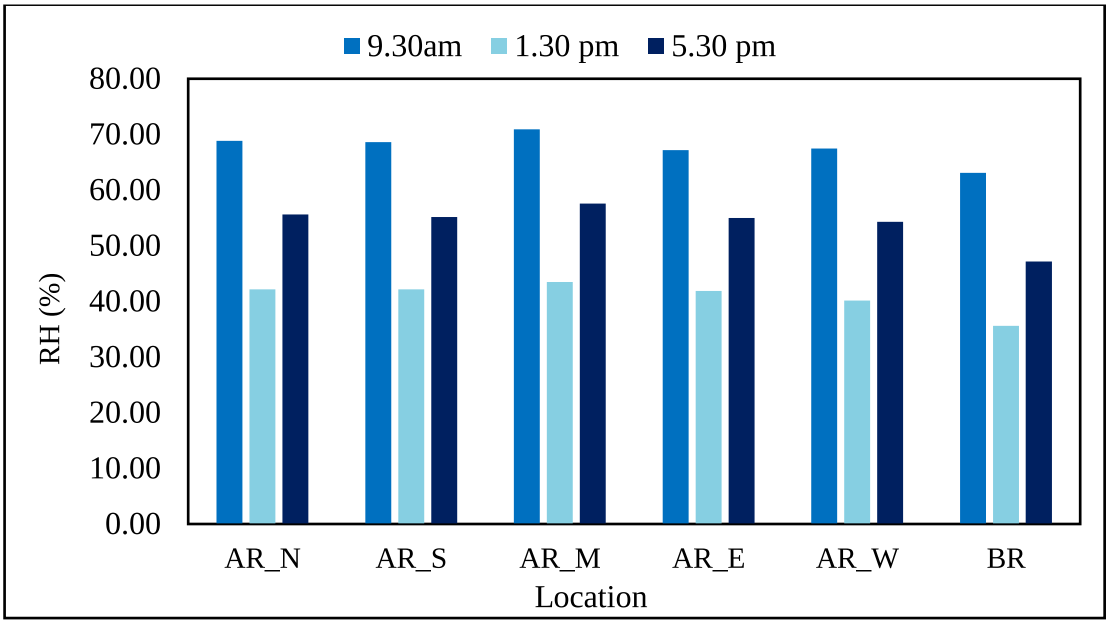


Figure 6. 4 Relative humidity variation in the experimental agricultural roof at different location and bare roof; (a) at 9:30 am, (b) 1:30 pm and (c) 5:30 pm, respectively, during December 2018 to May 2019.

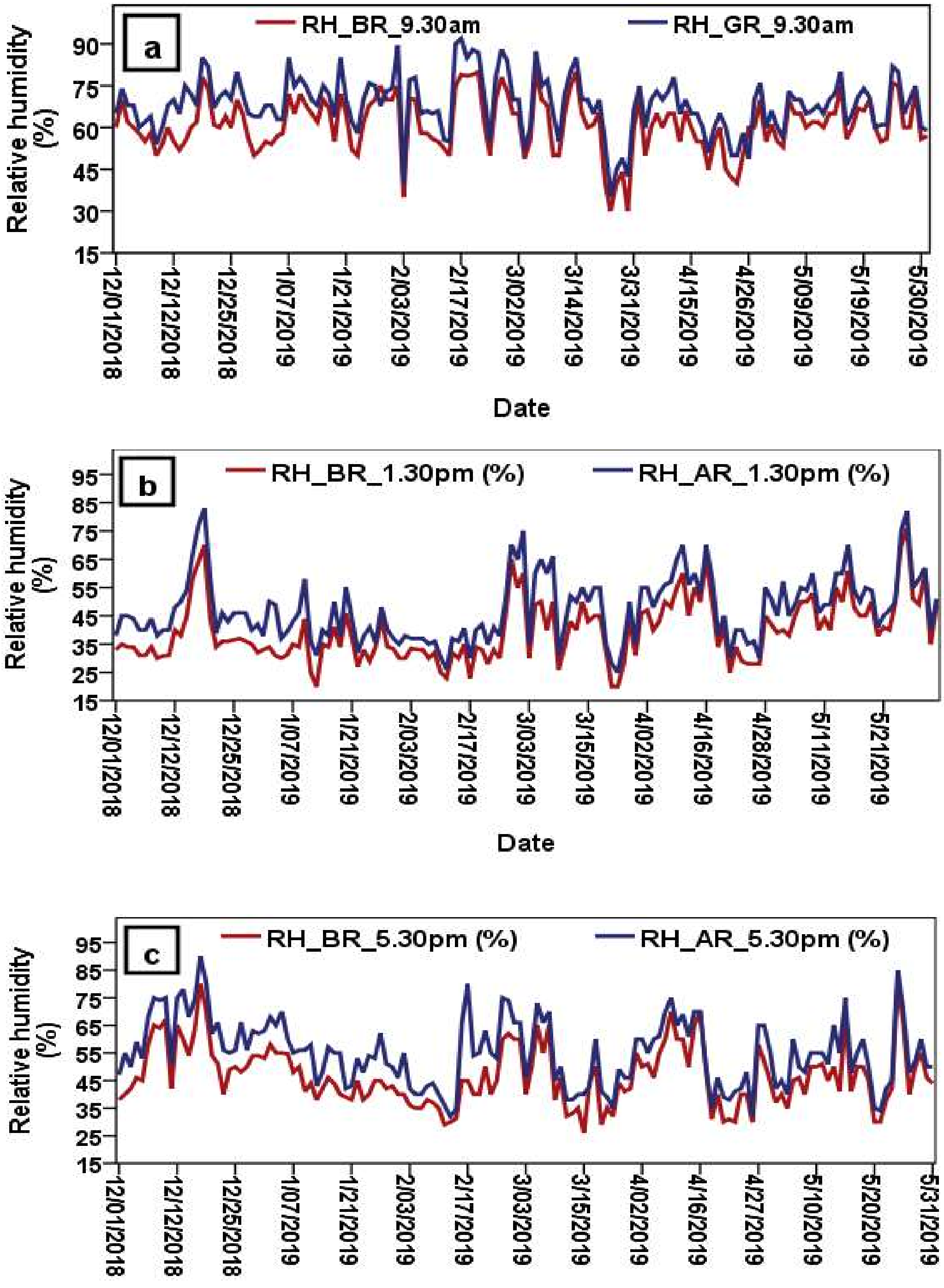


Figure 6. 5 Relative humidity trend in the experimental agricultural roof and bare roof; (a) at 9:30 am, (b) 1:30 pm and (c) 5:30 pm, respectively, during December 2018 to May 2019.

6.2.5 CO_2 Distinctions in the AR and BR

With An average 1.63% reduction of CO_2 concentration was observed at 1 m above the roof surface in the experimental AR compared to the adjacent BR within the period from December 2018 to May 2019. The significances of the concentration were analyzed through regression analysis and shown in Figure 6.6. However, it was observed that the mean concentration of CO_2 (ppm) was 400 ppm and 406 ppm in AR near the plants and in BR, respectively. The maximum concentrations were found to be 431.00 ppm and 440 ppm in AR near the plant and in BR, respectively. Different percentiles of CO_2 concentration were also analyzed. It has been found that the 75, 90 and 95 percentiles of CO_2 concentrations were 404 ppm and 408 ppm, 413 ppm and 410 ppm and 414 ppm and 419 ppm in AR and in BR, respectively. So, the study found that the AR had a higher respiration rate from plants that cause the differences in CO_2 concentration compared to the nearby BRs same as green roof [306]. Hence, AR is able to adapt the microclimatic changes in urban cities and the UHI effect by reducing heat-trapping gas concentration leading to thermal comfort at a local scale. A total of 141 days, which were represented by the x-axis and observed values CO_2 concentration (ppm) were represented by the y-axis in Figure 8. It indicated that in the AR, CO_2 concentration was comparatively lower than BR. From February to April, the maximum values were close to the regression line, i.e., the maximum values were found to be close to 401 ppm and 410 ppm for the AR and BR, respectively. So, the URTA plays a very crucial role in the microclimatic changes and controls the temperature and CO_2 rises (1 to 10 ppm) with and around the roofs.

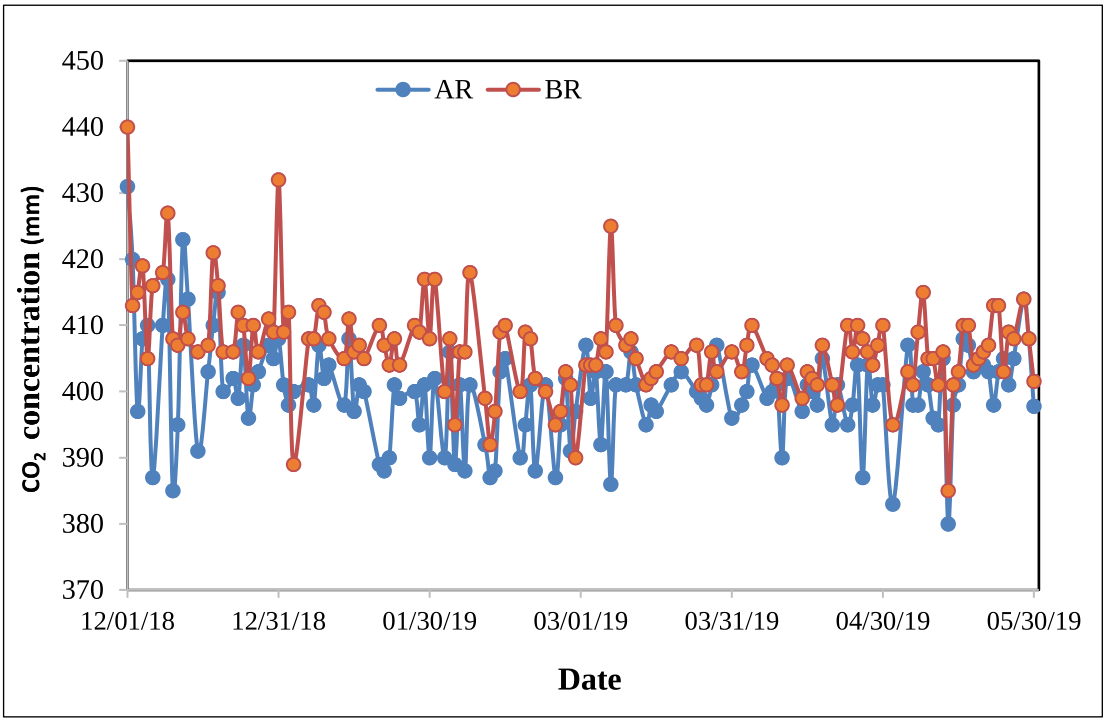


Figure 6. 6 Average CO_2 concentration in AR and BR from December 2018 to May 2019.

6.2.6 CDD and Cooling Load Potential Dynamics of Different Type of URTA

The number of degrees by which a daily average temperature surpasses a base temperature (20 °C) and may therefore need supplementary energy for cooling the room in different climates, is called cooling degree day (CDD) [313]. It has been found that, for the lower percentage of area coverage by ARs, CDD was nearly same or sometime lower or sometime 0.18°C higher than the adjacent bare roofs. However, for the higher percentage of area coverage by ARs, the CDD difference was found by 4. 5 °C. AR was more suitable for decreasing ambient temperatures and for reducing the cooling load between 32% and 100% [307] [308]. On the other hand, up to 60% green area coverage roofs, the mean CDD difference was found by 0.20 °C - 4.5°C. The maximum and average CDD difference between the room below the roof of experimental AR's (70% area coverage) and nearby BRs was found by 4°C and 1.8°C respectively [Figure 6.7]. The Figure 6.7 also represents that the highest CDD difference occurred at the month of March and April. On the other hand, the most conspicuous CDD difference was found by the 85% area coverage AR, which maintained its temperature changes compared to the other selected roofs during the day at 1:30 pm.

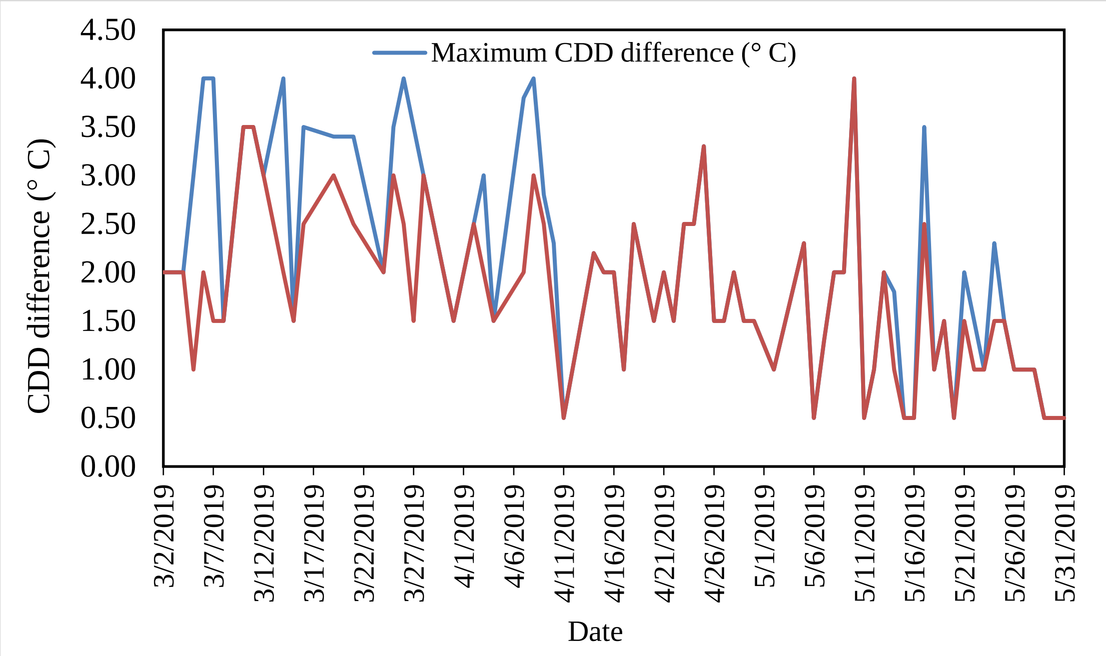


Figure 6. 7 Average and maximum CDD difference of room below the 70% green area coverage AR and room below the nearby bare roof from March’2019 to May’2019.

On the other hand, from Table 6.5 represents the minimum, maximum, mean, standard deviation of daily cooling load of different types of roofs during the month of March’2019 to May’2019. It is originating that maximum cooling load prerequisite at the 40 % area coverage rooftop agriculture as 1337.74 W/m2 and minimum cooling load prerequisite at the 85% area coverage rooftop agriculture as 772.31 W/m2 compare to other selected roofs. However, it is detected that among these roof’s indispensable cooling load, 85%, 80%, 70%, 60%, 50% and 40% green area coverage roofs basic cooling load are 12.15%, 14.43%, 16.21%, 18.06%, 18.81% and 20.34% respectively. Conversely, cooling load saving of those roofs is found by Figure 6.6). Therefore, due to the increases of area coverage of URA the daily peak cooling load value has decreased and cooling load saving increased significantly. As a result, cooling load will one of the most widely recognized parameters to analysis the building energy saving.

Table 6. 5 Daily cooling load (W/m2) requirements of different area coverage roofs by agriculture during the month of March'2019 to May'2019

Descriptio n	40% AR	50% URA	60% URA	70% URA	80% URA	85% URA
Mean	1320.0 4	1220.53	1171.92	1051.96	936.10	788.10
Std. Deviation	13.28	23.78	9.003	10.750	4.55	6.16
Maximum	1337.7 4	1254.55	1187.99	1069.17	948.04	798.46
Minimum	1287.3 7	1134.16	1146.90	1026.65	927.85	772.31

A paired sample t-test with a 95% confidence interval was used to compare the means of cooling load potential (KW/m2) of selected ARs and nearby BRs with six pairs (Table 6.5). There was a significant difference in cooling load requirement for the different area coverage of ARs (M = 0.788 to 1.30, SD = 0.0062 to 0.01332) and nearby BRs (M = 1.369 to 1.387, SD = 0.0108 to 0.0280). These results suggested that AR had a substantial cooling effect and depended on the roof area coverage by agriculture. Our research results suggested that when the agricultural roof was covered more than seventy percent, cooling load requirement decreased. The maximum cooling load prerequisite was 1337.74 W/m2 for the 40% area coverage AR, and the minimum cooling load prerequisite was 772.31 W/m2 at the 85% area coverage AR compared to other ARs [Table 6.6]. However, it was detected that among these roofs, indispensable cooling load varied from 12.15 to 20.34%. Therefore, due to the increases in area coverage of URTA, the daily peak cooling load value would be decreased and cooling load saving increased significantly. Building energy saving.

Table 6. 6 Paired Samples t-test statistics of cooling load (KW/m2) potential in the agricultural roof and bare roof.

Pair	Status	Mean	N	Std. Deviation	Correlation	t	df	Sig. (2-Tailed)
Pair 1	BR	1.383	72	0.0149	0.917	528.493	71	0.000
	AR	0.788	72	0.0062				0.000
Pair 2	BR	1.369	72	0.0091	0.499	467.390	71	0.000
	AR	0.936	72	0.0046				0.000
Pair 3	BR	1.382	72	0.0144	0.959	549.203	71	0.000
	AR	1.052	72	0.0108				0.000
Pair 4	BR	1.380	72	0.0108	0.952	497.653	71	0.000
	AR	1.172	72	0.0090				0.000
Pair 5	BR	1.434	72	0.0280	0.997	383.413	71	0.000
	AR	1.221	72	0.0238				0.000
Pair 6	BR	1.387	72	0.0138	0.962	150.617	71	0.000
	AR	1.320	72	0.0133				0.000

6.2.7 Energy Savings Dynamics of Different Type of URTA

The buildings with intensive, semi-intensive and extensive green roofs could save about 20–60, 10–45 and 20% energy consumption, respectively [310]. On the other hand, ARs could save 1 to 34% of the amount of total annual energy consumption, 10% to 33.33% of the space cooling load and 20% to 50% of the peak space load [311]. According to Tables 6.6 and 6.7, it was observed that energy consumption decreased in the high area covered ARs, and different percentile levels of energy savings were observed in all roofs with the increase of green areas. It was clearly observed that 85, 80, 70, 60, 50 and 40% of roof area covered ARs saved energy on top floor of a building by 59.45, 55.63, 39.81, 25.94, 18.88 and 5.87%, respectively.

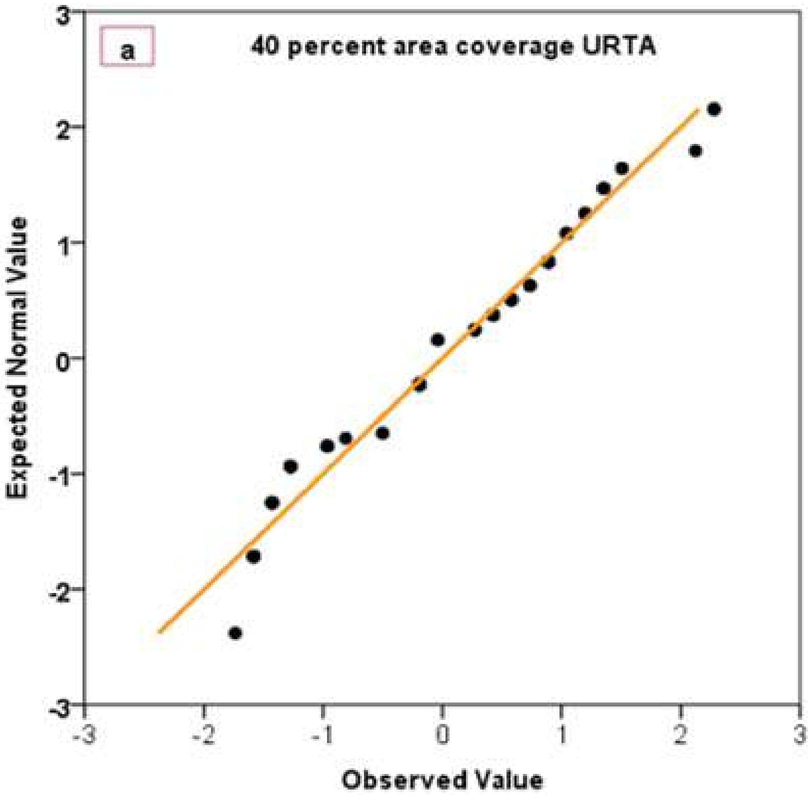
Table 6. 7 Daily average energy saving (%) with the different area coverage roofs by AR during the month of March 2019 to May 2019 compare to adjacent BRs.

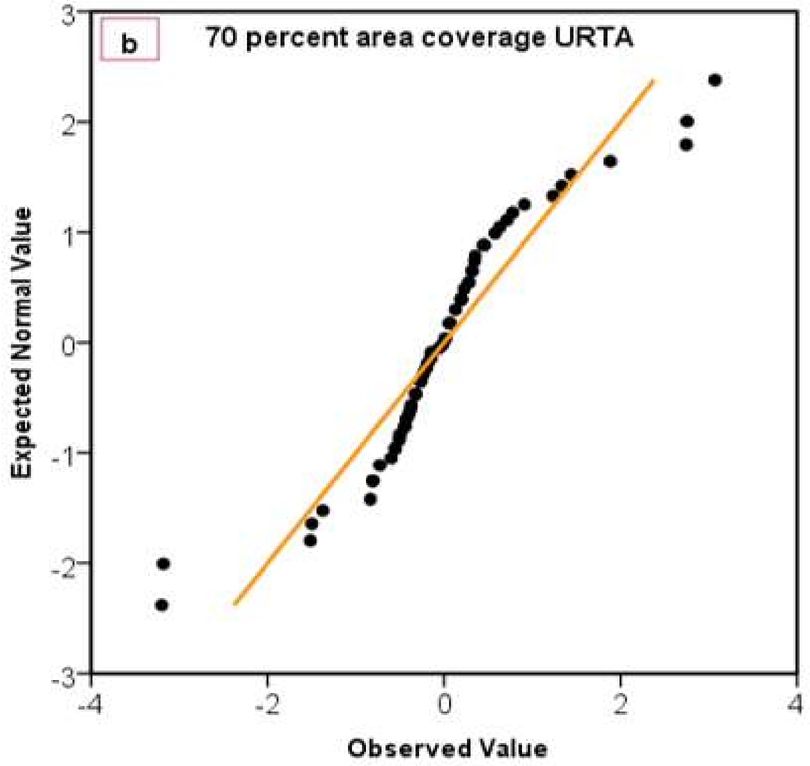
Types of Roof	Mean	Maximum	Minimum	Std. Deviation
40% coverage	5.87	17.68	−2.93	5.08
50% coverage	18.88	25.40	14.93	2.07
60% coverage	25.94	43.63	17.36	4.45
70% coverage	39.81	62.16	28.47	6.08
80% coverage	55.63	71.09	39.25	7.49
85% coverage	59.45	71.53	38.22	4.71

Table 6. 8 Daily average energy saving (%) with respect to different percentile in the different area coverage AR during the month of March 2019 to May 2019 compare to adjacent BRs.

Types of Roof Based on Area Coverage	Energy Saving in % at Different Percentiles				
	25	50	75	90	95
40% coverage	2.33	4.76	10.01	11.87	14.70
50% coverage	17.70	18.35	19.74	21.68	23.77
60% coverage	23.12	25.19	27.64	31.30	35.58
70% coverage	36.25	39.64	41.64	48.50	52.44
80% coverage	50.29	54.23	62.19	66.03	69.21
85% coverage	57.15	59.85	62.22	64.45	65.65

Sixty percent or below 60% area covered ARs saved energy up to 30%. In the case of 60, 50 and 40% of the roof area covered ARs, the 95th percentile of energy saving was as much as one-fourth to one-fifth compared to the 70–85% roof area covered ARs. The results showed that energy consumption differed in all roof options, which was closely related to the area covered by ARs, soil and density of leaves and plants. On the other hand, in the summer season, the energy consumption reduction was barely significant, which is shown in the quantile-quantile (Q-Q) plot normal distribution in Figure 6.9. The Q-Q plots represent the probability distributions of all values of energy savings by plotting their quantiles against each other and creating a perfectly straight line for the 40, 70 and 85% roof area covered ARs. From Figure 6.9, it was confirmed that there was a significant potential application of ARs as an energy conservation approach in buildings in hot and moist climatic conditions. However, it can be seen that the energy saving fluctuations of ARs were always less than the thermal fluctuations of BRs, especially in the warm months of the year. However, the equipment operation efficiency was not considered in this study to calculate the energy saving.


a
40 percent area coverage URTA
Expected Normal Value
Observed Value


b
70 percent area coverage URTA
Expected Normal Value
Observed Value

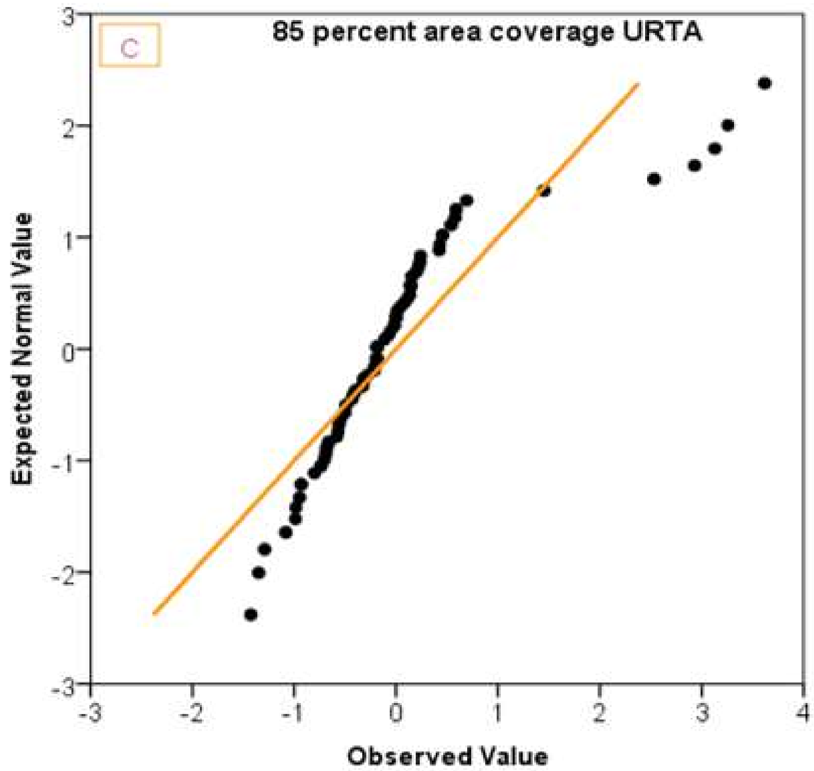


Figure 6. 9 Normal Q-Q plot of energy saving with the (**a**) 40%, (**b**) 70% and (**c**) 85% area covered ARs, respectively, during the months from March 2019 to May 2019 compared to adjacent BRs.

6.3 Socio-Economic Analysis

6.3.1 The typology dynamics of URTA

The opinions of the owners of URTA and physical field survey of their roofs is also found the three different attributes of the distribution level of produced goods and the planting interests behind the URTA initiatives compare between man and woman [Figure 6.12]. It is found that women are strongly related to each group of the criteria divided by different interests but with the distribution level, we focused more on the beneficiaries of the produced goods. On the other hand, the produced goods are shared between friends and peers or sold to known consumers as 66.15% consumed by own, 32.31% share with friends and relatives and 1.54% participants sell with stationary shopkeepers instead of bring another item that is required their URTA. The individual interests mainly consist of self-supply which includes any form of personal requirements that are based on individual interests. It can refer to pure self-supply but also to casual earnings when individuals or private households grow their own food to save money. It can also include different forms of recreation and work-leisure time balance that led to a benefit for the individual conditions of the practitioner of URTA. The 94.12% owners of URTA shared that if the production goods will be circulating between a definable community and known persons on a submarket through i) government selling and buying cell; ii) floating van of URTA goods and iii) apps of URTA product and related different materials where owners of URTA can get easily them require services including selling and buying. The interests and motivations behind the URTA initiatives are at the center of social and cultural welfares that result will be responsible for the urban environment and will have motivations of organic food production as well as economic encouragements. Growing food and its consumption in a community, meeting people in leisure time and sharing knowledge on different gardening practices can be drivers for URTA for individuals. It performs that the production of specific agricultural products can be a driver for participation in URTA initiatives or for individual crop growing [Figure 512]. Figure 5.12 represents the types of crop growing pattern of men and women participants of existing URTA. It is perceived that women are more interested to cultivate vegetables than men which could directly contribute to their family economic condition. Therefore, typology of URTA is fundamentally women searching as well women empowerment could easily widespread in the urban area and URTA would pervasive as a commercial culture which directly correlated with economic of the socialization. If the production goods would sell to the market to achieve financial success, they will able to need to meet the demand of the household members as well as independent from carbon intensive transport systems and fulfills the basic ideas of sustainability. Finally, it is also referred to produce specific one or two type's crops in a season like tomato, Brinjal that can directly process and served to the consumer regularly at a contract basis for prepare the RTA as a commercial purpose. Due to the higher density of the urban population, URTA can fulfill the required house hold agricultural products as like as rural areas.

6.3.2 Gender-Sensitive Socialization of URTA

Out of the total of 200 rooftop agriculture owners, it could be observed that 51.94% of owners of ARs were female and 48.06% were male, and the ages of the male and female owners were different. However, it was noticed that the URTA was mostly female and elderly male sensitive, where women clearly had an important role to play in in-creasing the productivity of rooftop agriculture. Therefore, the sensitivity of gen-der-oriented social dynamics of URTA was multifarious, with individuals expressing degrees of perception towards the four different age factors (Figure 6.10). However, personal socialization activities of URTA were identified most strongly among these four groups of age. So, age and sex were the most imperative social factors to put URTA into practice. Figure 6.8 represents the different year groups (1 = less than 40 years, 2 = 40–50 years, 3 = 50–60 years and 4 = more than 60 years) of males and females and their contribution to the implementation of URTA. Figure 6.10 characterizes that the 40–50-year-old group of females and the over 60-year-old male group were most perceived by the respondents' group of URTA. On the other hand, from the questionnaire survey, it was observed that the maximum everyday jobs of URTA were done mostly by women, including soil preparation, fertilizer application and water management. Some responsibilities were shared with labor such as loading the soil and heavy material transferring such as bamboo, rod sit, containers, soil and organic fertilizer, caring of the roof garden, etc. From the data analysis, the overall skillfulness of women had been in-creased by 68.78% through rooftop agriculture. So, gender contribution was highly related with URTA and their understanding of agriculture was enhanced through regular involvement in the cultivation of different fruits, flowers, vegetables and other plants in rooftop agriculture. It was found that personal capabilities about the commercialization of URTA products came out as strong factor among the three dynamic parameters. Mandatory in the building code and proper monitoring (36.92%) and subsidies, incentives and bank loans from the government (50%) and training on the agricultural system (13.08%) were the most perceived by respondents are shown in Figure 6.11 (a and b). It has also been shown from the previous studies that health (53%) and education (62%), planning social welfare (40%), social group integration (40%), community recreation (35%) and social empowerment (25%) were professed by respondents [313].

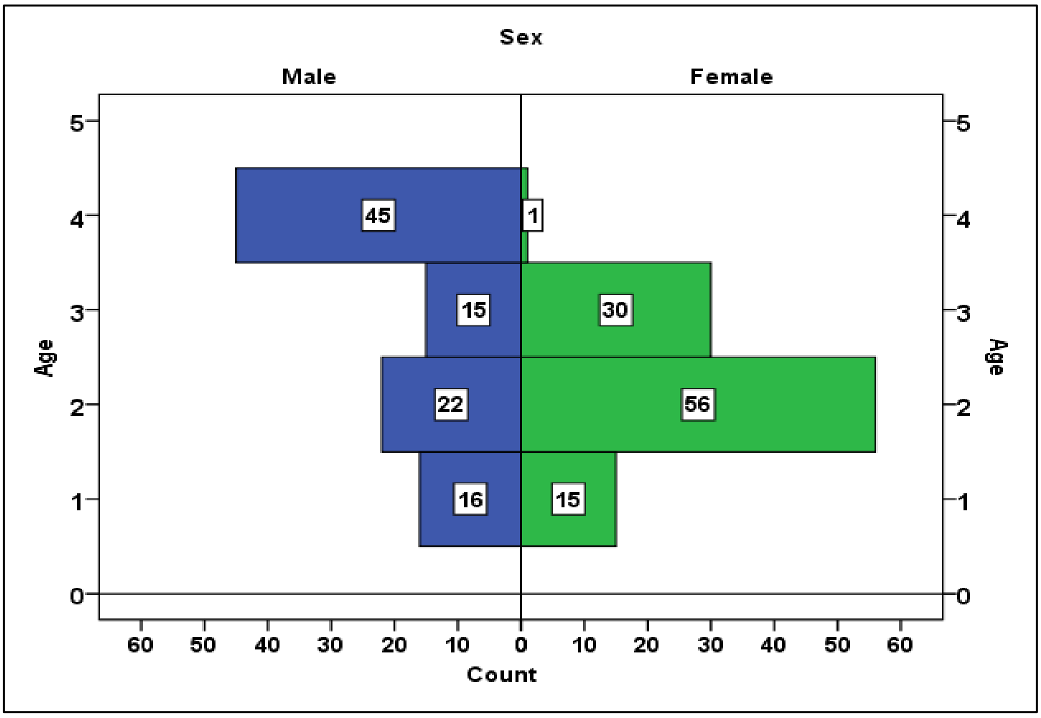
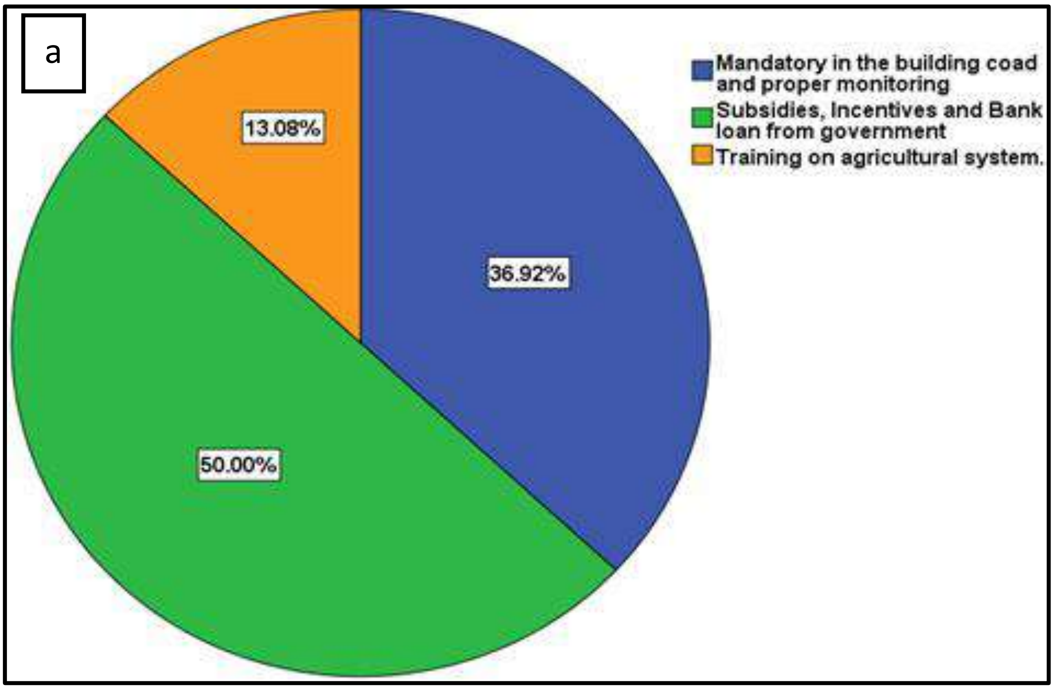


Figure 6. 10 Male–female sex pyramid owner graph of URTA.



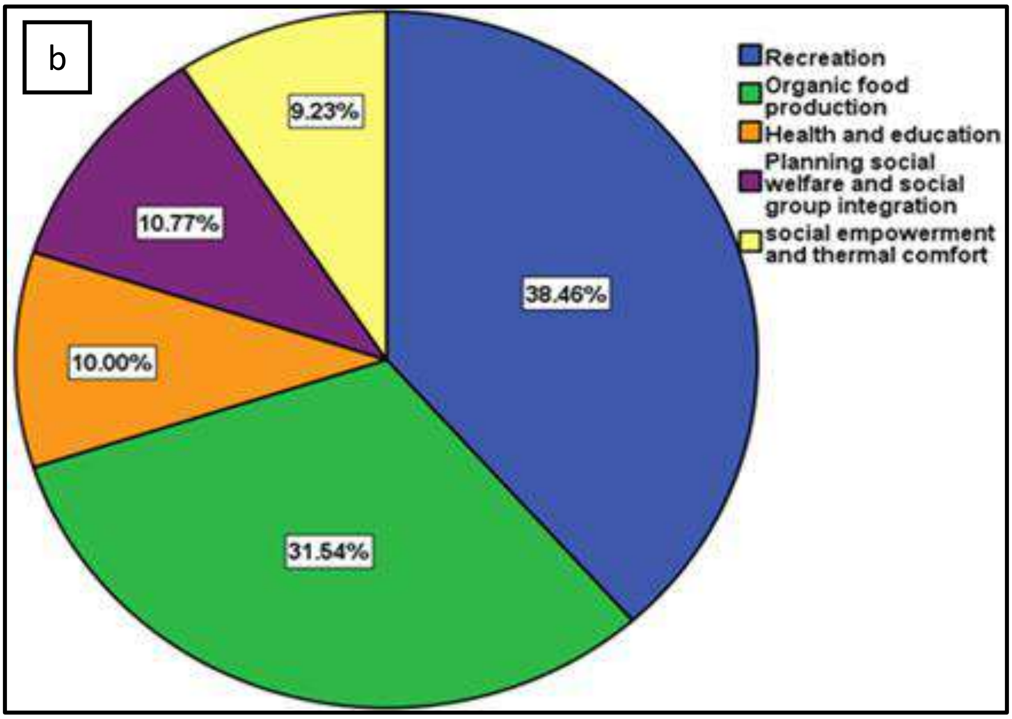
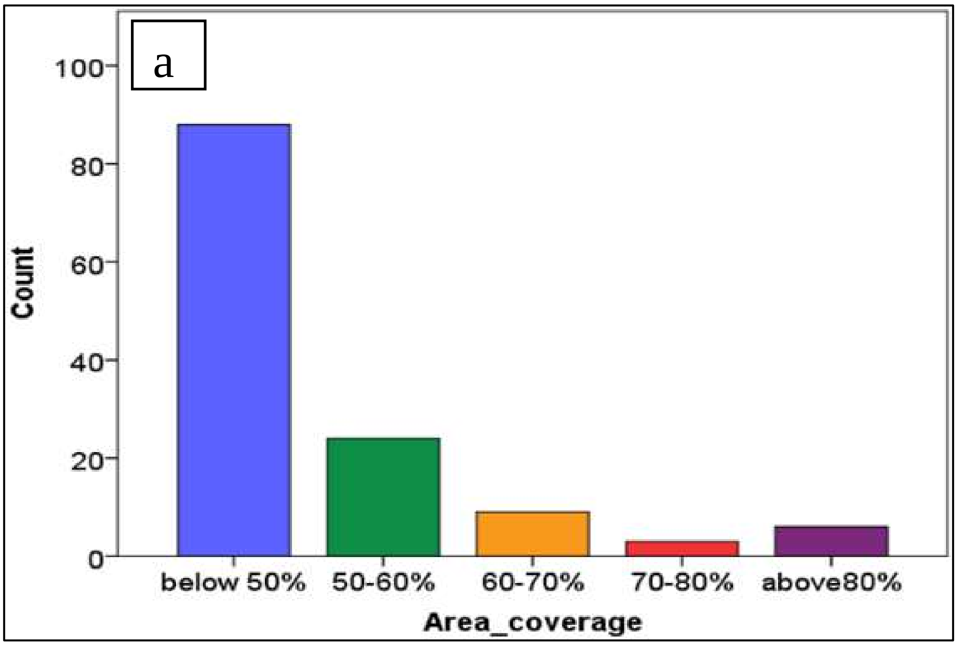


Figure 6. 71 City dwellers answer's percentage pie graph of widespread and reasons of URA

6.3.3 Barrier and complications of URTA implementation

An additional value of URA can be found in the inclusion of additional intentions than generating food, like work-leisure-time balance and social communities. Existing rooftop agriculture is individually too small [Figure 6.12 (a and b)] to be measured in the commercial indicator and occupants may not differentiate directly the degree of Improving health and education and social empowerment and thermal comfort in the urban areas when compared to nearby rural environment. Figure 6.12 (a, b) represents the present green area coverage of the roof by agriculture and type of problems is faced by URA implemented groups. It is observed 68% roofs are covered below 50% by URA, 19%, 8%, 4% and 1% roofs are covered by URA as 50-60%, 60-70%,70-80% and above 80% respectively. We also analysis the problem faced by URA owner in different groups on a scale from purely social interests as well most sensitive answer at the same question. The answers analysis allows grouping a set of objects to answers that are homogenous with each other. The average percentage of these answers' groups were found as owner of the flats members and building owners are not positive minded (16.13%), operation and maintenance of URA is difficult (38.46%), initial cost of URA is high (23.08%) and daily watering (22.31%). So, we found that each answer is depending on whether they implemented URA themselves. We also found that the owner of the buildings also answered that if they used up all these barriers, URA would contrivance not only the self-supply values but also commercial interest. And so, green roofs or rooftop agriculture also can create sustainable interactive community space where flat members or relatives can visit, and relax together to make themselves cheerier by enhancing the expressive comfort.



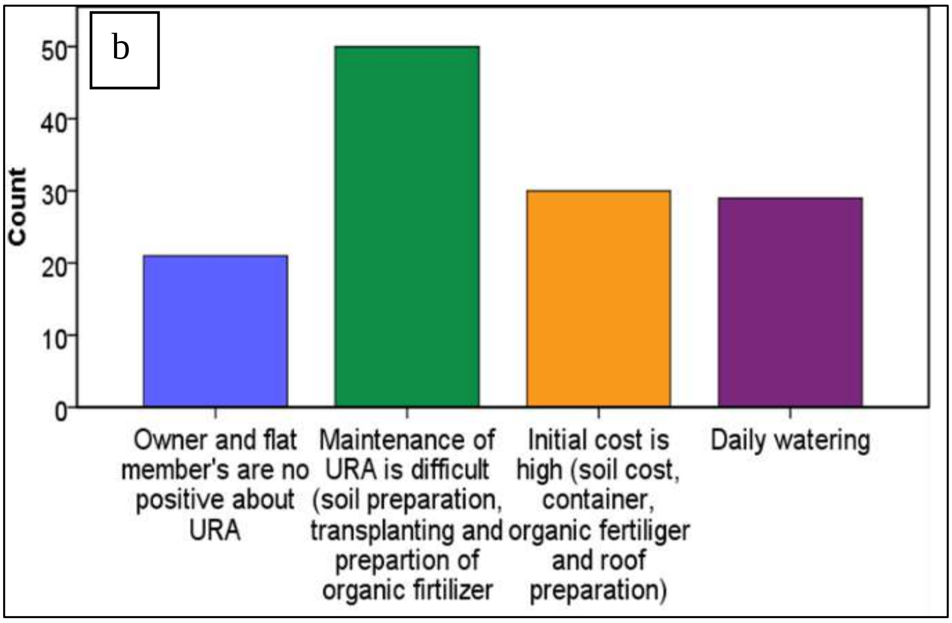


Figure 6. 12 Bar diagrams of (a) Roof area covered by existing URTA and (b) barrier to implementation of URA

6.3.4 The Empowerment and Commercial aspects of URTA

Commercial changing aspects of URTA refer to the procedure of produced goods for financial benefits. The goods produced are sold to the market. In order to achieve financial success, they need to meet the demand of the local population. URTA can fill gaps in niche markets like direct marketing in the city that is independent from carbon intensive transport systems and fulfills the basic ideas of sustainability. It can also refer to specific goods like different vegetables, fruits, flowers and any other crops that were produced in the city or food that is directly processed and served within city dwellers. Women wage earners from URTA also greatly value their employment. Data and information from the field survey and experimental URTA, it is shown that women in commercial agriculture are needed to both inform current interventions and build knowledge to improve future practice through URTA related training or workshop which would operate by government organization and also private companies and business or large institutions located on their own sites. So, investments and proper carrying of URTA can raise incomes and overall economic growths are essential for longer-term food security and improved well-being. However, it is obligatory to move from rooftop gardeners into commercial and high-value URTA where, owner of URTA may be competitive in wider regional and global agricultural markets. Commercial agriculture can include both staple crops and high-value products such as vegetables, fruits, medicine plant, nuts and non-food products such as flowers and ornamental plants with the help of efficient irrigation method and sustainable growing medium. On the other hand, from Figure 6.13 represents that rooftop owners or respondent are using the growing medium as pot of mud, plastic drum and permanent structure (31.54%), pot mud, plastic drum, bag, oil bottle and permanent structure (20.77%), Plastic drum and permanent structure (17.69%), pot of mud and plastic drum (8.5%) and permanent structure (2.3%) in their rooftop agriculture to carry the soil and plants. The less percentage (only 2.3%) of permanent structure is found mainly due to the high initial investment costs. Therefore, growing medium is the very essential element to expand the URTA into the commercial purposes that can be settled during the building construction according to the types of plants, satisfies building codes and safety requirements.

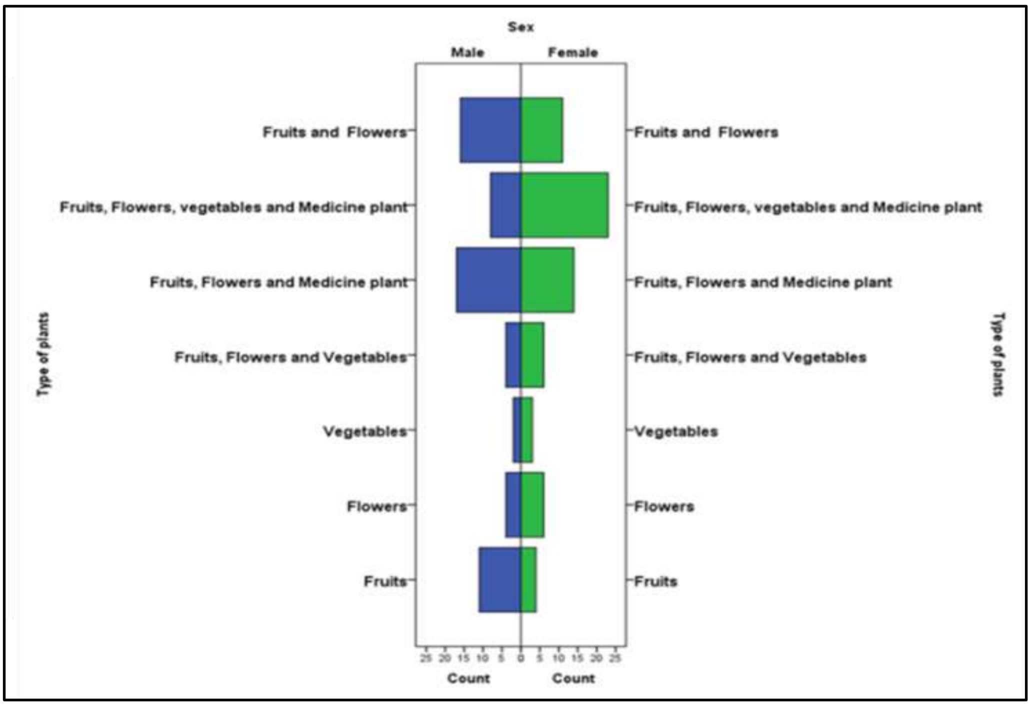


Figure 6. 13 Typology of existing URTA based on cultivation according to men and women

The longer material input in the construction makes them more expensive to build. In addition to higher initial construction costs, the materials of the URTA such as the pot of mud, jute's bag, bottle and plastic drum have shorter life spans compare to permanent structure and therefore need to be replaced more frequently. This is important because of affecting the crop yields. From the experiment it found that container size and depth is also very crucial issue for crop production and crop yields and varies crop to crop. It has been also found that if container depth and width will consider according to maximum root zone depth, soil will be saved by 57.14 % and yield will be increased by 20%-31%. However, access to the URTA is broadly widespread to residential buildings or individual URTA was very small-scale and only found as a hobby or recreation purposes where economic interests lead to in self-supply. Their form was typically more complex and less well-organized. That's why in the case of residential roofs, the roles of women are to achieving household food security, nutrition and growing markets for food and agricultural product as well as women empowerment will be achieved by URTA. URTA is also implementing through employees or institutional members through governments or non-governments project or plan but it is also very small-scale and only found on residential buildings not in the office buildings or institutional buildings. They are also similar in physical form and nature to social enterprise agriculture and are also competent to creating a job for employees with monthly fees due to carrying the plants and URTA related all activities. On the other hand, it has been also observed that women are showing higher levels of trust in organic processes of food production in URTA and all owner behavior show that they have an also positive opinion of organic food and some are willing to pay for healthier food. Therefore, in the case of URTA higher prices of the locally produced organic vegetables like, Tomato, Brinjal, Bottle Gourd, Chili, Bean, Spinach, Reed Spinach, Water Spinach, Green Spinach and related vegetables can be considered, supposing a short supply chain where the end user buys the produce directly from the owner of URTA, allowing a larger profit margin for the latter, and have an enlightened economic possibility of such a system.

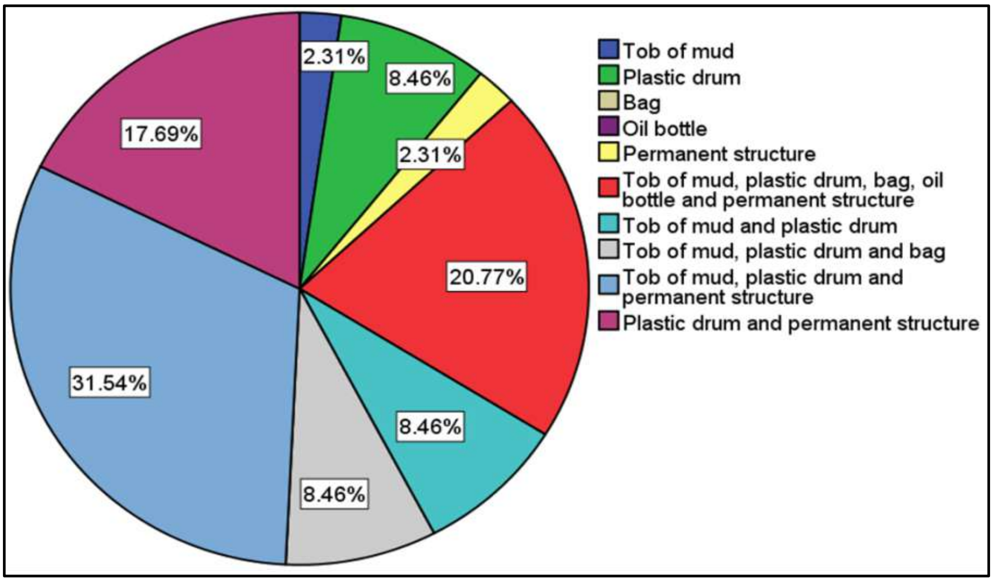


Figure 6. 8 Categories of growing medium or container in the existing URTA

6.4 Summary

This study aimed at observing the impacts of URTA on microclimate change and socioeconomic dimensions in the urban areas. The output of this study represents the stage for the holistic assessment of alternative solutions, integrating environmental and socioeconomic dimensions and putting URTA into perspective by comparing it to alternative uses of roofs as vacant urban space. The findings of this work reveal that the maximum temperature differences between the ARs and the nearest BRs were 0.45 °C to 5.5 °C during the summer season. It was found that 60–85% roof area covered by URTA were equally and highly effective for air temperature reduction compared to 50% or below roof area covered by URTA (maximum 1 °C to 1.8 °C). From the temperature differences analysis it was exposed that during the month of March in 85%, 80%, 70%, 60%, 50% and 40% rooftop agriculture, the mean temperature difference was by 4.76°C, 4.29°C, 3.37°C, 2.19°C 0C, 1.18°C and .41°C respectively. Similarly the mean temperature difference in April and May of those selected green roofs and bare roofs are found from histogram as 4.76°C, 4.29°C, 3.37°C, 2.19°C, 1.18°C and .41°C respectively and 4.41°C 3.51°C, 3.42°C, 1.85°C, 1.00°C and 0 °C C respectively. The minimum and maximum temperature difference of those selected roofs and bare roofs were also recoded as 3°C & 6°C, 2.10°C & 7.20°C , 2°C & 6.5°C, 1°C & 3°C, 0.1°C & 1.8°C and -1°C &1°C respectively. So, It is experiential that 50% and 40% area coverage URTA obtained a lower temperature reduction; recording a maximum of 1.8°C & 1°C and minimum .1°C & -.1°C at 1.30pm during the month of March to May respectively. 85%, 80%, 70% and 60% URA were equally and highly effective on air temperature reduction compared to 50%, 40% area coverage URA roofs and bare roofs at most hottest time over the day during the summer season. However, the most noticeable difference is shown by the 85% area coverage green roof, which maintains its temperature variances and standard deviation as .34°C and .58°C compare other selected roofs. Thus, the temperature difference should vary on percentage of area covered by rooftop agriculture persists during the day at 1.30 pm. The temperature reduction in green roofs indicated comparative temperature profiles and highpoint time while the temperature discrepancy among the different types URA roofs were acknowledged more evidently at 1.30 pm.

The relative humidity was increased by a minimum of 5% and a maximum of 10% in the ARs compared to the BRs. The results of this study also revealed that ARs were effective in reducing heat flow through the roof. Thus, the energy demand for cooling load in the top floor of the building was lowered. The URTA could achieve a saving of 3.62 to 32.28% the peak cooling load. It resulted in 5.87 to 59.45% energy saving with financial benefits compare to the adjacent BR. The increases in area coverage of URTA led to the decrease of the daily peak cooling load. It enhanced energy-saving significantly. The energy-saving fluctuated with ARs with the vegetated area, soil layer coverage and leaf area indices of plants.

It has also been found that URTA is mostly female friendly with the age group of 40–50 year. URTA becomes elderly male sensitive with the age group of over 60 years. It indicates that retired males are mostly involved with URTA. Economic sustainability of URTA depends on yields and prices. In this study, at a 12% discount rate, NPV becomes positive at the end of the fifth year, resulting in more cash inflow. URTA is an economically accountable process with financial benefits of yearly energy savings of 19.81%. Annual job creation is 29.84%, enhanced air quality advantage is 5.16% and the annual mitigation of heat island effect is 14.43%. So, the commercial dynamics of URTA refer to achieving financial success according to the demand of the local population. Investments and proper carrying of URTA can raise incomes and produce overall economic growths for longer-term food security and improved well-being. URTA also can provide sustainable, interactive community spaces for flat members or relatives and can enjoy health benefits through recreation and relaxation. URTA brings the unusable space into productive spaces and increases the property value of the building. It plays an important role in addressing a different range of micro-environmental challenges through adaptations.

URTA can play significant roles in producing fresh and affordable vegetables, enhancing cooling load and saving energy, improving urban micro-climatology through reduction of roof temperature and increasing the relative humidity and creating empowerment. The findings of this study may inspire urban planners and decision makers to recognize that URTA can provide measurable benefits both to the city dwellers and to the community to attain environmental and socioeconomic benefits in comparison to traditional urban roof uses.

Chapter 7

PERFORMANCE OF WATER SAVINGS IRRIGATION APPROACHES IN URBAN ROOFTOP AGRICUlTURE

7.1 Introduction

The Urbanization and population growth have been created in urban areas with a substantial concrete surface than adjacent rural areas facing the challenges of fresh food, water security, and agricultural land. Climate change stimulus's the rainfall in urban areas which affects ground water and the urban rooftop agriculture to cultivate different species of plants. For this aspect, fresh production and efficient water use management are today's major concerns to properly manage the roofs, open space, and water resources in an urban area. However, in urban areas, the gradual growth of private rooftop agriculture (URTA) is increasing through the owners of the building, do it out of a hobby or recreational purposes only without considering the efficient water management techniques and water productivity.

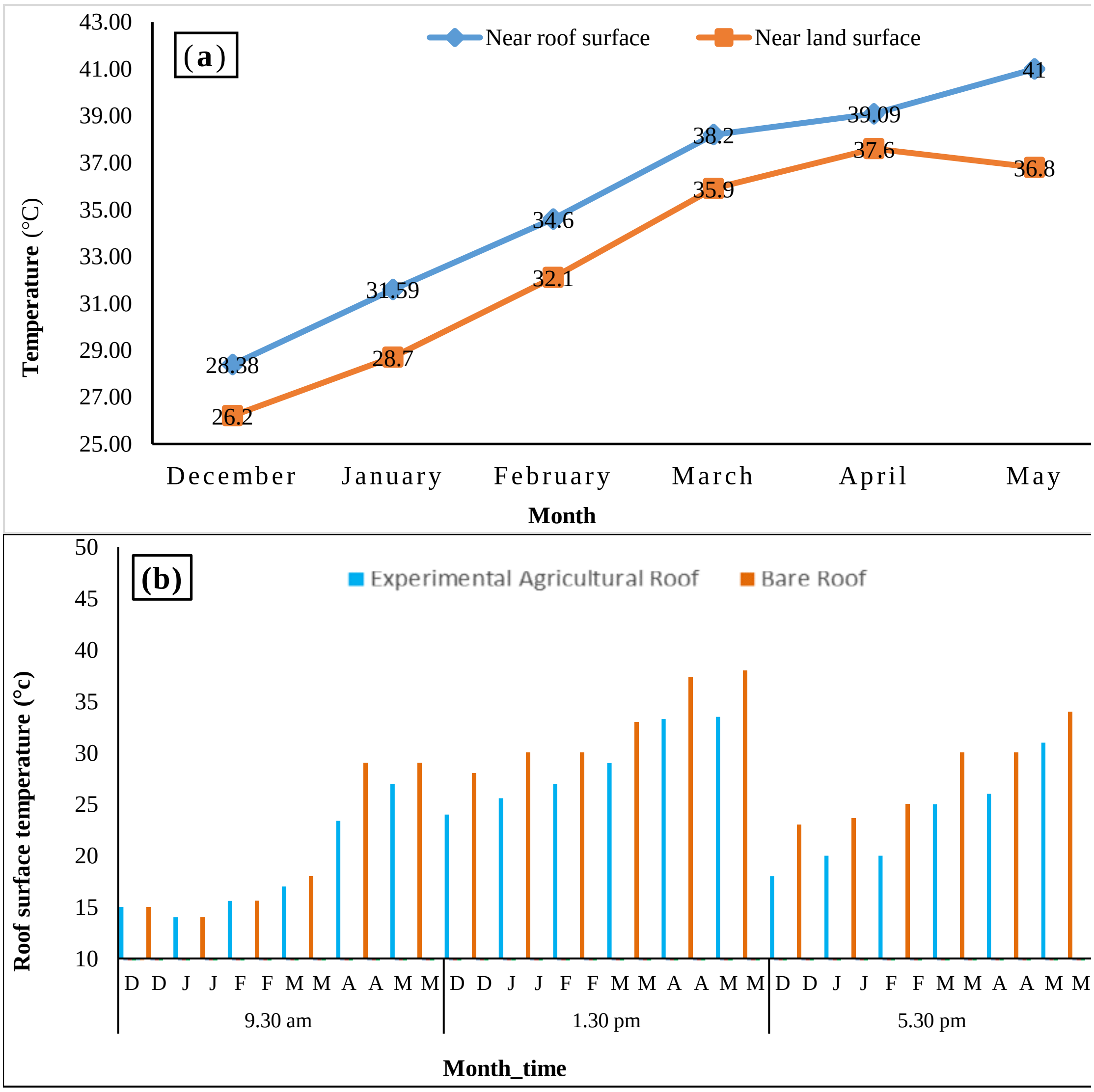
Dynamics of URTA as well as represents the significant roles of URTA in producing fresh and affordable vegetables, enhancing cooling load and saving energy, improving urban microclimatology like roof temperature reduction or relative humidity increase, and creating empowerment. The finding of this study may inspire urban planners and decision-makers to recognize that URTA can provide measurable benefits both to the city dwellers and the community to attain environmental and socio-economic benefits in a city compared to the traditional roof. URTA brings the unusable space into productive spaces and increases the property value of the building. It plays an important role in addressing a different range of micro-environmental challenges adaptation and energy saving on the top floor of the building envelope at the national and global level. This study also found that (chapter 6) in Dhaka city, the gradual growth of personal rooftop gardens is increasing through the sole owners of the buildings and there are some knowledge gaps on water requirements and efficient water management in the URTA. That's why URTA needs efficient water resource management supported like water saving drip irrigation technology to crop production without any stress or strain or over watering of plants. However, irrigation is an important component of agricultural management where greater production of food and fiber is required despite severe constraints of water resources. Therefore, crop water productivity and soil moisture dynamics in the URTA is a very crucial issue to increase the commercial value of URTA. With this aspect, in this chapter, the performance of an effective, efficient, and economically viable smart irrigation method drip irrigation system is considered for the cultivation and determination of water productivity of selected crops like Bottle gourd, Tomato, Chili, and Brinjal in the URTA. That's why groundwater and gray water harvesting were considered the source of irrigation water during the dry season. The questionnaire survey of existing rooftop gardens was also considered to observe the irrigation system in the existing URTA. The detail description of the data and the methodology can be found in Chapter 3 and Chapter 4, respectively.

7.2 Soil Physical Characteristics in URTA

According to the laboratory test and USDA soil textural classification, it was found that soil was silt loam and highly acidic (pH range is 5.5). The average sand, silt, and clay contents of the soil were found to be sand 9%, silt 78%, and clay 13%. It was also found that only 0.07% organic matter was obtainable in the soil. From the laboratory results, it has observed that the primary nutrients' (such as N, P, and K) available values were 1.40%, 78.93 µg/g (ppm), and 1.32 meq/100 g, respectively. The test result characterizes a lower amount of nitrogen presented in the soil, phosphorous values as very high and potassium values as also very high. The secondary nutrients such as Calcium (Ca), Magnesium (Mg), Sulphur (S), Boron (B), Copper (C), Iron (I), Manganese (Mn), Zink, etc., values were adequate in the soil and all of this range was very high (BARI, Fertilizer recommendation guide). The values of secondary nutrients were found to be 7.32 meq/100 g, 7.00 meq/100 g, 143.89 µg/g (ppm), 0.77 µg/g (ppm), 2.28 µg/g (ppm), 45.16 µg/g (ppm), 13.29 µg/g (ppm) and 4.47 µg/g (ppm), respectively. From the above result, the study found that the soil's physical properties depend on soil preparation as well as soil texture for rooftop agriculture and on the micro-climatic conditions of the roof [298]. Initial soil properties that were collected from the field for cultivation had a very low organic matter (0.07%) and the field capacity and permanent wilting point of the soil were only 25.2% and 19%, respectively. After mixing cocoa dust, compost, and dye ammonium phosphate and calcium carbonate (soil: cocoa dust: vermicompost = 2:1:1) the field capacity and permanent wilting point were found to be 33.58% and 19.80% on a volume basis, and were suitable for agriculture. Furthermore, it was also found that the prepared soil's bulk density was 1.04 gm/cm3.

7.3 Temperature in URTA under Drip Irrigation and Bare Roof without Irrigation Approach

Due to a higher near roof surface temperature [Figure 7.1 a,b] and sunshine hours on the roof compared land, access irrigation was required in URTA. The study found that URTA reduced air temperature and roof surface temperature by 1.2 °C to 5.21 °C and 3 °C to 12 °C, respectively, compared to the nearby bare roof [Figure 7.1 b,c]. From Figure 4, it is clearly observed that the variability of the air and roof surface temperature was lower on the agricultural roof than on bare roofs and also higher than on land during the period December 2018 to May 2019. It har been cleared that temperature (roof and air) on roofs significantly varied at 1:30 pm compared with 9:30 am due to irrigation, shadow-shading effect or the higher leaf density of plants on the agricultural roof.



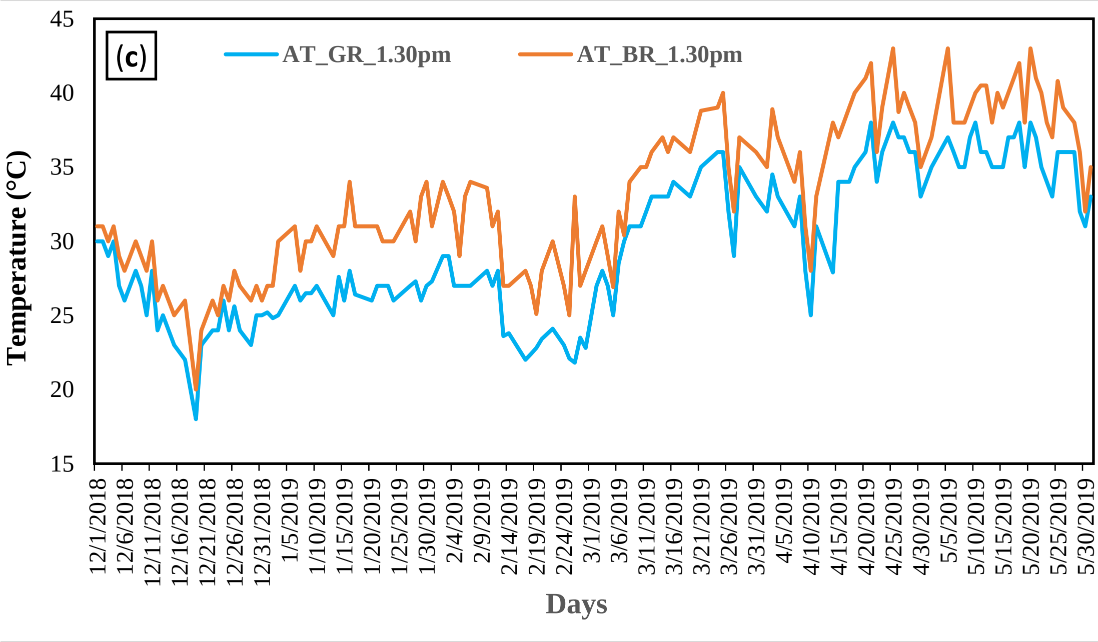


Figure 7. 1(**a**) Average near roof surface temperature and near land temperature variation; (**b**) Roof surface temperature variation in experimental agricultural roof and bare roof; (**c**) Air temperature variation at 1.5 m height in agricultural roof and bare roof from December 2018 to May 2019.

7.4 Irrigation Water Requirement of Tomato, Bringal, Chili and Bottle Gourd in URTA under Drip Irrigation and Traditional Irrigation Approach

The study found that due to high temperature, BARI Tomato-3 needed a total of 727 mm, 1345 mm, and 2016 mm of water for irrigation in URTA with the drip irrigation technique, traditional irrigation with container and pipe, respectively (Table-4.4). In this research, it has been found that the root zone depth of Tomato varied from 16 cm to 20 cm. The results revealed that the optimum irrigation water requirement for Tomato was around 54% excess of ETc. Based on this, the actual irrigation water for the Tomato crop in URTA could be recommended as between 76 mm to 290 mm/stage. It has also found that BARI Tomato-3 needs 76 mm, 125 mm, 236 mm, and 290 mm irrigation water at the initial stage, vegetation stage, flowering stage, and ripening stage, respectively, in URTA and depends. Figure 7.2 shows that applied water was high during the flowering stage and ripening stage of the development of plant parts and for flowers and fruits [312]. However, due to regular irrigation with mug, bottle or bucket, pipe or pipe with shower, a total of 46–64% excess irrigation water was used by the traditional method. The traditional irrigation requirement for BARI Tomato-3 is 95 mm to145 mm, 180 mm to 350 mm, 320 mm to 520 mm and 750 mm to 1000 mm at the initial stage, vegetation stage, flowering stage, and ripening stage, respectively, in URTA. However, it was exposed that for Tomato production in URTA, drip irrigation techniques save 46% and 64% of irrigation water compared to containers, and pipe and pipe with shower irrigation. On the other hand, it was also observed that the maximum reference evapotranspiration for BARI Tomato-3, BARI Bottle gourd-3, BARI Brinjal-8, and Bogra Local Chili over the crop growth period in the winter season with URTA were 6.41 mm day-1, while the minimum value was 2.58 mm day-1. A higher value of ETo during the latter crop growth period was due to a higher temperature, low relative humidity, higher sunshine hours, and greater wind speed. Similarly, BARI Bottle Gourd-3, BARI Brinjal-8 and Bogra Local Chili also need a total of 1093.45 mm, 1053 mm and 790 mm irrigation water for cultivation in URTA with the drip irrigation technique. It has also been found that total days for the growth stages of these crops were 120, 192 and 202 days, respectively. However, Figure 7.2 also reveals that in the case of the traditional irrigation system, BARI Bottle Gourd-3, BARI Brinjal-8 and Local Chili need 2460 mm (with container) to 4408 mm (with pipe), 1500 mm (with container) to 2430 mm (with pipe) and 1148 mm (with container) to 1875 mm (with pipe) depth of water for cultivation in URTA. From Figure 7.2, it can also be seen that the traditional irrigation water requirement for the BARI Bottle gourd-3, BARI Brinjal-8 and Local Chili is around 56% to 75%, 30% to 57% and 31% to 57% more than that for the drip irrigation technique. The effect of depth of water application with excess water was that the crop growth suffered, leading to decrease in yield and irrigation water productivity. The study was also conducted for the summer season for BARI Bottle Gourd-4 and BARI Tomato-4 and observed that these crops needed a total 511 mm, 721 mm, 945 mm and 1013 mm, 1246 mm, 1579 mm with drip irrigation, traditional container irrigation and traditional pipe irrigation, respectively. It has been found that the summer season needs 42.11% less irrigation for Tomato and 8% less irrigation for Bottle gourd compared to the total irrigation water requirement in the winter season. The study also found that Bottle Gourd required more irrigation than other crops such as Tomato, Brinjal and Chili in URTA for both traditional and drip irrigation methods. Furthermore, it has been also found that Bottle Gourd cultivation was more temperature sensitive and irrigation water productivity of Bottle Gourd was more responsive to regular irrigation at the flowering stage than at other stages. This study also observed that local Chili is more sensitive on excess irrigation and less irrigation is required due to rainfall during ripening stage. That’s why at the ripening stage Chili crop’s total irrigation water requirement was less compare to the others crops in the URTA. So, practice of proper water management primes not only saving valuable water but also increases crop water productivity.

Therefore, all the crops need frequent and regular irrigation at field capacity in URTA to increase crop water productivity [313]. Conversely, Figure 7.2 demonstrated water savings by drip irrigation compared to traditional irrigation and it has been clearly observed that, as a replacement for traditional irrigation, the drip irrigation technique saves 30–79% water in URTA [Figure 7.3].

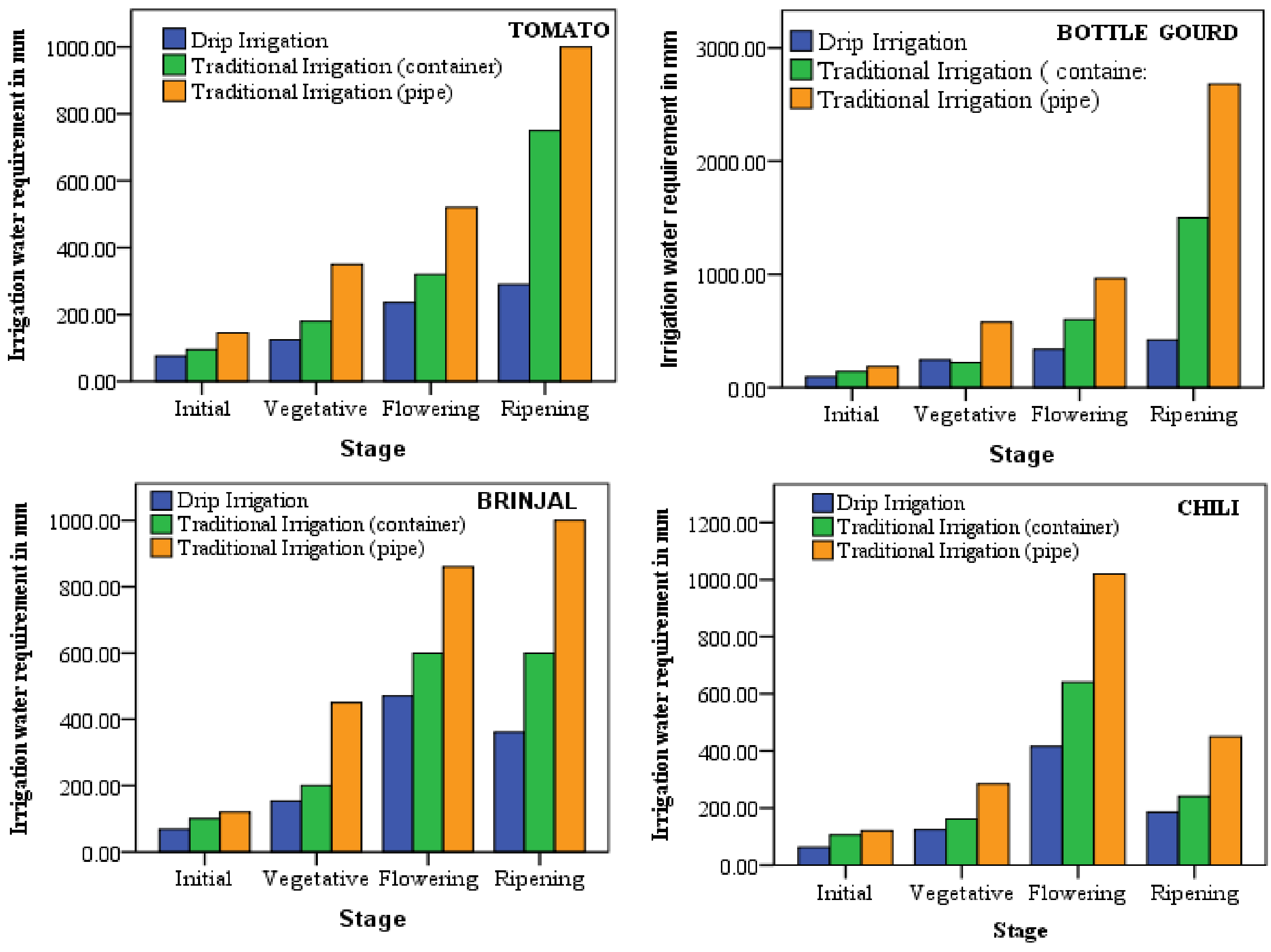


Figure 7. 2 Irrigation water requirement at different stages of Bottle gourd, Tomato, Brinjal and Chili with drip irrigation and traditional irrigation (container, pipe with shower).

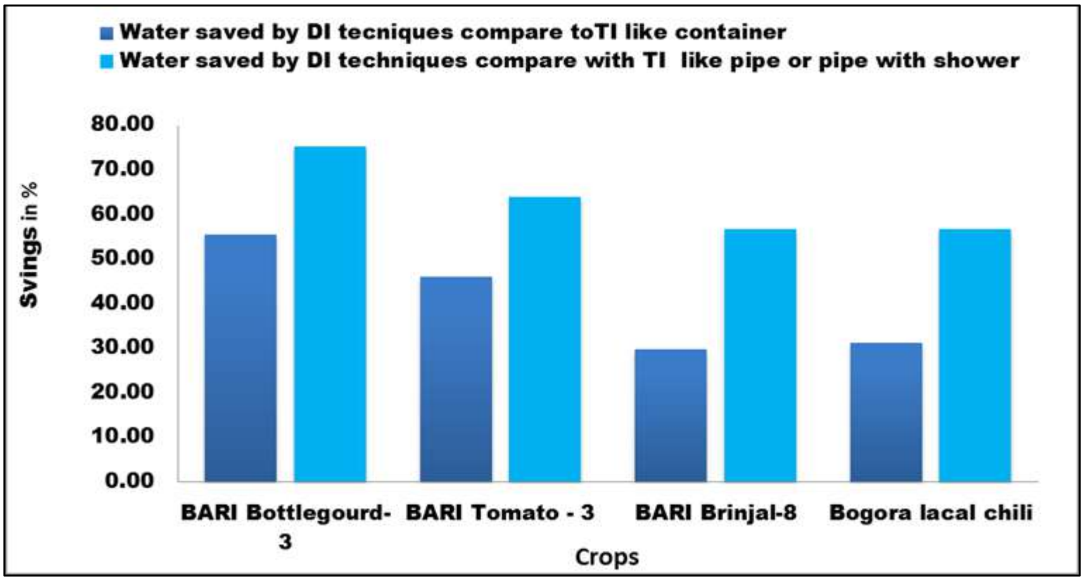


Figure 7. 3 Percentage of water-saving compared to traditional irrigation approaches.

The study also found in the second-year experiment that 18.78% irrigation water was saved through using a growing medium or container according to maximum root zone depth and soil texture, especially organic matter of the soil. The size and shape of BARI Tomato-3 and BARI Brinjal-8 were also similar during application of both groundwater and green water through drip irrigation techniques.

7.5 Moisture Content variation in the growing medium under Drip Irrigation and Traditional Irrigation Approach

Figure 7.4 shows the assessment of soil moisture (SM) under URTA during the first-year winter irrigation research season measured by soil moisture data logger before and after, (a) in the DI system and (b) in the TI approach. The results showed that soil moisture increased after completion of irrigation. The soil moisture after irrigation in the DI system was less than TI due to the direct water application in the soil as a result of closer proximity to the water emission point. Soil moisture increased immediately after irrigation by up to 29% in the DI system and up to 50% for the TI system of volumetric water content. Figures 7a, b also denotes that in the TI system on average soil moisture was higher by 10% and 23% in comparison to the DI system before and after irrigation [300]. Average soil water content was a relatively low (29%) in the DI system. This indicated that water lost in the TI system is significantly much higher than in the DI system. For this reason, in the DI system, soil moisture is readily available and plants can uptake it easily [316].

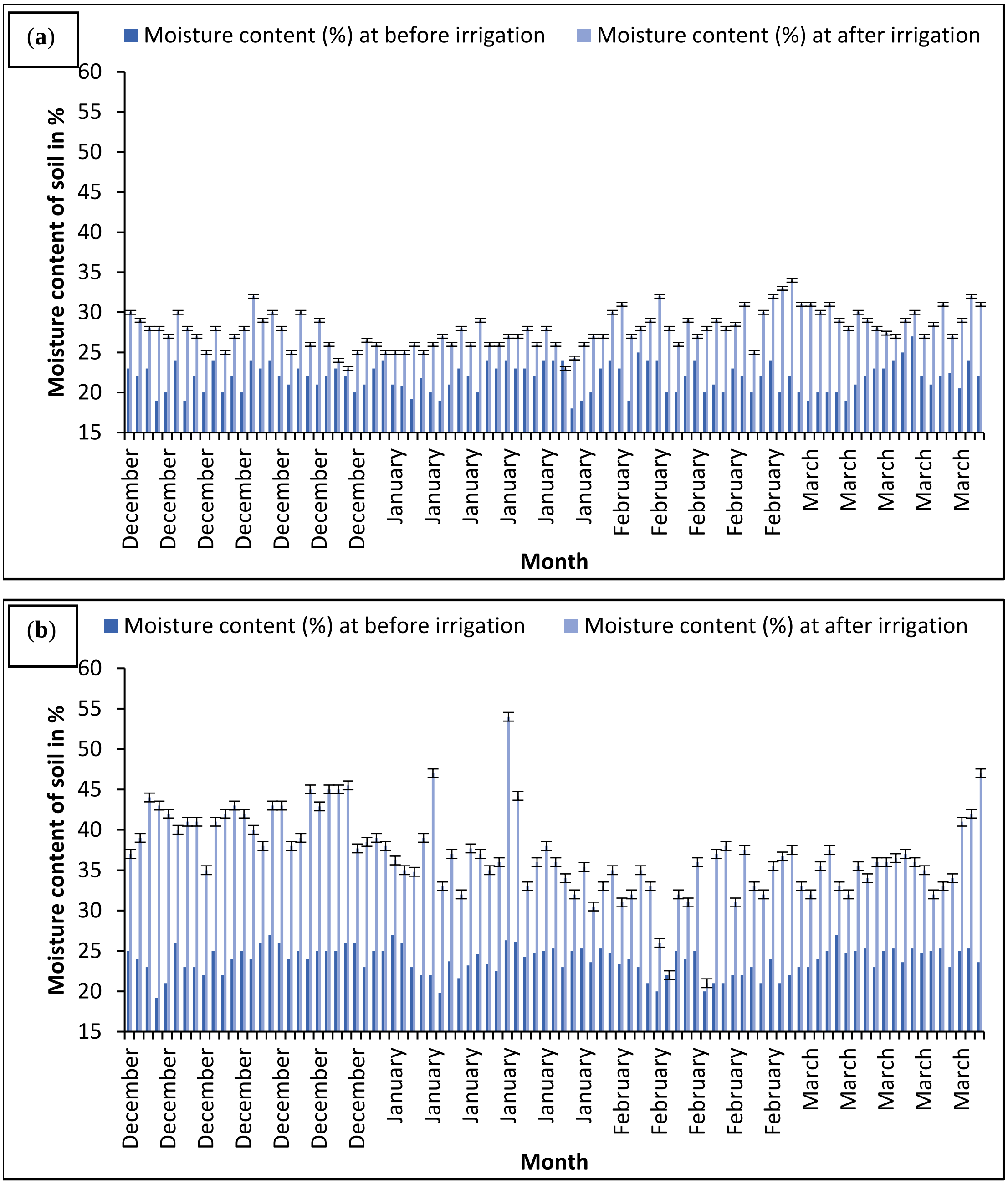


Figure 7. 4 Moisture content (%) at 15 cm depth before and after irrigation: (**a**) Drip irrigation (**b**) Traditional Irrigation.

It can be concluded that in the DI system soil moisture distribution occurs around the active root zone of crops and evaporation loss is minimum during irrigation with the DI system [317]. The maximum root zone depths of the selected crops were also observed during the entire experimental period for both DI and TI systems. The maximum root zone system is a very small response to the irrigation system. It was assessed for two irrigation systems (DI and TI) for the entire period of the study for the selected crops. The maximum root-length intensity of the plants was influenced by the irrigation system. It was found that for all crops most of the root system was concentrated at a soil depth of 40 cm of the container, and the maximum rootzone depth was found within 25 cm of the container (Figure 8) for drip irrigation and 35 cm for the traditional irrigation approach (container and hose pipe). On the other hand, the maximum root-length range was also found from 0.5 m to1.55 m, remaining in the soil inside the container

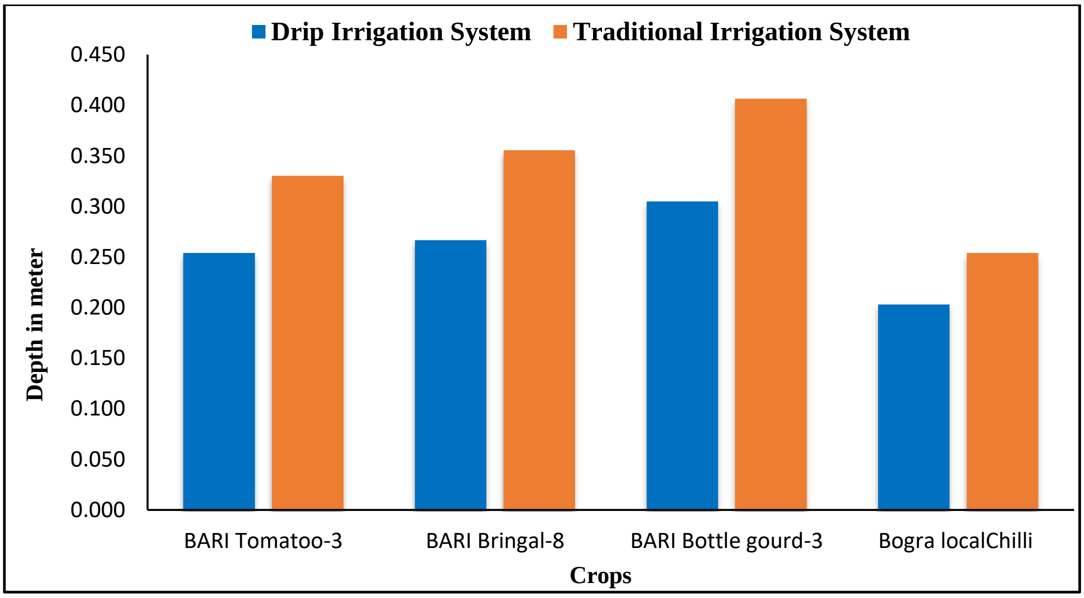


Figure 7. 5 Maximum rootzone depth of selected crops in URTA with drip irrigation and traditional irrigation.

7.6 Yield of Different Crops in URTA

Influences of the irrigation method, i.e., DI and TI, were analyzed considering the amount of irrigation water for the selected crops and their yields. From Figure 7.6, it is clearly visible that DI is successful in increasing yields for the crops. The drip-irrigated average seasonal yield for BARI Tomato-3, BARI Bottle Gourd-3, BARI Brinjal-8, and Bogra Red Chilies was found to be 2.35, 6.5, 2.1, and 0.65 kg/plant, respectively, for the winter season, whereas the BARI recommended marketable yield range per plant varies from 2–3 kg, 19–24 kg, 1.4–2.00 kg, and 0.7–0.75 kg, respectively. On the other hand, when irrigation was carried out in the traditional way the yields of these crops was found to be 1.92 kg, 1,8 kg, 3.5 kg, and 0.4 kg per plant, respectively. Similarly, in the summer season, the yields of BARI Tomato-4 and BARI Bottle Gourd-4 were found to be 0.85, 4.8, and 0.70, 4.5 kg /plant in drip irrigation and traditional irrigation method, respectively. The mean seasonal yield of BARI Tomato-3 and BARI Bottle Gourd-4 was found to be 0.85 kg/plant, 4.8 kg/plant, and 0.7 kg/plant, 4.5 kg/plant for the summer season experiment with drip and traditional irrigation method, respectively (Figure 7.6). Therefore, it was experimentally found that the yields of these crops were always higher with the DI system than with the traditional irrigation system for any season of the year (Figure 9). It was found that in URTA, the yield of BARI Bottle Gourd-3, BARI Tomato3, BARI Brinjal-8, Bogra Red Chili, BARI Tomato-4, and BARI Bottle Gourd-4 was increased through drip irrigation by 42.86%, 22.40%, 16.67% 62.50%, 21.43%, and 6.67%, respectively, compared to the container traditional irrigation. Similarly, the yield of these crops was increased by 44.44%, 18.69%, 23.53%, 62.50%, 25%, and 14.29%, respectively, compared to the pipe irrigation method. Pipe irrigation was carried out by applying groundwater.

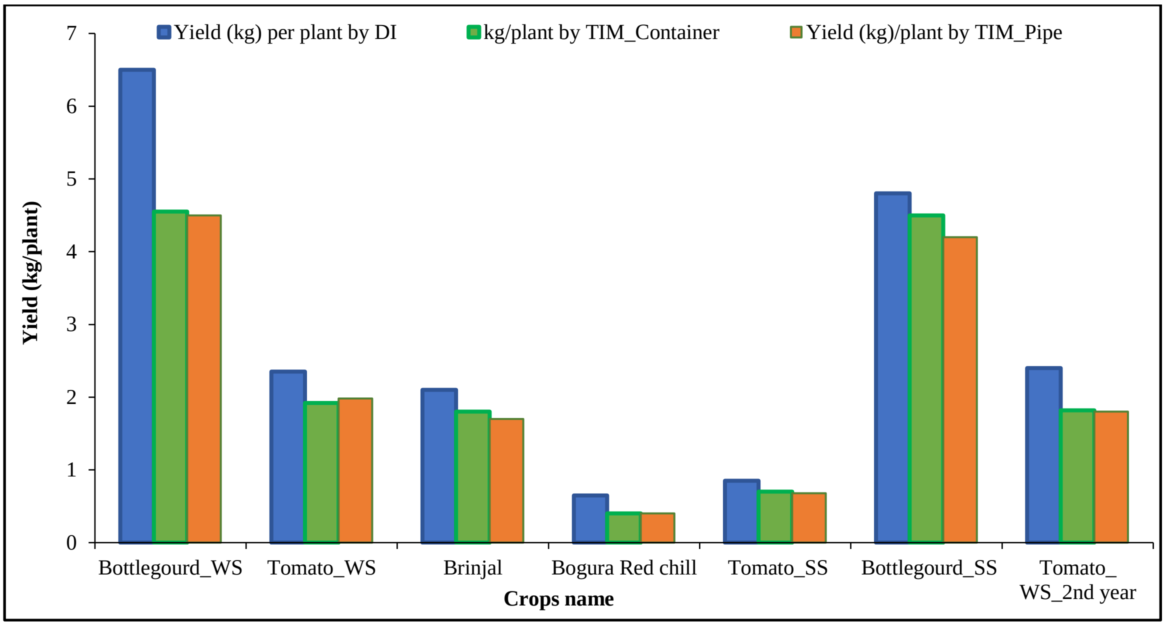


Figure 7. 6 Yield of selected crops in URTA during drip irrigation and traditional irrigation (container and pipe).

On the other hand, when rain and grey water were used in the irrigation, the yield of BARI Tomato-3 was very similar. Drip irrigation with rain and grey water also led to increased yield of BARI Tomato-3 by 31.87% and 33.33% compared to the container and traditional pipe irrigation. The differences in water use showed that the DI system improved the irrigation water use efficiency in comparison with a traditional irrigation system. The DI system has led to yield increase with the same irrigation water volume. This might be due to the efficient application of water according to crop water requirements. However, from Figure 7.6, it has also seen that yield of these crops is higher in the winter season than in the summer season.

7.7 Irrigation Water Productivity (IWP) in URTA

The study revealed that the average IWP of BARI Bottle Gourd-3 in the winter season (WS) in URTA is 0.59 kg plant−1 mm−1 for drip irrigation, 0.12 kg plant−1 mm−1 for traditional container irrigation and 0.14 to kg plant−1 mm−1 for traditional pipe irrigation. IWP of BARI Bottle Gourd-4 for the same treatments in the summer season (SS) was found to be 0.47 kg plant−1 mm−1, 0.36 kg plant−1 mm−1, 0.27 kg plant−1 mm−1. Similarly, IWP of BARI Tomato-3 for winter season with the same irrigation methods was 0.32 kg plant−1 mm−1, 0.12 kg plant−1 mm−1, and BARI Tomato-4 for the summer season was 0.17 kg plant−1 mm−1,0.1 kg plant−1 mm−1, 0.1 kg plant−1 mm−1, respectively. It has also been found that IWP for BARI Brinjal-8 and Bogra Red Chili is 0.2 kg plant−1 mm−1, 0.09 kg plant−1 mm−1, 0.08 kg plant−1 mm−1, 0.03 kg plant−1 mm−1, 0.02 kg plant−1 mm−1, respectively, for the drip irrigation method, traditional container, and pipe method. The IWP of a second-year experiment for BARI Tomato-3 was 0.39 kg plant−1 mm−1, 0.18 kg plant−1 mm−1 0.13 kg plant−1 mm−1 when grey and rainwater were used for irrigation. Therefore, the study exposed that the highest IWP in the first season was found for BARI Tomato-3 considering the area coverage and market price even though BARI Bottle Gourd was 0.59 kg. It has also been found from this research that grey and rainwater are more suitable for Tomato production and yield is increased by 21.88% compared to portable water. Figure 7.7 suggests that drip irrigation can achieve the maximum IWP for all selected crops compared to the traditional method. The results obtained in this study show that the IWP of BARI Tomato-3 can be increased with drip irrigation. The result indicates that watering is limited in conditions of drip irrigation, and reducing over-irrigation of crops could increase IWP by 305–391% for BARI Bottle Gourd, 116–166% BARI Tomato-3, 112% for BARI Brinjal-8, and 166% for Bogra Red Chili. However, drip irrigation will greatly increase the IWP and also increase the yield of these selected crops. For this reason, the actual irrigation is smaller than that traditionally planned. Furthermore, the Tomato, Bottle Gourd, Brinjal and Chili yields in that year were especially high due to applying drip irrigation according to the CWR and soil moisture on the basis of field capacity of the soil.

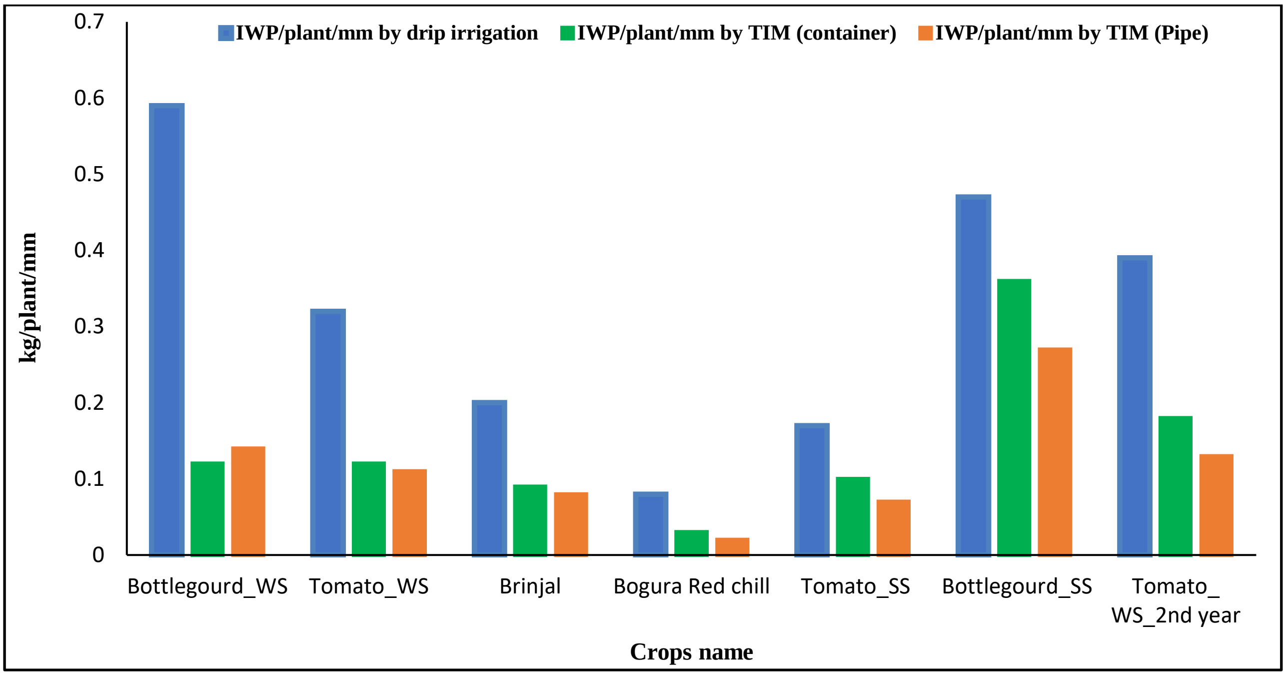


Figure 7. 7 Irrigation water productivity of selected crops in URTA with drip irrigation and traditional irrigation (container and pipe) method.

7.8 Irrigation Performance of Drip Irrigation System in URTA

In this study, a number of parameters are used to assess the performance of the drip irrigation system in URTA. The discharge, moisture content, distribution efficiency, application efficiency, field emission uniformity, emission uniformity, and absolute emission uniformity were considered to assess the performance of the drip irrigation system.

A P-P plot compared the expected discharge data set with a specified observed discharge data set of first, 1/3, 2/3 and last number of emitters. On the other hand, Q-Q plot compared the quantiles of emitter's observed moisture content data with the expected moisture content data. Figure 7.8 a represents a P–P plot (probability–probability plot) of discharge of first, 1/3, 2/3, and the last number of an emitter of each line. The figure also displays that the emitters' observed discharges are closely related to the expected discharge values which are statistically significant [59]. It has been found that the expected discharge is the same or near to the observed value. On the other hand, Q-Q (quantile-quantile) plots compared distributions by plotting their quantiles against each other. Figure 7.8 (b) represents the Q–Q plot of the moisture content probability plot, in which the resulting goodness of fit of the 45° line represents the difference between an observed and expected moisture content of soil and plant for the selected emitters in the URTA.

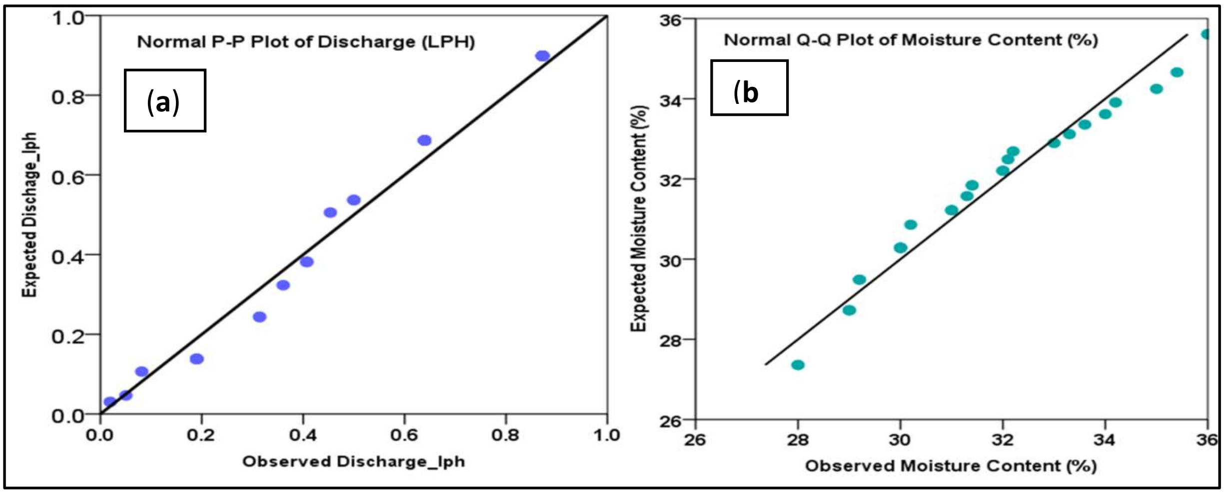


Figure 7. 8 (**a**) Normal P-P plot of observed and expected discharge (lph); (**b**) Normal Q-Q plot of observed and expected moisture content (%).

On the other hand, the one-way analysis of variance (ANOVA) has been used to determine the statistically significant differences between the means of discharge and moisture content of each emitter. Figure 7.9 denotes that moisture content is dependent on discharge and the line patterns in the points indicate that a higher discharge from the emitters contains a higher moisture content, but some container emitters did not maintain these patterns due to soil texture or sunshine direction. The study also found that the average moisture content of the first, 1/3, 2/3, and last emitter of each of the wight rows was 34.62%, 31.95%, 30.35%, and 25.535%, respectively, for the 1st year experimental setup and 34.84%, 32.56%, 32.20% and 31.78% for the 2nd year experimental setup. On the other hand, the average discharge of the first, 1/3, 2/3, and last number emitter of each of the 8 rows were 15 lph, 13.94 lph, 12.78 lph, and 12.32 lph for the 1st-year experimental setup.

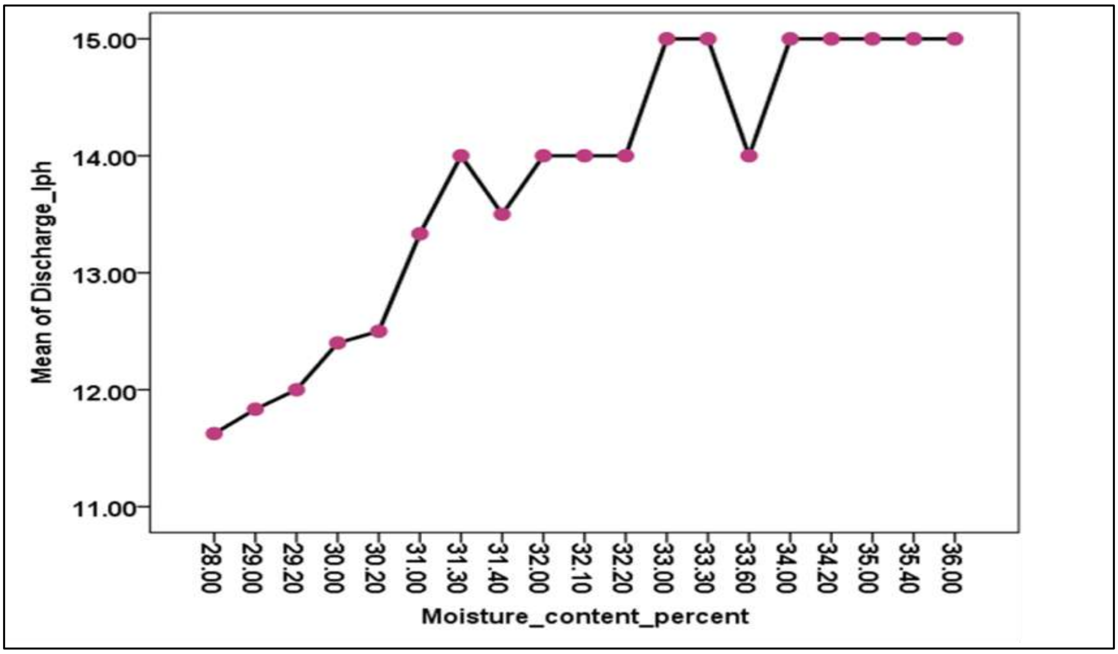


Figure 7. 9 One-way ANOVA mean discharge (lph) by moisture content (%).

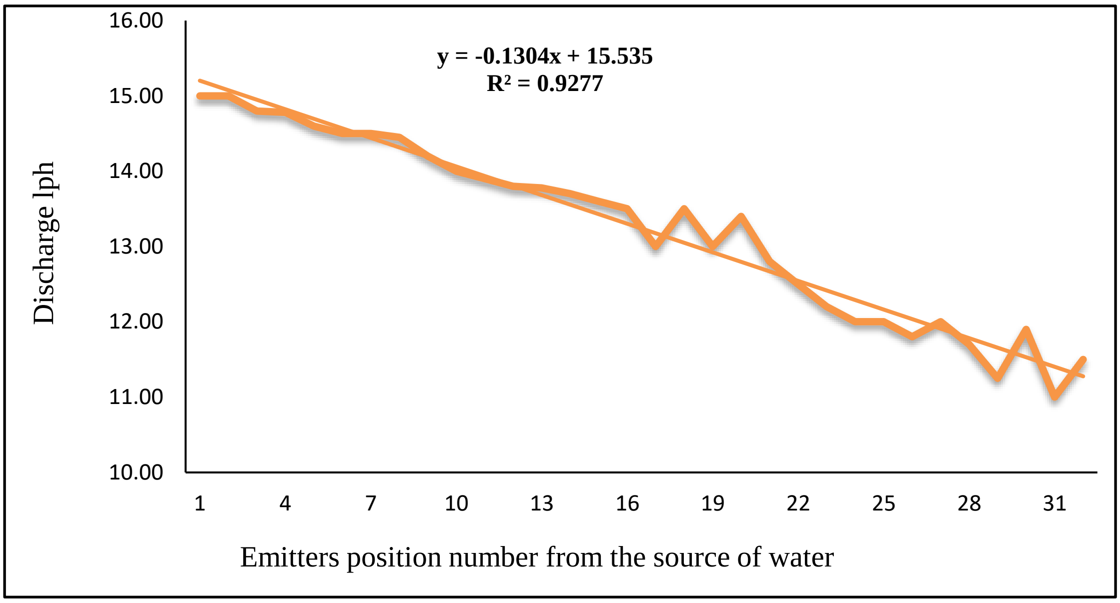


Figure 7. 10 Discharge variation of selected emitters of the drip irrigation system in URTA.

Figure 7.11 shows that the application efficiency of the drip irrigation system was 95.41% and 96% in the 1st and 2nd-year experimental setup. Distribution efficiency was 94.82% and 96% in the 1st year experiment and in the 2nd year experiment during the years 2018–2019 and 2019–2020, respectively. Similarly, the field emission uniformity values were 92.19% and 94% for the 1st year experiment and the 2nd year experiment during a similar year. Figure 7.11 also denotes that the absolute emission uniformity values of the emitter of the drip irrigation system in URTA were 89.94% and 91% for the1st year experiment and the 2nd year experiment during the years 2018–2019 and 2019–2020, respectively. Therefore, there are different performance parameters of drip irrigation system such as field emission uniformity (EU), design emission uniformity (EUd), and application efficiency (EUa and Ea) depends on the distance between emitter and source of water. In this study drip irrigation system has been installed with the restore of potable/green water source on roof where, distance from the source of water for the 2nd year experimental setup was nearer than the 1st year experimental setup. As per the above result, it has shown that the drip irrigation system operated excellently in URTA as the values of the EU were nearly equal or more than 90% in each case. A higher percentage indicates good performance of the drip irrigation system or acceptability for URTA. For the CV, the value was 0.094. This value indicates that the drip irrigation system showed average acceptance in URTA.

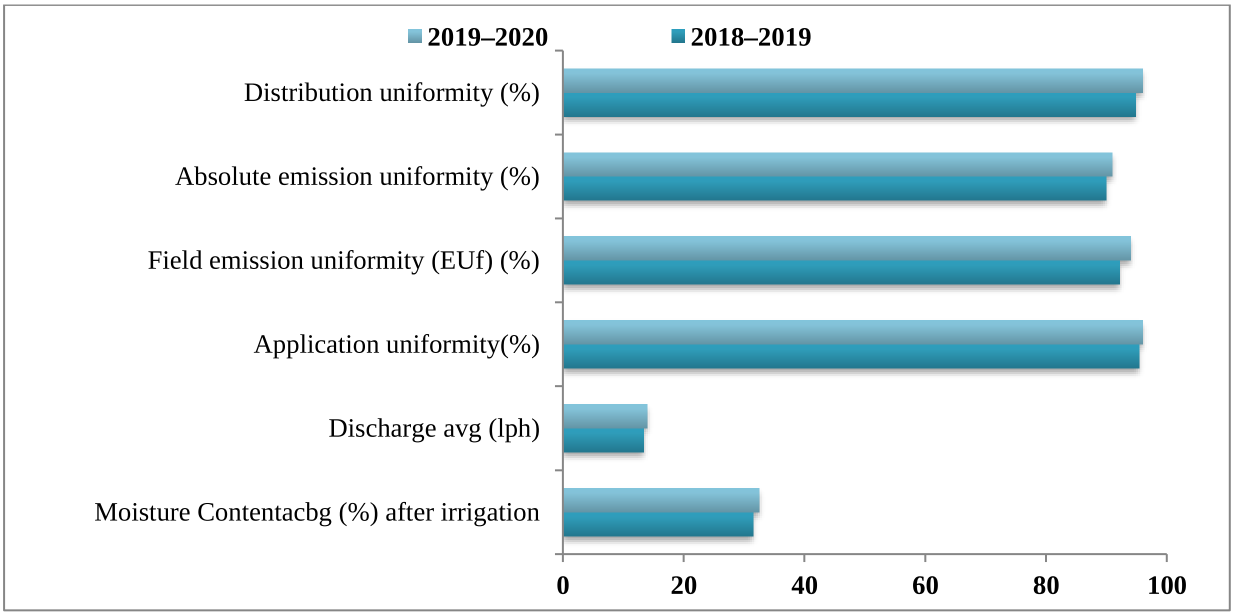


Figure 7. 11 Performance parameters of drip irrigation system.

7.9 Irrigation water requirement variation in URTA with land agriculture

The study has been demonstrated that roof surface, air temperature, and sun-intensity are the predominant factors controlling the response of soil properties to rooftop agriculture compare to the land agriculture. Irrigation water requirement 50 -55% higher than the land irrigation due to higher roof surface and near roof surface temperature. This study also observed that crop water requirement measurement through CROPWAT model, average minimum and maximum temperature of current roof weather was not work for water requirement in URTA. But if the minimum and maximum temperature considered at noon time, CROPWAT model the minimal difference was found between actual IWR for plants and CROPWAT model's IWR (Table 7.1]. On the other hand, the roof which has no obstacles such as shade of trees and buildings, irrigation water requirement for that RTA is high compare to the shady roofs. It has observed that at the time of 11 am to 3.30 pm soil become very dry at the lower and upper portion of container due to the higher roof surface and air temperature. As a result, irrigation water requirement in the URTA at the dry season that is for the month of January, February, and March is higher compare to the December, April and May and 2 times higher than the land cultivation.

Table 7. 1 Total Irrigation Water Requirement of Tomato using the BMD's weather data and current weather data of roof

Month	Rainfall (mm)	ETo (mm/day)	Duration	KC Value	Stage	ETc mm/stage	Depth of excess irrigation	Total IWR (mm)
November	20	3.71	Nov 19 to Dec 8	0.46	Initial	34.13	41.81	75.95
December	10	2.58	Dec 9 to Jan7	0.83	Vegetative	72.68	51.81	124.50
January	0	3.01	Jan 9 to Feb16	1.08	Flowering	95.67	140.44	236.11
February	45	3.61	Feb17 to March 13	0.86	Ripening	144.48	145.44	289.92
March	40	4.83		0.86				
Total						346.96	379.51	726.47

Note: Kc value has been considered according to BARI

7.10 Potable irrigation water savings using greywater in URTA

The study observed that greywater and rainwater were suitable for URTA to cultivate Tomatoes. Furthermore, there were no significant effects of greywater irrigation on plant, and yield. On the other hand, due to high roof surface temperature and air temperature in the roof, URTA required regular irrigation. Irrigation water quality of greywater and rainwater were analyzed for a wide range of chemical variables. Results suggest that the irrigation water quality of grey water (shower water) and rainwater was within the acceptable limit of standard range of irrigation water quality and therefore does not need extensive treatment beyond addressing plant's cultivation issues. From the experimental plot, it has been found that 72928 mm^2 growing medium or container needs 53 liters, 146 liters, 98 liters irrigation water for Tomato production with DI, TI (pipe), TI (bucket) system in the URTA (Table-7.2]. Since rooftop agriculture requires more water than land agriculture, it is very important to store the greywater and rainwater in the URTA especially for the month of December to April (dry season). In this study, the area of the roof was 216 m^2 and 70% roof area was covered with agriculture which may contain 155 number tubs/drums/Tomato plants that could save 8218 liters, 22777 liters, and 15204 liters potable irrigation water by greywater and rainwater with DI, TI (pipe), TI (bucket) system respectively in the URTA. This study indicated that irrigating Tomato plants with greywater and rainwater in an alternate pattern of irrigation with potable water and yield levels similar to that of irrigation with 100% potable water. This also meant that irrigating with greywater could reduce the pressure on potable water. This study also observed that 1500 liters concrete structure or continuous collecting greywater and rainwater storage structure was filled by greywater within the 5 (five) days from I (one) bathroom's usage water. That's why there is no need to use any potable water for Tomato cultivation on the rooftop agriculture and owner of the building can easily storage their bathroom's usage water with concrete structure or storage tank and then this reusable storage water can be lifted up and use with the help of motor for rooftop cultivation.

Stage	**IWR (mm)**			**Area of container(mm2)**	**Total Volume of water (mm3)**		
	DI	**TI (Pipe)**	**TI (Container)**		**DI**	**TI (pipe)**	**TI (mug/bucket)**
Initial	75.95	145	95	72928.89	5542595	10574689	6928244
Vegetative	124.50	350	180		9116110	25525110	13127200
Flowering	236.11	520	320		17211217	37923021	23337244
Ripening	289.92	1000	750		21149377	72928886	54696665
Total	726.47	2015	1345		53019300	146951706	98089352
Total amount of Irrigation water in liter					53	147	98

In spite of these high counts, no significant difference in yield levels was observed between crops irrigated with potable water, greywater and rainwater. The study also observed that plant growth and productivity were unaffected by water quality of greywater. These results emphasize the potential of domestic greywater as an alternative irrigation source of URTA. Therefore, irrigation with greywater and rainwater can save the use of potable water which would reduce the pressure on groundwater in an urban area.

7.11 Economic changing aspects of URTA

Figure 7.12 represents the results of an economic assessment employing the NPV approach of URTA. NPV was close to zero at the end of the fifth year at a 12% discounted rate. However, NPV became positive, which led to a greater cash inflow compared to cash outflow at a 12% discounted rate at the end of the fifth year within the life period of 15 years of URTA, and at the end of 14th year, NPV was close to zero when the internal rate of return (IRR) is 21.59%. In this study, the 12% discount rate was considered according to Bangladesh government development project proposal (DPP) appraisal. Due to the very highly sensitive productivity of URTA, the experiment led to a positive NPV after 5 years with proper carrying, including efficient water management techniques both in crops and leafy vegetables. Thus, it can also be concluded that the benefits depend on crop type, production and area covered of the roof by crops and would only be achieved towards the end of the life cycle of the first investment materials of URTA [318]. NPV results of the food production from the URTA scenarios revealed that first-year production was comparatively less than second-year production due to lack of technical knowledge and experience of organic food production on the roof.

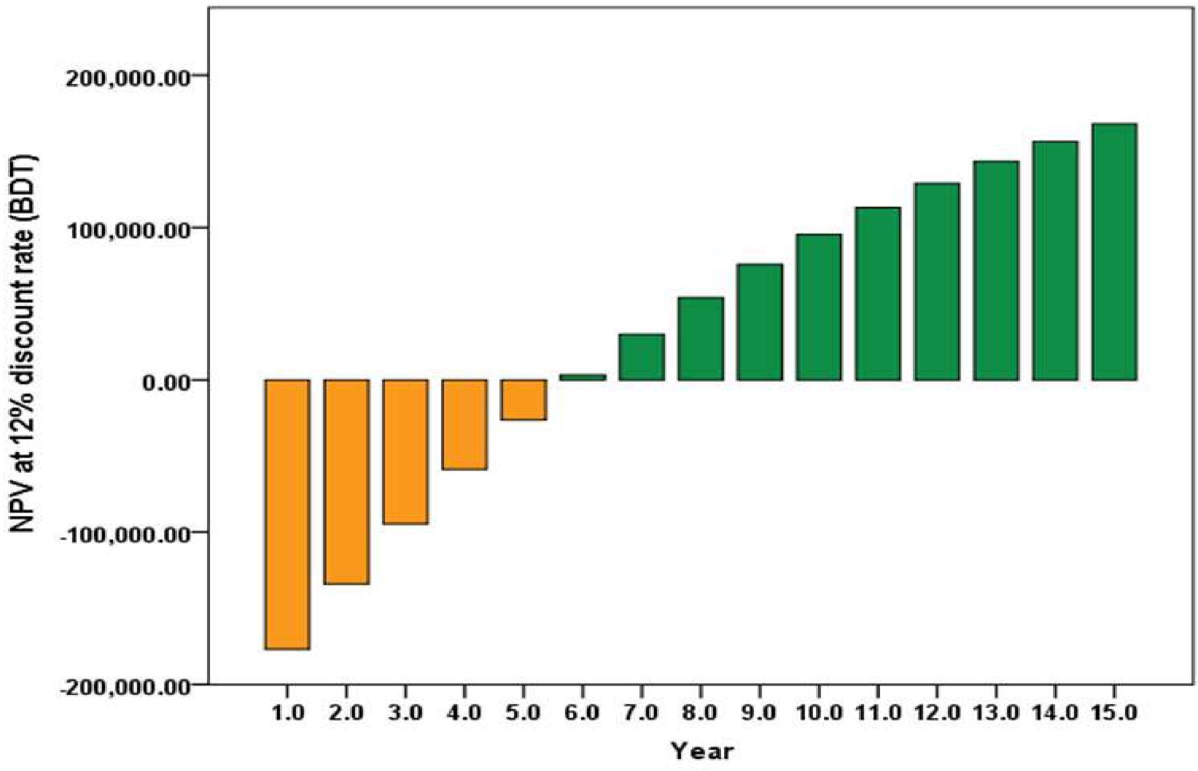


Figure 7. 12 Annual net present value (NPV) for the experimental AR in Dhaka at a 12% discount rate.

However, organic and soil-less cultivation on the roof top led to a positive NPV for its growing capability for around the year and provided a fresh supply of agricultural products to the consumer in a sustainable way. It may contribute to the whole year short duration of food supply chains by as much as 30.07%. The results concluded that 98 ha vegetable gardens and 2539 ha arable land could satisfy the demand of about 63,700 and 321,000 consumers through vegetables and cereal products, respectively [319]. This study observed that annual job creation advantage @BDT 138.90/m2 (29.84%) of the total benefits of URTA [Table 4.10]. Figure 7.13 represents the other benefits of the experimental URTA. Yearly energy savings were: BDT 6.04/KWH and BDT 184.44/m2/year, considering the fourth step of DPDC tariff, Bangladesh from 301 to 400 units, 6.04/KWh (19.81%). Annual AR-enhanced air quality advantage and annual mitigation of UHI effect are @BDT 2/m2 (5.16%) and @BDT 67.17/m2 (14.43%), respectively.

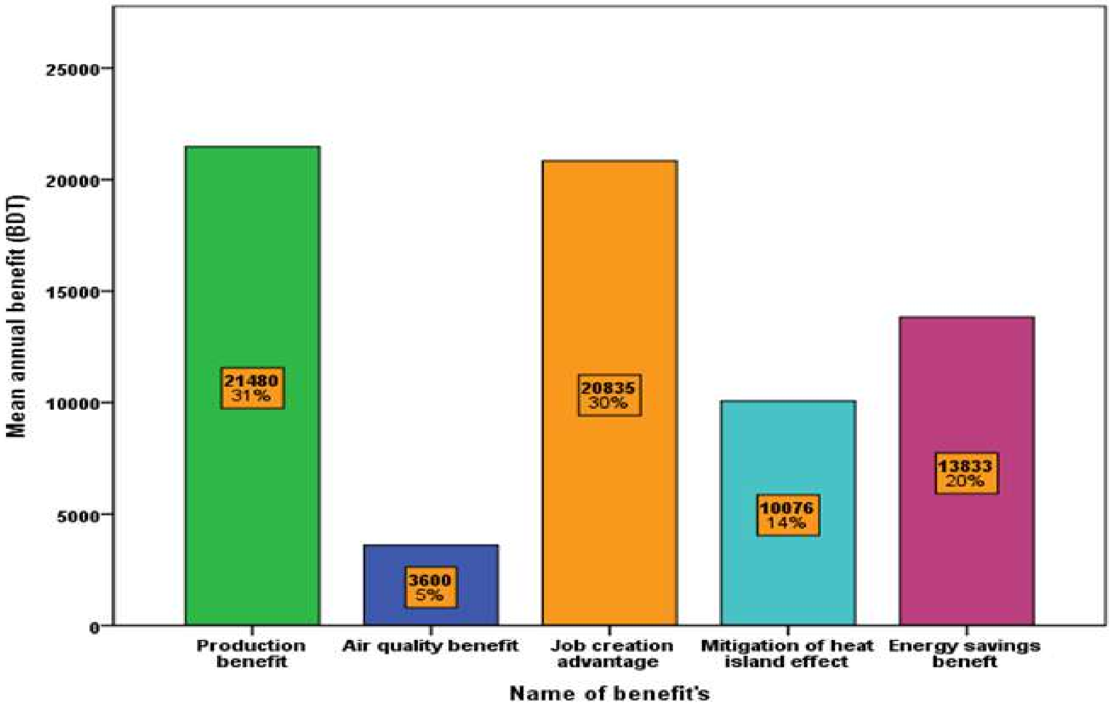


Figure 7. 13 Annual benefit of URTA according to the benefits from the experimental URTA.

7.12 Summary

In this chapter, aimed to assess the performance of efficient irrigation techniques via irrigation water productivity of selected species in URTA, compared to the existing traditional irrigation method. The outcome of this chapter shows high efficiency in saving green water through increase of water productivity, as well as when using grey and rainwater for URTA. URTA in combination with a drip irrigation system, rainwater harvesting and use of grey water, in the end, would lead to savings in the valuable existing water supply, reducing the cooling effect of the urban heat island, enhancing ecological activity and environmental conditions on a roof top and promoting socio-economic activities including healthy recreation and improving nutritional enrichment of the urban population with a fresh food supply, etc. All the above-mentioned activities might be considered as green adaptations towards achieving a green city in managing climate risk.

The research showed that the irrigation water requirement of different species of plants was different for URTA and was around 54% in excess of ETc, especially during the flowering and ripening stage. This study also found that a drip irrigation technique saved 46% to 64%, 56% to 75%, 30% to 57%, and 31% to 57% of the irrigation water requirement for production of BARI Tomato-3, BARI Bottle Gourd-3, BARI Brinjal-8, and Bogra Local Chili compared to the traditional irrigation water requirement. The study also found that 18.78% of irrigation water was saved by using a growing medium or container according to maximum root zone depth.

The results of this study revealed that the drip irrigation technique decreased the maximum rootzone depth of plants in the URTA by 25–33% compared to the traditional irrigation increases and applying more water than the DI system. However, the average seasonal yield for BARI Tomato-3, BARI Bottle Gourd-3, BARI Brinjal-8, and Bogra Red Chilies were increased by 42.86%, 22.40%, 16.67%, 62.50%, 21.43%, and 6.67%, respectively, by drip irrigation compared to the traditional container irrigation. Drip irrigation with rain and grey water was also found to increase the yield of BARI Tomato-3 by 31.87% and 33.33% compared to container and traditional pipe irrigation. The study also found that the average IWP in the winter season of the selected crops was 25.56% higher than in the summer season for URTA. The study also found that the yield was increased by 21.88% when applying grey and rainwater in comparison to potable water. The result indicated that the application efficiency, distribution efficiency, field emission uniformity, absolute emission uniformity, and co-efficient of variance were 95.41%, 94.82% 92.19%, 89.94%, and 0.094 for the drip system. Therefore, the performance of the drip irrigation system for URTA might be considered as standard and operational performance was excellent.

Green water use with drip irrigation technique opens the potential for unused open rooftop space to become creative useable spaces leading to many positive impacts upon many sectors, such as increase of irrigation water productivity, easy use and operation of URTA, decrease in the pressure of potable water supply in the city, increase of green activities, greener and cooler city rooftops, increase of supply of fresh agricultural products leading to a healthy environment, and huge climate dividends by reducing urban heat islands, if URTA is applied and encouraged by city corporations providing incentives such as tax rebates. It is expected that urban planners and decision-makers would recognize the importance of the use of both grey and rainwater in URTA and take necessary actions through city corporations to promote URTA in order to turn our city into a sustainable place in terms of environmental and socio-economic perspectives for city dwellers and the community. Economic sustainability of URTA depends on yields and prices. In this study, at a 12% discount rate, NPV becomes positive at the end of the fifth year, resulting in more cash inflow. URTA is an economically accountable process with financial benefits of yearly energy savings of 19.81%. Annual job creation is 29.84%, enhanced air quality advantage is 5.16% and the annual mitigation of heat island effect is 14.43%. So, the commercial dynamics of URTA refer to achieving financial success according to the demand of the local population. Investments and proper carrying of URTA can raise incomes and produce overall economic growths for longer-term food security and improved well-being. URTA also can provide sustainable, interactive community spaces for flat members or relatives and can enjoy health benefits through recreation and relaxation. URTA brings the unusable space into productive spaces and increases the property value of the building. It plays an important role in addressing a different range of micro-environmental challenges through adaptations.

Chapter 8

CONCEPTUAL MODEL OF WATER AND CLIMATE SMART URBAN ROOFTOP AGRICULTURE FOR SUSTAINABLE CLIMATE CHANGE ADAPTATION IN AN URBAN CITY

8.1 Introduction:

Climate and water-smart urban rooftop agriculture (WCSURTA) can be defined as sustainably increasing agricultural productivity and incomes in an urban area, adapting and building resilience to microclimate change, and reducing greenhouse gas emissions in urban regions. Development for climate change adaptation and food security has to elongate on knowledgeable urban decision-making processes. City dweller's involvement, rain and greywater harvesting, green building concern and rooftop agriculture with the integration of comprehensive and reliable information epitomize crucially, yet stimulating, pillars for successful outcomes of the conceptual model of WCSURTA. This conceptual model is an approach to upturn the practical, procedure and investment in an environment to get sustainable agricultural growth for food protection with light soil and green water under climate change. Different consensus approaches can be adopted to achieve this climate and water-smart agriculture.

Thus, this framework allows city dwellers to explore the consequences of scenarios that reflect the opinions of the majority and minority or are based on a balance between them. WCSURTA model perceptions are also contributing to the development of policy and planning tools for implement WCSURTA model. This WCSURTA conceptual model can lead to the invention of the potential result of climate variation on present and future sustainable crop production in rooftop agriculture, use of portable water application decreases, and mitigation of climate changes with the light soil and green water. Thus, this conceptual model permits variation of environmental factors such as water management and temperature reduction and simulates the area coverage of roof with crop response through many estimated growth parameters like crop yield and irrigation water productivity. This model also contributes valuable insights to the development of policy and planning tools of city development.

8.2 Description of CWSRAM

Formulation of the Climate and Water Smart Urban Rooftop Agricultural Model, Prioritizing constraints of CWSRAM are flexible in its capability to high yield agricultural production at a wide range of spatial and temporal scales. A typical analysis with the CWSRAM indicators starts with the identification of area coverage of roofs, irrigation system, and source of water and microclimate changes, which define the spatial resolution of the study. A simple flow-chart outlining this process is shown in Fig. 8.1 with the independent and dependent variables. The model was developed with the knowledge gain from the experimental setup and open-ended questionnaire from the participants of the existing URTA.

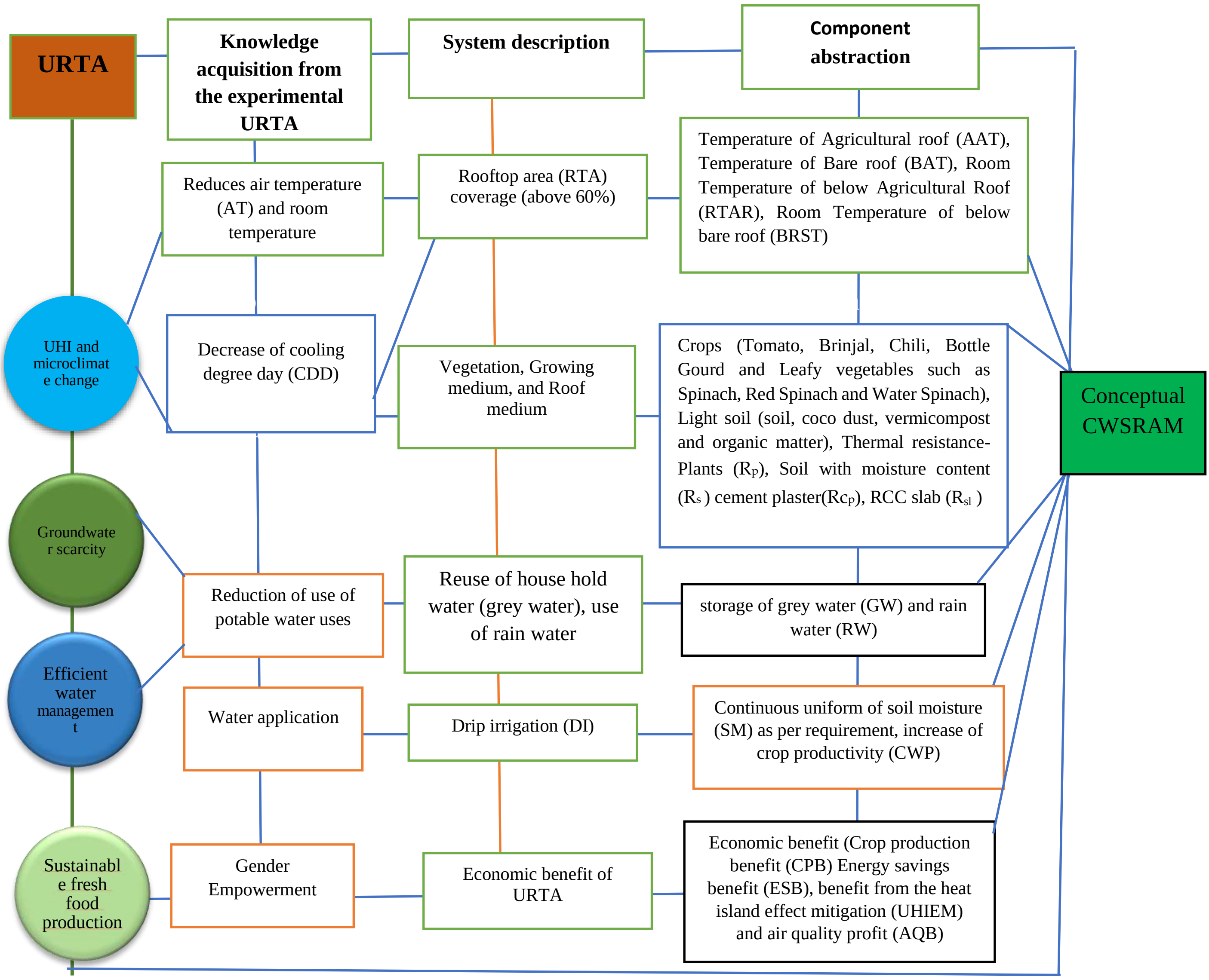


Figure 8.1 Conceptual model of CWSRA (Regular observation from November 2018 to November 2020)

This conceptual included the need for capacity development of different actors in national rooftop agricultural systems and the provision of appropriate incentives to involve the private sector in strengthening rooftop agriculture as commercial thinking. The factors, as well as the relative weights to apply as pillars of CWSRAM, were observed in this study. It has been expressed through a number of performances which are taken from the finding of the experiment of this research. For case in point:

8.2.1 Efficient resource management

Utilization of bare roof economically and produce sufficient fresh food on a commercial basis can be achieved sustainable food production in the urban area. From the questionnaire survey, it has shown that almost one-third area of the roof is used in the maximum existing rooftop agriculture and 2/3 is bare or wasted. That's why rulings, opinions, and stimulus of owners of the roofs help to explore their awareness to implement their bare roofs as a rooftop agricultural field. Furthermore, in this study, it has also been found that area coverage with agriculture plays a key role in microclimate changes. From the temperature differences analysis, it was exposed that during the month of March, the maximum frequencies of temperature differences were 5.5 °C, 4.5 °C, 3.5 °C, 2.3 °C, 1.2 °C and 0.45 °C in 85%, 80%,70%, 60%, 50% and 40% roof area covered by agriculture, respectively. However, spatial information has to be integrated into CWSRAM since implementing this model involves land-scape planning and aspects of criteria to the owner of roofs. In this point, CWSRAM is based on a deep-rooted set of methods that have been frequently applied to different planning contexts such as the targeting of ventures on the mitigation of urban heat islands and GHG emissions or the design of reserves the fresh food supply. That's why, roof area was considered as at least from 60% and up to 85% area covered by agriculture was considered as mandatory option to implement the CWSRAM. The multi-criteria option was also used in the efficient resource management. This model was developed by the advantages compared to the different area coverage conventional aggregation methods.

8.2.2 Smart use of water

In this study, it was observed that traditional irrigation practices used by existing rooftop gardeners were not catching optimum production. In case of traditional cultivation, needed enough water for cultivation. In this study, water-smart cultivation is symbolized by the permutation of four things such as soil smart, water-smart, fertilizer smart. So, conceptual CWSRAM involves water-smart cultivation in rooftop agriculture for sustainable food production by following different consensus scenarios.

1**. Soil keen:** 'Soil organic matter is a factor of soil that improves soil fertility and soil water holding capacity and reduces bulk density of soil. Low-cost soil fertility enrichment options are considered by adding green manures, composting, and animal manure in the soil that improved the water conservation capacity of the soil. The study was found that soil prepared by the ratio of soil: coco-dust and organic matter: vermicompost as 2:1:1 and planting appropriate crop varieties this mixture increased 8.38% soil moisture content as well as water 0.34 gm/cm3 bulk density reduces in the agriculture practices.

2. Water and irrigation smart: Yearly rainfall and grey water was selected as an indicator for improvement of water harvesting, water availability, and irrigation water productivity. The availability of water largely determines the yield of rooftop agricultural activities. Rooftop agriculture is very water-sensitive due to high roof surface temperature. The improvement of rainwater harvesting and management of greywater is the viable practices to increase the irrigation water productivity of URTA. The study found that rain and greywater mixture was suitable for cultivation to reduce the pressure on groundwater. This model also recommended that secondary source of water should be middle of the roof in such way that irrigation water can be equally distributed to the all plants. That's why CWSRAM save 80% potable water with the smart drip irrigation technology.

3. Smart management of fertilizer: Chemical fertilizer was avoided by vermicomposting and homemade fertilizer. Kitchen waste, upper layers of egg and bones wastage powder have used to make homemade fertilizer.

4. Smart growing medium: This study found that according to root zone depth of plant or crops container or any structure uses save as the growing medium of URTA that has circumvented pressure or surplus load of soil to cultivation different crops.

Therefore, water and soil smart agriculture is a balance of the above observes and maximizes water availability, conservation agriculture techniques for optimum yield in rooftop agriculture. These practices encompassed largely production potential with low capital investments. That’s why, water harvesting and water storage have obligatory in CWSRAM to reduce the pressure on potable water in the urban area as well as pressure reduction on groundwater.

8.2.3 Operation and maintenance cost

The operation and maintenance cost of URTA involved annual cost of soil, cost of new container, vermi compost, seeds, baby plants and the cost of different agricultural tools. These costs are directly related to the roof area coverage with agriculture and amount of use. Maintenance costs has considered to keep the whole system of RTA in perfect working condition. That’s why operation and maintenance has considered as a function of input for increasing crop production and better result of microclimatic parameters improving in CWSRAM.

8.2.4 Crops types and suitable place management

This study found that temperature stress was mostly affected the soil, availability of nutrients and water to the plant. Crop yields and variation of microclimatic parameters by the different plants in different places of roofs were different. That’s why crops types and location of the roofs are the other important parameters of this CWSRAM. Adjustment techniques can be enhanced by the crop varieties that are tolerant to heat and thus reduce the risks of climate situations. Similarly, the location of crops and production, rotation or shifting production between the crops, shifting production out of marginal areas, changing the intensity of the application of fertilizers and pesticides, capital and labor can help minimize the risks from climate change on the production of agriculture. Changing the time at which the fields are sown can also help the farmers to regulate the length of the growing season for better adaptation to the altering environment. Adaptations of farmers can also be involved by changing the timing of irrigation or the use of other elements like fertilizers. However, in this CWSRAM, climbing plants which need panel is considered at the East-West direction and other large canopy coverage also considered in the same direction. Small height plants were considered in the North-South direction of the roofs. This was done by the data of microclimatic parameters in the experimental roof within the period of November’2018 to June 2019.

8.2.5 Gender participation

Gender participation in economic activities ‘is understood as an indicator for women's empowerment and economic development. In this indicator of the framework, the changes of productivity such as more yield will contribute to spread the URTA as commercial thinking. Integrated CWSRA will Promote gender equality and improve livelihood structure and increase fresh food production to their individual family. Women and elder men are mostly supporting and carrying to implement the urban rooftop agriculture as well as acts as mitigation and adaptation tools. However urban farmers' accessibility to markets for selling their roof farms harvests and buying inputs as well as accessing extension services acts as a vaccination. CWSRAM reduced access adds additional risks for farmers under climate change and this model is supposed to support urban farmers to deal with the impacts of climate shocks such as losses of fresh food supply and gender empowerment.

8.3 Output/ dependent variables

8.3.1 Micro-climate change in an urban area

On the basis of observation and data analysis, we suggest that the research aimed at studying the present status of URTA or change therein over time and place will have to integrate the three magnitudes outlined above systematically in a conceptual framework (Figure 8.2). The cultivated roof area-based microclimatic parameters changes and production system embedded within a region should be at the center of the research on BR use as AR intensity. The indicators for roof area used for agriculture intensity should then systematically integrate the inputs to the production systems (e.g. roof, labor, and initial capital) with the outputs (i.e. microclimate changes, yield, and social value). This view, consistent with economic values, allows the study of the input-output relationships, such as the effects of diminishing returns or substitution effects of labor, skills, and capital [319]. The framework is also well-suited with the crucial concept of commercial URTA as a measure for mitigation micro-climate changes and allows analyzing the dynamic relationships of intensification and AR’s area coverage expansion. A conceptual model of CWSRA (green: dimensions of area-use intensity). This model proposes a new perspective on unproductive BR would a productive AR that were systematically linked three dimensions (ARs): inputs, outputs, and the associated system-level outcomes of area coverage-based production resulting from alterations of the system properties (e.g., micro-climate (roof surface temperature and air temperature reduce and energy saving) change, and improve gender empowerment). These relationships are key in understanding the reaction loops between cost and benefit and identifying the conditions under which sustainable strengthening can occur. On the basis of physical output indicators, much product increased from such an integration: beyond the temperature and humidity change scenario and crop water productivity, which already represents the ratio between output (production per square meter per year) and input (roof area), other ratios could be calculated in equivalence to the production function in economics.

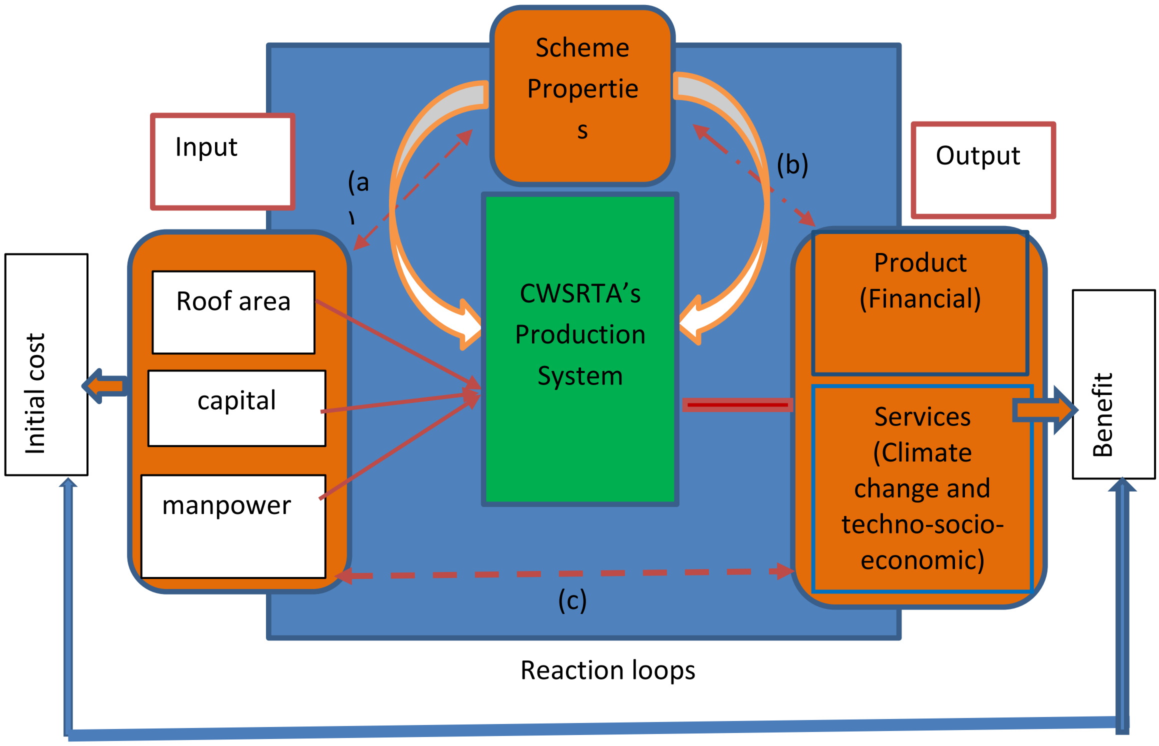


Figure 8. 2 A conceptual CWSRTA framework for adaptation to micro-climate change in an urban area

On the basis of physical output indicators, much product increased from such an integration: beyond the temperature and humidity change scenario and crop water productivity, which already represents the ratio between output (production per square meter per year) and input (roof area), other ratios could be calculated in equivalence to the production function in economics. The indicator 'cooling load and energy savings return on investment [304] for example, balances energetic inputs and outputs to and from roof area coverage with agriculture and can illustrate the net effects of saving or reduction strategies. The regular data observation reveals that, during the winter and summer season, tremendous gains in production and energy savings were found, which, depends on certain cases that are area coverage with agriculture, even falls below one [320].

In this framework inputs and outputs were simply assessing and also considered the outcomes of area-based production, which are the result of system properties and outcomes but are conclusive for the dynamics of the techno-socio-economic system. The ratios between inputs, outputs, and changes in ecosystem properties could provide deep insights into the society-nature interactions and would allow the opportunity to balance the costs and benefits of area coverage-based production. Furthermore, this was probable while clearly allowing and assuming the maximum outcomes of roof-use intensification strategies. The experimental examples of such integrative perspectives existed: at the level of area coverage with different shady plants, the agricultural products, the environmental impacts of production chains approaches have been developed based on life cycle assessments (LCA) of plants and also RTA [36]). This CWSRTA framework evaluated the environmental pressure such as temperature and relative humidity on different sides of the roof connected with crop products. The carbon dioxide concentration and carbon footprint approach concept [320]], also considered in this framework which aims to quantify the carbon emission related to the final consumption of products (e.g., food). Similarly, the local or global micro-climate change with URTA in every roof of apartment/building in the urban areas, the input or output could be a fascinating indicator that could be mandatory for the owner of building/apartment for evaluating proper productive use options and to identify sustainable land systems [321]. The URTA schemes would also allow addressing a growing challenge of roof area use systems science as a commercial perception, that is, the growing techno-socio impact in the society or inter-connections of roof use systems and their relation to roof-use intensification pathways would be created to the society. This would boost the analytical capacity of CWSRAM to explore compromises, collaborations, and reaction loops scientifically, and, thereby, inform decision-making for sustainable use of bare roofs as productive uses.

Climate change's negative effects are already being sensed, in the city center at the form of increasing temperatures, weather variability, urban ecosystem boundaries, and more frequent extreme weather events. Adaptation and mitigation planning is the core of coping plans for climate change such as action diplomacies passed by national governments through efficient management of bare roofs in the urban area. The assessment support framework planned in this study is designed according to the area covered with RTA and based on change the microclimatic parameters to support planners and decision-makers that aim to properly implement CWSRAM at the regional or national level. Such a planning process encompasses several sectors such as civil society or residential buildings, governmental institutions, and the building of the private sector making it mandatory to involve respective investor groups. Therefore, the conceptual model integrates multi-sectorial participant groups to contribute expert knowledge on the selection and importance of vulnerability indicators as well as CWSRTA practices that fit into an environmental and socio-economic condition of the country. Roof area coverage with URTA and irrigation water productivity reflects the microclimate changes in the urban areas. This was considered by different area coverage roofs with agriculture (40%, 50%, 60%, 70%, 80%, and 85%) including experimental roofs. The temperature, relative humidity, and CO2 data were collected from these roofs from November 2018 to May 2019. Cropping pattern selection has also been completed at a different site of roofs based on the solar direction on roofs. It has been observed that URTA is a very fundamental concern for microclimate change as well as human comfort and energy saving. From the experimental data it has been found that URTA saved energy consumption of the top floor's room of a building by 59.45, 55.63, 39.81, 25.94, 18.88 and 5.87%, respectively in the 85, 80, 70, 60, 50 and 40% of roof area covered compare to the bare roof which has discussed in chapter 6. It has been also originated that daily peak cooling load was proportional to the area coverage of roof with agriculture and cooling load saved by 12.15 to 20.34% in the AR compare to the nearby bare roof.

Thus, a short (adaptation) and long term (mitigation) perspective are integrated into the concept which should be considered in proper targeting and planning processes of urban rooftop agriculture. The microclimatic parameters such as air temperature, roof surface temperature, relative humidity, CO_2 were improved by improving agricultural practices in the roofs. Consequently, information about relevant microclimatic parameters of different area coverage (40%, 50%, 60%, 70% 80%, and 85%) of the roof through URTA has considered in the model to inform an assessment of the priority's practices of bare roofs. However, the amount of fresh food production and the financial benefit of individual preferences were also included in this conceptual model based on the result of experimental URTA. That's why CWSRAM was also developed on the basis of micro climate change adaptation as well as UHI reduction through URTA. Interventions of city dwellers has also analyzed and prioritized when they perform best across a potential spectrum of future climate and socio-economic scenarios.

8.3.2 Fresh food security

Due to the increased population in an urban area, more food is consumed than is produced in the rural areas. For this, urban food production and food will be crucial to improve productivity in developing countries in ensuring food security. As a result, the poor or middle-class households in urban areas with lower incomes were exhausted no longer support to buy fresh food for their livelihood activities. That's why this indicator was considered to reduce food insecurity and improved fresh food production in every household/ every/building/ urban bare place through CWSRTAM. Improved water productivity per unit of farm area; improved input-use efficiency of irrigation and green fertigation due to timely crop information, the growing medium is considered as one of the most prime features of CWSRAM as well as yield of production. According to types of plants, the growing medium or container would design which should permanent structure or also a container.

8.3.3 Reduce pressure on potable water and increase irrigation water productivity

The dynamic of URTA allocation in the CWSRTA model/framework is based on the minimum cost pathways to meet the fresh food demand and micro-climate change adaptation targets of every building user under a range of urban agricultural growth scenarios. The growth pathways, the priorities for investment are considered on baseline growth of URTA and adaptation to the micro climate-change. The roofs area uses patterns, smart use of irrigation technology and labor cost encompass combinations allocation of this model.

On the basis of physical output indicators, it was observed that climate change played a significant impact in the crop water productivity in the URTA. Rainfall and gray water (green water) were also affected the availability of groundwater, rooftop agricultural production, and related soil water conservation. Increasing storage of green water could influence the Tecno-socio-economic condition of city dwellers. This study verified the advantageous effects of crop production with efficient soil and water conservation with a focus on (i) traditional irrigation with groundwater; (ii) drip irrigation with groundwater and drip irrigation with green water. Green water-smart irrigation saved 46-64% crop water productivity and groundwater-fed rooftop agricultural production. 31.87% -33.33% yield in the URTA was also increased by the green water-smart drip irrigation system compared to traditional irrigation (Figure 8.3 a, b]. In the existing URTA most irrigation was done with the free pumping energy but in the case of green water areas, irrigation was done by energy for water pumping from the storage reservoir. Both of these inputs (groundwater and green water) required notable irrigation systems and combination water and energy in the commercial crop production at the URTA. The conceptual CWSRAM concluded the following water smart points;

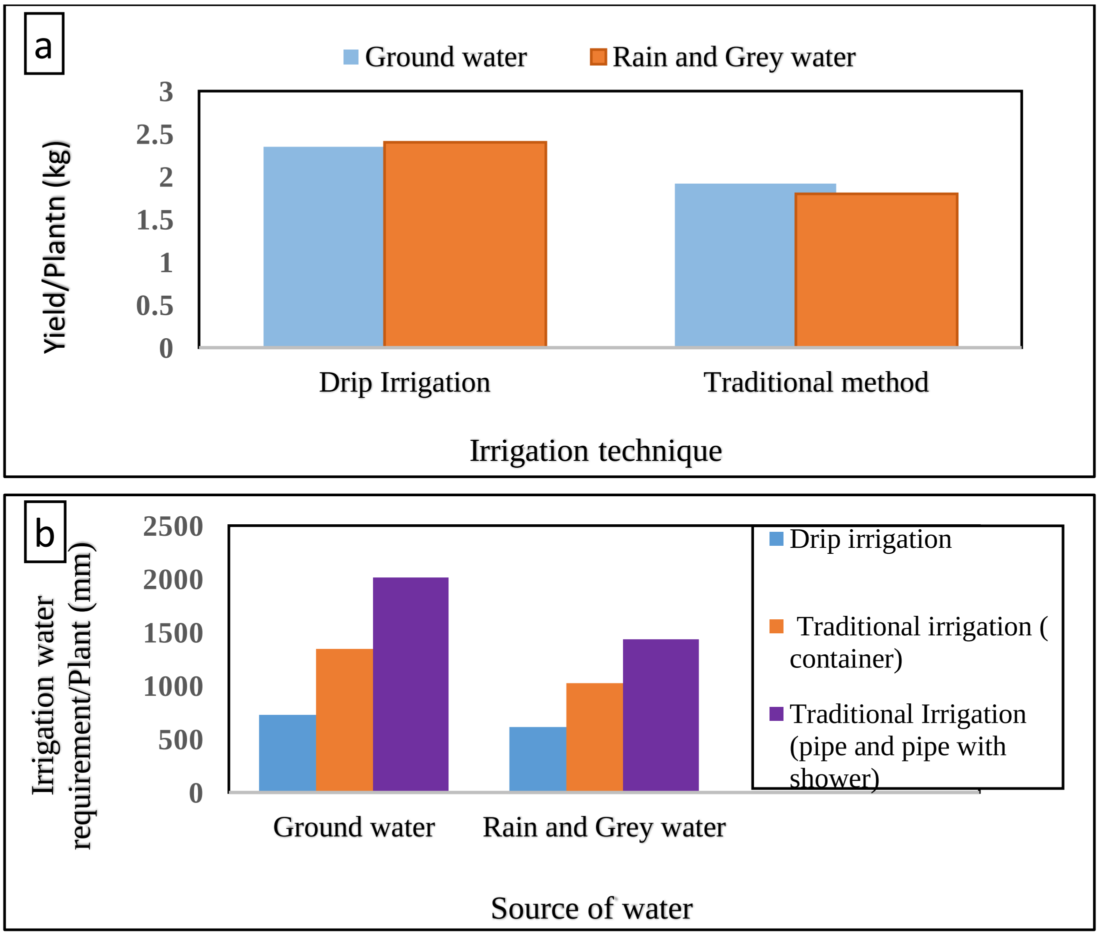


Figure 8. 3 (a) Average yield and (b) amount of irrigation water requirement practicing the different irrigation practice in the URTA.

point1: Reform agricultural roof and agricultural irrigation systems

This point encouraged the reconstruction of surface irrigation systems in the rooftop to increase irrigation efficiency, crop water productivity with the smart irrigation system to the all owners of the building. It also increased the consumption of resources like labor, water, micro-climatic green water used in rooftop agriculture increases the availability of irrigation water during the hot and dry periods as urban dwellers tend to increase green water use.

Point 2: Sustainable green water harvesting and storage systems

This point reorganized the storage system and re-use of green water to enhance adequate green water supply for rooftop agricultural production which recovered the green building rating system. As a result, agricultural water productivity and climate flexibility of urban dwellers increased through the green water fed irrigation. On the other hand, sometimes water was used on the plants to clean the leaves. From the questionnaire survey, it was also observed that 70% time of irrigation was done for watering in the container and 30% irrigation time was used by wetting the leaves. This 30% irrigation has considered by potable water and the rest 70% irrigation was considered with grey and rain water (rain water, and reuse of bath water). On the other hand, from Chapter 7, it has found that the efficient irrigation technology such as drip irrigation saved the 46-64% irrigation water compare to the traditional irrigation and also increased the water productivity by 6.67-42.86% compare to the traditional irrigation approach.

8.3.4 Increase gender empowerment

From the questionnaire survey and also experimental data analysis it has found that the five domains of gender empowerment, which comprise ten indicators. That's why CWSRAM has developed for woman and elder man for carrying the own rooftop agriculture. This model has adequate achievements of the five domains or is empowered in some combination of the weighted indicators that reflect 80% total adequacy. The five domains of empowerment are defined as follows:

This domain concerns decisions over agricultural production, and refers to sole or joint decision making over food and cash-crop farming.

i. Resources and income

Building with AR able to attain a significant contribution to LEED certification system. That's why this domain increased the value of a building through increasing the LEED rating point. Thus, this model has considered as resource efficiency through green construction, high quality of indoor air, and sustainable economic sources for women and elder man.

ii. Leadership

This domain concerns leadership in the community through open discussion group's membership in social media like Facebook, YouTube, and WhatsApp.

iii. Time

This domain concerns the allocation of time to take care regularly of the plants with satisfaction as like as leisure or physical activities.

8.4 Increases contribution space to attain SDG's Targets

CWSRAM provides an outline for complementary multiple dimensions of urban rooftop agriculture and fresh food supply techniques in an urban areas and micro-climate change which addressed the contribution to UHI impacts, global greenhouse gas emissions, green water management to climate change impacts, and the relationship between irrigation water productivity, incomes and food security. On the other hand, the food security, substantially increase water-use efficiency including water harvesting, environmental impacts of urban cities, and awareness raising on climate change adaptation and impact reduction are the very important targets of SDG 2, 5, 6 and 11 [Table 8.1]. Thus this model is the outline of achievement of those SDGs targets. Practices of the CWSRAM would mitigate emissions, increase resilience or adaptation, and increase productivity through URTA.

Table 8. 1 The SDG's targets that achieved by CWSRAM are given value.

Name of SDG	Number SDG's Target	Goal of SDGs	Function of CWSRAM
1. Zero hunger	Target 2.3:	By 2030, Double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment	CWSRAM design has considered higher irrigation water productivity and value of the buildings and also women empowerment. This target will be accomplished by the best practice of CWSRAM in city region.
	Target 2.4:	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	CWSRAM has considered as sustainable fresh food production for city dwellers

Name of SDG	Number SDG's Target	Goal of SDGs	Function of CWSRAM
Gender Equaity	Target 5.5:	Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision making in political, economic and public life	Effective participation priority was considered for women in the CWSRAM
Clean water and Sanitation	Target 6.4:	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	An efficient smart irrigation system has considered in this model.
	Target 6.A:	By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	Rainwater and grey water harvesting system has considered as mandatory in the irrigation system.
Sustainable Cities and Communities	Target11.6:	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air	This model will improve the air air quality to reduce the air temperature, improve relative

Name of SDG	Number SDG's Target	Goal of SDGs	Function of CWSRAM
		quality and municipal and other waste management	humidity and reduce CO_2 level.
Climate Action	Target13.3:	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	This target will be achieved by this model through training and workshop.

(source: Regular observation and questionnaire survey of existing rooftop gardens from November 2018 to November 2020)

So, the CWSRAM allows to identify the pathways to managing SDGs targets for city that is the constructing processes of more inclusive, sustainable and effective in delivering a sustainable climate and water smart agriculture.

8.5 Analysis of barriers/challenges to implementation of CWSRAM according to findings of the chapter 6 and 7

On the basis of observation and the experimental studies, CWSRAM addresses the environmental, social, and crop water productivity impacts of the interventions outlined of sustainable URTA. So, it is the present focus of urban dwellers to sustain the city. On the other hand, this study found the perceived barriers surrounding RTA in the DMA to implementation of this framework are presented in Table 2. Six main groupings were revealed: i) barrier or risk` associated with city dwellers/community in co-operation, ii) barrier accompanying knowledge gap with the soil-less production system, iii) risks of the sustainable irrigation techniques of fresh food products iv) Initial costing as well as techno-economic risks, v) sustainable production management risk and vi) eco-friendly crop production management risks. These obstructions were finalized on the basis of concerning the urban micro-environment and the system, city dwellers informed concerns about the integration, practice, access, involvedness, and aesthetics of experimental and existing URTA roofs. Apparent risks of food products with a commercial basis were related to the overcome ratio of above problems with soil-less growing, organic fertigation, and quality of the products associated with urban contamination. Finally, the community of the roof owners was questioned by the policymakers to keep the environmental and economic balance in the commercial URTA.

Table 8.2 Barriers associated in CWSRAM in DMA to implement commercial RTA with city dwellers scoring (high (+++), medium (++) and low (+)).

i) Barrier or risk` associated with city dwellers/community in co-operation:	
● Conflicts with the image of rooftop agriculture	+++
● Conflicts with image of roof damage	++
● Conflicts with potential commercial food production	+++
● Logistics support and management constraints for food products	++
● Little or less benefit from the production	++
ii) Barrier accompanying knowledge gap with the soil less production system,	
● Associated know-how is seeming as too complex	+++
● Risk that commercial projects are overtaken by large initiatives	+++
iii) Risks of the sustainable irrigation techniques of fresh food products	
● Drip irrigation production techniques management are so costly	+++
● Quality and Yield of products expected to be low	++
● Small root density related crops and Leafy vegetables are water sensitive due to container agriculture	+++
● Rooftop agriculture needs more water for production	++
iv) Initial costing as well as techno- economic risks	
● Uncertainty benefit about the overall initial costing	+++
● Little or no perceived economic benefit	++
● Challenges of unsustainable management	+

v) Sustainable and eco-friendly crop production management risks.

- Owner of rooftop agriculture are not trained (not professional) enough +++
- Opposition with other rooftop users and uses +++

CWSRAM practices and knowledge in different circumstances, given the importance of local context. It was finalized that this model is interrelated on agro-ecological and market-related factors. This may be adequate for estimating potential adoption rates of new crop varieties in the rooftop agricultural system. In all cases of this model, prioritization should have impacts on the three pillars, such as micro-climate change adaptation as well energy saving of building and UHI reduction, fresh food production, and sustainable gender empowerment increases.

All challenge concerns the level of accuracy in the tools of this model and should be needed to trigger investment and decisions at the government or policy makers' level for the sustainable URTA. Answered these challenges through questionnaire survey and finding of the experimental rooftop agriculture identified several adaptation planning and other decision-making domains. These findings concluded some greater emphasis with some confidence concerning future conditions which addressed market, governance, and policy enhancements. However, these challenges to some extent, given that investment and policy decisions may be made as mandatory to the building owners or community. The governance and policy for the sustainable CWSRAM has described in following section.

8.6 The policy and governance to sustainable CWSRAM

The section addressed a variety of enablers and activities that may be needed to sustain a URTA. The factors that could facilitate CWSRAM interventions generally depend upon the nature of the intervention and the impact pathway envisaged. Identifying these facilitating factors, as well as the relative weights to apply to this model depend on owners of RTA engagement through participatory methods. Many of the interpositions have actions that are designed to address immediate needs, and few are implicitly coupled with larger-scale, longer-term strategies. This point highlights the numerous gaps in information concerning particularly the mitigation and social impacts of different interventions. In many countries, different types of initiatives/rules/policies/ promote incentives are implemented for green appreciation

[308]. Singapore's green building movement launched in 2005 with policy, tax rebate, incentives with a target of making the city greenery at least 80 percent of buildings within 2030. On the other hand, green banking ensures environmental and social well-being and promotes environmentally friendly technologies [321] [322]. The GOB has taken various innovations and policy support to prevent environmental pollution and mitigate climate change negative impacts such as Bangladesh Climate Change Strategy and Action Plan (BCCSAP), Forest and Climate Change (MoEFCC) emphasize the climate change impacts for green development. Furthermore, the GOB has approved a number of policies such as Forest Policy (1994), the Energy Policy (1995), the Water Policy (1998), the National Conservation Strategy (1995), the National Environment Management Action Plan (1995), the Environment Conservation Rules (1997), and the Environment Court Act (2010) to encourage green innovation in the country as well as ensure environmental well-beings [323] [324]. On the other hand, the GOB has already given special attention to urban green spaces and green infrastructure, green banking, and green credit through different policy guidelines and where, Bangladesh Bank encourages financing for green projects to ensure sustainable development in the country [325] [326]. Dhaka South City Corporation (DSCC) and Dhaka North City Corporation (DNCC) have already announced 10 percent tax rebate for rooftop, balcony, or the compound under the Ministry of Environment, Forest and Climate Change, the Ministry of Agriculture, Civil Society, Urban Planners, and environmental organizations.

The main obstacles of URTA are primarily related to a lack of understanding, lack of knowledge about the cultivation system, high initial economic cost, unsatisfactory message, and non-integrative policymaking. In this study, we suggest recommendations for government policymaking processes and efficient rooftop agricultural outline interpretation. We have done these by the opinion of rooftop gardeners and by finding experiment results. The policy may consider the probability that superficial barriers are linked with different areas and earning scales and may therefore most vulnerable climate change risks to large metropolitan and peri-urban areas (e.g., economic competition), risks on the city level (e.g., increases in noise or smell), and risks on the micro-level (e.g., particular health risks related to URTA products). In particular, demonstration and dissemination activities, as well as participatory policymaking, can narrow the communication gap between URTA developers and citizens.

Therefore, from above discussion and the light of the policies of other countries including Bangladesh, from the findings of experimental and questionnaire survey, the study has suggested some policies to city dwellers: This policy may be included in the existing policy for the potential of climate-water smart interventions in sustainable urban city.

Administration and policy:

- URTA may be include in building code
- Rain and greywater harvesting system and use may be compulsory for URTA.
- A drip irrigation technology may be mandatory for URTA
- At least 60% area of the roof should be covered by agriculture and then incremental tax rebate may be proposed for each 10 % URTA.
- Every existing residential building including offices, commercial buildings may be included under rooftop agriculture with necessary repairments.
- Above 80% of the roof's area coverage with agriculture should be summarized under the incentive or prizes from the government rooftop management committee.
- More developed area's existing roofs may be under URTA and it may be done by a government circular.
- Bank loan and incentive may be ensured for owners of URTA

Community organizers

Community organizers could create a rule for every rooftop owner and it may do by-

- Open planning process may be choosing unused or abandoned buildings and rooftops, thereby minimizing competition
- Local natural resources use in URTA may be keep it within the re-cycle's resources from house or neighborhood
- Soil-less techniques or combine soil-less techniques CWSRAM design may be compulsory for the owners of URTA
- Educational programs, monthly meetings, art and creativity, soil preparation, and rooftop agriculture-related know-how question games may be included to the community organizers.

8.7 Application of CWSRAM

A suitable ease management design has been developed for the application of the CWSRAM in urban areas. Urban areas are one of the most vulnerable to climate change. Incidence of extreme heat stresses, knowledge gaping about sustainable agriculture, and another climate, and social-related challenges are posing threats to rooftop agricultural production in urban areas. This study considered major crops like Tomato, Brinjal, Bottle gourd/Bean, Chili, and leafy vegetables in the winter and summer season. These types of crops covered 70%-85% area of the roof. Improved ground and green water-fed technology were also considered in this design which is also a smart irrigation technology categorized separately to mark its distinction from the irrigated technologies. However, finally, this study highly recommended that rooftop agriculture would be implemented in such a way that the roof may be covered by plants at least 70%. This CWSRAM also finds out the following points to the implementation design of URTA:

- Climbers may be cultivated at the east-west side of the roof;
- Small trees and thorny plants may be cultivated at the north-south side of the roof;
- Shrubs may be cultivated at the middle part of the roofs or below the climbers
- Herbs may be cultivated bellow the climbers

8.8 Summary

The CWSRAM model or framework represented the rooftop agricultural production and consumption techniques to meet adaptation of microclimate change, fresh food needs for the city dwellers. This model is very flexible to achieve the SDG's target of 2.3, 2.4, 5.5, 6.4,11.6 and 13.3. Improving food protection, adaptation to micro-climate change, and sustainable use of the natural resource (water, soil, use all products more competently) have less changeability and greater reliability is the output of this model. On the other hand, more fruitful and sustainable rooftop agriculture requires a most important change in the way of the use of roof areas, green use of natural (water and soil) resources management through this CWSRAM's techniques.

Chapter 9
CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This study is about to recognize the dynamics of LST with vegetation cover changes over the developed and developing area of DMA from the remotely sensed data. This study also identifies that how temperature reduced and energy saving are changed with area coverage changes of rooftop with agriculture or vegetation. It is also recognized the water requirement dynamics of crops in the rooftop agriculture and water saving approach with the drip irrigation techniques. The economic analysis of URTA was also analyzed for sustainable RTA and finally developed a conceptual climate and water smart rooftop agriculture framework with some suggestion to include in the government policy.

This work covered the assessing the potential of urban roof top agriculture as a climate change adaptation tool through efficient water management. This work also covered economic trends of URTA from the unusable space into productive spaces and increases the property value of building. It has also understood how urban heat island is increasing and how URTA act as a climate change adaptation tool with green and smart use of irrigation techniques.

Finally, this study developed a conceptual framework of URTA which allows city dwellers to explore the consequences of scenarios of their own activities about rooftop agriculture that reflect the sustainable opinions of the majority and minority or are based on a balance between them. This study also developed policy and planning tools for implement CWRAM. This conceptual model can lead to the invention of the potential result of climate variation on present and future sustainable crop production in rooftop agriculture, use of portable water application decreases, and mitigation of climate changes with the light soil and green water. Thus, this conceptual model permits variation of environmental factors such as water management and temperature reduction and simulates the area coverage of roof with crop response through many estimated growth parameters like crop yield and irrigation water productivity. This model also contributes valuable insights to the development of policy and planning tools of city development. The key findings that can be drawn based on the research described in this thesis are as follows:

- The spatial and temporal variation of vegetation and their effects on LST changes as per percentiles of 50th, 75th, and 90th conclusions that hot spot zones are as-assembled in the most developed areas where vegetation coverage is lower than the developing areas; LST is increased in the built up areas by 13.74% compared with the growing, developing areas where vegetation coverage area is decreased by 6.74% in the growing, developing areas compared with developed areas; and the highest vegetation category was found for the growing and developing areas, built up area was 2.44% to 25.49% and water body, and others occupied 1.47% to 3.26% of the total area.

- The findings of this work reveal that the maximum temperature differences between agricultural roofs (ARs) and nearest BRs were 0.45°C to 5.5 °C and during the summer season. It has also been found that 60-85% area covered by URTA were equally and highly effective for air temperature reduction compared to 50% or below area covered by URTA (maximum 1°C to 1.8°C). The relative humidity was increased by a minimum of 5%, and a maximum of 10% in the agricultural roof (AR) compared to the BR.

- The results of this study also revealed that agricultural roofs were effective in reducing heat flow through the roof. Thus, the energy demand for cooling load in the top floor of the building was lowered. The URTA could achieve a saving of 3.62 % to 32.28% the peak cooling load. It resulted in 5.87% to 59.45% energy saving with financial benefits compare to the adjacent BR. The increases in area coverage of URTA led to the decrease of the daily peak cooling load. It enhanced energy-saving significantly. The energy-saving fluctuated with the rooftop agriculture with vegetated area, soil layer coverage, and density of plants.

- It has also been found that URTA is mostly female friendly with the age group of 40-50 year. URTA becomes elderly male sensitive with the age group of over sixty years. It indicated that retired male group of males were mostly involved with URTA. Economic sustainability of URTA depends on yields and prices. In this study, at a 12% discount rate, NPV becomes positive at the end of the ^{5th} year resulting in more cash inflow. URTA is an economically accountable process with financial benefits of yearly energy savings of 19.81%. Annual job creation is 29.84%, enhanced air quality advantage is 5.16%, and annual mitigation of heat island effect is 14.43%.

- The study also discovered that 18.78% of irrigation water was saved by using a growing medium or container according to their maximum root zone depth. This study indicates that rain and grey water can also be used as a irrigation water in the URTA and the physical quality and taste of cultivated crops were the same as when irrigation is done by portable water.

- This research shown that after irrigation in the TI system, 23% soil moisture was higher than the DI system. The results revealed that the maximum root zone depth increases 25% - 33.33% by traditional irrigation compare to drip irrigation due to applying more water than DI system. However, the drip irrigated crop's average seasonal yield was increased by 6.67% - 60% compared to the container traditional irrigation. Similarly, the yield of those crops was increased by 14.29% - 62.50% compared to the pipe irrigation method. Drip irrigation with rain and grey water also increased the yield of 31.87% - 33.33% compare to the container and pipe traditional irrigation. pipe traditional method. It is also found from this research that grey and rain water is more suitable for Tomato production and yield is increased by 21.88% compare to the potable water.

- The study also revealed that the application efficiency, distribution efficiency, field emission uniformity, absolute emission uniformity and co-efficient of variance was found by 95.41%, 94.82% 92.19%, 89.94 %, and 0.094. The drip irrigation system in URTA saved water, time and labor cost which is standard and operated excellently by the owner of rooftop agriculture.

- This study revealed that to achieve food security in the urban areas, rooftop agriculture required sustainable development with adaptation to climate change. Improving food protection, adaptation to micro-climate change, and sustainable use of the natural resource (water, soil, use all products more competently) have less changeability and greater reliability in the outputs. This study found that city dweller's involvement, rain and greywater harvesting, green building concern and rooftop agriculture with the integration of comprehensive and reliable information epitomize crucially, yet stimulating, pillars for successful outcomes of the conceptual model of CWSRA.

- The CWSRAM model or framework represented the rooftop agricultural production and consumption techniques to meet adaptation of microclimate change, fresh food needs for the city dwellers. This model is very flexible to achieve the SDG's target of 2.3, 2.4, 5.5, 6.4,11.6 and 13.3. Improving food protection, adaptation to micro-climate change, and sustainable use of the natural resource (water, soil, use all products more competently) have less changeability and greater reliability is the output of this model. On the other hand, more fruitful and stretchier rooftop agriculture requires a most important change in the way of the use of roof areas, green use of natural (water and soil) resources management through this CWSRAM's techniques.
- This conceptual model is an approach to upturn the practical, procedure and investment in an environment to get sustainable agricultural growth for food protection with light soil and green water under climate change. Different consensus approaches can be adopted to achieve this climate and water-smart agriculture. i) integrated smart irrigation technologies where irrigation would do by reusable and rainwater ii) smart medium for plant growth with different organic matter and container according to the root zone depth iii) Maximum roof's area coverage agriculture selection for energy-smart food systems.

9.2 Recommendations

- Impact of URTA on climate change according to the conceptual model in the urban city was partially performed in the experimental roof only. Therefore, further studies are needed to application of the CWSRAM in the existing agricultural roof according to the findings of the study.
- In this study manually operated drip irrigation system has been used, that's why smart and sensor operated irrigation system and its performance is needed to investigate in the rooftop agriculture.

- This study has been conducted using only the impact of urban rooftop agriculture on micro-climate changes and thereby may also be investigated more research is needed to investigate the combined effects of green roof and agricultural roof, and vertically micro-climate changes with RTA.

- Irrigation water requirement was calculated by current roof air condition and that's why extra irrigation was required. Therefore, maximum and minimum roof surface temperature may be use to run the CROPWAT 8.0 model for finding the irrigation water requirement and crop production in URTA.

- The questionnaire survey has been conducted randomly within the DMA for only analysis the microclimate changes according to the different area coverage of roofs. Therefore, further survey and studies are needed to find the percentage of rooftop agriculture in DMA to find the changes in climate impact factors on UHI, and other IPCC scenarios may also be examined, e.g., RCP scenarios – RCP2.6, RCP4.5, and RCP6.0.

- In this study, all analysis was done by Microsoft Excel and SPSS, further studies are needed using the upcoming regional climate model and life cycle assessment related software to find more information and important points.

- In this study only two seasons was considered for experiment and find out the benefits of URTA. It is necessary to regular observation at least two years.

9.3 Limitations of the study

- Lack of cloud-free satellite images for the mapping of normalize difference vegetation index (NDVI) analysis, especially for the month of April and May.
- Lack of accurate measurement of leaf area index (LAI) of the selected agricultural roof for calculating energy saving of different area coverage roof with agriculture.

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Appendix A

Supplementary Tables

Table A. 1 Monthly & Yearly Maximum Temperature in °C from BMD

Station: Dhaka

Year	Jan.	Feb.	Mar.	Apr	May.	Jun.	Jul.	Aug	Spt.	Oct.	Nov	Dec.	Annual
2008	29	30.6	34.6	36.9	36.7	35.4	34	36	34.8	34.8	32.3	29	36.9
2009	28.1	33.9	36	39.6	37.8	36.5	35.7	34.3	35.3	35.8	33.9	29	39.6
2010	29	31.2	37.3	37.9	36.9	35.8	35.1	35.1	34	35.7	33.2	29.7	37.9
2011	27.8	31	34.5	35.8	35.3	36	35.4	35	36.2	34.5	32.4	30	36.2
2012	28.5	33	37.3	37.1	36.2	36.7	34.3	34.5	36.5	34.4	32.4	28.5	37.3
2013	28.1	32.4	36	37	37.1	36.4	34.6	35	35.7	35.2	32.1	30.5	37.1
2014	28.5	30.4	38	40.2	38	37	35.8	34.4	34.8	36	33.8	29.2	40.2
2015	29.9	32.2	36.4	35.5	36.4	36.5	35.5	34.7	36.5	35.5	32.9	30.3	36.5
2016	27.6	34	34.8	39	37	36	34.6	36.1	34.7	36	34.5	31	39
2017	30.2	32	33.6	36.5	37	36.1	35.8	34.2	36	36.5	33.2	29.4	37
Avg.	28.7	32.1	35.9	37.6	36.8	36.2	35.1	34.9	35.5	35.4	33.1	29.7	

Table A. 2 Monthly & Yearly Average Humidity in %

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
2008	69	61	67	64	70	80	83	81	81	77	69	79	73
2009	72	55	53	66	72	74	80	82	81	73	66	69	70
2010	71	56	59	67	71	79	77	78	79	74	68	66	70
2011	69	54	57	64	76	80	79	82	77	73	67	73	70
2012	66	52	57	69	70	77	79	78	79	71	68	77	70
2013	65	55	55	63	78	76	77	80	81	78	66	72	70
2014	72	62	52	56	68	78	77	82	76	72	66	77	69
2015	70	63	52	68	71	77	81	79	78	73	69	68	70
2016	68	63	59	72	74	75	82	77	82	74	73	72	72
2017	62	57	67	72	73	80	83	83	82	79	67	76	73
Avg	68.4	57.8	57.8	66.1	72.3	77.6	79.8	80.2	79.6	74.4	67.9	72.9	

Table A. 3 Monthly Prevailing Wind Speed in Knots and Direction of Dhaka

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	3.6	3.2	3.8	3.4	3.4	3.3	3.4	2.8	2.8	9.6	2.5	3.3
2009	3.3	4.1	4	4.1	3.8	3.1	4.3	2.8	4.2	2.3	2.8	2.4
2010	2.9	3.3	3.8	4.1	3.7	3	2.4	2.2	2.6	2	2.9	2.4
2011	2.2	2.4	3.8	2.4	3	2.7	2.4	2.4	2.6	2	2.3	2.1
2012	2.4	3	2.5	2.6	2.5	3	2.7	2.5	2.2	2	2.2	2.3
2013	2.3	2.2	2.6	2.8	3.2	2.3	2.7	2.7	2.2	2.9	2.1	2.3
2014	2.5	2.5	2.4	2.2	2.8	2.1	2.4	2.4	2.1	2.1	2.1	2.2
2015	2.2	2.4	2.2	2.5	2.3	2.6	2.4	2.7	3	1.9	2.5	2.1
2016	2.7	2.6	2.3	3	3.6	2.4	2.3	2.8	2.1	2	2.5	2
2017	2.2	2.3	2.5	3.1	2.5	2.4	2	2.2	2.2	3.3	2.4	2
Total	26.3	28	29.9	30.2	30.8	26.9	27	25.5	26	30.1	24.3	23.1
Avg.	2.63	2.8	2.99	3.02	3.08	2.69	2.7	2.55	2.6	3.01	2.43	2.31

Table A. 4 Monthly average Sunshine hours data of Dhaka

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	4.7	6.6	5.9	8.5	7.7	4.2	3.1	4	4.4	5.8	7.9	3.9
2009	5.7	8.7	7.3	8.3	6.8	5.9	4.7	3.9	4.1	6.2	6.7	4.8
2010	5.7	6.7	8.3	7.3	6.7	3.7	4.9	4.4	3.8	5.8	6.2	6.2
2011	4.9	7.5	7	6.8	5.5	3.5	4.1	2.5	5.1	6.1	6	4.4
2012	4.6	7.1	7.6	7.1	6.2	2.9	3.9	3.8	4	6	5.6	3
2013	4.5	7	7.9	6.5	3.6	4.8	4.4	3.3	3.6	4.5	7	4.1
2014	4.2	6.3	8.6	8.6	6.7	3.3	3.9	3.2	4.8	5.8	5.2	2.8
2015	4.4	5.4	8.5	6.4	6.4	4.7	2.5	3.4	4.2	6.1	6.2	4.6
2016	5.1	6.2	7.1	7.4	5.8	5.5	3.4	4.8	4	5.3	5.6	5.2
2017	6.2	7.3	6.1	6.1	6.8	4.2	3	3.4	3.8	4.9	5.6	4.4
Total	50	68.8	74.3	73	62.2	42.7	37.9	36.7	41.8	56.5	62	43.4
Avg.	5	6.88	7.43	7.3	6.22	4.27	3.79	3.67	4.18	5.65	6.2	4.34

Table A. 5 NDVI classification and area coverage by different land covers for the corresponding month of March to May from 1988 to 2019 in Motijheel, Gulshan, Uttara, Demra and Pallabi

Location	Month	Types of land coverage	Area coverage (km^2)			Percentage of the total area		
			1988-1992	2000-2004	2014-2018	1988-1992	2000-2004	2014-2019
Motijheel	March	Water body and Others	0.57	0.77	0.12	12.18	16.37	2.61
		Buildup Area	2.27	2.88	3.21	48.39	61.35	68.51
		Vegetation	1.85	1.04	1.35	39.43	22.28	28.88
	April	Water body and Others	0.44	0.77	0.12	9.28	16.37	2.61
		Buildup Area	2.02	2.88	3.21	43.09	61.35	68.51
		Vegetation	2.23	0.75	1.35	47.63	15.99	28.88
	May	Water body and Others	0.58	0.81	0.18	12.39	17.28	3.90
		Buildup Area	1.85	2.23	2.77	39.40	47.47	59.11
		Vegetation	2.26	1.65	1.73	48.21	35.25	36.99
Gulshan	March	Water body and Others	57.75	171.96	44.96	3.77	11.24	2.94
		Buildup Area	329.99	780.52	883.71	21.57	51.01	57.76
		Vegetation	1142.26	577.52	601.33	74.66	37.75	39.30
	April	Water body and Others	58.90	174.26	49.82	3.85	11.39	3.26
		Buildup Area	316.49	777.53	866.01	20.69	50.82	56.60
		Vegetation	1154.61	578.21	614.17	75.46	37.79	40.14
	May	Water body and Others	79.07	179.38	55.12	5.17	11.72	3.60
		Buildup Area	315.86	776.45	872.04	20.64	50.75	57.00
		Vegetation	1135.06	574.16	602.84	74.19	37.53	39.40
Uttara	March	Water body and Others	3.05	1.32	0.07	8.26	3.57	0.18
		Buildup Area	12.85	21.97	28.13	34.80	59.52	76.22
		Vegetation	21.02	13.62	8.71	56.94	36.91	23.59
	April	Water body and Others	2.63	0.75	0.06	7.13	2.04	0.17
		Buildup Area	12.85	22.82	28.25	34.83	61.84	76.55
		Vegetation	21.43	13.33	8.59	58.05	36.12	23.28
	May	Water body and Others	2.95	2.83	2.26	7.99	7.66	6.13
		Buildup Area	13.51	22.15	17.80	36.59	60.02	48.23
		Vegetation	20.46	11.93	16.85	55.42	32.31	45.65
Demra	March	Water body and Others	2.11	2.69	0.77	2.34	2.98	0.85
		Buildup Area	2.70	5.25	11.59	2.98	5.81	12.82
		Vegetation	85.55	82.42	78.01	94.68	91.22	86.33
	April	Water body and Others	2.05	2.06	0.72	2.27	2.28	0.80
		Buildup Area	2.20	5.61	10.73	2.44	6.21	11.87
		Vegetation	86.11	82.69	78.91	95.29	91.51	87.33
	May	Water body and Others	2.95	2.83	2.26	3.26	3.13	2.50
		Buildup Area	13.51	22.15	17.80	14.95	24.52	19.70
		Vegetation	20.46	11.93	16.85	22.64	13.20	18.65
Pallabi	March	Water body and Others	0.24	0.77	0.07	1.43	4.52	0.42
		Buildup Area	4.24	7.53	9.81	24.93	44.30	57.69
		Vegetation	12.52	8.70	7.12	73.64	51.18	41.89
	April	Water body and Others	0.25	0.90	0.11	1.47	5.29	0.62
		Buildup Area	4.27	7.54	9.82	25.12	44.34	57.79
		Vegetation	12.48	8.56	7.07	73.40	50.38	41.58
	May	Water body and Others	0.26	0.95	0.12	1.51	5.60	0.70
		Buildup Area	4.33	7.39	9.83	25.49	43.46	57.85
		Vegetation	12.41	8.66	7.05	73.00	50.94	41.45

Table A. 6 Descriptive statistics of air temperature (AT) of the green roof (experimental roof) and bare roof from December'18 to May'19

Roof type_time	Total no. of days	Descriptive Statistics of air temperature in 0C					
		Range	Minimum	Maximum	Mean	Std. Deviation	Variance
GR_9.30 am	142	20.00	14.00	34.00	23.53	5.94	35.33
BR_9.30 am	142	20.20	15.80	36.00	26.14	5.70	32.52
GR_1.30 pm	142	20.00	18.00	38.00	29.71	4.98	24.79
BR_1.30 pm	142	23.00	20.00	43.00	33.13	5.21	27.16
GR_5.30 pm	142	17.00	18.00	35.00	27.01	4.55	20.71
BR_5.30 pm	142	20.20	18.80	39.00	29.67	4.98	24.80

Table A. 8 Descriptive statistics of temperature differences at different types of green roofs and bare roofs in the March to May'19.

Types of roof	Statistic			Types of roof	Statistic			Types of roof	Statistic		
85% area coverage URA	Mean		4.81	70% area coverage URA	Mean		3.37	50% area coverage URA	Mean		1.01
	95% Confidence Interval for Mean	Lower Bound	4.55		95% Confidence Interval for Mean	Lower Bound	2.83		95% Confidence Interval for Mean	Lower Bound	0.85
		Upper Bound	5.08			Upper Bound	3.91			Upper Bound	1.18
	5% Trimmed Mean		4.85		5% Trimmed		3.27		5% Trimmed Mean		1.02
	Median		5.00		Median		3.00		Median		1.10
	Variance		0.34		Variance		1.41		Variance		0.13
	Std. Deviation		0.58		Std. Deviation		1.19		Std. Deviation		0.36
	Minimum		3.00		Minimum		2.00		Minimum		0.10
	Maximum		6.00		Maximum		6.50		Maximum		1.80
80% area coverage URA	Mean		4.62	60% area coverage URA	Mean		2.02	40% area coverage URA	Mean		-0.04
	95% Confidence Interval for Mean	Lower Bound	3.90		95% Confidence Interval for Mean	Lower Bound	1.79		95% Confidence Interval for Mean	Lower Bound	-0.36
		Upper Bound	5.35			Upper Bound	2.26			Upper Bound	0.27
	5% Trimmed Mean		4.62		5% Trimmed		2.03		5% Trimmed Mean		-0.05
	Median		4.00		Median		2.00		Median		0.00
	Variance		2.53		Variance		0.26		Variance		0.47
	Std. Deviation		1.59		Std. Deviation		0.51		Std. Deviation		0.69
	Minimum		2.10		Minimum		1.00		Minimum		-1.00
	Maximum		7.20		Maximum		3.00		Maximum		1.00

Table A. 9 Descriptive statistics of CO_2 concentration in green roof and bare roof

Descriptives			Statistic	Std. Error
CO2_Concentration in ppm_GR	Mean		400.06	.63949
	95% Confidence Interval for Mean	Lower Bound	398.80	
		Upper Bound	401.33	
	Median		401.00	
	Std. Deviation		7.56	
	Minimum		380.00	
	Maximum		431.00	
CO2_Concentration in ppm_BR	Mean		406.72	.60420
	95% Confidence Interval for Mean	Lower Bound	405.53	
		Upper Bound	407.92	
	Median		406.00	
	Std. Deviation		7.14	
	Minimum		385.00	
	Maximum		440.00	

Item	Percentiles						
	5	10	25	50	75	90	95
CO2 (ppm)_GR	387.00	389.10	397.00	401.00	404.00	408.00	413.80
CO2_(ppm)_BR	395.10	400.00	403.00	406.00	410.00	414.90	418.00

Table A. 10 Maximum root zone depth, container details and yield of selected vegetables

Exp. status	Name of crops	Maximum rootzone depth (m)	Height (m)	Diameter (m)	Average weight (kg)	Average Yield/plant (kg)	Soil saving (%)/pot	Yield/plant_ increasd (%)
1st_year experiment	Tomato	0.20	0.60	0.31	35.00	2.10	-	-
	Brinjal	0.25	0.60	0.31	35.00	1.44	-	-
	Bottle Gourd	0.31	0.60	0.31	35.00	5.50	-	-
	Chili	0.20	0.60	0.31	35.00			
2nd_year experiment	Tomato	0.26	0.36	0.31	15.00	2.52	57.14	20.00
	Brinjal	0.21	0.36	0.31	15.00	1.44	57.14	0.00
	Bottle Gourd	0.32	0.36	0.61	48.00	7.20	-37.14	30.91

Appendix B

Supplementary Figures

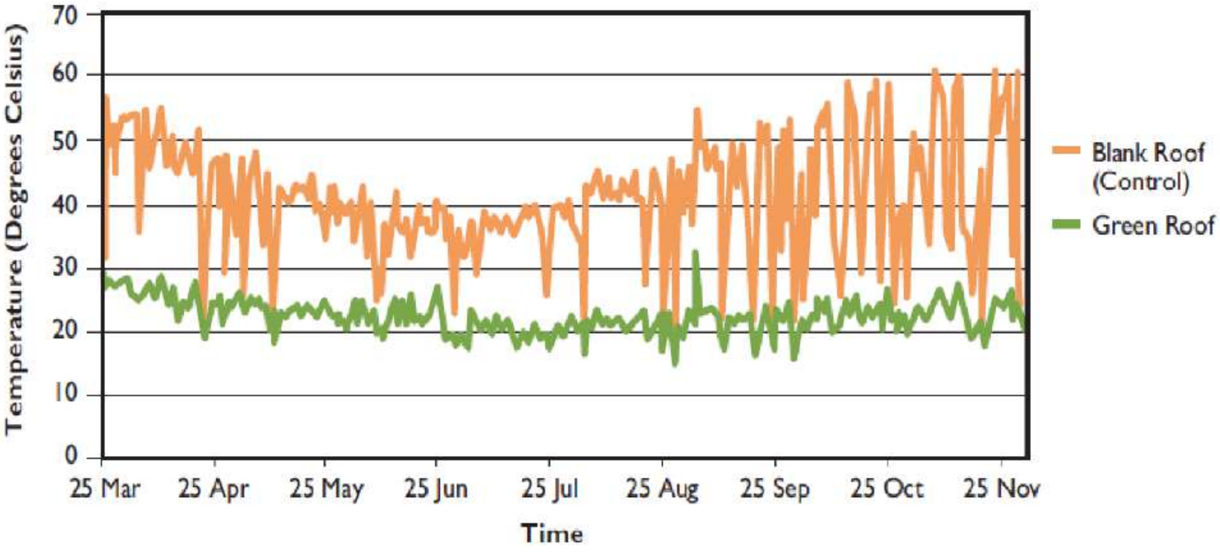

Figure B. 1 Temperature trend in the blank and green roof [261]

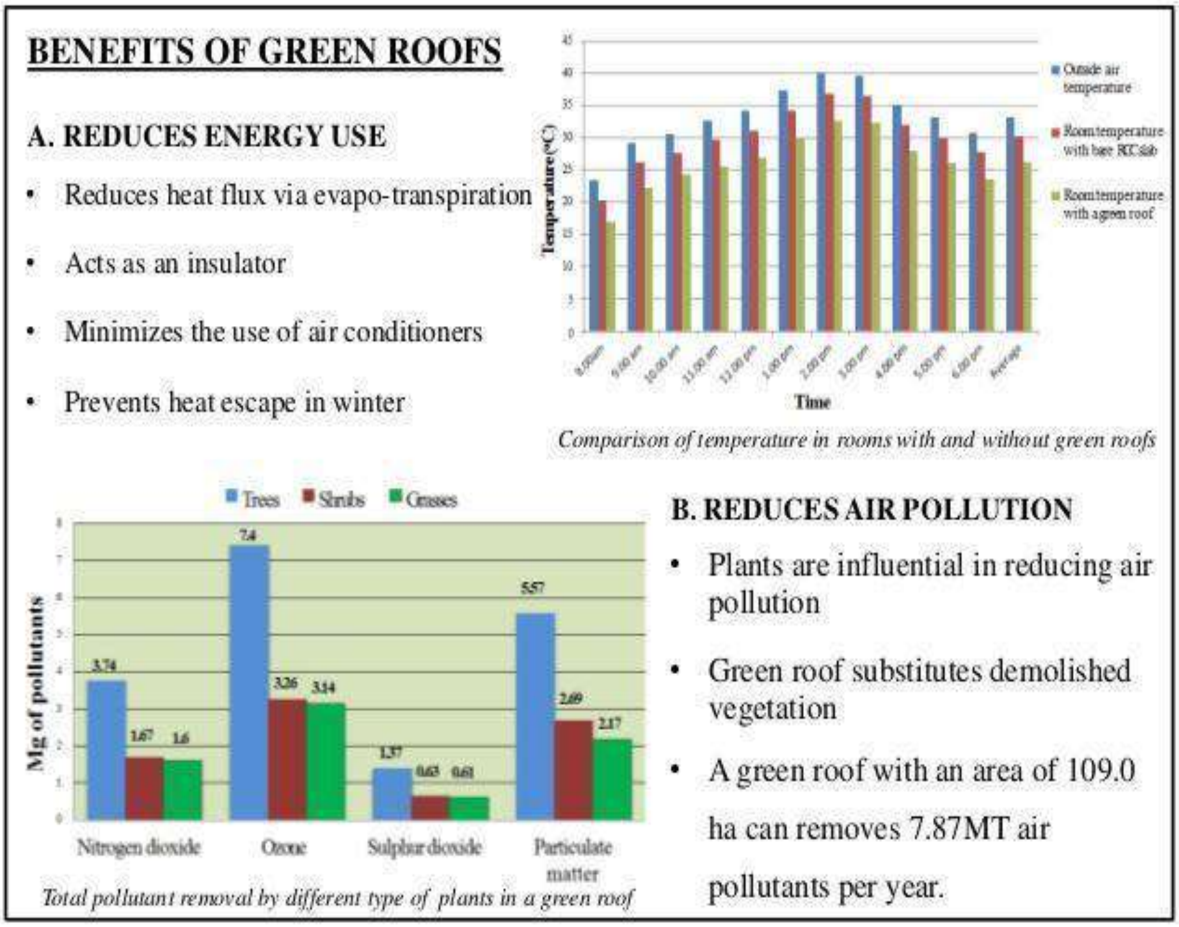

Figure B. 2 **Benefits of green roofs**

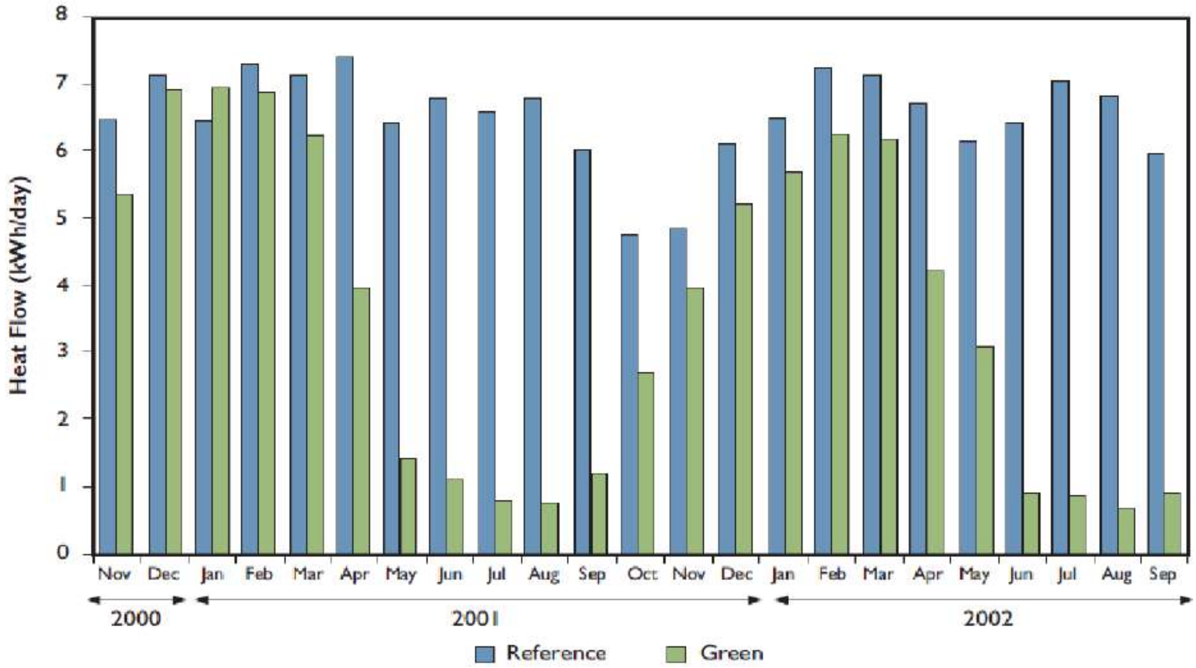

Figure B. 3 **Heat flow in the bare and green roof**

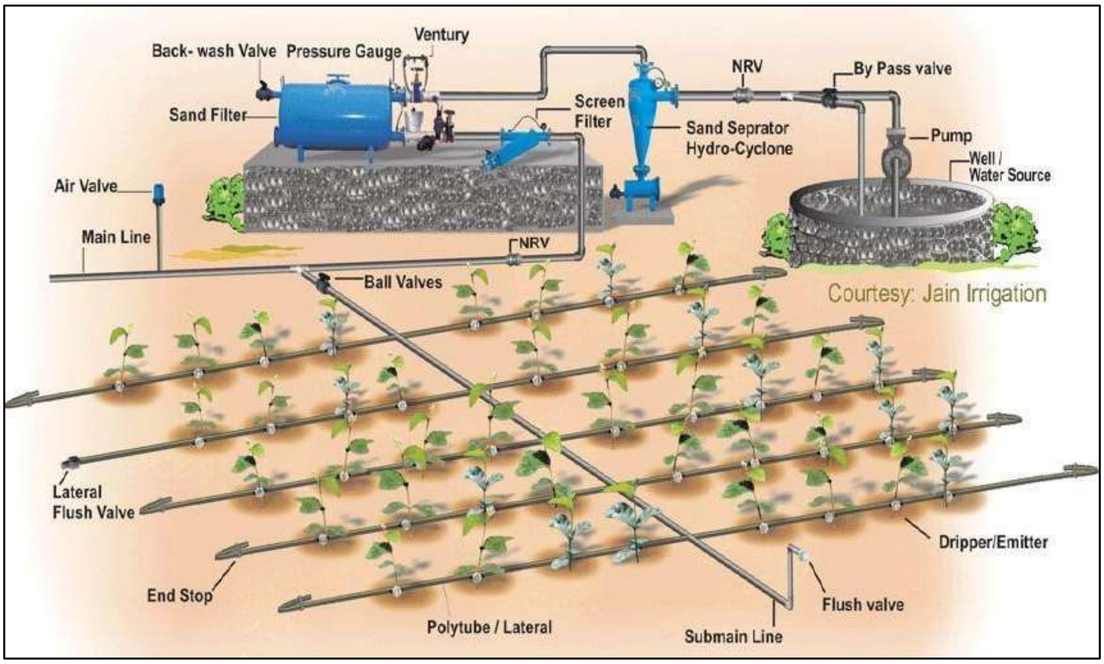

Figure B. 4 **Drip irrigation setting scenario**

Figure B. 5 Figure: Different type of drip irrigation equipments for URTA: (a)- Drip irrigation with timer; (b) Drip irrigation with mobile aps automatic system; (c) Drip irrigation with solar timer

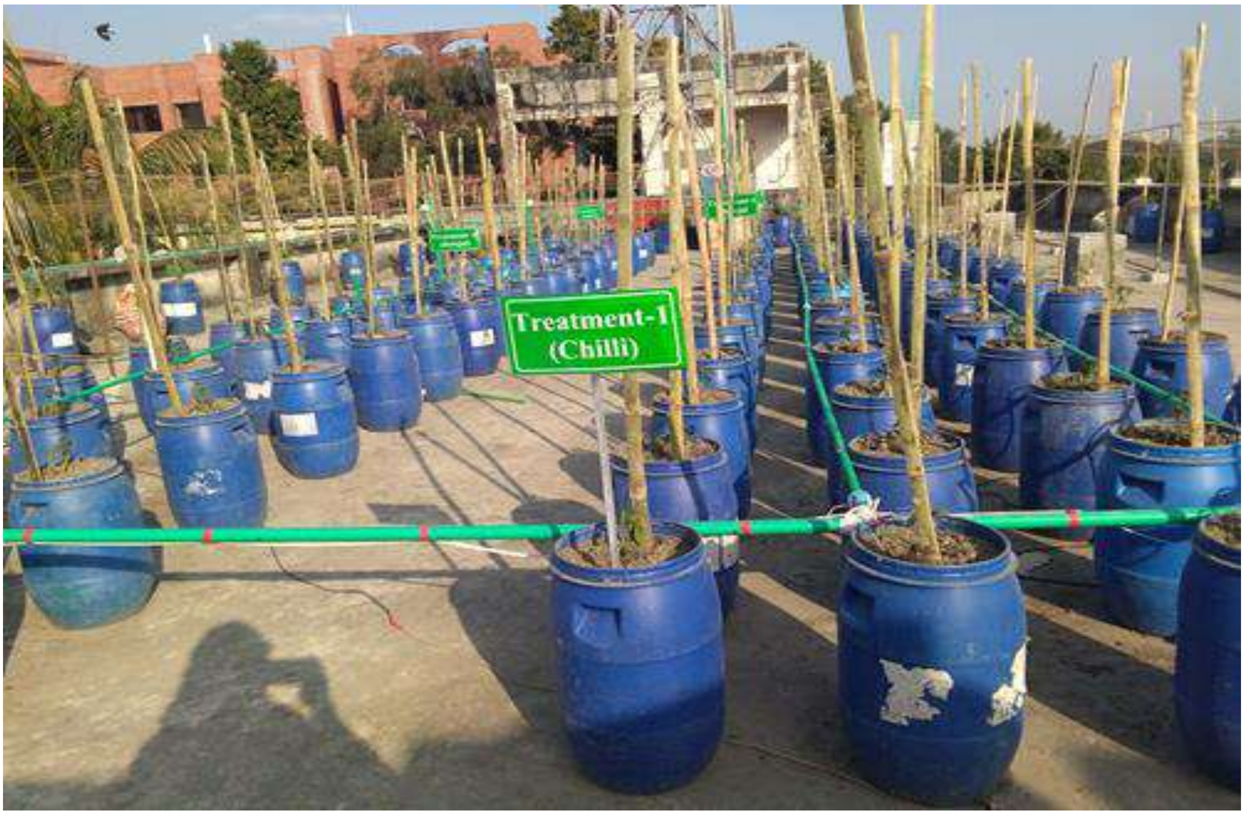

Figure B. 6 Experimental Set-up of RTA

Figure B. 7 Different vegetables cultivation scenario in the URTA.

Figure B. 8 Data collection scenario in the Experimental plot

Figure B. 9 Chili production scenario in the Experimental URTA

Figure B. 10 Leafy vegetables cultivation scenario in the experimental agricultural roof

Figure B. 11 Soil moisture measurement scenario

Figure B. 12 Chili production scenario in the experimental agricultural roof

Figure B. 13 BARI Brinjal-8 production scenario in the experimental agricultural roof

Figure B. 14 BARI Bottle Gourd 3 and BARI Bottle Gourd 4 production scenario in the experimental agricultural roof

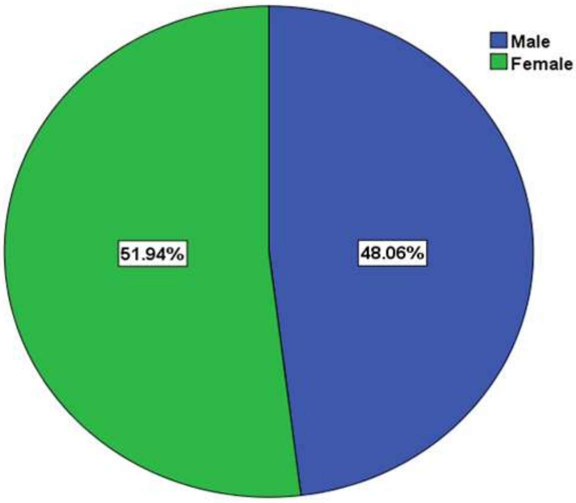

Figure B. 15 Pie graph of male-female owner of the rooftop agriculture

Appendix C

Secondary Data

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1988	1	19	19.7	20.4	21.1	21.3	21.4	20.4	19.3	20.1	20.1	19.8	20.2	20.9	20.8	20.7	20.7	19.7	19	19.3	19.3	19	19	20.6	20.1	21.9	18.3	17.4	18.7	19.1	19.4	18.9
1988	2	19.7	20	21	21.6	21.5	22.9	21.7	21.3	22.1	22.7	22.9	23.1	23.9	24.2	22.9	23	22.9	21.9	22	22.7	23.2	25.2	21.6	22.8	23.8	22.4	23.7	24.8	26.1	99	99
1988	3	23.2	24	24.2	23.6	24.9	26	25.9	27.1	26.4	27.5	27.2	24.3	26.2	22.5	24.7	25.5	27.6	27.5	24	26.2	25.1	24.9	25.8	26.3	28	29.3	28.8	27.9	27	28.8	29.3
1988	4	30.4	29.7	30.9	31.6	30.8	30.9	31.4	31.7	31.1	31.4	30.4	31.1	31.6	28.5	24.5	26.6	27.4	28.7	29.6	25.7	24.7	26.3	28.2	29.3	27.7	28.1	30.7	29.4	24.3	26.6	99
1988	5	27.9	29.8	29.5	30.2	29	28.7	26.9	29.4	30	30.5	31.2	29.3	27.6	29.4	26.3	26.8	28.3	28.7	27.5	27.2	27.7	28.2	29.8	28.7	29.2	30.5	30.9	30.9	27.2	26.1	25.5
1988	6	29.3	30.6	30	31.3	32	31.8	28.4	30	28.1	26.7	28.4	26	25.1	26.6	25.8	25	26.5	29.4	30.1	30.7	29.3	28.8	27.9	27.1	28.4	26.5	27.4	28.1	29.5	30.4	99
1988	7	29.9	28.6	29	27.9	27.1	27	26.5	26.8	27	28.2	27.7	28.6	29.6	29.5	28	30.9	29.7	28.9	30	30.6	30.2	28.5	28	29.1	29.1	28.8	29.2	29.9	29.7	29.7	30.3
1988	8	30.3	30.2	28	29.2	29.5	28.8	30	29.4	28.1	28.4	28	29.1	28.3	28.5	28.3	29.8	29.7	29.1	30	29.3	29.6	28.5	28	28.5	29.3	29.3	29.4	27.8	26.9	29.7	29.9
1988	9	29.9	28.7	28	28.9	27.3	27.8	29	27.8	27.5	28.4	30.3	29.9	28.5	29.9	30	26.9	29.4	31.4	31.9	29.5	30.5	30.4	30.1	30	31.1	31	30.9	31.2	29.1	30	99
1988	10	29.3	28	28.6	28.8	29.5	28	27.6	27.1	27.4	28.5	29.9	30.4	27.3	28.6	29.2	28.7	29.1	29.7	23.5	25.4	26.4	26.6	26.6	26.8	27	26.9	27.2	27.1	27.1	27.2	27.2
1988	11	26.2	25.7	25.6	25.7	26.4	25.9	25.5	26.1	25.9	25.5	25.4	25.3	24.7	24.6	24.8	24	23.6	24.1	25.1	24.9	25	24.9	24.5	24.4	22.9	21.8	24	21.9	21	20.7	
1988	12	20.7	22	23.5	23.3	23.4	23.2	21.9	21.2	21.2	21.4	21.8	21.9	21.5	21.2	19.9	19.9	20.2	20.3	20.5	21.2	20.6	20.6	20.4	20.7	20.4	20.6	21	20.7	18.6	19.9	19.3
1989	1	19.8	20.1	20.5	19.1	19.3	19.4	19.5	19.7	20.3	16.9	16.1	15	15.3	15.9	16.7	16.7	16.7	16.6	16.5	16.5	16.8	16.9	17	17.5	17.9	17.2	17.5	17.4	18.2	18.2	18.3
1989	2	19.8	20.7	21.1	20.8	23.5	24.5	23.8	22.2	21.2	21.4	21.8	20	19.9	23.4	23.3	24.3	23.5	22.4	21.2	16.9	18.6	20.5	21.2	21.1	21.2	22.4	23.1	25.3	99	99	99
1989	3	25.1	25.6	24	22.9	23.1	24.2	25.3	25.9	26.1	25.8	24.5	24.2	25.6	26.1	26.5	26.4	26.7	27	27.7	27.8	27.7	29.6	30.3	30.1	29.1	29.1	29.9	28.1	24.1	24.8	27.3
1989	4	27.7	29.9	30.6	30.4	29.1	28.7	28.8	29.3	29.5	30.1	29.5	30.2	30.5	30.8	30.7	30.7	30	30	31.1	31.5	30.6	31.3	31.4	31.4	31.1	29.9	27.7	28.2	25.2	26.7	99
1989	5	28.6	30	30.4	31.4	31.1	31.9	31.8	32.5	32	31.3	31.5	31.1	26.8	28.9	26.8	26.2	27	28.5	31.1	30.2	27.5	29.2	31	29.2	29.4	28.2	28.3	25.8	30	26.3	30.3
1989	6	28.9	29.7	26.2	29.1	28.4	28.8	29.5	31.2	31.5	31.8	28.5	29.7	27	27.4	26.8	30	28.5	29.4	28.9	28.8	27.2	27.8	30.2	30.1	30.2	30.2	30.1	29.3	28.2	28.4	99
1989	7	28.1	27.7	28	29	28.3	28.4	28.2	28.4	29.6	29.8	28.3	27.7	27.6	27.5	29.3	29.4	29.9	30.5	29.7	29.8	30.7	30.3	29.9	29.4	30.4	29.8	29.1	27.5	26.5	26.3	26.9
1989	8	27.6	29.2	28.9	29.4	29.4	29.3	29.3	28.8	29.1	30	29.6	28.7	29.6	30	29.3	29.5	29.8	30.2	30.1	30	28.4	30.7	30.6	29.5	30	31.2	30.6	30.6	30.8	30	28.9
1989	9	29.4	30.8	30.2	28.6	26.7	28.2	30.1	30.7	30.5	28.5	28.8	27.6	27.5	27.5	29.9	29.7	30.2	28.4	28.2	28.2	28	26.5	26.7	28.2	28	26.4	26	26.3	28.1	29.1	99
1989	10	30.3	30.3	30.4	30.7	28.7	28.1	29.1	26.4	27.3	25.4	26.7	27.3	28.4	29.7	30.1	29	26.2	23.9	26.6	26.2	27.3	27.4	26.4	25.5	25.8	26.9	27.5	26.4	26.6	26.1	26.3
1989	11	25.9	25.6	26.1	26.5	26.7	27.1	24.5	23.7	23.3	23.5	23.7	23.7	24	23.6	24.1	25.5	24.7	23.7	22.2	22.9	22.8	22.8	22.7	21.9	22.4	22.6	22.8	22.4	22.8	22.1	99
1989	12	21.2	20.4	21.1	20	19.3	18.9	18.9	18.7	18.8	18.9	19.1	19.1	19	18.9	20	21.1	21	20.3	19.6	19.3	19.7	20.4	20.8	21.1	20.7	16	16.9	17.3	16.5	15.5	16.5

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1990	1	16.3	16.8	17.1	16.9	15.7	17.1	18	17.8	17.2	16.9	15.7	17.9	19	18.9	19.5	19.3	19	19.5	18.6	19.8	21.3	21.8	21.2	21.7	21.9	21.9	22.6	23.1	22.8	22.7	21.7
1990	2	22.8	22.3	22.2	21.7	22.2	22.4	22.4	22.4	23.2	24.5	22.9	23.2	23.6	20.1	20.7	21.8	21.3	22.6	22.7	22.5	22.1	20.2	21.3	22.7	22.1	20.8	23.8	25.1	99	99	99
1990	3	23.7	23.5	20.6	20.6	22	19.6	21.4	23.5	24.5	23.7	25.4	20.9	21.1	23.4	24	24.4	27.4	28.5	27.6	27.7	28.3	28.7	26.6	21.1	20.4	23.5	23.2	21.4	23.1	25.8	24.8
1990	4	22.6	25.3	25	20.9	21.8	24.4	25.5	25.1	27.9	28.8	29.1	29.1	29.3	28	28.8	29	28.6	28.7	26.8	26.3	29.7	30.1	30	29.2	28	25.7	28.1	27.5	27.3	28.7	99
1990	5	27.3	28.1	29	26.2	28.5	30.2	28.7	30.1	29.5	28.1	28.7	27.8	27.2	26.1	23	28	30.3	30.9	28.7	25.8	29.7	28.5	30.3	31.2	27.1	28.8	28.8	28	26.4	29.5	28.4
1990	6	26.1	28.4	29.6	30.2	28.1	29.1	30.9	30.5	26.2	28.2	30.2	30.6	29.5	28.7	29.2	30.1	29.9	29.9	29.2	29	29.7	29.3	28.1	29.1	30	28.5	28.4	29.8	29.8	28.6	99
1990	7	29.7	28.7	26.9	27.5	27.2	28	28.1	27.2	26.9	28.5	28.1	28.4	28.1	27.9	28.1	27.3	28.6	28.7	28.5	28.2	28.4	29.1	29.3	28.6	28.9	28.6	28.1	26.9	27.9	28.4	29
1990	8	27.8	27.6	27.3	28.5	28	27.9	28.3	29.6	29.9	29.3	30.3	29.8	29.3	28.9	28.3	28.3	29.1	29.5	30.4	30.3	28.4	29.3	30.2	30.1	28.6	29.8	29.6	29.7	29.8	30.5	31.1
1990	9	30.5	28.6	28	28	28.4	28.9	29.1	29	29.3	27.9	29.1	29.1	29	29.5	30	29.3	27.3	27	28.1	29	29.1	29.5	29.2	27.5	27.9	27.9	27.5	27.4	27.4	27.9	99
1990	10	27.7	27.2	26.7	26	29	29.9	27.3	25.2	25.1	24.9	26.9	27.9	27.7	28.5	27.3	26.3	26.7	27	27.2	27	26.7	27.4	27.2	25.8	25.2	24.8	25.4	25.3	25	25.5	25.5
1990	11	25.8	27.5	27.8	23.7	25.4	26.4	26.5	27.1	27.3	27.4	25.5	27.3	28.1	27.6	26.4	24.6	25	25.2	24.9	25	25.4	25.5	25.3	25.3	24.7	23	22.5	21.9	21.4	20.9	99
1990	12	22.2	23.2	22.5	21.7	22	22.3	22.4	22.1	21.9	21.8	22	21.4	20.9	20.5	20.1	20.7	20.8	18.5	20	20.4	20.5	19.5	19.8	19.7	19.1	19.3	19.6	20.3	20.8	20.6	20.2
1991	1	20.6	19.2	17.3	16.5	17	17.8	18.2	18.7	19.9	19.4	20.4	20.3	19.6	19.3	17.8	17	17	17.5	17.3	17.3	16.4	18	18.8	18.2	17.7	18.8	20	20.8	21.5	21.5	22.2
1991	2	23.5	23.2	21.7	19.4	20.2	20	21.5	22.6	22.6	22.7	23	24.9	24.1	22.1	22.6	20.6	21.6	22.7	23.1	23.2	23.2	25	24.6	25.4	26.9	27.7	24.1	24.7	99	99	99
1991	3	23.5	24.8	24.8	26	25.8	25.4	24.9	24.9	27.2	28	27.5	25.4	24.2	26.5	27	28.5	29.3	30	29.8	30.2	30	29.3	26.6	24.9	25.1	27.2	27.6	28.5	27	26.9	26.7
1991	4	28.1	29.3	29.7	29.3	29.7	26.6	26.8	26.3	26	24.5	26.6	28.8	28.9	29.7	29.7	30.8	31.1	30.4	31.1	31	29.9	29.6	29.2	28.6	29.6	30.3	30.4	27.1	25.8	27.6	99
1991	5	29.9	30	27.2	28.4	26.2	28.3	29.9	29	29.1	28.5	26.4	28	27.5	26.1	25.8	25.6	26.7	24.5	25.5	26.8	26.1	24.9	27.9	27	29.2	27.5	26.1	25.5	29	29.8	28.6
1991	6	26	25.7	28.7	29.3	26.3	27.4	28.1	28.7	27.9	28.7	26.8	27	28	28.7	28.8	28.7	27	26.2	28.6	30.4	30.4	30.9	30.5	30.1	27.3	29.5	30.2	29.5	28.8	29.3	99
1991	7	28.9	29.9	28.3	27.5	27.5	28	29.5	28.4	29.1	29.4	29.7	30.3	30.2	30.6	30.2	29.2	28.7	28.2	27.3	28	27.1	27.8	28.9	29.9	30.4	30.7	30.7	30.1	28.7	28.4	29.3
1991	8	29.3	27.5	27	28.3	29	28.4	29.1	28.9	29.1	29.2	29	29.2	29.1	29.1	28.6	28.2	27.9	29.5	29.7	31.7	29.7	28.2	28.6	29.1	29.5	28.9	29.3	29.2	29.4	29.3	26.5
1991	9	28.4	28.6	26.9	26.9	27.1	27.7	26.7	27.5	26.8	26.4	28.8	29.1	26.9	28	25.9	28.8	29.1	29.7	30.1	30.6	29.9	28.7	27.1	26.4	27.2	25.2	27.7	28.3	28.7	29.2	99
1991	10	29.9	30.7	27.8	28.7	27	26.8	27.4	28.6	28.5	28.9	28.9	27.6	24.3	25.8	25.7	26.8	27.8	27.6	27.2	26.7	26.5	26.3	27.4	27.8	27.7	27.5	28.1	28.2	25.9	25.9	23.1
1991	11	25.1	25.8	25.7	25.9	25.2	25.1	24	24.2	24.5	24.3	24.7	24.5	24.1	23.4	23.5	23.3	23.9	23.8	23.7	21.9	21	21.2	21.5	21.1	21.5	21.7	21.9	22.4	21.4	20.7	99
1991	12	19.7	20.2	19.9	19.5	19.5	19.8	20.4	21.9	23.5	23.6	22.8	21.8	21.2	20.6	20.9	19.7	19.7	19.2	19.3	19.2	19.8	20.2	21.9	19.6	16.9	16.6	16	16.2	16	15.5	16.6

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1992	1	16	16.1	15.8	17	17.1	16.5	17.5	17.8	18.2	18.6	18.7	20.2	17.1	16.2	18.1	19.4	19.1	18.4	17.6	18	18.9	18.3	19.6	19	19.4	19.8	20.9	21.1	22.1	21.6	20.9
1992	2	20.1	21.4	20.6	19.9	20.2	21	20.7	20.1	20.1	20.8	18.8	18.4	19.1	22.4	21	20.2	20.5	20	19.5	21.5	20.9	21.6	21.8	20.7	20.6	20.4	21.8	20.3	22.8	99	99
1992	3	25.9	24.7	23.8	23.7	25.2	26.1	26	24.4	25.2	25.7	26.8	27.1	27.2	28.2	27.9	25.5	26.1	26.8	27	27.2	27.3	27.5	28.7	29.2	29.4	29.1	29.5	29.4	29.8	29.6	29.5
1992	4	28.6	28.7	29.2	30.3	29.1	28.9	29.7	29.9	30.2	30.4	30.8	30.5	30.7	30.9	30.8	31	29.5	29.9	29.9	29.9	30.4	30.6	30.8	31.3	30	29.1	28.9	26.6	29.5	28	99
1992	5	27.5	25.2	23.3	25.5	27.4	28.8	29.3	30.9	30.5	30.2	31.1	31.2	31	28.8	29.7	31	31	30.6	29.5	28.4	26	27.4	26.4	28.9	26	24.1	26.2	28.6	29.8	28.1	30.2
1992	6	30.1	30.9	31.5	31.3	31	30.9	30.8	28.7	29.7	28	29.2	28.2	28.8	30.1	31.2	30.5	30.5	30	29.3	29.7	29.2	28.6	28.1	27.4	29.3	29.5	26.4	27.1	29.2	29.6	99
1992	7	29.2	29.4	27.5	29.1	28.5	28.2	27.9	29.2	29.1	27.8	26.7	28.4	29.4	29.6	29.3	27	27.7	27.7	27.5	27.1	27.6	28.7	29.4	31.1	29.4	29.9	28	28.3	29.7	29.3	27.3
1992	8	28	28.3	28.8	29.2	27.9	26.7	27.7	27.3	28.1	28.6	28.6	31.3	30.6	30.1	29.3	29.3	29.4	29.7	29.3	28.8	28	28	28.2	29.5	30	28.3	28.1	29.2	29.5	30.3	30
1992	9	29.3	29.8	29	29.9	29.9	29.8	30.2	29.4	29.9	29.2	27	26.8	28.9	29	29.4	30	29.6	28.9	30	30.2	30.3	31.1	29.4	28.7	27.4	27.5	26.9	26.1	25	27.1	99
1992	10	28.4	29.2	29.6	27.1	28.3	28	29.6	29.8	28.8	28.2	29.2	28.9	28.7	26.9	26.8	27.1	27.4	27.7	27.6	26.5	24.7	26.1	26	25.4	25	24.4	25.1	26.2	26.9	27.5	28.1
1992	11	28	27.7	26.5	26.4	25.5	25.5	25	23.7	23.8	24.9	23.6	24.5	23.5	23.5	22.4	22.3	22.4	23.5	24.1	24.2	24.7	22.8	22.5	19.9	20.2	21.1	21.7	22	23.3	21.7	99
1992	12	21.7	20.7	20.2	20.6	20.7	19	18.7	18.7	19.1	19.1	18.1	18.1	18.1	18.2	17.8	17.7	17.4	17.4	17.5	17.4	17.4	17.8	18.3	18	17.7	18.9	17.8	17.4	18.3	18.4	18
1993	1	18	16.3	18.3	19.8	17.5	18.4	20.9	22.2	22.1	19.3	18.6	19.4	18.5	15.8	16.1	16.7	17.3	17.7	15.3	14.9	14	14.6	15.2	15.2	15.2	16	16.5	18.2	20.2	22.6	21
1993	2	19.5	19.8	21.2	21.1	22	20.7	20.7	21.3	22.1	22.1	22	23.4	24.5	25.1	25.2	25.5	26.5	25.5	24.3	22.1	21.1	18.7	19	21	21.2	23.7	23.8	23.9	99	99	99
1993	3	23.6	23.4	23.3	23.2	22.9	22.9	22.7	23.7	24.6	26.2	26.4	27.4	27.4	27.8	28.2	27.5	26	24.8	26.8	25.9	23.7	22.9	23.8	25.7	21.8	22.7	24.1	23.7	22.9	23.7	25.9
1993	4	27.7	27	28.1	29.1	29	30.3	29.7	28.9	27	27	24.6	24.8	24.5	27.4	26.7	25.4	29.4	28.8	29.4	28.5	28.5	29.9	25.4	27.7	28.4	27.5	27.6	28.1	27.1	25.5	99
1993	5	23	24	26.8	29.2	29.7	26	22.2	23.8	26.4	27.9	25.3	28	26	28.4	29.4	23.3	28.7	24	27.1	27.5	29.1	30.1	30.5	30.3	30.9	30.5	28.8	27.7	27.9	28.4	29.7
1993	6	25.7	28.2	28.3	29.8	30.2	29.5	29.2	27.9	30	30.8	30.5	26.1	28.7	30.7	29.1	28.2	26.9	25.9	26.8	28.8	29.4	27.7	28.9	29.5	26.9	28.4	30	30.4	29.4	29.2	99
1993	7	27.2	27.9	29.4	29.7	28.8	27.1	29.1	29.3	28.2	28.9	29.3	30.1	30.4	29.3	27.6	27.8	27.6	28.9	28.2	28.7	26.6	26.8	26.2	26.9	29.3	29.4	29.3	29.7	30.2	29.4	29.9
1993	8	29.3	28.9	28.8	28.1	27.4	28.6	29.9	28.8	28.5	29.2	29	28.1	29.2	29.6	29.2	28.7	28.8	29.3	28.7	27.9	27.4	28.1	27	25.8	27.4	28.5	27.7	28.5	29.2	28.8	26.6
1993	9	26.4	25.7	25.5	28.6	28.9	28.3	28.2	28.6	29.4	29.6	30.7	28.1	28.5	27.7	27.6	28.5	29.4	29.7	31	29.2	28.5	27.9	27.6	28.2	27.5	28.7	28.7	27.8	26.2	28.3	99
1993	10	28.5	27.6	28.5	27.8	29	28	29.3	29.3	29.2	29.4	28.2	28.5	26.9	26.2	25.7	26.2	27.2	26.7	27.4	26.6	27	28	25.5	25.4	25.7	25.3	25.9	24.8	25.4	26.2	26.4
1993	11	25.2	26	23.9	23.8	24.7	25	24.7	24	24.4	24.7	24.7	23.7	24.3	24.2	24.3	24.1	24.2	24.7	24.4	24	22.9	22.5	22.6	22.5	22.4	22.5	22.2	21.1	21.6	21.8	99
1993	12	21.9	21.3	21.3	20.7	20.9	21.3	21.1	21.3	21.7	21	20.3	20.2	20.2	19.2	18.1	18.4	18.6	19.3	19.9	19.4	19.1	18.5	18.4	18.8	19	18.6	18.6	19	18.7	19.2	20.3

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1994	1	19.4	18.9	19.6	19.4	19	18.4	18.4	17.9	18.3	18.4	19.2	19.5	20.7	20.8	21.5	19.2	16.6	17.3	18.2	19	18.9	18.2	18.1	17.8	18	19.3	20.7	20.7	20.8	21.9	18.9
1994	2	19.9	15.6	16.2	17.7	19.1	18.6	20.7	21.1	18.8	18.8	18.4	19.2	20.3	20.6	21.6	21.7	21.8	22.9	21.8	22.6	24.4	19.7	20.7	18.8	19.2	20.4	22.5	24.3	99	99	99
1994	3	24.2	21.9	22.4	23.4	25.9	27.1	25.1	24.3	23.6	23.1	24.3	26.5	27.9	27.9	28.5	28.6	28.6	29.1	29	28.9	29.5	29.2	28.7	29	27.9	26.3	23.7	24.8	24.4	23.9	27.1
1994	4	25.8	23.8	25.2	25.9	27.7	28.9	29.7	30.5	29.3	29.7	29.6	28.6	29.3	31	31.2	28.4	26.1	26.2	26.4	26	24.5	22.4	26	26.6	28.7	29.2	28.2	30	31.1	29.8	99
1994	5	29.4	30.3	31.8	31	31.2	30	29.6	27.2	26.8	27.7	30.3	30.8	31.4	30.8	28.6	26	26.6	25.3	28.8	25.4	28.1	28.9	28.3	28.6	27.1	27.9	30.6	31.1	31	30.5	30.8
1994	6	30.6	31.4	30.9	31.1	26.1	29.8	30.5	30.1	30.3	29	28	28.3	28.9	29.1	29	28.5	27.1	27.7	28.4	27.9	29.1	29.5	29.3	29.5	28.7	29.7	28.2	26.7	27.5	29.2	99
1994	7	29.6	28.2	29.1	28.8	29.6	28.9	27.2	29.3	29.6	30	29.8	30	28.8	29.7	29.8	29.8	30	28.6	27.9	28.7	28	28.3	28.6	30	30.1	29.9	30.6	29.9	29.1	29	29.9
1994	8	30.7	29.1	29.2	29.1	29	28.6	30	29.5	29.8	28.7	27.9	27.6	28.2	28	29.2	29.5	29.2	28.9	28.7	29.9	29.5	27.9	28.7	28.1	27.9	29.8	30.1	30	29.7	29.6	27.2
1994	9	29.3	29.6	30.1	29.2	28.2	29.1	29.5	29	26.9	27.3	28	27.5	29.1	29.5	30.5	29.5	29.2	29.1	28.2	29.5	28.7	28.8	28.7	29	28.4	28.8	28.8	28	28.7	28.7	99
1994	10	29.8	28.2	29.2	26.2	26.8	26.9	26.4	28	27.4	26.4	29.1	28.9	27.7	27.2	27.4	27.8	26.3	26.6	27.1	27.6	27.3	27.1	27.8	27.2	26.2	26.3	26.8	26.4	26.6	26.4	26.7
1994	11	26.4	26.6	25.6	25.6	25.9	25.8	25	25.3	25.6	24.6	25.2	25.3	24.8	22.2	21.9	22.7	22.3	21.9	21.7	22.4	23.3	23.6	22.5	21.4	20.7	21.2	21.4	20.8	21.7	21.7	99
1994	12	21	20.1	19.6	20.2	20.1	20.1	19.6	19.8	20.4	22.5	22.7	19.5	16.7	17.5	18.5	18.3	18.1	17.9	17.8	18	17.7	17.5	17	18.4	19.3	18.3	18.1	19	18.4	17.7	17.8
1995	1	18.3	14.8	14.2	15.1	17.1	19.1	19.8	20.3	17.7	19.8	20.2	18.6	17.5	16.1	18	19.6	19	17.8	18.7	17.2	16.9	16.1	16.4	17.1	15.1	17.4	17.9	19	18.7	18.1	18.4
1995	2	19.2	19.4	18.4	19.6	18	18.4	18.8	19	20.9	21.1	23.1	23.3	25	25.1	23	20	20.3	21.5	20.9	21.9	23.3	24	21.8	21.3	19.6	20.8	21.7	23.8	99	99	99
1995	3	23.7	23.2	23.8	22.6	22.1	24.4	23	23.4	25.1	23.3	21.7	24.3	23.3	23.5	24.9	25.6	26.9	28.3	28.5	28.6	28.9	29.6	28.9	30.6	30.9	30.2	27.9	27.5	28.6	27.8	28.6
1995	4	30.6	29.6	29.3	30.1	29.4	29.5	28.8	26.3	27.8	29.6	27.5	27.5	29.3	28.5	27	28.7	29.9	30.7	31.6	30.4	30.2	31.2	31.8	31.4	31.1	31.8	31.4	31.8	31.1	31.9	99
1995	5	31.2	32.3	31.3	31.9	28.5	30.5	31.6	29.7	30.2	29.6	30.1	30.3	30.8	29.4	26.8	26.8	26	30.1	29.8	29.8	29	29.6	30.4	30.5	29.8	30.6	31.2	30.8	31.1	31.3	30.8
1995	6	31.4	31.4	31	29.2	29.6	29.3	29.7	29.8	31.4	30.8	30.2	27.4	27.8	30.4	30.6	29.2	25.1	26.9	27.1	28	28.9	28.9	27.9	28.1	29	29.4	30.1	29.7	30.6	30.2	99
1995	7	29.1	28	27.8	26.9	26.1	27.6	28.9	29.9	29	28.6	28.2	28.3	29.3	29.5	29.5	29.5	29	29.6	29.6	29.6	27.7	26.6	27.7	29.3	29.5	27.9	27.7	28.4	28.6	28.8	29.4
1995	8	30.2	29.5	27.2	28.2	28.5	30.1	29.6	28.4	29.4	29.6	29.2	27.8	26.5	29.5	28.3	29.5	28.7	27.7	27.9	27.1	28.6	29.1	30.2	29.9	29.8	28.6	30.1	30.4	30.7	30.2	30.6
1995	9	29.9	28.6	27.8	28	27.1	28.4	29.3	30	27.9	28	28.6	28.7	29.4	30.5	29.9	29	26.8	27.1	29.2	29.1	29.5	29	29.2	28.4	28.1	27.4	27.9	27.8	28.2	28.3	99
1995	10	28.3	28.7	29.5	28.5	28.2	28.5	29	25.6	27.1	28.7	28.4	28.8	29.3	28.7	28.5	28.4	28.6	26.9	26.8	27.7	26.8	28	28.1	26.8	26.2	26.4	26.3	25.6	26.7	27.3	24.5
1995	11	25.8	26.3	25.7	25.2	25.2	25.9	26.6	27.6	24.2	25.3	26.1	23.5	23.6	23.7	24.7	26.2	26.4	24.9	23.4	23.2	22.8	21.3	22.3	23.4	22	21.7	19.8	19.4	20.3	20	99
1995	12	19.7	19.6	18.5	18.5	19.2	19.5	19.8	19.7	19.6	19.8	20.2	20	20.4	18.2	17.9	18.1	18.1	18.2	18	17.8	18.3	19.2	20.5	19.2	21	20.7	19.1	16.4	16.8	18.4	19.1

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1996	1	20.2	20	19.7	19	19	18.5	18.5	19.4	20	19.6	20.6	19.9	17	17.5	19.6	21.8	17.6	17.4	16.3	16.3	15.8	16.9	16.8	18.2	17.3	17.8	18.9	18.8	17.4	15.9	16.6
1996	2	18.6	19	19.7	20.9	20.8	21.9	20.5	20.8	22.6	22.3	22.7	21.4	20.6	20.3	21.7	21.5	20.9	20.8	21.3	22.5	21.4	24.7	24.8	26.1	27	23.7	24.6	21.7	22.6	99	99
1996	3	23.1	24.4	24.6	25.6	23.5	24.8	25.7	27.4	27.8	27.6	28.1	28.2	29.1	28.8	28.8	29.1	29.9	29.2	29.6	29.8	29.9	26.8	28.2	28.2	27.7	25	25.7	27.5	28.6	29.5	28.3
1996	4	28	27.9	27.9	28.9	29.2	28.8	29.9	30.2	30.3	29.9	29.5	30.1	31.1	30.8	31.9	31.9	31.3	28.8	29.9	31.7	31.2	27.9	27.8	25.4	24.9	22.5	27	27.2	26.1	28.7	99
1996	5	27.6	27.7	30.2	30.1	30.4	29.8	29.1	29.9	31.1	30.7	28.8	27.3	29	28.2	28.3	30	27.7	29.2	30.3	30.2	31.4	31.2	31.7	31.8	31.9	30.7	30.7	29.6	28.6	25.5	27.8
1996	6	27.5	25.1	28.3	25.6	28	29.5	27.1	28.2	28	30.1	28.4	29	29.7	30.8	30	30.8	26.8	29.6	29.4	26.9	26.6	28.5	27.7	27.2	27.9	27.8	29.3	29.3	28.3	26.7	99
1996	7	27.1	28.3	27.8	28.5	28.6	28.4	28.7	29.2	29.8	29.5	28.6	26.8	29.6	29.8	29	28.8	29.9	30.1	29.9	29.8	29.9	29.4	29.3	29.7	29.5	27	27.5	28.4	29.8	29.1	29
1996	8	29.8	28.7	28	29.2	28.3	27.8	27.7	27.3	28.8	29.2	29.1	29.7	27.9	28.3	27.7	27.6	26.8	26.7	26.2	26.8	25.8	27.2	28.8	28.9	30.2	30.1	30.4	28.4	28.4	28.4	28.5
1996	9	28.6	28.9	29.9	28.5	28.7	28.8	28.5	29.1	30	29.8	29.4	28	31.1	31.8	32.1	28.5	28.3	28.8	28.5	28.9	27.6	28.2	29.6	28.9	29.1	28.4	28.1	28.3	28.3	29.3	99
1996	10	30.6	29.5	28.3	29	28.9	24.4	26.8	25.8	25.9	26.7	27	26.9	27.7	27.5	27	27.3	27.1	26.5	26.8	26.8	27.4	27.3	27.4	27.2	27.9	26.5	24.7	24.3	25.4	23.7	24.5
1996	11	25.4	25.7	27	28.8	28.5	27.9	27	26.4	25.5	23.9	23	22.8	22.9	23.2	23	23.3	22.8	22.4	22.8	23.2	22.2	22.5	21.2	20.4	18.8	20.5	20.3	20.3	20	20	99
1996	12	21.5	24.2	23.8	24	22.5	22	20.1	19.3	18.5	18.1	18.8	19.3	18.1	19.1	18.3	17.8	18.1	17.6	19.5	19.2	19.7	19.1	18.9	19.7	19.7	19.4	19.2	18.9	19	19.2	19
1997	1	19.6	19.8	17.9	18.4	18.1	17.8	18.3	18.9	18.7	19.2	18.4	17	17.4	17.8	17.8	19.5	17.1	16.1	16.2	18.7	17	16.3	14.7	14.9	15.2	15.6	16.7	17.4	17.4	17.6	20.4
1997	2	19.7	18.2	21.2	21.3	20.3	19.7	17.4	16.2	19.9	18.7	19.6	19.1	17.7	20.6	23	24.3	23.5	22.1	22.9	20.3	21.3	21.2	20.2	20.4	21.3	24.3	23.7	23.2	99	99	99
1997	3	24.7	25.9	26.7	27.2	25.9	26.4	26.2	25.9	25.5	27.8	27.9	28	27.9	26.3	27.8	29	28.8	28.4	29.1	29.1	28.1	27.3	25.2	25.1	25.3	26.3	26.6	27.9	25.7	23.1	24.1
1997	4	26.7	24.3	25.4	25.8	23.3	25.6	25.4	22.5	24.9	25.5	25.3	24	25.9	27.2	23.8	27.2	27.3	28	29.4	29.5	29.1	27.9	22.6	27.6	26.3	23.7	24.3	24.7	26.8	28.4	99
1997	5	28.1	29.2	30.1	28.9	28.5	29	26.2	28.5	29.7	28.8	30.8	31.2	31	30.3	31.4	29.5	30.8	30.9	28.3	29.1	30.9	30.3	25.7	27.9	27.4	26.4	25.9	25.9	25.6	27.9	30.6
1997	6	30.8	29.5	29.8	30.3	30.7	28.3	28.6	27.7	27.8	29	28.2	29.1	29.5	29.8	30.6	29.8	29.5	28.3	28.9	27.5	27.8	28.2	30.1	28.3	30.6	30.2	27.8	28.3	27.7	28.4	99
1997	7	29.7	28.3	28	29.3	29.1	29.6	29	29.9	26.9	26.5	26.8	26	26.4	28.9	29.5	30.4	30.1	29.6	28	26.6	26.5	28.4	29.2	30.3	30.8	30.4	29	29.2	30	28.9	27.8
1997	8	29.1	29.8	31.1	30.6	29.1	29.5	29.2	28.9	28.3	27.8	27.5	27.9	27.2	27.6	28.9	29.3	29.8	30.1	29.9	29.7	28.8	28.7	28.2	29.7	31.3	31.1	31.9	29.4	28.5	27.5	28.6
1997	9	28.9	29.2	28.8	29.2	27.7	27	28.5	27.7	28.1	29	28.7	27.7	26.3	28.3	28.2	27	29.4	29.4	29.8	27.8	29.1	27.6	27.8	29.1	27.4	25.7	25	27.9	25.7	26.1	99
1997	10	26.6	26.6	27.2	26.9	27.7	28.4	28.8	28.8	27.3	27	27	26.7	26.8	26.5	26.3	26.5	26.3	26.2	26.1	26.3	26.4	26.3	27	26.5	26.5	25.9	24.6	24.9	25.1	24.3	24.9
1997	11	24.9	24.5	24.4	24.2	25.3	25.4	26.2	25.5	26.2	25.5	25.6	24.7	22.4	23.6	22.7	22.9	21.9	23.1	23.7	24	23.4	22.1	22.6	24.4	24.7	24.9	24.5	22.8	21	22.9	99
1997	12	21.2	21.5	21.3	20.8	20.8	21	21.4	21.5	20.6	18.6	18.5	18.9	19.6	18.4	18.7	18	18.5	19.7	17.6	15.4	16.6	16.3	15.4	16.9	17.3	18.6	17.9	18	18.5	20.1	20.7

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1998	1	18.6	16.6	16.8	13.3	14.5	13.7	13.2	13.8	14.6	13	13.7	15.2	18.9	18.9	17.8	19.7	20	19.4	18.3	18.3	14.3	16.1	16.5	17.4	19.1	20.1	20	19.8	19.1	20.1	19.6
1998	2	20.4	20.5	21.4	20.2	18.9	18.4	17.4	18.5	18.8	19.8	20.2	20.5	20.8	21.1	22.7	24.4	24.6	23	23.8	23	22.4	22.3	23.6	24.9	24.7	23.9	23.9	23	99	99	99
1998	3	22.2	21.3	22	23.2	24.5	26	22.8	20.7	21.9	24	26.2	25.7	25.1	25.3	24	24.1	25.3	25.8	26.1	26.9	28.3	29.3	23.7	20.8	23.9	24.3	25.4	25.7	26.7	21.8	22.1
1998	4	24.4	25.4	26.5	28.4	28.4	26.1	25.9	26.1	26.5	28.7	29.6	30.3	30.6	30.6	29.1	27.9	25.5	27.9	26.9	25.7	26.1	25.4	23.1	24.7	28.3	28.7	28.6	28.3	29	30.2	99
1998	5	29.5	24.8	24.9	28.4	23.7	27.1	29.1	29.4	31.1	28.5	27.2	30.1	30.9	31.9	31.6	28.3	30.4	31.5	31.4	31.7	32.8	32	31.9	29.1	28.1	25.2	25	24.9	29.5	30.3	31.5
1998	6	32.1	32	27.5	31.4	31.8	32.1	31.7	32	31.5	29.9	30.7	31.1	30.8	31.1	31	30.4	30.9	31.2	31.2	31	29.6	30.6	30	30.1	28.8	29.7	29.9	29.6	30.2	30.5	99
1998	7	30.4	29.9	29.4	28.8	28.2	28.1	28.9	28.7	29.3	29.4	28.3	27.4	28	26.7	26.9	28.6	27	27.7	28.5	29.8	27.4	28.4	27.3	28.9	30	30.2	30.2	29.7	29.5	30.3	30.7
1998	8	30.7	30	28	28.5	29.7	29.3	29.5	30.1	30.4	29.3	28.3	28.6	27.1	27.6	28.5	29.4	26.8	27.7	29.1	29.4	30.7	29.2	29.8	29.4	28.2	28.1	28	29.4	29	28.5	28.6
1998	9	29.8	28.8	29.5	28.4	28.9	27.7	28.6	27.9	26.7	27.7	27.7	28	28	27.8	29.5	28.7	28.3	30.1	30	27.1	26.7	29.4	30.4	29.3	30.7	31.3	30	28.2	29	27.6	99
1998	10	28.1	28.1	27.6	28.1	29.9	30	29.8	30.5	30.6	30.2	29.8	30.4	29.2	29.3	27.4	27.4	28.6	29.5	29.7	27.5	28.3	27.7	28	27.8	28.3	28.7	28.6	27	27.4	24.9	26.1
1998	11	25.4	26.7	26.1	25.7	25.9	25.6	25	25.3	25	25.2	25.6	25.3	24.5	25	25	26.5	27.2	27.7	27.9	27.5	27.3	22.5	23.1	22.8	23.4	21.6	22.3	22.8	23.2	23.2	99
1998	12	23.1	22.2	22.1	22.3	21.9	22.1	22	22.3	21.9	21.5	21.3	20.7	21.8	21.3	20.4	20.6	19.9	19.6	19.6	20	19.4	18.7	18.2	18.1	18.4	20	20.2	19.4	18.5	17.5	17.1
1999	1	19	19	19.5	20.1	19.4	20.1	19.8	19.3	19.3	18.2	16.1	15.2	17.3	17.4	18.2	18.5	18.2	18	17.5	18.5	18.8	18.1	18.9	20.1	20.6	18.6	19.6	21	21.2	19.9	18.2
1999	2	19.5	20.8	22.1	23.3	22.4	21.7	21.9	23	23	20.8	24.3	24.9	23.8	23.6	23.2	23	23	22.9	23.9	22.4	23.5	22.7	24.3	25.1	25.8	28	26.1	24.1	99	99	99
1999	3	24.1	23.6	24.1	23.8	25.6	27.1	27.1	28.7	29.9	29.9	29.5	28.5	27.9	25.7	25.6	26.6	28.4	29.2	28.2	26.8	26.9	28	28.2	28.5	29.3	29.2	29.8	29.2	28.7	29.9	29.3
1999	4	30.1	30.5	30.8	30.4	30.1	30	30.5	28.6	24.7	28.7	30.3	30.8	31.4	31.8	31.8	31.5	30.2	29	30	30.9	31.4	30.9	30.8	31.7	31.6	32	32.2	32.1	31.3	31.5	99
1999	5	31.8	32	32.3	32.4	30.4	26.5	29.2	26.1	26.6	29.8	26.8	28.7	25.9	23.6	25.2	27.5	27.8	28.3	26.8	27.7	28.1	28	30	29.4	30.3	30.3	29	27.9	26.9	30	31.3
1999	6	31.4	26.4	29.1	30.2	30.4	29.6	31	31.9	28.5	29.9	27.8	29.4	29.8	30.6	30.2	30.4	29.8	29.6	29.6	28.9	29.3	27.9	27.7	27.1	25.2	26.9	27.6	28.3	28.4	27.1	99
1999	7	26.3	27.3	27.9	29	29.5	27.8	27.9	29.8	28.2	27.4	25.8	26.8	27.4	28.6	29.8	29.7	29.6	28.2	27.8	27	27.8	28.7	28.9	29.8	30.8	29.8	29.1	28.4	29.3	28.3	31.1
1999	8	30.2	29	28.8	29.3	29.7	29.2	28.7	28.6	28	28.8	29.1	28.2	27.2	26.6	26.4	28.2	29	28.7	28.8	29.2	28.7	29.5	30	29.9	28.1	28.3	27.4	27.3	27.7	27.8	28
1999	9	28.9	29.1	29	29	29.7	29.2	28.2	28.4	28.3	27.6	26.9	27	28.3	27.6	29	29	29.7	27.6	28.4	28.1	26.9	25.7	26.2	27.4	28.6	28	28.4	28.1	29.2	28.9	99
1999	10	26.9	27.7	28.5	28.5	28.1	26	28.8	29.1	28.7	27.8	27.7	29.4	28.1	25.9	27.9	27.6	26.9	24.8	26.7	26.1	26.3	26.9	28	28.5	28	27.8	27.7	28.1	27.3	27.1	27.8
1999	11	27.6	25.5	26.8	26.3	27	25.8	25.2	25.6	25.4	25.2	24	23.7	23.8	23.1	24	23.6	23.5	23.2	23.1	22.9	22.2	22	22.2	21.6	21.4	21.9	22	21.8	21.4	21.6	99
1999	12	21.5	21.3	21.1	20.4	21.7	20.9	21	21.8	23	23	23.4	22.9	22.9	22.7	19.9	20.2	21.3	21.4	21.5	21	20	20	19.3	19.9	20	19.9	19.9	19.8	19.9	19.1	18.2

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
2000	1	18.7	19.5	16.5	15	16.7	14.1	13.9	14.5	16	17.6	19.2	20.1	20.7	22.1	21.1	20.9	18.4	17.3	17.5	19.9	19.8	20.4	21.4	20.8	20.7	20.9	20.5	21.3	18	18.3	19.5
2000	2	20.1	21.5	22.3	22.2	19.2	19.2	20.8	20.1	19.4	20	21.2	20.5	22	21.5	19.7	19.3	20.7	20.2	20.3	20.8	19.2	21	22.3	22.2	22.4	20.9	21.1	21.5	21.3	99	99
2000	3	23.9	24.3	25.2	25.9	26.1	26.2	27.2	24	24.9	24.1	26	24.7	22.2	22.5	25	24	24.9	25.1	26.2	26.2	25.6	26.3	25.7	26.7	26.8	25.3	25.8	27.3	28.1	27.2	27.4
2000	4	28.4	29.2	29.3	29.6	29.5	29.1	29.1	30	29.6	29.9	28.9	27	29.5	26.2	25	27.6	29.1	29	29.9	27.8	25.5	29.4	27.4	24.2	25.5	21.3	26.4	26.2	28.8	29	99
2000	5	27.2	23.8	24	27.2	28.4	28.2	28.6	28.9	29.9	29.2	30.5	31.8	32.6	29.7	31.8	29.2	29	29.6	25.9	26.7	27	27.5	27.4	28.4	27.3	26.8	24.9	24.1	26.7	26.6	28
2000	6	30.5	31	31.9	31.2	30.3	28	28.3	27.6	29.1	27	28.2	28.6	29.9	29.6	28.6	29.6	29.7	29.7	28.8	27.9	28.6	28.5	28.6	27.9	26.7	29.1	30.1	29.3	29.5	30.3	99
2000	7	30.5	31	31.5	31.9	31.2	30.3	28.2	28.5	28.2	29.2	30.9	28.7	28.4	28	29.3	30	29.1	26.7	26.6	27.3	27.2	26.8	27.8	27.5	28	28.3	28.6	28.9	29.8	30.1	29.8
2000	8	27.8	26.2	27.6	29.1	30.1	29.7	30	30.1	29.5	28.9	29.1	28.8	26.9	28.8	28.5	28.6	29.5	29.3	29.4	28.8	29.4	30.2	30.2	30.9	30.9	30.1	29.8	30.2	29.3	28.1	26.6
2000	9	28.4	28.9	29.7	27.9	29.1	29	28.5	29	28.9	29.4	29.6	30.7	29.9	29.5	28.2	29	27.9	26.9	26.2	25.1	28	28	26.2	28.3	28.9	29.4	29	29.7	29.9	29.4	99
2000	10	26.1	25.8	27.9	28.4	28.7	29	26.8	28.9	28.4	27.2	28.6	29.7	29.6	29.8	30.5	30.3	28.5	28.5	29	29.2	28	26.7	28	27.9	27.8	28.2	23.7	21	21.3	23.8	25.4
2000	11	26	26.8	26.8	26.5	26.1	25.7	25.3	25.2	25.1	25.2	25.1	25.5	24.8	24.5	23.9	24.1	23.8	24.2	24.9	24.8	24.8	24.5	24.4	23.8	23.3	22.6	22.7	21.4	20.8	22.1	99
2000	12	22.5	20.8	19.5	20	19.9	19.7	20.8	21	19.7	20	19.8	19.6	19.6	19.7	19.6	20	19.6	20.1	19.7	19.4	20.2	21	20.6	20.1	20.2	19.9	21.3	20.7	19.6	20.3	19.7
2001	1	21.2	22.1	20.4	16.8	15.7	14.5	15.9	17.2	18	17.5	16	16.9	16.4	16.8	18.4	19.3	19.8	19.8	20.3	20.6	19.2	19.7	20.6	19.6	16.5	16.3	16.6	18.1	18.7	19.2	21.8
2001	2	21.5	21.3	20.6	20.4	19.9	21.1	20.1	18.9	19.9	19.4	20.7	21.4	22	23	23.3	23.9	24	25.2	24	24.4	23.6	23.2	23.7	24.7	25.9	26.4	25.1	25.6	99	99	99
2001	3	25	25.8	24.3	23.7	22	23.4	24	24.7	24.3	24.4	24.8	25.5	26.3	28.4	27.9	27.3	27.9	27.3	27.8	28.7	29.6	29	27.3	28.2	28.7	28.7	28.5	26.4	29	28.3	27.9
2001	4	26.3	26.1	27.6	29.8	30.8	29	30.8	30.7	30	30.4	30.2	29.8	28.6	25.8	27.6	28.3	27	25.8	27.2	29.6	30.7	31.2	31.1	31.4	31.8	30.7	30.2	29.4	28.1	25.8	99
2001	5	28.1	25.2	25.1	25.2	25.7	26.5	24.2	23.7	26.3	24	25.5	26.6	28.6	30	30.4	28.8	30.7	30.5	29.1	28.6	29.8	28.9	28.8	27.6	28.5	27.9	29.3	30.9	27.4	27.8	28.6
2001	6	27.7	28.1	27.4	26.8	25.8	26.2	26.8	28.8	28.1	30.1	30.3	30.2	28.3	25.7	26.2	27	26.9	26.6	26.7	28.1	29.1	29.4	29.4	29.1	29.2	29.5	28.1	29.6	28.5	27.1	99
2001	7	28.3	27.7	29.3	30.2	30.8	30.6	30.4	30.4	29	28.1	28.3	27.3	28.6	28.7	29.6	29.2	29.5	29.3	28.1	28.3	29.4	29.4	29.2	28.6	27.5	28.4	28.3	28.6	27.4	27.5	27.7
2001	8	29	28.9	29.8	30.2	27.8	28.1	29.7	29.3	29.4	29.6	30.2	29.9	29.8	29.2	29.2	28.7	30	30.3	31	29.7	29.4	29.3	29.8	29.2	29.7	29.8	28.6	29.5	29.5	29.3	29.5
2001	9	29.4	29.9	30.4	30	29.2	28.2	28.6	27.9	29.2	28	28.7	28.3	27.7	30.1	30.2	28.5	27.3	26.3	27.4	28	28.5	29.8	28.5	25.9	29.5	30.1	29.4	28.9	30.3	27.1	99
2001	10	27.3	27.4	26.6	27.6	28.7	28.5	29.8	28.1	28.3	27.9	28.9	28.8	28.2	26.3	28.6	28.1	26.5	24.7	26.8	27	27.3	28.5	29.5	29.6	28.4	28.4	25.9	27.1	27.4	26	24.3
2001	11	25.7	26	26.6	27.2	26.9	27.2	24.3	24.2	25.4	25.7	23.1	23.1	24.9	25.6	25.4	24.4	25.2	25.5	22.8	23.4	24.1	24.5	23.4	23.4	23.3	23.5	23.4	22.9	22.5	21.7	99
2001	12	20.3	20.3	20.3	20.3	21.2	21.4	20.6	21.1	21.7	20.5	21	17.8	17.4	18.8	19.2	19.8	20.4	19.7	19.8	19.9	18.3	18.3	18.7	18.8	19.5	20.6	20.2	20	19.6	19.7	20.1

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2002	1	19.4	18.5	18	20	19.7	20.8	19.6	20.3	20.2	19.8	19.3	18.1	18.4	18.8	20.5	21.7	22.3	21.5	22.1	21.7	22.4	22.1	19.1	18.6	17.6	17.6	19.6	16	19.4	19.5	18.5
2002	2	19	18.7	18.8	19.4	19	19.8	21.6	23.2	23.1	24	24.5	23.9	22.7	21.1	20.7	22.8	23.7	25	23.6	23.8	25.2	23.9	23.9	25.6	25	23.6	22.8	23.4	99	99	99
2002	3	25.2	26.1	22.5	24.7	22.9	24.3	23.6	23.8	26.8	27.7	27.3	27.1	25.6	27.1	27	27.4	27.4	27.4	27.7	29.2	29.2	28.5	26.5	27.4	25.9	26.2	23.9	25.9	26.1	26	27.5
2002	4	27.2	22.6	21.1	25.6	26.9	29	29.2	27.1	27.5	28.7	25	25.8	27.2	28.4	27.7	29.1	29.3	29.7	30.1	29.7	29.5	25.1	28.5	29.3	29.4	26.9	27.2	29.4	27.4	27.2	99
2002	5	27.8	26	26.2	27.3	25.3	21.8	27	27.1	28.9	27.2	26.2	29.1	29.8	29.7	29	30.6	31	30.5	30.1	32	31.5	29.2	28	26	27.1	23.5	25.1	26.2	26.7	28.6	28.5
2002	6	26.5	28.2	28.8	27.7	28.9	30.7	26.5	27.3	27.4	27	27.7	26.5	26.4	28	29.6	29.5	29	30.2	30.4	29.7	28.1	26.4	28.3	28.9	28.3	28.1	30.3	28.9	28.9	27.4	99
2002	7	26.7	27.5	27.8	27	28.5	28.7	28.4	28.2	28.5	27.6	28.8	30	28.8	28.1	29	29.2	28.8	28.5	28.6	29.5	26.5	27.2	29.3	29.6	27.9	30.4	29.7	27.7	29.7	29	29
2002	8	29.7	26.6	28.1	27.5	29.9	30	29.7	30.7	28.8	28.7	28.2	27.9	27.2	27.8	28.1	27.6	28.1	28.5	27.8	28	27.7	29.7	28.6	29.1	28.6	27.9	28.9	28.8	29.4	29.7	29.8
2002	9	30.1	29.6	28.7	27.9	30.3	27.5	30.4	30	28	28.1	27.4	29	30	30	29.4	27.8	29.3	30.3	30.2	30.6	29.3	28.5	27.9	27.7	28.1	28.8	26.3	28.4	28.7	29.3	99
2002	10	30.2	30.3	30.1	30.2	30	30.4	30.5	29.1	28.8	26.9	26.5	28.6	28.3	25.6	25.6	26.2	27.9	24.8	25.1	26.6	27.1	26.7	25.9	26.4	27.1	27.3	26.8	25.5	24.7	24.6	24.5
2002	11	26.4	25.4	26.7	27	26.1	26	26.5	25.9	26.3	26.4	24.7	21.1	22.1	22.1	22.3	22.6	22.7	22.9	22.7	23	22.7	21.8	22.2	22.6	23.3	23.4	23.6	23.7	24.1	24.4	99
2002	12	23.9	22.9	21.9	21.7	20.7	21.8	21.9	21.9	21.9	20.7	20.4	20.6	21.2	21.7	21.5	20.9	21.1	21.1	22.6	21.8	21	19.2	17.9	17.3	17.3	18.9	17.9	17.9	17.3	16.3	15.9
2003	1	18.2	18.5	20.3	19.5	17	15.8	13.8	13.1	11.9	12.7	13.1	13.2	13.4	14.7	13	14.1	17.2	18.6	19	17.6	15.2	12.4	14.9	16	17.5	17.3	17.8	18.6	19.7	18.8	20.4
2003	2	20.5	20.9	21.2	21.6	19.6	20.5	21	22.4	23.1	22.7	23.1	20.9	21.7	21.1	20.9	21.8	21.7	22.4	23.4	23	21.8	21.2	21.7	22.4	23.6	24.6	25.4	25.9	99	99	99
2003	3	27.4	27.6	28.1	27	19.4	20	20.8	22.5	22.8	24.3	22.8	20.6	22.7	22.1	24.4	23.1	21.4	24.2	24.6	24.7	24	25.1	26.5	26.7	28	27.7	26	27.2	27.7	24.6	23.6
2003	4	27.9	28.9	29	25.6	28.2	29.6	30.8	30.9	30.2	30	29.5	30.1	30.3	28.4	28	29.7	29.6	30.1	30.2	25.7	25.7	26.9	28.5	30.2	30.5	30.5	30.8	27.8	26.1	27.5	99
2003	5	27.4	24.4	29.4	30.6	30.9	28.6	29.8	27.8	26.8	28.2	29.9	29.4	31.1	29.9	28.8	29.6	30.6	31.1	29.9	29.8	26.6	28.9	28.7	27.5	29.4	31.5	31	30.7	31.3	31.5	32.1
2003	6	32.1	32.2	31.7	30.3	26.5	29.2	27.4	28.6	28.1	25.8	26.6	27.8	29.3	26.9	29	28.2	28.5	28.3	29.5	27.1	26.5	26.8	27	29.4	29.2	28.7	28.1	27.6	27.6	27.3	99
2003	7	28.3	29.4	29.6	29.3	30	29.6	28.8	29.2	29.9	29	28.8	28.2	28.8	29.6	29.8	29.6	30.8	30.8	30.1	30.3	29.5	29.5	31.6	30.2	28	29.7	29.3	28.4	27.2	27.8	28.2
2003	8	27.6	28.2	29.5	30.8	31.6	31.3	30.9	30.7	30	27.8	28.1	27.4	29	28.9	29.6	30	30.8	29.9	28.9	29.5	31.1	28.9	28	28.9	30.4	30.7	29.9	28.3	27.8	28.8	29
2003	9	28.1	28.3	28.2	29.9	29.9	29.3	27.7	28.3	29	29.9	28.7	28.1	27.8	28.8	28.6	29.1	28.7	28.5	29.9	28.2	28.6	28.4	28.1	27.6	26.3	26.6	28.2	28.7	27.4	29.4	99
2003	10	30.4	26.2	28.6	28.9	28.7	28	24.8	25	27	26.3	27.5	28.5	28.4	28.7	29	28	28.4	26.6	29	28.6	28.6	27.9	28.5	28.1	27.5	26.6	26	27.1	27.9	27.8	28
2003	11	27.1	27	27	26.1	25.9	25.5	26	25.9	24.5	25.2	25.1	24.6	25.1	24.5	23.8	23.7	23.7	23.3	23.3	23.5	22.2	21.5	21.7	22.7	22.6	23.1	23.1	21	20.2	20.9	99
2003	12	21.6	21.5	21.1	21.1	21.2	20.7	20.4	20.6	21.7	21.7	21.3	21.4	21.7	22.2	22.9	22	20.7	20.7	21.2	21.8	21.6	21.4	21.5	19.8	19.5	19.6	19.4	16.8	16	17.8	15.6

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
2004	1	14.4	13.5	14.1	14.8	15.9	15.1	19.2	18.3	14.4	17.8	19.1	19.5	18.4	18.4	19.8	19.9	19.1	19.5	20.3	19.6	19.2	20.3	21.6	20.2	19.1	18	17.5	17.5	19	20.4	21.5
2004	2	22	21.3	16.9	16.5	16.7	18.2	19.6	19	20.1	20.8	21.2	21.7	21.6	22.1	23.3	22.7	22.9	22.9	23.9	23	22.6	22.4	22.8	23.3	24.5	23.6	25.4	25.9	26.6	99	99
2004	3	26.8	25.1	23.7	25	24.4	25.5	21.7	24	27.1	21.3	22.8	25.5	27.9	28	28.3	29.6	28.4	28.1	28.5	29	28.8	29.2	29.1	28.9	28.9	29.3	29.3	29.6	29.2	29	29.3
2004	4	25.8	28.1	29.4	26.6	28.5	26.3	24.3	27.2	25.7	25.8	29	28.3	29.5	30	30.6	30.8	30.8	28.3	24.3	26.2	29.2	29.9	24.7	26.7	28.3	29	26.1	28.2	28.4	29.5	99
2004	5	31.2	31.5	31.7	31.6	32.2	32.6	31.8	31.7	31.6	31.5	31.1	31.8	31.8	30.9	31.8	32.1	30.7	31.3	31.6	29.9	27.1	27.7	23.9	28	29.5	30.5	29	30.2	29.1	28	30
2004	6	29.1	28.5	25.8	28.5	30.5	26.7	29.7	31.1	30.6	30.5	28.6	28.7	27.8	27.6	28.1	28	29.5	26.7	27	28.1	26.9	27	30	26.8	27.6	27	29.3	29.5	29.8	30.4	99
2004	7	31.1	30	29.3	29.4	29.1	29.2	26.9	28	27.8	29.1	28.3	26.9	28.8	29.7	27.5	27.9	28.4	28.8	26.6	26.9	27.8	28.9	29.5	27.3	29.3	29.5	29.5	28.9	28.3	28.8	29.6
2004	8	30.2	30.2	30.7	28.2	27.4	28.1	28.5	28.2	28.6	28.9	29	28.8	27.4	28.8	29	29.8	30.3	30	29.8	29.8	30.1	29.6	29.8	30.5	29.4	28.1	27.8	29.7	29.7	28.5	28.5
2004	9	30.1	28.6	28.7	28	28.8	29.6	30.1	30	27.9	27.2	26	25.2	24	24.5	25.2	24.9	27.4	27.7	28.7	28.7	27	27.2	28	29.1	27.5	28.9	29	27.1	26.3	28.5	99
2004	10	29.1	29.7	28.8	26.8	26.1	25.6	25.7	24.4	25.9	27.2	27.9	28.5	27.4	26	25.7	26	27.1	27.2	26.9	27.6	27.7	26.6	27.4	26.9	26.9	26.5	26.6	26.6	26.6	26.3	25.4
2004	11	25.5	25.4	25.6	25.2	24.6	24.6	24.5	24.4	24.7	23.4	23	23	22.6	22.6	21.9	22.8	22.6	23	22.9	23.5	23	23.4	23.3	23	22.8	22.6	22.7	23	21.7	21.7	99
2004	12	21.9	22	23	22.3	21.2	21.5	22.8	22.7	21.5	22.1	22	22.5	22.2	22.5	22.2	21.6	21.5	21.7	20.5	21.1	22.5	21.4	20.2	21	19.7	18.8	16.4	17	17.9	17.7	18.3
2005	1	18.8	19.4	21.2	20.7	20.5	20.4	20.3	19.7	17.9	18.5	16.3	18.4	17.8	18.1	18.4	18.5	18.9	19.8	19.8	17.7	17.2	16.1	17.6	18.6	18.6	18.9	19.2	19.9	19.9	21.1	22.1
2005	2	19.7	19.2	17.4	18.6	18.5	20.9	22.8	23	23.5	23.1	22.9	24.8	26.1	24.6	25.1	26.1	26.8	26.7	25.6	26.1	26.9	24.3	24	23.3	23.5	23.8	24.2	24.3	99	99	99
2005	3	26.8	27.7	28.4	28.7	28.8	28.8	28.1	28	27.8	28.7	25.7	23.3	26.6	26.7	26.8	27.8	27.9	26.4	27.5	28.7	29.1	28.1	22	21.8	24.8	26.9	27.3	28.3	27.8	25	24.1
2005	4	27	28.7	27.5	27.1	28.4	29	28.8	29.4	29.3	28.7	28.3	28.7	29.4	30.2	30.3	29.8	29.8	30.8	31.4	30.3	31.1	31.2	30.4	29.7	28	27.6	28.1	28.4	25.2	26.5	99
2005	5	26	28.1	28.5	26.5	25.2	27.3	28.5	26.5	29.2	30	31.5	27.9	28.3	29.5	27.7	30.5	25.5	29.2	26.6	26.1	28	25.6	27.7	28.5	30.7	31.1	31.1	31.6	31.6	31.6	31.9
2005	6	31.8	32.2	31.8	29.2	28	30.9	30	31.6	31.3	31.4	31.2	31.6	28.9	28.7	29	28.1	30.9	31.8	30.9	31.3	31	28.8	28.8	28.1	28.3	29	27.1	26.1	26.9	27.2	99
2005	7	27.2	26.7	25.6	26.8	26.8	29.9	30	29.9	28.9	28.6	27.7	29.1	26.5	26.3	25.8	28.6	29.7	29.7	29.5	28.4	29.3	28.7	29.5	29.6	30.1	29.6	29.3	29.7	29.7	29.5	30.3
2005	8	31.1	30.2	29.1	28.3	28.8	28.4	29.4	28.4	28.3	28	28.5	28.8	30.2	29.3	29	28.8	29.8	28.9	28.6	28.1	27.9	28.3	29.1	27.7	27.9	28.9	28.5	30	30.4	30.7	29.5
2005	9	28.9	30.1	29.9	29.7	27	30.3	26.8	29	29.3	28.3	28.9	29.4	28.6	29.2	30.8	30.8	30.2	30.3	30.7	26.2	28.5	27.3	28.4	27.7	28.3	29	29.5	28.8	28	26.7	99
2005	10	25.1	25.9	27.1	27.4	27.2	27.5	28.7	27.2	29.2	29.3	27.9	29.1	29.1	30.2	29.8	28	26.6	25.2	26.3	23.9	24.6	24.5	21.8	24.2	26.7	27.3	28	27.2	27.9	27.5	26.3
2005	11	25.5	26.1	26	25.8	25.6	25.4	25.4	26	26.7	26.3	25.7	23.9	22.4	23.2	23.5	24.1	24.1	22.5	22.6	22.8	22.6	22.9	23	22.6	22.2	21.2	21.7	22.5	22.6	21.2	99
2005	12	21.3	22.2	22.5	22.4	21	21.1	20.3	20.4	20.1	20.2	19.6	20.9	20.9	19.9	21.6	21.8	22.2	22.4	21.2	20.9	22.5	21.3	21.5	21.1	21	20	19.5	20.3	18.5	19.7	20.4

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2006	1	19.9	20.2	19.3	19.3	19.5	19.2	18	15.5	14.4	14.7	16.2	16.3	17	18	18.8	17.7	19.4	20.5	21.3	21.2	20.2	19	18	19.4	19.6	19.7	19.4	21	21.5	21.5	21.1
2006	2	21.5	22.1	22.7	22.7	22.2	22.1	22.1	23	23.3	23.2	22.7	23	24.5	24.2	25.4	26.5	26.2	26.4	26.7	26.5	26.6	27	26.9	27.8	27.7	27.7	28.2	27.6	99	99	99
2006	3	26.9	26.4	24.1	26.4	26.2	27.7	27.9	28.5	29.7	29.3	23.1	24.9	25.8	26.7	27.8	26.6	27	25.8	25.1	24.7	27.7	28.5	27.5	27.5	29.5	30.8	30	30	28.7	29.7	30.1
2006	4	29.1	29.6	27.5	24.6	25.7	27.2	28.3	28.6	29.1	29.1	29.3	29.7	28.5	29.4	29.8	29.2	29.5	25	27	27.5	28.7	27.9	29.4	27.8	29.4	29.7	28.2	30	31.4	31.4	99
2006	5	31.6	30.6	31.2	30.9	30.6	29.1	24.6	28.9	28.9	27.2	27.6	23.2	27.3	26.8	28.7	30.2	31.5	31.6	30.8	30.1	29.7	30.8	29.7	29.4	31.1	26.6	27.6	27.2	27.5	30.3	30.2
2006	6	27.6	26.2	27.9	28.8	28.3	28.1	28.6	29.1	27.6	26.1	30.6	31	30.6	27.8	29.8	28.7	30.9	28.7	29.6	28.5	29.5	29.2	29.9	29.3	29.3	29.7	30.1	29.8	30.7	30.6	99
2006	7	31.6	30.8	29.2	29.3	29.6	28.6	29.4	27.9	28.1	27.4	27.8	29.7	29.9	30.3	29.4	30	30	29.3	27.4	28.3	28	28.4	29.4	30.1	31.1	29.1	28.9	29.2	27.6	29.2	30.3
2006	8	30.3	30.4	28.7	28.5	25.5	27.5	28.8	28	30.4	30	31	30.6	29.9	29.3	30.7	30.4	29.2	29.8	28.5	28.5	29	27.4	27.2	28.9	29.5	29.5	30.9	29.4	28.4	29.3	28.3
2006	9	30.5	28.3	29.1	29	30	30.1	30.5	28.1	29	27.4	26	26.5	29.7	29.4	29.7	30.4	28.7	30.1	29.4	25.5	24.8	25.4	25.8	28.2	28.3	28.6	30.1	28.9	28.6	28.4	99
2006	10	27.4	28.8	30.1	30.7	29.3	27.7	29.2	29.4	29.6	29.8	29	29.1	27.5	27.4	28.3	28.3	27	27.2	26.9	25.4	27.1	27.2	27.5	27.3	26.6	27.7	28.1	26.5	27.2	26.8	26.2
2006	11	24.6	26.5	27.4	27.4	25.9	26.8	25.7	25.8	25.4	25.4	24.7	24.1	24.5	24.3	24.8	24.7	24.7	25.1	23.5	24.2	24	22.7	22.9	24.4	23.7	22.5	22.1	20.1	20	20.5	99
2006	12	20.1	20.5	20.5	20.4	20	20.7	21.3	21.3	21.7	21.5	21.7	22.6	19.8	19.6	19.7	20.4	22.1	21.1	21	22	22.2	21.7	22.5	21.6	20.5	19	18.6	19.8	18.5	18.1	18.9
2007	1	17.5	18	17	13.7	14	15.7	14.3	16.3	15.2	17.6	17.7	19	18.4	16.1	16.8	16.6	18.2	18.5	17.2	18	18.5	19.8	18.7	18.9	20	19.8	20.3	20.9	21.1	22	22.2
2007	2	21.9	21.3	21.1	22.9	21.5	20.3	21.4	19.8	21.5	22.5	23.1	20.8	19.6	19.1	18.4	19.2	20.7	20.6	20.5	20.5	21.5	22.4	23	23.2	24.3	22.8	23.8	24.6	99	99	99
2007	3	22	19.7	22.6	22.2	22.1	22.3	22.5	22.4	23.1	24.9	27.1	27.3	26.6	23.9	25	22.4	23.2	24.1	25.4	27.7	26.6	25.8	28	28.8	28	28.2	27.7	28.3	29	30.6	30.3
2007	4	29.6	29.6	30	29.6	29.5	29.5	28.8	29.2	30.1	28.8	22.5	21.5	26.2	27.8	29.2	29.9	28.3	28.1	29.8	30.1	27.5	27	26.6	28.1	27.6	26.5	25.4	28.2	28.5	30.5	99
2007	5	31.4	31.5	30.2	30.9	31.3	31.1	28.3	29.6	28.5	29.9	30.6	29.2	31.1	25.3	24.5	28.8	29.9	30.5	29.6	27.5	29	30.8	31.4	29	30.6	30.9	31.3	32	32.4	32.5	32
2007	6	29.9	31.3	29.5	27.7	25.3	26.6	28.3	27.3	27.8	24.1	26.3	27.8	28.3	29.8	27.3	26.4	27	30.4	30	29.7	31.3	29.1	29	29.8	30.6	31.3	31.7	29.1	27.8	29.1	99
2007	7	28.3	28.3	28.5	27.8	28	28.1	28.6	28.9	30.2	29.6	30.7	30.9	31.4	30.1	29.3	28.4	29.1	28.2	27.3	27.4	25.1	24.6	27.7	26.8	27.4	25.7	26.6	28.1	27.8	28.8	28.2
2007	8	27.9	28.4	30.2	30.8	31.1	30	28.9	28.9	31.8	32.4	29.3	27.8	27.9	29	27.7	27.8	27.4	29.3	28.8	28.7	29.4	30.2	29.9	28.1	28.3	27.4	28.4	29.4	29.4	28.5	30.1
2007	9	30.4	30	29.9	28	27.6	27.5	27.5	26.4	28.5	27.3	27.3	28.9	29.2	29.2	28.4	29.9	29.3	28.7	29.5	30.7	30.9	29.4	26.7	27.7	27.3	29.6	29.1	29.3	29.5	28.2	99
2007	10	28.3	29.2	30.1	30.5	30.9	31.6	28.1	25.6	26.1	28.2	28.3	28.5	28.9	27.8	25.7	24.6	27.8	24.7	26.6	25.9	26.2	26.3	25.7	25.2	24.8	25.2	25.2	25.2	25.5	27.2	26.9
2007	11	26.7	25.5	26.2	25	25.3	25.8	25.8	25.9	26.2	26.1	25.4	24.9	24.5	23.7	19.6	21.3	22	23.4	23	22.9	22.8	22.5	23.4	22.9	22.7	22.8	22.4	22.1	22.4	22.5	99
2007	12	22.3	22.1	21.6	21.1	20.8	21.2	21.2	20.9	20.4	19.7	19.4	20.2	20.6	21.8	21	20	18	19.4	19.3	18.5	16.7	17.7	17.7	17.9	18.2	19.1	19.5	19.1	19	19.7	19.7

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2008	1	19.5	19.5	20.1	21.5	20.7	20.7	20.8	20.6	20.1	20.3	21.9	19.9	19.3	17.6	17	18.5	19.9	18.8	21.5	22.3	21.1	18.4	18.5	16.6	16.4	17.1	17.6	16	16.3	15.4	15.8
2008	2	16.6	16.8	18	18.4	19.7	22	23.8	23.8	19.9	20.1	19.4	18.2	17.5	18.1	17.3	18.1	19.6	21.6	20	18.9	19.8	21.1	21.6	23.2	23.6	23.5	22.3	22.3	23.6	99	99
2008	3	23	24.8	25.4	23.8	22.7	23.4	23.6	24.9	26.6	26.7	26.6	27.9	27.6	27.3	27.9	26.8	28.4	28.3	27.8	26.3	26.8	28.5	26.5	25.5	27.6	27.5	27.7	29.1	28.5	28.4	28.9
2008	4	27.2	25.5	25.4	23.2	26.8	27.4	27	27.3	26.8	29.1	30.7	30.2	29	29	29.5	29.8	29.6	30.1	31	31.3	31.3	32	31.7	31.3	30.7	30.7	30	30.6	31	31.4	99
2008	5	31.3	28.7	29.8	29.6	29.7	29	28.1	28.6	29.6	28.2	30.2	30.7	30.2	30.1	31.3	30.8	29.3	28.5	28.2	28.9	30.7	28.4	29	28.4	27.4	26.5	28	29	30.8	29.9	29.5
2008	6	30.8	26	28.3	29.4	27.6	28	28.7	28.1	28.9	28	28.7	30.4	30.6	30.1	31	28.8	27.6	27.8	26	26.6	29.2	29.5	29.5	29.4	30.7	29.8	28.8	28.8	28	27	99
2008	7	26.5	27.9	26.7	28.2	27.2	28.7	27.9	27.9	29.1	28.3	28.7	28.2	28.4	28	27.5	27.5	28.7	28.4	28.3	27	28.8	29.2	29.3	30.2	29.9	30.2	30	29.7	29.2	29.7	29.7
2008	8	29.7	30.5	28.4	29.1	28	29.2	30.3	31.2	29.4	27.5	27.9	29	28.5	28.9	28.4	28.7	28.5	28.1	27	28.6	28.9	29.4	29.2	29.8	29.7	28.7	28.8	27.2	26.6	27.8	30.1
2008	9	30	29.3	29.6	28.7	27.9	28.9	29.8	28.5	29.1	30.4	30.3	30.6	29	29.6	29.6	28.9	28.5	28	28	28.4	27.7	28.1	27.9	28.9	29.8	28.1	28.1	27.9	29.4	28.3	99
2008	10	29.8	27.4	26.6	28.1	26.3	26.4	27.6	27.9	26.8	27.5	28.2	29	28.6	28.9	29.3	29.7	29.5	29.1	28.6	29.9	29.2	28.4	28.9	25.3	21.7	20.5	20.8	23.5	24.4	25	26.4
2008	11	26.1	26.6	26	25.9	25.7	25.5	26.2	26.1	24.8	24.3	23.8	23.5	23.5	23.1	23.3	22.4	22.4	22.6	23.5	23.8	23.9	23.1	22	21.1	21.2	22	22.6	22.2	22.1	22.4	99
2008	12	23.4	22.4	22.4	22.1	22.7	22.8	22.9	22.5	23.4	22.4	22.9	22.1	21.4	21.7	20	18.8	17.7	18.2	17.3	17.1	17.2	19.9	20.5	20.2	18.7	18	18.8	18	19.5	18.9	18.8
2009	1	18	19	17.6	17	18.4	19.7	20.6	21	20.6	19.8	20.4	20.5	17.7	17.2	18.9	19.3	20.1	20.8	20.6	20.3	20.1	17.6	17.9	18.1	20.7	23.1	22.2	21.8	21.4	20.5	20.2
2009	2	20.4	20.2	20.2	19.9	22.1	22.8	23.4	23.1	22.3	21.6	22.2	22.5	22.5	22	22.5	23.8	23.6	22.9	23	22.6	23.1	25.7	25.2	25.8	27.7	27.5	26.8	26.7	99	99	99
2009	3	24.6	24.4	25.5	25.3	27.5	27.9	27.2	27.8	28.6	28.3	27.6	26.1	26.4	27	27.2	26.5	27.5	27.3	28.3	28.2	29.2	26.9	27.4	28.9	28.4	27	24.9	27.7	26.6	27.2	24.9
2009	4	27.1	27.9	28.1	28.9	29.6	28	29.8	30.8	27.2	29.8	30	30.1	31.1	30.9	30.9	29.9	27.2	30.6	31.1	30.9	31.3	31.3	31.7	32.3	32	32	32.4	31	30.6	29.9	99
2009	5	29.2	24.8	25.6	29.4	31	29.3	30.4	31.6	31.8	30.9	28.2	27.9	27.6	27.7	27.2	27.5	27.3	26.2	30.4	31.5	32.2	31.5	31.5	29.7	26.7	27.9	29.2	31.4	28.4	30.9	28.7
2009	6	29.3	29	26.7	30.4	30.3	29.8	29.3	29.7	29.9	30.1	30.6	29.4	30.2	30	31.5	32	31.7	32.5	31.1	31.3	31.6	31.9	32.1	30.7	30.2	30.4	30.3	28.7	28.6	27.3	99
2009	7	27.8	27.3	26.8	28.4	29.8	29.8	28.5	29	28.4	28.1	29	29.4	30.8	29.4	28.6	28.7	30.1	31	31	31.2	30.1	28.7	29.4	29.2	31	29.4	28.6	27.4	27.1	27.3	28.4
2009	8	30.1	29.9	29.7	30.2	27.5	28	30.2	29.3	30.2	30.5	30.2	30	29.7	29.3	27.4	28.5	28.3	28.1	27.4	27.9	27.4	29.5	28	27.9	29.6	28	26.8	28.6	30.5	28.1	28.9
2009	9	29.9	30.8	29.3	29.6	27.6	29.3	30	27.4	28	27.7	28.9	30.9	31.2	28.7	27.3	27.8	28.2	28.5	28.8	29.2	26.8	26.2	26.1	27.8	28.9	30.6	30.7	29.1	29.8	30.1	99
2009	10	30.8	29	28.1	28.1	27.3	26.9	28.1	27.4	28.5	28.1	27.7	27.7	28.3	29.1	27.5	26.9	28.5	28.4	28	26.4	26.9	26.3	27.4	27.1	27.4	27.1	26.7	26.4	27.1	26.8	26.1
2009	11	26.5	27.6	28.4	27.8	26.7	27.5	26.9	26.4	25.8	25.2	25.3	26.1	26.3	28.2	27.4	28.7	24.8	23.7	23.2	23.2	21.5	20.3	20.5	21.2	22.4	21.9	20.9	20.9	20.8	21.3	99
2009	12	21.8	21.8	21.8	22	21.4	20.9	20.7	19.6	20.4	17.7	18.8	18.2	19.1	20.1	20.7	20.7	21.4	22.2	22	21.4	20.3	20	19.6	18.1	17.3	18.7	18.5	18.3	18.3	18.8	18.6

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2010	1	16.5	16.7	14.7	13	16.1	15	17.2	18.2	19.7	18.5	15.1	13.2	14.4	18.9	18.8	14.8	16.2	14	14.5	17.1	18.9	19.5	19.9	19.9	21.3	21.1	20.5	20.7	20.7	20.5	20.9
2010	2	19.5	19.7	19.7	20	19.2	19.1	20.4	20.9	21.7	22.8	22.8	24	22.7	23.5	22.7	24.5	24.4	22	21.8	22.8	21.8	22.7	23.2	22.4	25.1	24.9	24.8	25.1	99	99	99
2010	3	26.4	27.3	27.3	27.8	28.3	28.6	28.9	27.5	27	26.3	25.9	26	26.7	28.4	26.8	26.8	27.9	28.5	27.7	28.7	30.5	29.8	29.7	29.6	29.4	29.1	29	29.4	29.7	29.9	30
2010	4	30.6	30.7	30.6	30.2	29.6	31.1	31.1	31.4	30.9	31.3	30.9	30.7	30.9	30.8	30.8	29.8	30.3	28.4	30.7	31.4	31.5	31.3	31.5	31.1	31.2	29.4	28.2	28.8	28.5	27.8	99
2010	5	30.8	27.8	30.2	29.6	28.9	29.3	28.6	28.6	31	32	32.2	32.2	31.9	28.9	30.6	30	31.6	31.5	31	29.2	25.8	27.7	29.1	28.7	29.3	29.1	28.8	27.8	29.4	30.6	27.1
2010	6	31.1	30.2	26.8	26	26.4	28.8	31.3	31.7	31.7	31.6	31.5	29.3	28.4	29.4	30	29.8	27.7	28.9	29	28.8	30.4	29.7	31.2	30.1	29.3	28	29	28.2	26.1	29.4	99
2010	7	30.4	29.5	29.5	30.1	28.7	29.8	30.3	30.1	30.5	30.1	29	28.6	28.6	30.1	30.1	31	30.8	30.7	30.5	29.3	29.4	30	30	29.4	28.9	29.1	30.5	31	29	28.7	26.9
2010	8	28.8	30.2	30	29.2	29.8	29.8	30.9	29.4	31	30.6	29.3	29.1	29.1	29.1	29.3	29.1	29.7	30.3	28.5	28	28.9	29.3	29.9	29.4	28.6	28.8	28.7	29.7	30.5	30	29.5
2010	9	30	30.8	29	30	29.6	30	30.2	30	30.4	29.9	29	28.8	28.9	27.9	27.3	28.2	28.8	28.3	27.1	28.7	28.4	28.1	29.6	28.4	27.5	28.2	29.9	27.6	29.3	28.7	99
2010	10	29.6	30.1	30.9	31.3	28.8	26.2	24.5	24.7	25.4	26.9	27.6	28.7	29.9	29.3	29.1	29.3	28.5	29.9	30.7	30	29.9	27.9	28.6	28.5	28.8	27.7	27.2	26.3	26.1	27	27.3
2010	11	25.7	24.4	26.1	26.4	27.3	27.6	26.9	27.2	26.5	25.7	24.9	24.9	25.2	25.4	25.1	24.8	25	25.5	24.9	25.4	22.9	22.2	21.9	23.1	24.1	24.1	24.3	24.8	24	21.8	99
2010	12	21	20.5	21.5	22.2	23	22.6	24.3	22.6	21	22.8	22.4	20.8	20.3	18.1	18.4	18.9	19	19.7	20	20.2	19.2	19	17.6	17.3	17.1	18.4	19.6	19	18.7	19.4	19.5
2011	1	21.1	18.4	14.9	17.2	17.5	18.2	17.7	17.8	19.5	16.1	12.5	12.1	11.5	12.9	15.5	18.7	15.7	14.8	17.7	17.8	16.8	17.5	17.3	18.6	19.4	20.3	19.5	19.5	18.5	19.6	21.3
2011	2	20.9	21.4	20.7	20.8	21.4	22.2	21.8	23.8	23.1	21.1	20.4	21.1	22.4	22.9	25.2	25.4	22.5	21.4	23.2	23.9	21.6	23	23.3	23.4	23.6	24.4	24.1	22.5	99	99	99
2011	3	23.8	24	24.7	26.3	27.4	26	25.2	25.5	28	26.6	26.3	25.6	27.2	26.9	27.2	26.6	26.5	26.5	27.2	28	28.4	27.7	28.6	28.2	27.9	27.7	25.9	25.2	25.1	24	23.8
2011	4	26.5	26.3	26.4	25.8	25.5	27.3	28.9	29.3	29.1	29.9	27.8	29.5	30.8	27.6	28	28	30	30.6	29.8	27.1	27.4	28.9	29	27.8	26.7	29.1	26.6	24.9	27.4	28.9	99
2011	5	30.1	28.4	28.4	26	26.4	28.6	29	30.6	29.1	28.7	24.8	29.4	27.8	29.4	31	30.9	29.4	29	25.5	28.9	27.6	27.5	26.5	27	27.4	30	28.7	28.7	29.1	29.1	28.3
2011	6	29.8	27.4	29	31.2	31.6	31.7	30.6	28.9	29.8	30.5	26.7	30.1	30.9	29.4	29.3	27.5	26.3	26.4	29.7	28.6	29.7	30.3	30.8	28	29.6	27.7	28.1	27.7	27.5	28	99
2011	7	26.8	26.5	27.4	28.1	29.2	28.7	27.3	29.1	30.2	30.7	31.3	30.1	30.2	30	29	29.6	29.8	28.1	27.9	27.9	26.9	27.1	29	29.1	30.6	29.9	30.7	31.1	31.6	31.5	30.9
2011	8	31.8	30.3	29.8	29.8	26.9	28	27.3	26.6	26.3	26.4	27.4	28.2	26.6	28.2	29.4	27	26.4	28.4	29.1	29.3	29	28.4	28.6	27.3	28.5	28.3	29.7	29.8	30.6	30.8	29.9
2011	9	29.2	27.4	29.4	30.3	29.8	29.4	28.8	27.2	28.4	29.8	29.7	32.1	30.6	28.4	28.6	27.1	27.4	28.5	28.7	29.5	29.2	29.2	29.2	27.9	29.1	29.7	28.7	29.4	30.3	30.9	99
2011	10	28.1	28.7	28.7	29.2	30.5	30.6	29.6	28.5	27.7	27.8	29.4	28.9	28.8	29.1	29.1	28.7	29.3	27.6	28.2	29.6	27.4	25	26.8	27.5	27.3	27.3	26.7	27.1	26.9	26.5	26
2011	11	24.9	24.4	24.6	24.1	24.1	23.6	24	25	24.5	24.1	24.3	25.2	25.4	24.5	24.2	22.8	23.7	23.1	22.4	22.9	23.4	23.7	23.6	23.7	24.7	23.5	23	23.1	22.9	22.6	99
2011	12	23	23.2	23.9	23	22.6	22.8	22.4	23.4	22.5	20	21	21.3	19.8	18.1	16.3	16.6	14.5	15.7	14.8	15.7	14.3	14.4	13.4	14.6	16.6	18.2	20.4	21.7	21.7	21.8	21.8

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
2012	1	23.1	19.5	19.3	19.8	19.6	20.1	20.2	21.7	18.6	19.7	19.4	15.8	15	16.7	17	16.7	18.8	19.8	20.7	20.8	17.3	17.3	17.4	17.4	17.2	18.5	18.5	19.1	19.7	20.5	20
2012	2	20.3	18.9	19.7	20.9	20.2	21.6	21.5	22.6	22.3	18.9	19.5	19.4	19.6	21.4	23.7	23.7	22.9	22.6	21	21.5	22.5	24.2	24.9	25.8	25	24.9	23.4	24	25.1	99	99
2012	3	24.8	24.8	25.2	25.8	26.7	28	28.2	27.4	26.9	25.7	26.4	26.3	25.9	26	24	25.5	26	25.2	27.3	28.3	28.7	29.1	26.7	27.7	28.8	29.3	29.3	29.5	29.8	29	29.7
2012	4	29.1	30.1	30.9	30.1	29.7	22.6	22.7	24.8	21.6	23.2	26.7	25.2	27.4	29.1	27.1	28.6	30.3	28.2	29.8	29.5	27.7	30.7	30.6	30.7	28	29.2	30.7	29.5	30.4	29.6	99
2012	5	25.9	26.2	28	24.4	28.6	29.5	30.4	31.5	30.9	31.3	29.7	30.6	30	31.6	30.2	28.7	29.7	30.6	30.2	30.2	31.5	32.1	31.3	30.6	31.8	32.4	32.2	30.6	31.8	30.5	29.7
2012	6	28.3	30.8	31	30.5	27.9	28.9	29.8	31.4	32.1	31.9	31.4	31.7	31.9	31.9	29.1	26.6	28.8	28.3	30.1	29	29.8	29.2	28.1	26.8	27.5	30.5	28.1	29.3	30.6	30.1	99
2012	7	30.6	29.7	28.7	29.6	29.3	29.3	29.9	28.8	29	28.9	29.7	28.5	30	27.9	29.8	29.7	28.2	27.9	28.7	29.8	29	28.9	29.8	30.1	29.8	28.9	28.4	29	28.3	28.6	27.9
2012	8	28.4	29.3	29.6	30	28.5	28.5	28.9	28.6	30.2	29.8	29.1	26.7	26.9	29.5	29.9	30.7	30.1	30.2	29.7	27.5	26.9	28.8	29.3	29.4	29.8	30	28.9	29.8	30.1	29.7	30.3
2012	9	30.2	30.5	29	27.5	27	27.6	30.9	31.1	28.4	28.8	29	28.6	28.6	28	28.8	27.9	28.3	29.5	29.5	29.7	29.9	30.2	29.9	28.5	29.3	29	28.6	30	28.4	28.9	99
2012	10	30.6	29.5	28.8	26.7	27.9	28.5	29.6	29	27.6	27	27.6	27.5	26.4	26.6	28.2	28.9	29	29.4	29.2	28.5	27.8	28	27.6	26.6	25.6	25.7	26.6	26.2	27.2	27.7	27.9
2012	11	27.6	27.6	24.8	22.5	23.5	23.2	24.8	24.5	22.9	22.4	22.3	22.6	22.9	22.6	23.4	23.5	25.3	26.4	27.2	26.8	25.7	23.3	21.8	21	20.4	20.6	20.3	21.1	21.8	21.2	99
2012	12	21.8	22.1	22.2	21	20.2	19.7	19.7	20.1	19.8	19.2	19.1	20.9	21	21.5	21.2	20.3	19.9	16.6	17.9	17.5	17	15.3	16.2	16.9	15.6	15.1	14.8	12.7	14	15.1	16
2013	1	17	18.4	18.9	19.9	18.7	18.2	17.1	12.5	10.4	12.3	12.5	15.8	16.8	17.7	18.5	18.6	19.4	20	21.6	21.5	19.6	19.4	19	18.5	15.7	16.1	17	18.2	17.9	19.6	20
2013	2	19.6	21.4	22.3	22.3	23.2	23.8	24.2	22	20.7	21.5	22.5	23.3	23.4	22.4	23.8	23.5	19.1	17.9	20.4	22.3	23.1	24.5	24.8	25.9	25.8	25.5	25.6	25.2	99	99	999
2013	3	24	24.4	24.8	25.5	25.1	26.1	26.5	26.2	26.2	27	26.5	27.5	26.8	28.3	29.5	28.5	26	26.4	27.9	28.4	28.5	27.9	28.1	29.2	29.7	30.2	29.7	29.8	28.4	28.8	29.2
2013	4	27.4	29.2	30	31.1	30.2	29.2	29.7	30.6	30.9	30.3	30.7	31.2	31.1	29.7	28.6	25.6	25.6	26.7	27.5	27.6	27.5	24.8	26.9	29	30.1	31.5	28.4	28.4	30.4	30.6	99
2013	5	31.3	31.3	31.7	27.9	25.2	23.6	26.5	27.4	27.8	30.4	29.7	26.8	28.7	27.8	28.5	23.4	28.8	28.8	30.6	27.5	26.7	26.4	25.6	25.8	28.4	30	30	29	28.4	26.9	25.6
2013	6	30.3	31	32.2	32.1	31.5	29.2	26.4	30	29.7	31.2	32.1	31.2	30.9	29.2	30.5	31.9	32	32.2	29.6	29.7	30.9	30.9	30.9	30.3	27.9	28.8	29.4	27.4	26.9	27.5	99
2013	7	29.4	29.8	29.6	28.3	30.4	30	29.5	30.6	30.3	30.4	29.7	29.2	28.6	28.7	30.5	30	29.4	29.8	28.9	28.7	30.1	31.1	30.9	30.6	29.4	27.7	26.9	26.1	27.9	29.1	28.3
2013	8	29.1	30.2	30.2	29.2	29.2	26.9	27.5	28.3	29.7	27.6	27.7	28.1	29.4	28.2	27.6	27.6	28.6	28.4	28.4	27.1	27.9	29	30.2	30.1	31.3	28.7	28	28.6	28.7	29.3	29
2013	9	29	29.1	29	29.1	28.8	29.3	29.3	25.8	27.8	27.8	28.8	29.2	31.4	27.7	29.6	29.1	29.5	29.5	29.8	30.3	29.8	29.2	30.6	30.2	27.4	28.3	28.7	28.4	26.8	26.6	99
2013	10	28.5	30	28.1	25.9	26.6	26.3	26.9	27.9	28.3	29.2	29.4	28.9	29	29.3	28	27.6	28.7	29.4	29.6	27.4	25.4	24.9	25.4	27.4	24.4	23.4	24.9	26	26.8	25.5	25.4
2013	11	25	25.4	26.1	24.4	24.4	24	24.5	24.5	24.7	25.4	25.2	24.2	23.9	23.5	23.9	25	22.9	24.5	23.2	22.1	21.8	22.7	22.7	22	22.3	22.7	22.4	23.2	23.6	23.4	99
2013	12	23.7	23.5	22.4	23.4	23.1	22.4	22.5	22.6	22.3	22.4	22	20.1	20	19.4	19.1	19.5	19	19.3	18.8	19.7	20	20	21	20.8	17.4	17.5	16	16.6	16.8	17.3	16.4

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
2014	1	19.2	19.3	18.2	16.9	17	17.1	17	16.6	14.4	15.7	20	19.5	20	17.2	15.8	16.7	17.2	20.1	20.3	18.6	16.7	19.2	21.4	21	21.2	19.7	17.5	17.1	19.3	20	18
2014	2	18.4	19.3	17.6	16.2	19.6	21.1	21.9	23.6	23.1	22	22.4	21.5	20.7	21.6	19.6	18.8	17.9	18.8	21.2	21	20.9	21.9	23.1	23.4	24.3	22.7	23.4	22.3	99	99	99
2014	3	23.4	23.4	24	23.9	23.2	23.7	23.3	22.8	23.7	24.5	24.6	26.1	27.1	26.8	25.9	25.8	26.5	27.9	28.3	27.4	27.1	27.2	26	26.5	27.1	28.5	30.2	30.5	31.5	31.5	31.6
2014	4	30.7	30.9	29.7	25	27.7	27.9	29.5	29.9	30.5	29.6	30.2	30.8	30.1	29.7	29.8	31.6	31.3	32.2	31.8	32.6	32	32.4	32.8	34.4	32.2	31.5	32.2	29.4	30.4	31	99
2014	5	29.4	29.5	28.7	30.3	28.4	31.3	27.7	30.6	32.3	31.6	28.7	31.4	31.1	30.9	30.6	31.9	31.8	32.3	32.2	32.1	31.9	32.3	33.1	28.4	27.5	29.3	28.5	27.9	30.4	27.6	26.9
2014	6	27.4	27	29.2	30.7	31.7	31.7	31.7	32	32	31.3	27.8	32.3	30	32.2	31	31.3	28.4	29.3	28.4	27.7	27.3	27.4	26	27.5	30	29.2	28.8	29.2	28.6	29.6	99
2014	7	29.6	29.1	28	28.2	26.9	29.5	30.6	29.7	30.8	31	30.6	31.8	31.3	30.6	29.1	28.1	29.3	29.8	29.8	29.3	27.3	28.1	29.2	29.3	30.7	31.1	28.4	28.9	29.3	30.3	29.9
2014	8	30.5	30.4	28.9	28.5	29.2	28.5	29.4	29.5	29.7	29.7	29.8	29.6	27.4	26.7	27.7	27.5	28.4	28.8	27.9	28.6	29.5	28.6	28.6	29.2	28.4	27.3	27.9	27.4	30.2	29.6	28
2014	9	28.6	29.5	30	29.8	29.4	29.8	29.6	29.4	29.8	30.3	29.9	29.9	29.9	30.5	29.7	29.5	29.8	30.2	28.5	26.7	28.2	27.8	27.6	27.1	28.5	27.9	29.6	29.8	28.6	29.2	99
2014	10	30.1	29.4	29.9	30	30.5	30.3	29.3	29.1	29.5	29.5	26.6	27.8	27.6	28	29.2	28.9	27.5	26.4	27.1	27	26.9	27.7	27.1	26.7	27.2	26.4	24.5	23.4	24.5	25.2	25.2
2014	11	26.3	25.9	26.7	26.8	26.2	27.5	28.3	29.2	27.4	26.3	25.6	25.5	25.4	24	22.8	23.1	23.6	24.4	24.5	24.5	23.6	22	21.8	21.5	21.5	20.9	21.6	21.2	21.1	21.4	99
2014	12	21.4	21.7	21.7	22.1	22.3	23.4	19.1	18.5	18.6	18.9	17.5	16.4	17.5	19.9	19.9	21.7	18.7	16.1	17.8	19.9	20	19.3	18.8	19.9	19.4	14.1	14.8	15.9	15.6	18.2	19.4
2015	1	22.1	23.7	24.7	22.6	19.4	18.9	17.2	17.6	17.5	17.6	15.6	17.1	18.7	20.3	19.7	21.3	18.2	14.1	14.4	15.1	16.5	19.3	20.4	19.8	20.5	20.5	21	21.3	21.1	19.1	17.8
2015	2	18.1	19.7	20.9	21	22.3	20.2	19.4	20.9	21.8	21.3	20.2	20.1	20.3	21.9	21.5	21.8	22.4	23.4	20.5	23.1	24.6	24.5	25.8	26.1	25.9	26.7	26.4	25.9	99	99	99
2015	3	27.5	26.4	24.8	22.3	22.5	21.5	22.3	24.5	25.7	25.4	24.1	24.1	24.8	26.9	28.5	26.8	27.2	26.2	26.1	26.6	26.3	26.8	28.5	29.9	29.6	28	29.1	29.2	28.4	28.7	26.7
2015	4	25.2	27.1	27.9	26.9	24.9	25.9	25.8	26.8	29.1	29.9	30.1	28.9	28.2	29.2	30.8	30	29.6	29.4	26.3	29.4	30.1	27.8	27.4	27.4	23.8	25.9	27.3	28	28.9	28.4	99
2015	5	29.1	28.9	30.2	30.5	31	30.8	27.5	25.7	29.8	29.8	27	27.2	30.7	31.7	28.3	29.3	29.3	29.6	30.4	31.3	31	32.1	32	28.4	30.6	29.9	29	29.1	29.7	29.5	31.5
2015	6	31.9	30.4	31.8	32.3	31.7	30.8	31.4	31.6	31.5	27.8	26	28.8	26.6	28.2	28.4	28.4	29.3	29.3	31	30.7	29.8	27.6	28.1	28.2	27	26.7	26.5	27.5	29.3	29.5	99
2015	7	29.4	29.2	29.7	30.7	28.9	30.7	29.8	28.4	26.6	27.1	30.3	30.2	31.5	31.1	27.2	28.2	27.3	26.8	26.1	26.7	28	27.6	29	27.3	26.9	27	26	28	31	30	25.2
2015	8	26.6	27.8	29	29.8	30.5	30.4	29.4	30.1	30.7	30.7	30.6	30.1	29.5	28.8	29.7	29.2	29.4	28.9	28.7	27.1	27.4	29.2	28.9	29.7	30.1	29.9	29.5	29	29	29.1	28
2015	9	27	26.7	27.7	27.5	27.9	29.3	28.9	30	30.5	29.9	29.3	30.6	29.5	30.1	30	30.4	30.5	30.8	27.5	26.4	27.9	27.7	26.9	28.3	29	29	29.1	29.7	30.4	31.2	99
2015	10	31	30.8	28.9	30.1	29.5	29.4	29	26.2	28.7	28.2	27.9	25.9	25.5	26.4	26.5	27.9	27.7	28.3	28.3	27.9	27.6	27.8	27.4	26.8	26.3	26.6	26	25.9	26.3	27.2	25.8
2015	11	24.8	25.8	26.4	26.8	26.1	26.3	25.2	25.2	24.3	24.8	24.8	24.8	24.3	24.9	24.5	24.9	24.7	24.3	23.7	24.3	24.4	24.1	23.4	23.3	22.9	22.5	22.2	22.9	23.3	24	99
2015	12	24.6	24.1	24.4	22.8	22.6	23	22.1	21.7	22	21.9	22.2	23.8	23.1	20.8	19.6	18.6	18.2	17.5	17.9	17.4	17.5	18.4	18.3	19.1	18.3	18.4	18.8	18.7	19.1	19.2	19.7

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2016	1	19.8	20.1	19.7	20.8	20.3	20.1	19.9	20.4	20.5	19.3	19.1	18.6	18.5	19	19.1	19.7	19.5	19.8	20	18.3	18.2	16.2	16.1	16.1	16.1	15.6	18.4	19.2	19.2	18.9	20.8
2016	2	21.3	21.4	22.1	21.1	19.9	19.9	21.2	22.4	23.4	22	23.1	23.9	22.8	23.7	24.9	24.9	24.7	26.2	27.3	28	28	25.9	26.2	23.5	24.9	26.2	25.9	25.9	26.2	99	99
2016	3	25.6	25.8	27.4	27.3	27.3	26.3	26.1	27.3	28.8	29	28.9	29	26.9	26.2	27.8	27.4	26.7	27.8	26.2	27.2	28.8	29.4	28.5	27.7	28.4	29.7	28.9	24.5	25.9	27	23.5
2016	4	22.3	25	27.4	28.9	28.6	30.2	30.2	30.6	30.4	30.9	31	31.5	31.3	31.1	30.9	30.9	30.9	30.4	31.3	30.8	30.9	31.4	31.7	32.5	31.9	31.8	31.4	31.6	32.1	32.1	99
2016	5	29.5	26.4	28.7	28.5	28.7	28.3	26.3	28.8	29.2	30.7	31.2	28.4	25.2	28.8	30.5	31.3	31.2	28.7	27.3	25.8	24.7	29	30.6	27.8	27	28.6	28.7	26.6	28.5	30.1	28.6
2016	6	29.5	31.3	31.5	31.5	30.1	29.3	27.3	29.7	28.5	30.9	27.2	26.5	27.7	28.6	29.6	30.5	29.9	29.3	30.2	30.7	30.1	29.9	30	30.9	31.5	31	31.2	31.4	31.3	30.9	99
2016	7	30	29	28.1	28	27	27.3	30.2	30.5	29.8	29.4	30	29.9	29.6	30.3	29	27	28.4	28	28.1	29.2	28.9	27.5	27.8	28.7	27.9	27.8	29.6	29.7	29	28.9	29.7
2016	8	29.5	29.7	30.7	31.1	29.8	29	29.2	29.5	27.9	26.9	28.6	30.3	29.6	29.8	30.6	29.5	29.2	29.8	30.7	30.6	26.8	28.6	29.4	31.1	31	29.7	30.8	28.3	30.1	31.2	30
2016	9	29.1	29.7	29.1	29.3	28.3	28.8	29.2	29.8	30.4	30.2	28.9	28.4	26.7	28.6	30	30.2	29.6	29.6	27.9	27.7	28.3	28.1	29.4	27.8	29.7	27.7	30.1	28.3	29.7	30.2	99
2016	10	29.2	29.2	30.1	31.1	28.9	27.6	28.3	28.9	28.8	28.9	26.7	27.2	27.8	28.6	29.1	29.7	30.2	29.5	30.4	29.9	29.4	28.5	28.4	28.1	28.8	28.9	25.8	26.6	26.9	27.5	28.2
2016	11	29.1	29.5	29.1	25.1	22.5	22.8	23.7	24.5	24.8	24.5	24.1	24.2	24.9	24.6	24.6	24.9	24.1	23.3	23	23	23	22.6	22.8	23	22.8	22.6	22.4	23.1	23.1	22.9	99
2016	12	23.3	23.5	23.8	24.1	22.8	22.8	22.1	22	21.8	21.3	21.7	21.5	20.3	19.8	20.3	20.1	21	21.5	21.3	21.3	20.9	21.4	21.8	21.8	22.3	22.6	21.5	20.1	20.7	20	19.7
2017	1	20.6	21	21.6	20.7	18.7	18	18.9	19.7	20.2	19.8	19.4	19.3	17.4	17.2	18.6	18.2	18.1	19.8	21.5	20.3	20.6	21.3	20.6	21.6	21.3	22.6	21.6	22.2	20.8	20.4	20
2017	2	21.2	20.4	20	21.6	23.8	23.6	23.8	22.6	20.9	21.7	22.5	23.8	23.5	23.6	24	23.8	23.8	24.5	24.5	24.8	26.5	26.3	24.4	23.3	22.3	22.9	24	23.8	99	99	99
2017	3	24.5	26.5	26.7	25.5	25.5	24.6	25.4	24.1	23.6	25.1	22.7	24.1	23.7	22.9	23.4	23.2	26	23.3	25.3	20	23.1	25.5	26.9	28.3	24.2	26.7	28.1	27.4	26.7	29.1	29.2
2017	4	29.5	28.9	28.4	26.7	24.2	26.5	29.8	29.8	29.6	30.4	30.5	29.7	30.6	30.6	28.2	26.5	29.1	29.9	26.6	26.2	25.3	22.1	24.4	23.1	28.4	29.8	29.7	30.1	27.7	28.4	99
2017	5	26.8	27.7	30.3	29.7	30.6	30.1	30.3	31	26.4	29	31.2	30.5	30.5	29.9	27.2	26.7	28.2	30.3	31	32	31.6	32.2	32.8	32.4	32.6	29.2	30.3	30	30	27.4	28.8
2017	6	26.4	28	31.3	30.1	27.2	30.8	31.6	30.3	30	30.9	28.5	25.7	29.4	28.8	29.2	27.2	28.5	29.6	25.7	28.4	29	29.6	30.1	30.5	29.9	30.3	30.2	29.9	30	29.9	99
2017	7	29	28.4	28.1	27.7	27.7	29.6	29.4	29.3	29.8	28.8	26.7	28.1	28.6	29.6	30.8	31.8	30.6	30.6	27.2	27	27.8	28.9	27.6	26.6	26.3	26.8	29.5	31.2	29	28.7	30.5
2017	8	30.1	28.4	28.8	30.2	30.2	29.2	29.1	30.4	29.7	29.7	28.3	26.6	28.2	28.2	28.1	28.1	29.5	28.8	30.1	30.2	28.7	28.8	28.1	29.7	28.8	29.2	29.6	29	29.6	30.4	28.1
2017	9	29.1	29.1	29.1	30.6	30.5	30.8	30.2	30.4	29.5	27.1	25.8	28.7	28.7	29.4	29.4	31.8	28.2	29.7	27.2	28.5	29.1	30.5	31.2	31.7	30.4	30.2	29	28.1	26.9	27.5	99
2017	10	27.4	28.7	29.6	30.5	30.7	29.6	28.2	28.1	27.2	29.4	30.3	30.4	30.2	29.9	29.1	29.7	30.3	29.3	26.5	24.4	24.2	24.6	27.6	27.1	26.5	26.4	26.1	25.1	25.5	21.9	23.5
2017	11	25.2	25.6	25.7	27.2	27	27.1	27	26	25.2	25.4	25.4	26.6	27.1	26.3	23.6	22.8	25.5	26.8	25.7	25.1	24	22.8	22.8	23	22.6	22.6	23.1	21.7	21.6	21.3	99
2017	12	21.8	22.2	21.8	21.3	21.1	22.7	22.7	22.8	21	22.1	22.8	23.4	22.9	22	20.7	19.7	20.5	20.5	18	19.1	20.3	20.5	21	21.3	21.5	21.4	21.1	19.4	19.7	21.6	21.6

Daily average Dry-Bulb Temperature data in Celcius of Dhaka

Year	Mo	Days																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2018	1	20.6	20.2	18.4	15.7	16.1	16.8	14.1	13	16.6	16.3	13.8	15.1	15.7	14.6	15.7	17.7	18.8	20.1	20	18.3	19	17.7	19.8	19.6	20.5	19.6	17.1	17.1	17.6	18.2	19.1
2018	2	19.1	19.6	20.1	22.4	22.2	21.7	22.2	21.9	23.1	23.6	22.2	23.3	23.9	23	22.3	22.4	21.8	22.5	23.6	24.5	24.8	25	26.1	25.8	27.3	23.4	25.3	25.8	99	99	99
2018	3	25.9	26.7	27.4	28.2	28.1	27.4	26.2	25.9	25.6	25.5	26.3	27.5	26.5	27.6	28.4	27.3	27.5	28.1	27.8	27.1	28.4	28.1	28.4	29	29.6	27.2	27.6	28.9	28.8	25.1	24.2
2018	4	27.5	26.1	28.6	27.6	27.7	26.5	26.7	25.8	28.3	28.6	26.9	27	28.4	26.5	28.7	29.7	25	27.8	27.2	28.6	26.6	28	29.6	30.2	27.5	26.8	26.7	29.2	22.3	22.7	99
2018	5	27.4	25.2	26.7	25.9	26.9	29.4	27.2	29.6	27.8	24.4	25.8	27.5	26.9	27.7	28.5	23.8	27.7	25.8	27.9	26.9	26.3	28.1	26.7	28.7	28.9	30.7	31.3	30.6	29.9	30.6	26.1
2018	6	26.6	28.8	28	29	30.3	30	31.2	30.7	30.9	28.9	29	28.3	29.2	31.8	29.6	27.7	30.2	31.4	26.5	30.2	30.8	30.7	28.2	29.4	27.8	29.5	28.6	28.6	29.7	29.9	99
2018	7	30.1	29.1	27.2	27.5	29.5	30.4	30.8	29.9	29.2	29.7	30.2	30.2	30.4	31.1	30	29.7	28.6	30.8	33	31.1	28.7	29.1	27.3	27.1	27.4	27.2	28	27.8	28.9	28.8	29.4
2018	8	28.4	27.6	28.5	28.8	29.1	29.5	30	30	29.6	30.8	30.6	29	31	31.3	31.3	30.6	30.6	32	30.2	29.4	29.1	30	29.9	29.6	30.1	29.9	29.4	29.5	29	29.7	30.7
2018	9	29.9	28.3	29.7	29.5	29.8	29.2	29.3	30.3	30.2	29.7	29.1	29.4	27.9	28.5	30.1	30.7	31.6	32.1	31.8	28.9	28.2	28.5	29.7	30.4	29.7	30.1	28.4	30.5	30.4	31.4	99
2018	10	30.3	30.6	31.1	29	29.3	28.4	29.4	29.7	28.3	25.7	25.2	24.6	24.6	25.2	27.1	27.2	26.6	27.3	27.8	27.6	27.6	27.7	27.1	27.1	27.1	26.6	27.5	23.2	23.7	25.6	26.8
2018	11	27.4	26.8	27.3	27.5	27.6	25.7	24.6	24.8	23.3	23.1	23.5	24.4	23.9	23.8	24.8	25.2	24.8	23.2	23	22.4	22.4	22.7	22.7	22.5	22.6	23.6	24.8	23.6	23.1	22.5	99
2018	12	22.2	21.9	22.1	22.5	22.7	21.3	21.2	21.5	21.2	20.3	21.3	21.2	22.2	22.6	21.7	22.3	20	18	16.7	17.1	19.3	19.9	19.8	20.4	19.5	19.2	18.8	17.9	17.5	18.2	19.5

Note: 99 represent the missing values ; source of data: BMD, Dhaka.