Enhancing Urban Sustainability: Integration of Green Infrastructure on Urban Leftover & Grey Space in the Context of Dhaka

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ABSTRACT

Urbanization, a global phenomenon has gained attention due to Poor urban planning often posing hazards to individuals' and environment. This research investigates negative impacts of leftover and grey areas and their utilization to promote sustainable urban environment by enhancing ecosystem services by implementing Green Infrastructure specifically focusing on Dhaka's context. The objective is to assess the strategy's feasibility and impact on achieving Sustainable Development Goal 11, through both qualitative and quantitative analysis including field survey, green area assessment, thermal environmental measurement, structured interview and relevant case study analysis is done to understand the current scenario and priorities. Findings highlight the loss of green spaces exacerbating environmental issues, particularly thermal conditions. Furthermore, the misuse of leftover spaces has negative environmental, social, and economic repercussions, yet presents an opportunity for green integration, minimizing the challenges of acquiring large green development areas that's appreciated by dwellers and scholars. The case studies shows the feasibility, significance and potentiality of implementing various scale, pattern of Green Infrastructure. The outcome offers valuable insights and policy recommendations for policymakers, local government officials, architects, and urban planners to enhance integrated urban development and climate-resilient plans for Bangladesh.

Keywords: Green Infrastructure, Urban grey spaces, Leftover space, Ecosystem Services, Healthy sustainable environment.

INTRODUCTION

Background of the Study

Following rapid urban expansion, Dhaka has emerged as one of the globe's most densely inhabited cities and was built mostly without careful urban planning due to rapid urban growth (Mowla & Ashrafuzzaman, 2014). Dhaka City, formerly known for its calm, beautiful parks, well- maintained streets, and plentiful vegetation, has transformed into an urban landscape dominated by buildings and concrete constructions (Mowla, 2011), since it's harder to use available land for green space conservation due to rising land values and demand (Akhter, 2013; Nayeem, 2016). UNEP recommends that developing cities set aside 25% of their land for healthy green spaces (Shuvo & Hakim, 2013) where Dhaka has 8% of its land (Rahman & Zhang, 2018). According to Shuvo & Hakim (2013), 88% of Dhaka's urban landscape is built-up, indicating large amount of built and grey area compared to the rest smaller green space. Research shows that urban green spaces and Ecosystem Services are linked and help humans to promote health and well-being. Urban sustainability as the interaction of social, economic, and environmental systems. According to Davis et al., (2008) to improve urban settings, one must first understand the definition and relationship between human and urban ecology. Furthermore Unconscious urban growth creates and maintains leftover and grey spaces. Azhar et al., (2020) found urban residual places unsafe yet promising which needed to integrate into urban fabric for aesthetic & affective purpose. Given rising property values and limited land, recycling these zones can be an alternative instead of one huge eco-design project, where entire city becomes an eco-design project and this scale enhances independence, usefulness, and sustainability (Islam, 2018). Urban green landscaping are useful to reduce environmental damage and Utilizing available leftover/grey spaces as resources can be a solution to climate resilience and pollution at this critical time to maintain balance in Dhaka's fast growing urban environment.

Problem Statement and Rationale of the Study

In Bangladesh, particularly in Dhaka, land scarcity and escalating property values is increasing and diminishing green spaces becoming common. The city grapples with a multitude of environmental challenges, including the proliferation of heat islands, decreased carbon sequestration, heightened energy consumption, and diminished ecological footprints. Adding to these challenges is the scarcity of open-green spaces, particularly acute in Old Dhaka with only 5% and slightly better in New Dhaka with 12% (Mowla, 2011). With a stark contrast to the rapid loss of greenery over the past three decades, with 56% of green spaces disappearing, including a significant 88.24% healthy vegetation (Nawar et al., 2022). This results in reduced ecosystem services according to Rahman & Szabo (2021). Moreover urban growth often leaves certain spaces undeveloped or underdeveloped. Khan & Hyde (2012) concerns that these spaces endanger society and the environment. The dire need to quickly deal with uncertainties emerged upon their current uses. According to some recent studies about leftover and grey space condition of Dhaka city its numerous problematic conditions been found. In Malibagh, beneath flyover becomes dumping zone of solid, clinical, human, industrial, chemical etc (Shishir, 2022; Author, 2023). According to study 900 tons waste are dumped in backyards & landfills, 400 tons dumped on the roadside & in open space causes air pollution by emitting toxic substances, pollutants, solid particles, smog by burning, methane & carbon-di-oxide by burning down (Khan & Hyde, 2012; APO,2007). Dumping grounds and waterlogged areas become breeding grounds for mosquitoes, leading to diseases like dengue fever and harmful pathogenic activity (Khan & Hyde, 2012; Author, 2023). The capital's Gulshan Lake is highly polluted from indiscriminate solid and liquid waste dumping (Siddiqui & Islam, 2021). Vacant spaces often turn into illegal slums, with dwellings under flyovers, in roadside spaces, and on sidewalks, making these areas unhygienic. For example, Korail slum has grown beside Banani Lake, worsening its condition and filling it up (Khan & Hyde, 2012; Author, 2023). The bazaar under Khilgaon flyover and near Khilgaon Rail Gate has made the area more crowded and unhealthy due to open waste dumping. Similarly, Mayor Hanif Flyover is known for its unhygienic, unhealthy bazaar environment that has developed over the years (Khan & Hyde, 2012; Sabbir & Ali, 2021; Author, 2023). The negative use of space makes the area unsafe, less desirable, and ultimately decreases land value. Business prospects are hampered by shifting property lines beneath the flyover and competition among local authorities for unjust vendor subscriptions (Sabbir & Ali, 2021). In summary, environmental challenges including waste dumping beneath flyovers and on roads, leading to air and water pollution, water clogging, and disease outbreaks; Socio-cultural issues stem from illegal slum development and unauthorized bazaars under flyovers, causing hygiene concerns, security threats, and fostering illegal activities; Economically, these areas decrease land value, hinder business opportunities, and face property line disputes, impacting urban development negatively.

These studies underline the problem statement of pressing need for comprehensive strategies to address environmental, socio-cultural, and economic issues of urban lands while prioritizing the preservation and expansion of green spaces for a sustainable and healthier urban planning and management strategies, indicates a solution for re-using or revitalizing urban grey and leftover area and reviving urban green with available land. In studies Kaloustian et al., (2018) recommend using small abandoned or created spaces, mostly leftover ones in Municipal Beirut, some of which may be privately owned, to reduce urban warming. Cappa et al., (2022) suggest pocket urban parks may influence microclimate. According to Kasarabada (2020), design creates excess space where most are empty roof tops, flyovers, & unattractive areas behind buildings. Adding these places to a city's fabric can change its image. In particular, grey spaces could test UN SDGs 2030 goals. Islam (2018) discusses urban ecology & eco sustainability. He proposes plantations, green roofs, pocket parks, roadside plants to minimize pollution, eco-friendly landscapes to restore urban biodiversity, biomes, & more to promote healthy urban life & eco-sustainability. This research investigates the role of green infrastructure that provides ecosystem services , how functional small to large green infrastructure can minimize environmental problems, land waste, maximize land value, promotes monetary ,non-monetary benefits of urban ecology and evidence based effective outcomes which is feasible in the context of Dhaka.

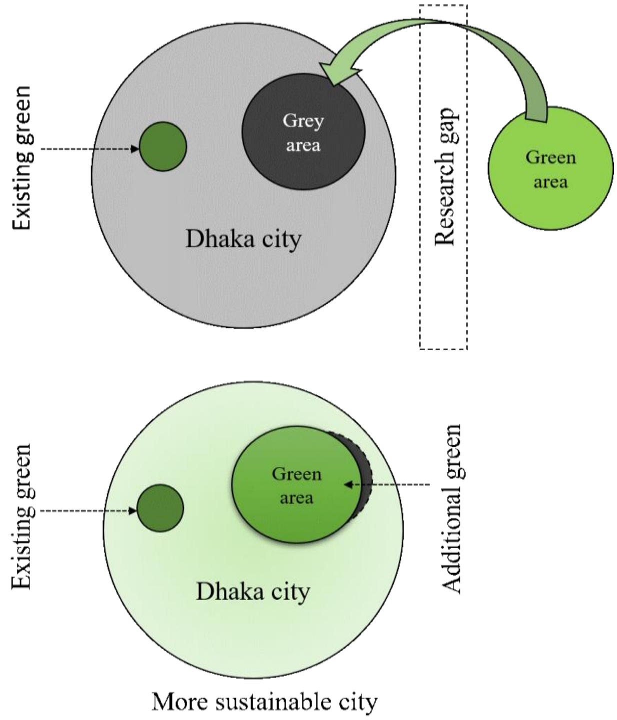

Fig. 1 The research gap of identifying specific zones and turning into green. (Source: Author, 2023).

Research Questions

1. What are the typologies of grey & leftover spaces that exists in the study context?
2. It is possible to utilize of grey & leftover spaces and transform into urban green spaces?
3. Can green infrastructure reduce the negative environmental impacts?
4. d) Can environmental sustainability be achieved by implementing green infrastructure in urban grey & leftover areas?

Research Objectives

The general objective of this research are studying & identifying the leftover, grey spaces to utilize them for sustainable environment, assessment of using the spaces to revitalize urban green to promote ecosystem services for a better, healthier & sustainable urban context and studying Green Infrastructure & its potentiality that will be feasible in our context.

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OB1 – Leftover, Grey Area

Identify grey, leftover spaces, considering land value, to determine if the land can be reused to enhance its usability and value for the community.

OB2 – Revitalization of Green Spaces

Use the land to revitalize urban green areas, promoting ecological balance for a healthier and more sustainable environment. Study the types, significance, and potential of green infrastructure, exploring how different types can be utilized functionally rather than just aesthetically.

METHODOLOGY

The research was meticulously conducted through several stages. Employing a combination of qualitative and quantitative methodologies and utilizing both primary and secondary data sources. Secondary data sources such as research papers, journals, thesis paper, newspapers, books, websites, as well as documents from institutions like CEGIS, City Corporation, and Urban & Rural Planning were scrutinized. To acquire primary data, a strategic approach was adopted. To grasp the urban context of Dhaka and understand the typology and availability of grey and leftover areas, a selective study area within the DSCC zone site was chosen for a comprehensive field survey to assess the variety of leftover and grey areas, as well as the conditions of green spaces within them. A sample size of n=100 was selected for structured interviews, employing convenience sampling to facilitate efficient data collection. Thirteen structured open-closed ended questions were designed to capture insights from local dwellers who are frequent in these spaces. Additionally, to evaluate the impact of green infrastructure on the thermal environment, temperature, relative humidity, and wind speed were measured at six individual stations. Lastly, secondary data analysis was conducted on case studies to compare practical solutions and assess their feasibility within the context of Dhaka.

RESULTS

Built Area and Green Cover Change of Study Area

This research needs to understand urban fabric and identify grey, leftover spaces to integrate green infrastructure. It was important to identify zones in an urban context for research and a better result. Researcher choose the DSCC zone site showing in Fig. 2, Fig.3 to achieve goal, which covers part of Ward 1's (previously Ward 24's) Khilgaon C block and part of Ward 11's Bagicha, Tilpapara, and Railgate. This busy neighborhood is near Motijheel, Kamalapur, Jatrabari, and Rampura and connected by major roads. The area approximately covers 0.447 km^2 range.

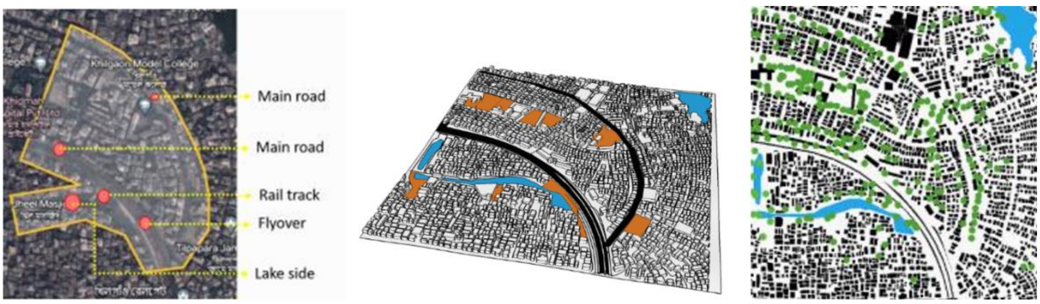

Fig. 2 (1) Selected study area and stations; (2) three dimensional perspective of study area showing urban density and solid-open green area ratio (Source: Author, 2023).

Researcher can effectively introduce Green infrastructure on identified zones, at residential zones both planned and unplanned, road-side, lake-side, rail-track, underneath flyover, and more in the study area. According to researcher's personal experience and surveys, this fast developing neighborhood has lost many of its green spaces to accommodate increasing urbanization. From available secondary data and map analysis starting from year 2002 to 2023 a drastic change in built-green area ratio can be seen. In year 2002 the percentage of developed urbanized area (building in general commercial & residential, different roads & pedestrian etc) -69% Urban green sparse green coverage 15 % which only includes roadside plantation & plantation in the Govt. quarter. Water body amount 6% & open field or open breathing area only 15% that was only under educational institutions, no public area were designed yet (Fig.3).

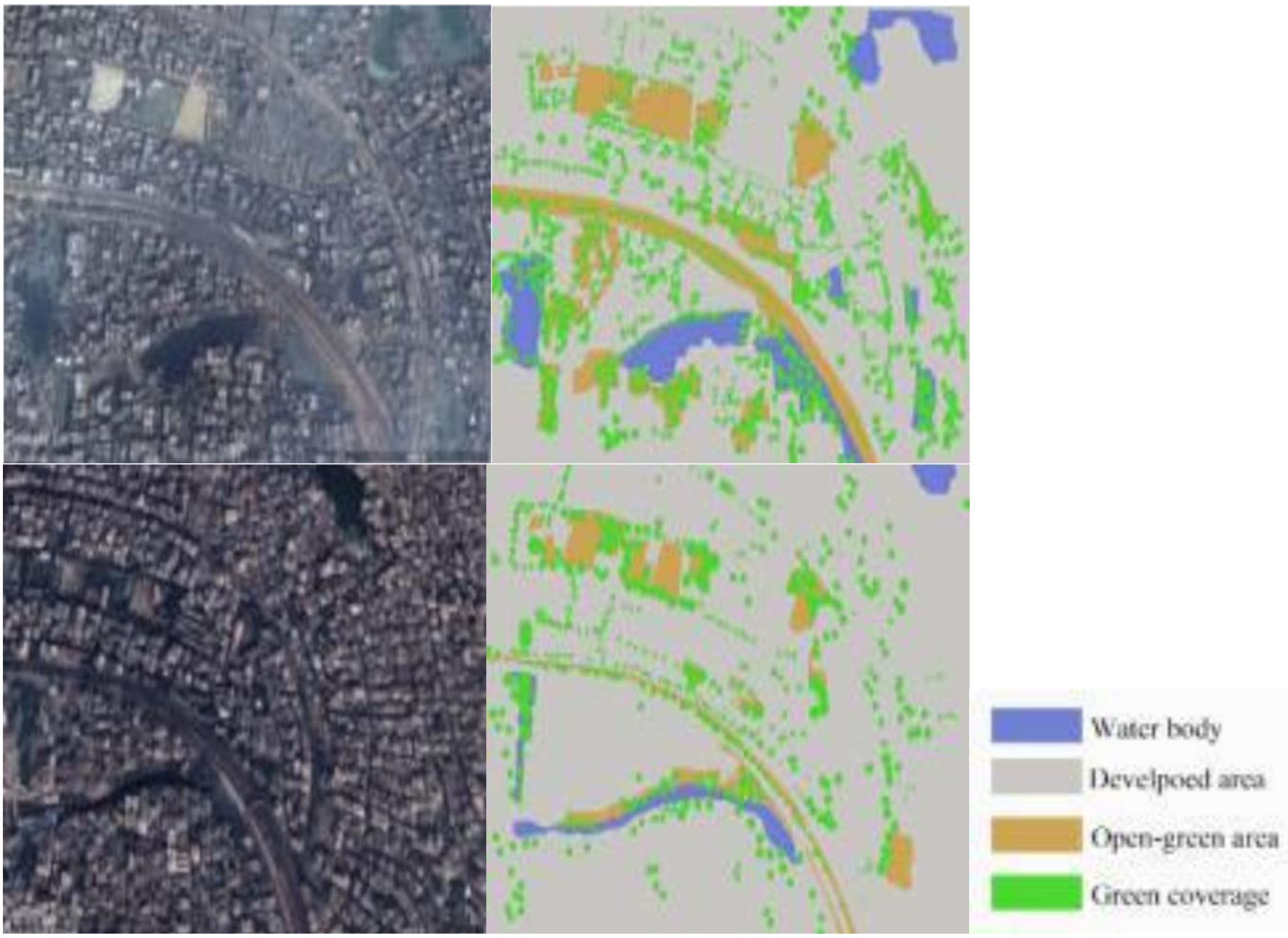

Fig.3 (1) Study area condition 2002 (Google earth, 2023); (2) Study area Land use & green coverage map (Source: Author,2023); (3) Study area condition 2023 (Google earth, 2023); (4) Study area Land use & green coverage map (Source: Author, 2023).

In 2023, the water body went from 2.38% to 2.04 losing 0.34% of its prior area, with about 6-7% of the area going under construction in just 3-4 years. The ratio of green to open space appears to have changed at larger portion decreasing from 14.10% to 9.39%, approximately 4.71% less, & decreasing from 5.74% to 4.69% for open space as a result of rapid urban development (Fig. 3). The analysis reveals a substantial urban expansion and the introduction of new infrastructure and functions in the period spanning from 2002 to 2023. This expansion has resulted in a reduction in the availability of public spaces featuring open green areas and other forms of vegetation, along with a notable depletion of water bodies. These findings echo the concerns expressed by researchers regarding the loss of land and green spaces within urban environments. Moreover, this trend is anticipated to persist, as dedicating a significant area exclusively for green

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development is not deemed feasible. Consequently, there is a pressing need to explore alternative approaches that can be integrated into the existing urban context to address these challenges effectively. The following Table 1 outlines the observed changes. The Table 1 highlights that land scarcity is a significant challenge arising from rapid urbanization, urban growth, and the expansion of grey areas. Research indicates that 15.53% of the region has been utilized for urban expansion, exacerbating the issue meaning leftover and grey area has increased greatly. Despite increasing urban populations, there is a noticeable decline in open and green spaces, suggesting an unmet demand for green area.

Table 1. Summary of Land use & green cover change from 2002 to 2023 (Source: Author, 2023).

Year	**Developed area**	**Green coverage**	**Water body**	**Open-green area**
2002	68.35%	15.28%	6.28%	10.09%
2007	70.03%	14.51%	4.18%	10.48%
2012	76.50%	13.32%	2.93%	7.24%
2017	77.83%	14.10	2.38%	5.74%
2023	83.88%	9.39%	2.04%	4.69%
Changes over year	+15.53%	-5.89%	-4.24%	-5.4%
Status	Increased	Decreased	Decreased	Decreased

Field Survey Data & Analysis

As the project focuses on diverse urban area types that can be used, distinct zones must be chosen for study stations. Even though the researcher has surveyed the entire area, some stations have been identified & are briefly addressed that are showing in Fig.6 below.

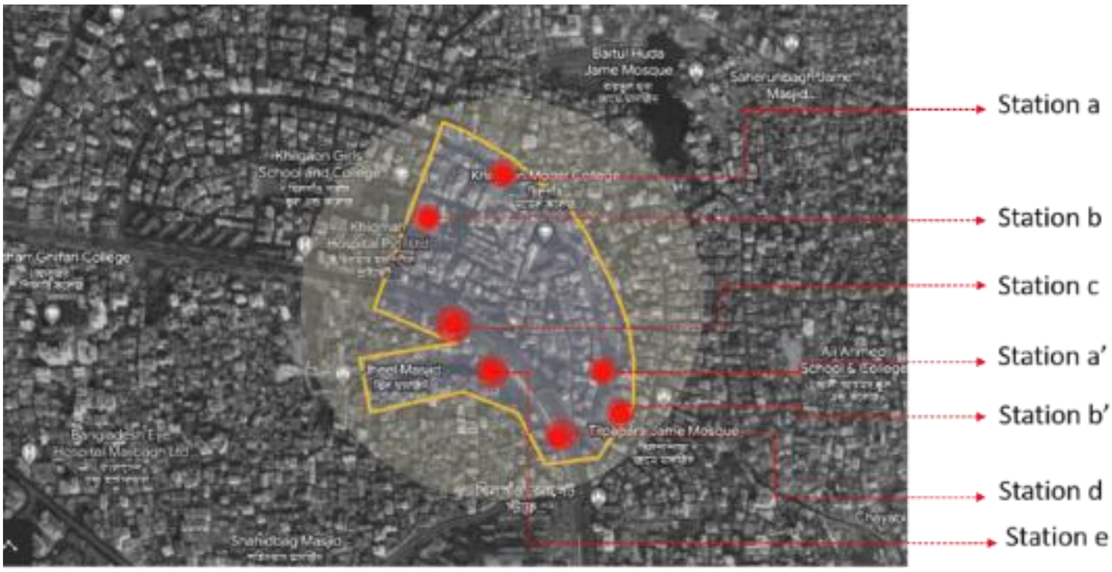

Fig.4 Urban station for field survey (Source: Author, 2023, Google map).

Urban Station a, a’ – Main road network point for study

Urban Station b,b’ – Play ground, field, gathering space .

Urban Station c- Sidewalks besides railway track.

Urban Station d- Sidewalks & condition of existing water body.

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Urban Station e- Underneath flyover & surrounding roads.

Urban Station f- Buildings**.

**For residential building a station named f selected for study purpose that may represent other buildings as well.

Leftover/Grey & Green Area Analysis

A comprehensive field study in the specified research zone revealed that rapid and mostly unplanned growth has created various unclear spaces. These areas can be defined, undefined, anticipated, unforeseen, or purposefully or unintentionally created. The public knows that these sites are used for a variety of activities, which harms the environment and other factors. Due to land shortages and urban ignorance, this problem persists. Another finding was that the study area's green space is unsatisfactory. Sustainable development in this area has received insufficient attention; as a result, green spaces are degrading. The research area is losing open green spaces, with the remaining regions mostly used by government. The lake is in its worst condition. Additionally, the lake became a trash dumping site. The blue zone shrank over time, as shown in Fig.4. This study was justified by Khan & Hyde (2012) and Mowla (2011)'s study on urban grey zones in Dhaka and lost or losing green space. This matches field survey results. The present field investigation confirmed Khan & Hyde (2012)'s findings about the people and groups living in these ambiguous spaces, including small and large businesses, illicit establishments, makeshift retail outlets, waste disposal sites, impoverished settlements, unlawful operations, parking facilities, and drug-related activities. These areas harm the environment and cause aesthetic pollution. Table 2 and Table 3 below provide a final overview of the physical field study.

Table 2. Findings from the field study regarding grey/leftover- green area condition (Source: Author, 2023)

Aspects	Urban Station a, a'	Urban Station b,b'	Urban Station c
Images	  Fig. 5 (Top & bottom) Pedestrian area beside main road (Source: Author, 2023).	  Fig. 6 Illegal shop beside road and field; The field with less green coverage (Source: Author, 2023).	  Fig. 7 Leftover space besides rail track Turned into slum (Source: Author, 2023).

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Current condition	Moderate (user's perception and researcher's observation). Causing environmental, economic and social impact.	Moderate (user's perceptionand researcher's observation). Causing economic and social impact.	Worse (user's perception and researcher's observation). Causing environmental, economic and social impact.
Occupier of vacant area	Illegal shop, tea stalls, parking, slum	Illegal shop, slum, store.	Illegal shop, slum, store.
Current Uses	Dumping zone, illegal activity like drug abuse, illegal shop.	Dumping zone, illegal shop.	Dumping zone, slum, illegal shop & activity.
Vegetation condition	Moderate (according to survey & case study comparison)	Not enough (according to survey & case study comparison)	Moderate (according to survey & case study comparison)

Table 3. Findings from the field study regarding grey/leftover- green area condition (Source: Author, 2023).

Aspects	**Urban Station d**	**Urban Station e**	**Urban Station f**
Images	  Fig.8 (Top & bottom) Lake side pedestrian and vacant spaces (Source: Author, 2023).	  Fig.9 (Top & bottom) Underneath flyover (Source: Author, 2023).	   Fig. 10 (Top & bottom) Residential building on ground, elevation and roof top (Source: Author, 2023).
Current condition	Worst (user's perception and researcher's observation). Causing environmental and Social impact.	Worst (User's perception and researcher's observation). Causing environmental, economic and social Impact.	Moderate (user's perception and researcher's observation).
Occupier of vacant area	Illegal shop, slum, parking area, rickshaw garage	Illegal shop, slum, parking area, rickshaw garage	Shop, parking
Current Uses	Dumping zone, slum, illegal shop & activity	Dumping zone, parking, illegal activity	Dumping zone, illegal activity
Vegetation condition	Moderate (according to survey & case study comparison)	No vegetation (according to survey & case study comparison)	Moderate (according to survey & case study comparison)

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Thermal Environment Measurement

The researcher conducted thermal environmental measurements to underscore the significance of green infrastructure in urban settings. Temperature, wind speed, and relative humidity were assessed in outdoor areas and building structures to evaluate comfort levels. Detecting extreme temperatures is critical for ensuring the health and safety of individuals engaged in various activities. Monitoring air flow and humidity is essential for understanding atmospheric moisture levels, which impact people's perception of temperature and their ability to regulate body heat. The findings highlight the importance of green spaces in urban environments to mitigate high temperatures, enhance microclimates, and enhance overall well-being and quality of life. The researcher selected six locations within the study area, measuring at a height of 1.5 meters (5 feet) above ground level, based on the condition and pattern of plantation. Data collection occurred between August 8th and September 12th. Data collection began at 11 am and ended at 2 pm, the warmest time of day. The zeal-clock-hygrometer and Mini Thermo-Anemometer was used to collect data. Following that, the data were computed and documented to aid the researcher in proving the plantation's relevance in an urban setting.

Fig.11 (Left) Zeal Clock & Hygro-Thermometer.(Right) Extech 45118: Mini Thermo-Anemometer (Source: Google).

Stations Locations & Factors

Station 01 (23°45'3.41"N, 90°25'27.99"E) located on Shahid Baki Road, this station has a notable width of approximately 40 feet and pedestrian activity on both sides, but lacks preexisting plantations or natural shade. Station 02 (23°45'7.70"N, 90°25'15.36"E) situated near Station 01, this station features a diverse array of trees, including narrow linear trees and larger canopy trees. This varied landscape potentially influences the microclimate, extending the duration of comfortable conditions and causing temperature fluctuations. Station 03 (23°45'3.65"N, 90°25'25.44"E) includes secondary roads with a width of 20 feet, bordered by tall structures on both sides with a building-to-road width ratio of 3:1. The layout promotes laminar airflow but results in a reduced Sky View Factor (SVF). Restricted air movement and heat-absorbing concrete, combined with no plantation, contribute to increased humidity and temperature levels over time. Station 04 (23°45'2.26"N, 90°25'20.22"E) features extensive plantings, dense canopies, and exposed soil surfaces, creating a varied microclimate. Despite a low SVF and a reduced road-building height ratio, the environment fosters conducive settings for public activities. Station 05 (23°45'1.65"N, 90°25'23.58"E) showcases an extensive rooftop garden and indoor-outdoor plantations, highlighting the significant advantages of plantings for both buildings and environmental purposes. Station 06 (23°45'0.57"N, 90°25'29.90"E) exemplifies a common roofing situation with a flat roof directly exposed to sunlight and lacking indoor-outdoor plantations. This exposure results in the absorption of heat, leading to elevated temperatures within the indoor environment.

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Environmental Data Analysis

Differences in Average Temperature, Relative Humidity & Wind Speed of Outdoor Environment

Table 4 illustrates that Station 01 initially records a temperature of 29°C at 11:00 AM, which gradually rises to a peak of 38.5°C at 01:00 PM, before decreasing to 36.6°C at 02:00 PM. The temperature difference from the lowest to the highest point is 9.5°C. This increase in temperature at Station 01 can be attributed to two primary factors: exposure to direct sunlight and the thermal properties of surrounding materials, which absorb and reflect heat. The thermal profile is influenced by various elements, including low relative humidity, the ratio of broad highways to building height, and a high Sky View Factor (SVF). A high SVF indicates significant exposure to the open sky and a lack of vegetation cover. In contrast, Station 02, characterized by abundant tree cover, exhibits a lower temperature, starting from 29°C at 11:00 AM and rising to 36.3°C at 01:00 PM, which is 2.2°C less than Station 01. This temperature difference is primarily due to the extensive coverage provided by the tree canopy. The stations exhibit a temperature difference of 1-3°C, underscoring the importance of vegetation. Additionally, Station 01 records lower relative humidity compared to Station 02, with wind speeds averaging higher at 2.6-0.4 m/s in Station 01 due to fewer obstructions from plantations, whereas Station 02 records lower wind speeds around 0.8-0.1 m/s. Factors such as the Sky View Factor, moisture content from evaporation, and wind flow patterns and speeds play crucial roles. At Station 01, the absence of vegetation allows for freer wind flow, but the lack of shade and moisture absorption from evaporation contributes to higher temperatures, making the environment less comfortable compared to Station 02, where plantations provide shade and moisture. Notably, relative humidity remains consistently similar or higher at greenway study points compared to bare study points.

Station 03 initially recorded a temperature of 32°C at 11:00 AM, rising to a maximum of 37.1°C at 12:00 PM. This increase in temperature is due to direct exposure to sunlight, intensified by surrounding objects that absorb heat. Conversely, Station 04, located on the opposite side of the roadway, experienced a lower initial temperature of 30.85°C. Despite a rise in temperature over time, reaching 36.08°C, Station 04 benefited from the presence of linear to semi-large canopy trees, providing ample shade. This resulted in a reduced temperature difference of 0.9-1.75°C, creating a more comfortable microclimate compared to Station 03. Station 03 maintains a high SVF, resulting in higher humidity levels despite limitations on air circulation caused by the presence of trees. Wind speed at Station 03 ranges from 0.9-0.6 m/s due to laminar airflow effects, whereas Station 04 experiences lower wind speeds of 0.4-0.1 m/s due to obstacles from both plantations and buildings, as shown in Table 5. Station 03 faces challenges related to elevated temperatures due to heat-absorbing materials and difficulty in releasing heat over time. In contrast, Station 04 benefits from the presence of mature trees, which effectively mitigate heat, contributing to a more pleasant microclimate and enhanced user satisfaction. The study of temperature, relative humidity, and wind speed is presented in Table 4 and Table 5.

Table 4. Differences in average Ta & RH station 01, 02, 03 and 04 (Source: Author, 2023).

Survey hour	**St.01 Averg Dry Bulb Temp. (DBT), in C^o (T1) (Almost bare land)**	**St.-02 Averg. Dry Bulb Temp. (DBT) In C^o (T2) (linear plantation)**	**Temperature Difference ∆T=T1-T2 In C^o**	**St.01 Averg. Relative humidity (RH1) % (bare land)**	**St.02 Averg. relative humidity (RH2) % (linear plantation)**	**Relative humidity Difference ∆RH=(RH1-RH2) %**
11 am	29.0	29.0	0.0	56	56	00
12pm	32.85	31.85	1.0	31	35	04

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01 pm	38.5	36.3	2.2	22	22	00
02 pm	36.9	33.4	3.5	32	35	03
Survey hour	**St.03 Averg. Dry Bulb Temp. (DBT),in C⁰ (T3) (Almost bare land)**	**St.04 Average Dry Bulb Temperature (DBT) In C⁰ (T4) (linear plantation)**	**Temperature Difference DBT ∆T=T3-T4 In C⁰**	**St. 03 Averg. relative humidity (RH3) % (Almost bare land)**	**St.-04 Averg. relative humidity (RH4) % (linear plantation)**	**Relative humidity Difference ∆RH=(RH3-RH4) %**
11 am	32.60	30.85	1.75	56	57	01
12pm	37.10	36.08	1.02	63	65	02
01 pm	34.70	34.20	0.5	66	66	00
02 pm	34.90	32.00	2.9	41	41	00

Table 5. Differences in average wind speed of station 01, 02, 03 and 04 (Source: Author, 2023)

Survey hour	**St.01 Average Wind Speed (WS1) (m/s) (Almost bare land)**	**St.02 Average Wind Speed (WS2) (m/s) (linear plantation)**	**WS Difference ∆WS= WS2-WS1 (m/s)**	**St.03 Average Wind Speed (WS1) (m/s) (Almost bare land)**	**St.04 Average Wind Speed (WS2) (m/s) (linear plantation)**	**WS Difference ∆WS= WS4-WS3 (m/s)**
11 am	2.6	0.4	2.2	0.6	0.1	0.5
12pm	0.9	0.8	0.1	0.6	0.4	0.2
01 pm	0.3	0.1	0.2	0.8	0.3	0.5
02 pm	0.4	0.4	00	0.9	0.3	0.6

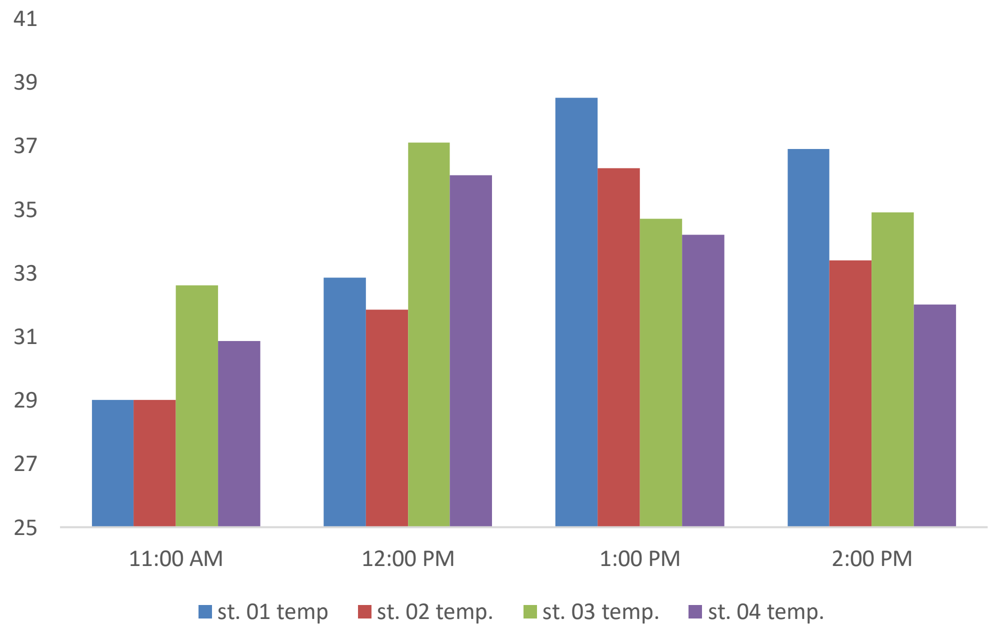

Chart 1. (1) Temperature differences in 4 stations (Source: Author, 2023).

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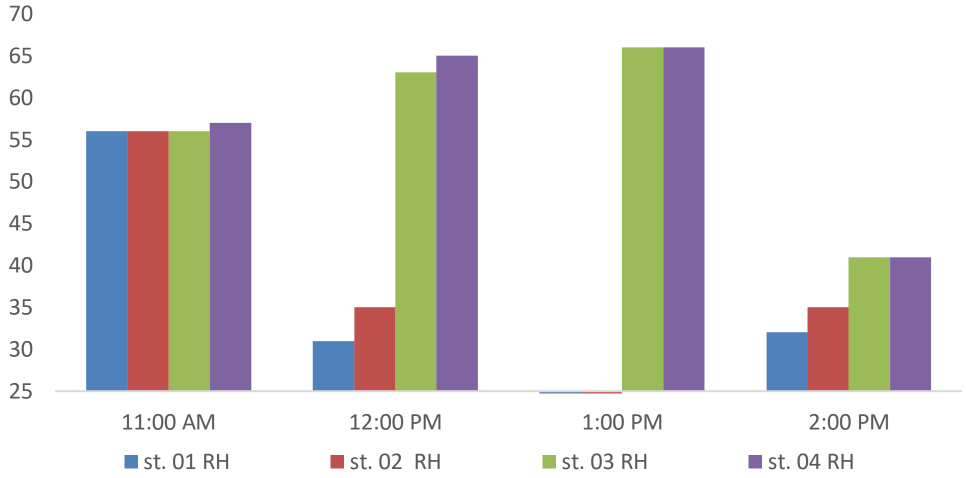


Chart 2. (2) Relative Humidity differences in 4 stations (Source: Author, 2023).

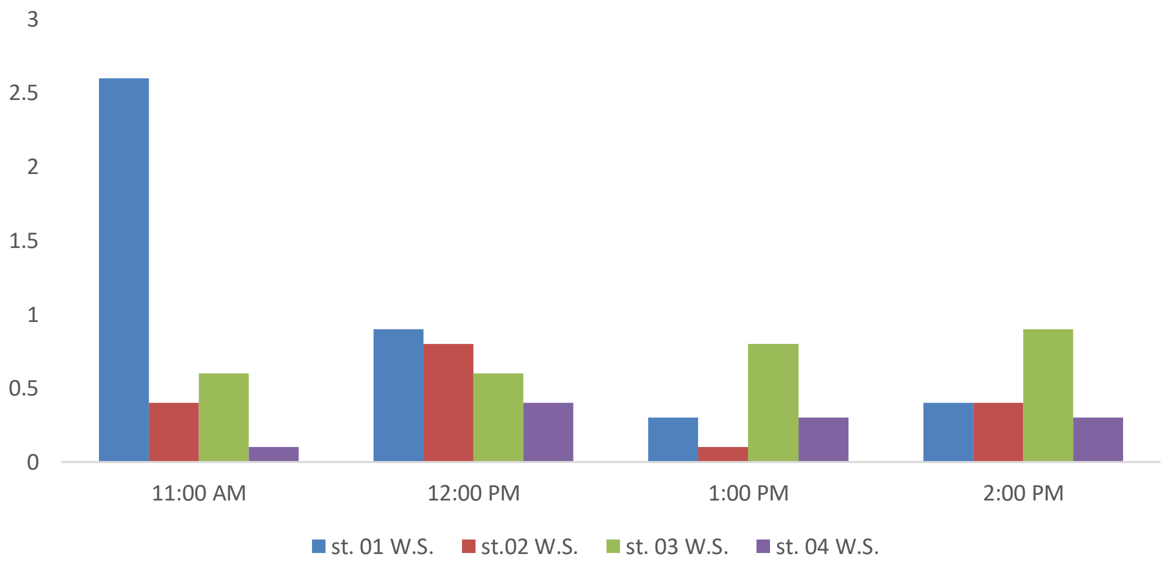


Chart 3. (3) Wind speed differences in 4 stations (Source: Author, 2023).

Charts 1, 2, and 3 depict the fluctuations in temperature, relative humidity, and wind speed across four stations at various times throughout the day, namely 11 am, 12 pm, 01 pm, and 02 pm. These variations signify the impact of factors such as the position of the sun, level of exposure, changes in sunlight intensity, and alterations in microclimate induced by factors like vegetation cover, open spaces, types of heat-absorbing materials, and urban design. The findings of the study emphasize that Station 02 and Station 04, distinguished by their abundance of greenery, offer superior comfort and more favorable environmental conditions compared to the other stations. This observation underscores the significance of vegetation in moderating microclimates and enhancing the overall quality of the environment.

Differences in Average Temperature & Relative Humidity in Indoor Environment

The analysis presented in Table 6 illustrates the impact of rooftop gardens and plantations on temperature regulation in Station 05 compared to Station 06. Station 05, which features both a rooftop garden and outdoor plantations, demonstrates significantly lower temperatures in comparison to the average outdoor temperature and outdoor surface temperature. Data from Station 05 reveals an average total temperature of 33.95°C, notably lower than the outdoor surface temperature of 41.62°C, indicating a substantial difference of 7.67°C. This highlights the effectiveness of plantations in providing shade and regulating indoor heat. In contrast, Station 06, lacking plantations, experiences higher indoor temperatures (36.2°C) and larger disparities with outdoor temperatures (1.4°C) and outdoor surface temperatures (12.3°C). The absence of plantations allows surfaces to directly absorb heat, resulting in less comfortable indoor conditions. Throughout the study period, the temperature difference between Station 05 and Station 06 ranges from 3.5°C to 1.3°C. Additionally, Station 05 exhibits lower relative humidity levels compared to Station 06. These findings underscore the significant role of rooftop gardens and plantations in moderating microclimates and mitigating heat islands, ultimately enhancing comfort and environmental quality.

Table 6. Differences in average Ta & RH station 05, 06 (Source: Author, 2023)

Survey hour	**Avg. outdoor temp. In ⁰ C**	**St.-05 Avg Surface Temp. outdoor**	**St.-05 Avg. indoor Temp.DBT, In ⁰ C(T5) (with plantation)**	**St.-06 Avg Surface Temp. outdoor**	**St.-06 Avg. indoor Temp. (DBT) In ⁰ C (T6) (without plantation)**	**Temp. Difference ΔT=T5-T6 In ⁰ C**	**St.-05 Avg. indoor relative humidity (RH5) % (with plantation)**	**St.-06 Avg. indoor relative humidity (RH6) % (without plantation)**	**Relative humidity Difference ΔRH = (RH5 -RH6) %**
11 am	37.3	41.8	33.9	50.2	36.4	3.5	59	67	08
12pm	38	40.9	33.8	51.6	35.6	1.8	48	64	16
01 pm	38.2	42.5	34	47.4	37.5	3.5	56	57	01
02 pm	37	41.3	34.1	44.2	35.4	1.3	50	62	12
Total avg.	37.62	41.62	33.95	48.5	36.2	2.25	53.25	62.5	10

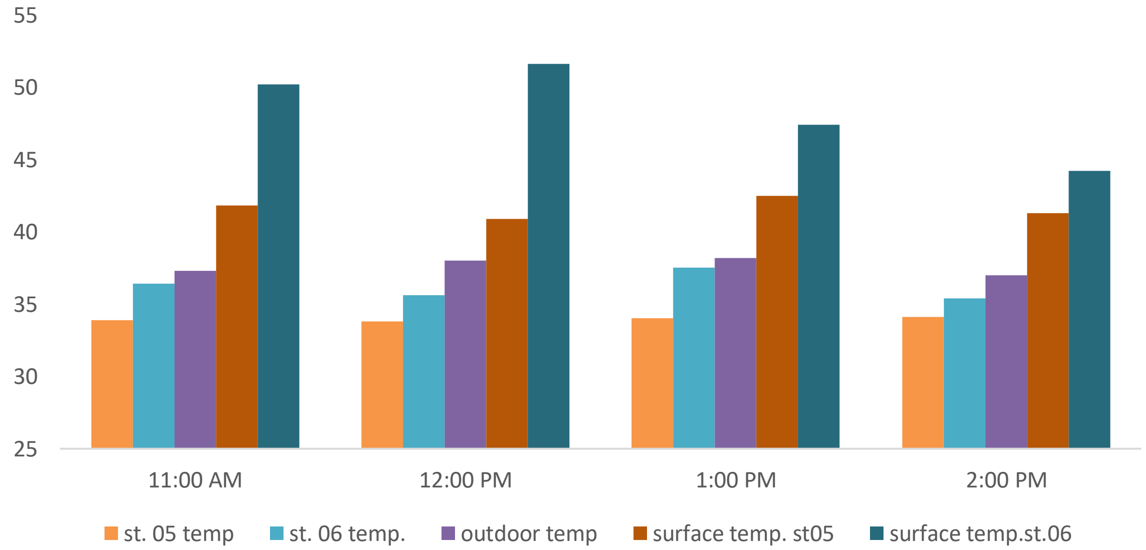


Chart 4. (1) Temperature differences in station 05 and 06 (Source: Author, 2023).

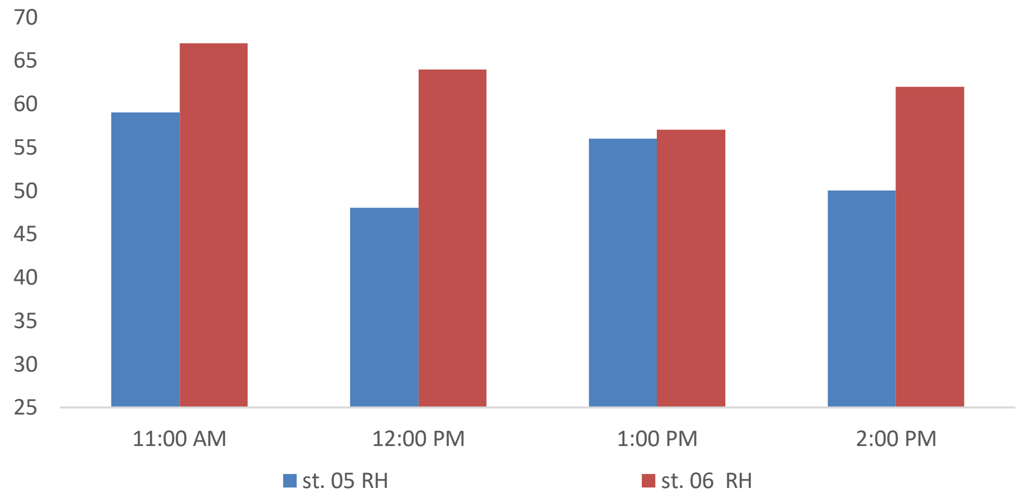


Chart 5. (2) Relative Humidity differences in station 05 and 06 (Source: Author, 2023).

Chart 5 and Chart 6 display the comparative differences in temperature and relative humidity, highlighting the significant impact of plantations. The fluctuations observed in both temperature and relative humidity are influenced by factors such as the presence of greenery above and the surrounding urban infrastructure signifying importance of plantations and station 05 is preferable than station 06.

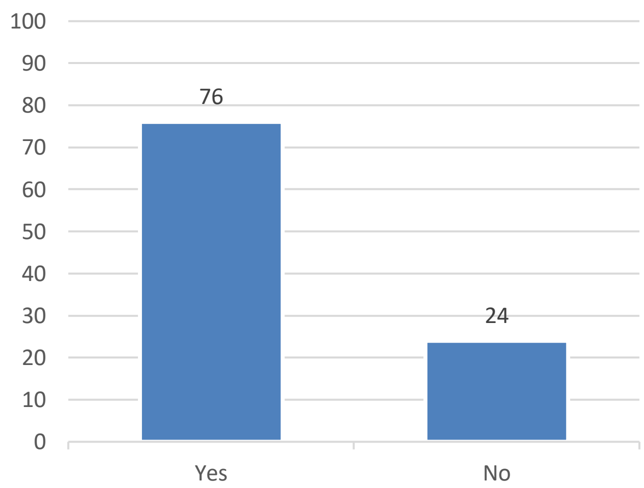
Questionnaire Survey Analysis

After conducting an extensive questionnaire survey and analysis, the researcher has concluded that a majority of the residents in the study area have identified issues stemming from unplanned urban growth. This survey has provided valuable insights into their perspectives and thought processes regarding the grey or leftover spaces outlined in the preceding sections, which, while not problematic for some (24%), present concerns for many (76%). A significant portion of individuals expressed ignorance about these features, underscoring the need to integrate urban development and planning more comprehensively into the urban fabric. Some respondents identified "urban grey/leftover areas" as unused, vacant, or misused spaces in the urban landscape, often associated with unsafe and unethical activities (78%). Local residents have encountered numerous incidents in these areas, prompting them to advocate for improvements (86%). There is a widespread desire for green (65%) and others open spaces (29%) in the neighborhood, seen as essential for both relaxation (41%) and social gatherings (38%). While the creation of large green spaces may not be feasible, most respondents support a plantation program in various locations. However, there are also individuals in need of housing and livelihood opportunities, particularly those with lower incomes. Nevertheless, following discussions, even these individuals expressed interest in plantation initiatives and sought better-planned environments to ensure their well-being. Respondents agreed that limited access to land, poverty, and a lack of environmental awareness contribute to the misuse and degradation of the environment. Many remarked that the neighborhood was cleaner and greener in the past, attributing the loss of green spaces to development projects such as building and road construction, which have irreversibly altered the landscape. A common sentiment among respondents is the need for accessible urban green spaces, with a preference for their development in unused areas such as roadsides (40%), pedestrian zones (35%), and building blocks (37%), underneath flyover (55%), beside rail track (43%). Plantations are seen as a means to improve the microclimate by controlling temperature (56%), controlling pollution (48%), reducing heat island (47%), and reducing noise pollution (26%) and enhance the overall environmental quality (41%) of these spaces according to them. The findings of this survey align with previous studies and corroborate the researcher's observations. Below in Table 7 and charts are some documented questionnaire responses aimed at understanding the priorities of the local residents.

Table 7. Participant's perspective regarding the project objective (Source: Author, 2023).

Aspects	**Preference (%)**	**Remarks**
Identified urban grey area as a problem	76	Mostly Preferred
Interested in improving urban grey area	87	Mostly Preferred
Interested in improving environment by plantation	90	Mostly Preferred
Interested in green development program	95	Mostly Preferred
Total participants = 100		

1. Due to unplanned & rapid urban growth has generated some spaces that are typically empty, such as unused, grey spaces between buildings, beneath flyovers, & adjacent to highways & roads, rail tracks. Do you agree that it is appropriate to label this region as unused "leftover" area?



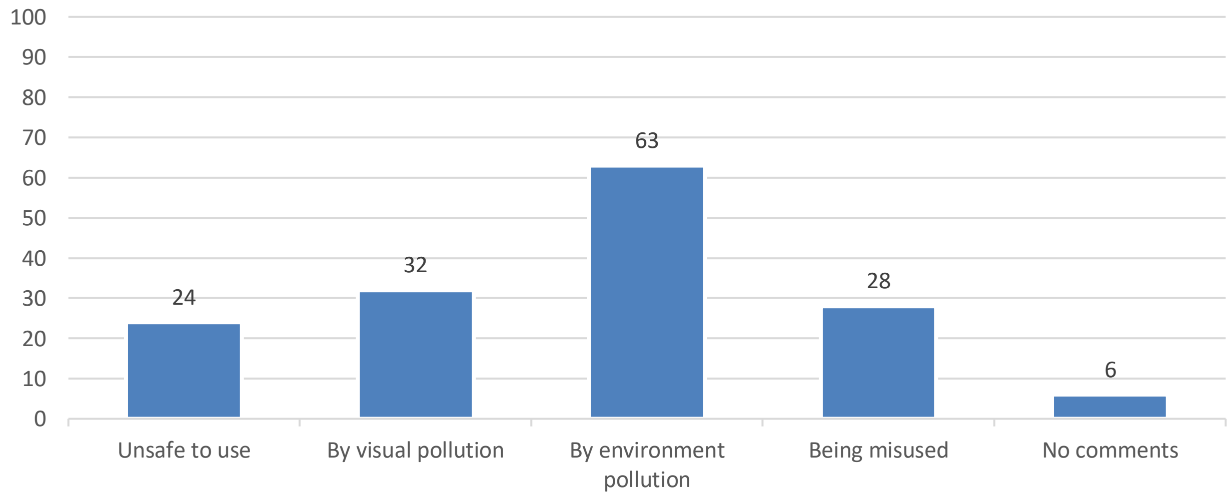


Chart 6. Classifying public perception on urban leftover grey space percentage and perception on these spaces (Source: Author, 2023).

2. In the course of our daily activities, we occasionally come into direct or indirect contact with these places, which may eventually turn into trash dumps or are misused. Which spaces upset you the most, & do you believe they needed to be improved?

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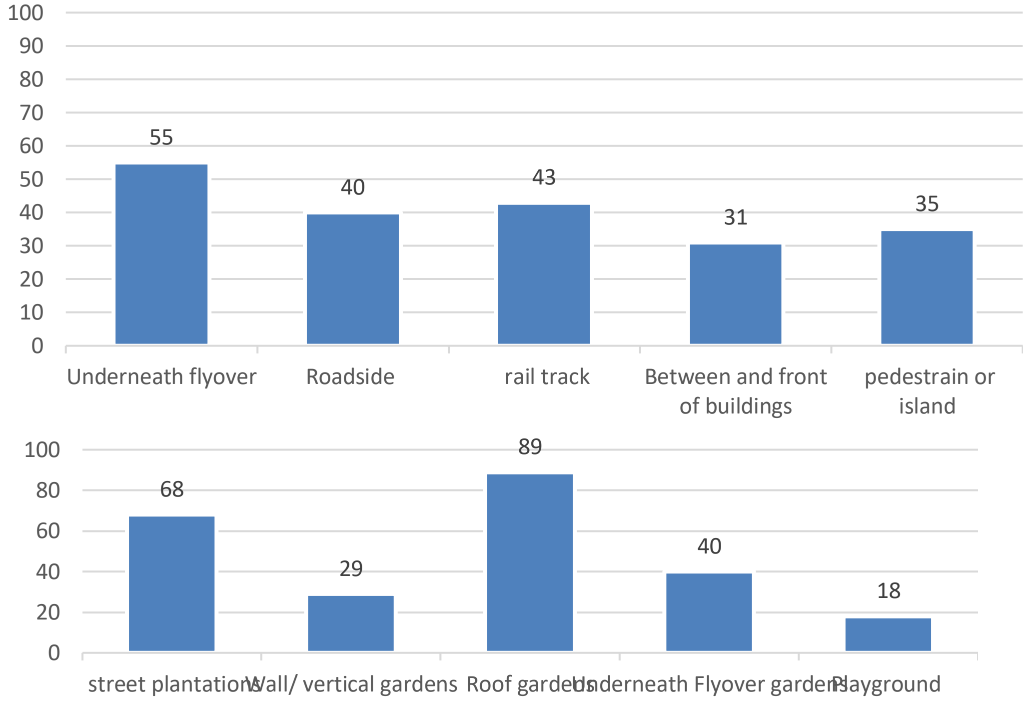

Chart 7. User perception & preferencee of urban leftover grey space percentage (Source: Author, 2023).

3. Do you believe that any community may benefit from green development? If so, how does that affect in your point of view?

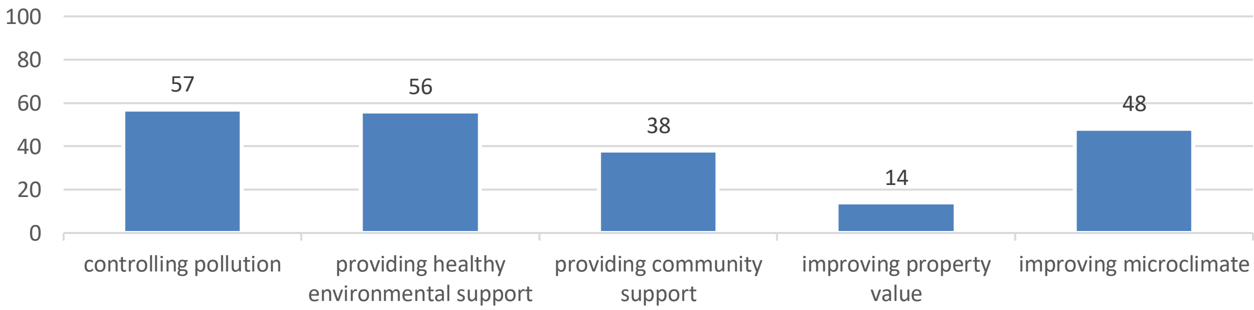

Chart 8. User's perception of how a community can be benefited from green area percentage (Source: Author, 2023).

Types & functionality of Green Infrastructure

The integration of green infrastructure into urban leftover and grey zones has a unique and remarkable impact on the urban microclimate. Globally, practices such as green urbanism, biophilic design, and urban agriculture are increasingly being adopted to foster sustainable urban environments, offering eco-friendly solutions. In this section, the study demonstrates how green infrastructure can be implemented in various urban grey and leftover spaces, providing environmentally friendly solutions to integrate these areas into the main urban fabric. In landscape design, various types of plants are utilized, including trees, shrubs, herbs, climbers, and creepers, each with its unique ability to interact with and influence the environment. These plants can be integrated into different types or patterns of spaces based on their typology. It is crucial to identify the influence of vegetation on climate components. The section below illustrates the suitability and criteria of different plants for this purpose, present a variety of green infrastructure strategies tailored to our

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context, showcasing their feasibility if properly maintained and planned.

Herbs

Herbs are characterized by green, fragile stems and a short life cycle of two seasons. They typically have a low branch count and quickly grow in various soil types. Medium-sized shrubs, shorter than trees but taller than vegetables, reach heights of 6–10 meters, play a crucial role in improving urban air quality, according to Koul & Thakur (2016), contribute to multi-level air filtration by cycling gases and nutrients like CO^2 and O^2, reduce pollution practically by impinging, absorbing, and accumulating contaminants on their leaf surfaces. These plants are ideal for various applications such as vertical gardening, surface plantation, roadside plantations, and general gardening. Utilizing smaller-sized herbs makes it easier to maximize spaces like underneath flyovers, roadside areas, urban pocket parks, rooftops, and their surroundings. Additionally, leftover areas can be effectively utilized through this type of plantation.

Fig.12 (1) Vertical plantation in Maxico (Source: google) (2) Revitalization of underneath flyover (Source: Dezeen). (3) Urban agricultural landscape in Cuba urban area.(4) Roof garden & plantation in context of Dhaka. (Source: Islam, 2018).

Shrubs

Small shaded area and direct solar radiation in open spaces. Shrubs hinder the natural wind flow in human level, but a large or smaller shrub allows airflow in human level. RH is high in human level. Sometimes filters air and create barrier. Flowering shrubs are good in terms of aesthetics (Tasnim,2018). Shrub plants absorb carbon dioxide during photosynthesis, helping to mitigate climate change by storing carbon in their biomass and in the soil, filter air pollutants such as dust, smoke, and pollen, thereby improving air quality in urban and suburban areas, extensive root systems of shrub plants help to stabilize soil and prevent erosion, Dense shrubbery can act as a natural barrier to reduce noise pollution. This type of plantation is highly suitable for urban eco-landscaping, roadside gardening, rooftops, and building surroundings. By incorporating smaller-sized herbs and plants, it becomes easier to optimize and beautify spaces such as underneath flyovers, urban pocket parks, road side leftover areas, roof top and building surroundings etc.

Fig.13 (1) Roof garden (Source: Islam, 2018). (2) South East Clay Green Street Project in Portland is depicted (source: Tasnim, 2018). (3) Jakob Rope Systems factory, Vietnam(Source: Dezeen)

Climbers / Creepers

Climbers cannot stand on their own due to their weak, long, and thin stems, but they can use artificial supports to ascend and sustain themselves. The tendrils of these plants rise. Some climbers are jasmine, runner beans, pea plant, sweet gourd, and money plant. Plants that creep are called creepers. Their delicate, long, narrow branches cannot support their own weight or stand straight. Strawberry, pumpkin, watermelon, and sweet potatoes. According to Lee et al., (2019), climbers and creepers may be feasible urban options because to their low space and aid needs. Their role in environmental sustainability is crucial, albeit being smaller. They stabilize soil, reducing the risk of erosion, help filter pollutants from the air, including dust, smoke, and volatile organic compounds (VOCs), thereby improving air quality, creating more comfortable spaces, store carbon, reduce noise pollution. They absorb sound and block views they also add beauty, shade, privacy etc. These plants are ideal for urban eco-landscaping, roadside gardening, rooftops, and building surroundings by maximize limited space, covering walls, fences, and other structures with greenery.

Fig.14 (1) Climber & creeper as vertical garden or green walls (Source :Dezeen). (2) Roof top plantation in Dhaka (Source: Hossain, 2009). (3) The second ring road's viaduct in Chengdu, the capital of Sichuan Province in southwest China, is covered in luxuriant creepers (Source: CGTN, 2017).(4) The Garden residential building, USA, by MAD (Source :Dezeen).

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Trees

A tree species is a wooden perennial plant with a single stem or trunk, a large height, and above-ground branches. Tree canopy or shade affects how much daylight reaches the ground. In sunny areas, a small, dense canopy may emerge. Light barely penetrates a deep canopy. Scientists classify forest canopies as open, moderate, or dense (Nayeem, 2016). In urban green strategy, canopy typology is essential before developing a place. Canopy type affects space, activities, and microclimate. Create shaded spaces.it Allows gentle wind movement or Wind Speed (WS) in human level and filters or guides the movements in. Relative humidity is high under the tree. Works as Natural air purifiers, absorbing harmful pollutants and releasing oxygen, regulate climate by moderating temperatures and humidity levels, absorb rainwater, preventing soil erosion, and replenishing groundwater, essential for maintaining healthy ecosystems. In case of our context. Neem Arjun, Tetul, Chattim, Albizia, Raintree, Sharnachapa, Bokul, Nageshar, Ashok, Hijal, Tamal, Polash, Daruchini, Tejpata, Korpur, Mehgoni, Krishnachura, Radhachura, Shetchandan, Bashak, & other trees may be planted for parks & green spaces in the city (Islam,2018). Dhaka is plagued by dust and smoke, but Mandar and Neem trees may survive. Korobi, Kolke, and Acacia can endure dust and other particle matter, as well as auto- emissions' sulphur-dioxide (Islam, 2018).

Fig. 15 (1, 2) Roadside plantation in Dhaka (Source: Google; Tasnim, 2018). (3) Tree plantation & its type of canopy can provide shade & change the local environment, case study of Baltimore before-after. (Source: Chesapeake Tree Canopy Network, 2019).

This case study demonstrates how various types of plantations can be seamlessly integrated into the urban fabric, utilizing grey and leftover spaces such as roadsides, lakesides, areas underneath flyovers, building surfaces, and rooftops. It provides concrete evidence of how green plantations are being employed in diverse spaces to maintain a comfortable and sustainable environment through eco-friendly solutions and aligns with the findings of thermal environmental data that plantations plays vital role to regulate thermal environment. Additionally, this approach is not only feasible but also financially advantageous, offering a cost-effective means of enhancing urban greenery. Our national forestry policy and national environmental policy highlight the importance of plantation and forestry practices in vacant lands, roadsides, and both private and public properties. While efforts are being made to adhere to these policies, the current plantation programs are insufficient. Instead of waiting for large-scale green development, smaller-scale solutions tailored to specific needs, spaces, and plant types can be quite feasible for Dhaka to regulate the microclimate, and By utilizing different types of spaces and surfaces for green infrastructure, the heat-absorbing areas will decrease, thereby limiting the heat island effect. The rapid evaporation and shade provided by plants will enhance the cooling effect, making the environment more comfortable in the initial phase. Additionally, with other significant advantages of plantations, the microclimate will be regulated simultaneously.

DISCUSSIONS

The results of this research highlight the importance of considering leftover and grey areas along with green infrastructure in urban planning, development, and design. The primary objective of this study was to enhance cities' environmental sustainability, quality of life, and address various urban challenges by transforming abandoned spaces into green areas. By examining Dhaka's urban conditions, green area ratios, environmental degradation, and the context of grey and leftover areas, this study provides valuable data, maps, and case studies. The research explores the potential of redeveloping urban ecology, opening up grey regions, and utilizing ecosystem services to offer sustainable solutions for urban spaces and the environment, benefiting future generations. Despite the fast-paced nature of city life, the survey reveals that people value greenery and seek it out whenever possible, albeit with limited environmental awareness. Poverty exacerbates the misuse of grey/leftover areas and environmental degradation, as evidenced by urbanization and land shortages. According to findings Cities are cleaner and cooler when vegetation absorbs air pollutants and minimizes the heat island effect. Create community breathing space and improve land value and ecological services to prevent climate change and benefit society and the economy. Case studies and literature reviews compared to field research reveal that ecological or plantation methods have been used globally for urban environment improvement for years. It shows how urban "grey /leftover areas" may become attractive green places. The findings could improve urban planning standards, rules, and guidelines, making cities more sustainable and habitable, boosting the economy by increasing real estate values, business, and tourism. It proves policymakers and investors should consider green infrastructure's financial benefits However, our nation's history reveals that not all actions succeed. If we view the Green infrastructure technique as a superior choice for improving our environment, we can reach our goals in the near future with proper preparation, study, strategy, and policy.

The study also has some limitations. Urban grey leftover regions, green spaces, infrastructure, socioeconomic characteristics, and environmental factors are poorly documented in official database and access, quality of relevant data was not directly provided, thus the researcher has to create the maps for the study and green-built area study, which could compromise accuracy and thoroughness. These limitations may limit study data collection, analysis, and fieldwork. The sample population and stakeholders' poor participation may limit study completion. In green infrastructure project design and execution, low stakeholder participation may limit viewpoints and ignore essential aspects. Their narrow perspective may be due to lack of environmental and urban development understanding, environmental negligence, and poverty. This study may not fully capture the temporal aspects of green infrastructure development and its effects due to the short survey period and the limited survey area and sample size. Additionally, other impacts of plantations, such as noise and dust reduction, were not measured, which presents a limitation of the study.

There are immense future possibilities for this research study. Future research on green infrastructure in Dhaka's urban leftover and grey areas is crucial as its one of the strategically plan for developing a sustainable community and city with respect of economic, environmental and social aspects. This project will advance this field, fill knowledge gaps, provide and promote idea of leftover and grey spaces to be utilized for betterment. The above elements influence legislative decision-making, resource allocation to new possibilities and challenges, and most importantly long- term sustainability as we are currently facing numbers of negative environmental impacts. This approach also considers geographical and social factors, community participation, climate change concerns, and cross- disciplinary collaboration to offer viable strategies for urban sustainability in an evolving global landscape and offers great opportunity to rethink the city from the point of individual to larger group.

CONCLUSION

The research highlights the importance of considering environmental issues & urban planning in order to effectively tackle the challenges presented by rapid urbanization. The aims is reinvent the utilization of urban spaces, eliminating Land loss & promoting eco-friendly ways. The research acknowledges the possibility of incorporating green infrastructure into these leftover, grey areas that lack vegetation, with the aim of creating cities ecologically resilient, able to reduce the effects of climate change, & prioritize the welfare of their inhabitants. The habitants also prioritizing redeveloping the urban spaces with green infrastructure that will not only improve the urban environment but also reach sustainable goals (SDGs). The data analysis and case studies highlight the potential for this strategy to be implemented, but in order for it to be successful, private, public, and non-governmental organizations must all be taken into account. Overall, the research's thorough methodology provides a plan for cities to enhance their livability, vibrancy, & adaptability by utilizing the untapped potential of urban grey & leftover zones. This is a plea to adopt green urbanism, & green infrastructure which involves integrating environmental sustainability into urban development to benefit current & future urban residents.

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