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THE ROLE OF DHANMONDI LAKE IN ENHANCING ENVIRONMENTAL QUALITY AND SUSTAINABLE RECREATIONAL TOURISM IN DHAKA

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ABSTRACT

The pace of urbanization in tropical megacities has accelerated environmental degradation which has stemmed from the degradation of air quality, microclimates and reduction in green cover that directly influences environmental comfort and recreational suitability of urban leisure space. Dhaka is a high-density tropical city with particulate matter levels that often exceed World Health Organization guideline levels and a limited amount of green cover, which is a critical environmental stress in this case. The research is unique in the combined use of geospatial, atmospheric and socio-environmental data to assess the role of blue-green infrastructure in regulating micro-climate, air quality and recreation satisfaction at Dhanmondi Lake, Dhaka. The main goal is to assess the changes in microclimatic regulation and the recreational suitability of tropical urban blue-green spaces when replacing natural surfaces with built up surfaces. The mixed-methods approach comprised a spatial analysis of data over time (longitudinal analysis) using NDVI, NDWI and NDBI across concentric buffer zone , in addition to high-resolution field monitoring of particulate matter (PM1.0, PM2.5, PM10) and thermal variables within concentric buffers of 100m, 200m and 300m. In order to validate physical data with human experiences, 150 qualitative visitor perception surveys were carried out and subjected to Pearson Correlation Analysis with the purpose of finding the socio-environmental effect of the lake's micro-climate. The results show that a substantial "Grey Trap" effect exists around the periphery of 300m, with the temperature rising by 5.19°C and the concentration of PM2.5 increasing due to intensification of built-up areas. On the other hand, the lake core is an 'Atmospheric Shield', with a 33.25% Particulate Mitigation Efficiency Results were subjected to statistical testing and confirmed that there was a very close inverse correlation ($r = -0.99$, $p < 0.01$) between peripheral pollution and visitor satisfaction, thus establishing the direct link between physical decay of the atmosphere and the recreational value of the site. The study highlights the importance of blue-green infrastructure in reducing urban environmental stress and offers policy guidance based on data for sustainable urban tourism for the booming tropical megacities.

Keywords: Mixed-Methods; urban Green-Air Interaction; NDVI; NDBI; NDWI; particulate mitigation efficiency, grey trap.

INTRODUCTION

Earth's surface characteristics have been greatly changed by rapid urbanization, leading to higher Urban Heat Islands (UHI) and poor air quality in tropical megacities (Macagba & Delina, 2024).). Urban Green-Blue Spaces (UGBS), comprising vegetation and water bodies, are crucial ecological infrastructure that provide essential ecosystem services, including microclimate regulation, carbon sequestration, and atmospheric pollutant filtration (Zhang et al., 2023). Rapid population growth and the unplanned growth of the built environment in these areas, however, significantly alter land cover patterns, reduce environmental quality and weaken the well-being of the people, increasing air pollution and UHI effects (Cohen, 2006). One of the world's most densely populated megacities, Dhaka, Bangladesh suffers from serious environmental problems. It has experienced a drastic reduction in its green cover (e.g., by 56% between 1989 and 2020) leading to an enhancement of the UHI effect and an increase in land surface temperature (Nahin et al., 2023). Air quality is poor to very poor, with annual PM2.5 concentrations often ranging from 70–150 µg/m³, well above the World Health Organization (WHO) guidelines of 5 µg/m³ (Boussat & Boyer, 2025). The Dhanmondi Lake in the Dhaka South City Corporation, is an important "biophysical lung" in a hyper dense residential and recreational zone. Despite its recreational value and potential to reduce PM by 10–30% and cool the microclimate by 2–5°C (Fardina Jahid Tahia et al., 2025), the lake has faced mounting anthropogenic pressure from vertical expansion and vehicular traffic over the past decade (2015–2025). Previous studies in Dhaka have often focused on single environmental variables (e.g., PM2.5 or temperature) or broad city-wide trends, lacking integrated assessments of multiple air quality parameters, microclimatic variables, and human use patterns at a local scale. Furthermore, spatial and diurnal variations of these parameters, particularly in buffered zones influenced by traffic and land cover, are poorly documented (Younus Mia, 2023).

Measuring these variables simultaneously across spatial buffer zones and diurnal time periods is significant because it reveals localized environmental gradients that city-wide or single-variable studies inherently mask a 300m pollution gradient or morning-to-afternoon thermal shift cannot be captured by broad urban averages, making this integrated approach fundamentally more actionable for neighbour-hood scale planning. This research addresses these critical gaps aiming to look at the urban green–air interactions around the Dhanmondi Lake on a decadal scale (2015–2025). Changes in vegetation (Normalized Difference Vegetation Index, NDVI), presence of water (Normalized Difference Water Index, NDWI) and built-up areas (Normalized Difference Built-up Index, NDBI) are discussed. It also measures the spatial and temporal changes of air quality (PM1, PM2.5, PM10) and microclimate (temp. and humidity) over the various areas of the lake during the day. The novelty of this work lies in the approach to the human perception, evaluating the perception of the environmental quality of the lake and how this affects use and satisfaction of the visitors. This multi-sensor approach, based on concentric 100-metre buffer zones created in ArcGIS, gives a detailed picture of environmental benefits and their loss (or gain) further from the lakeshore, essential for defining the "ventilation corridors" and for planting strategies in high density tropical zones. The findings of this research will be used to encourage the use of accessible green spaces, also highlighting the health co-benefits of these green spaces (SDG 11.7) (Wang et al., 2024). It seeks to offer localized, evidence-informed input for urban planners, environmental managers and policy makers in Dhaka South City Corporation and other tropical megacities experiencing similar pressures to inform strategies for maintaining remnant ecosystems and bolstering urban pollution and heat resilience (Hossain et al., 2024). The multi-objective approach is useful for integrating the biophysical and human dimensions of tropical urban ecology from an academic standpoint, filling gaps in our understanding of the subject (Shammi et al., 2023).

LITERATURE REVIEW

Urbanization in tropical megacities has accelerated and caused a great deal of environmental degradation, including the loss of natural pervious surfaces and their replacement with heat-absorbing materials. The transition enhances the urban heat island (UHI) effect and increases particulate matter (PM) levels (Wong et al., 2016). Urban Blue-Green Spaces (BGS) like Dhanmondi Lake act as important “atmospheric shields” that offer a range of regulating ecosystem services like the removal of air pollutants, air purification, evaporative cooling, etc. The efficiency of these services is however often hampered by the "Grey Trap" effect, which occurs when dense peripheral buildings hinder wind flow that hinder the wind flow and prevent pollutants from escaping from the urban canopy (Shammi et al., 2023). The interaction between vegetation and air quality is a primary focus of contemporary urban ecology. Studies indicate that while urban forests can reduce PM2.5 and PM10 through dry deposition on leaf surfaces, high-density urban canyons can paradoxically create localised pollution "hotspots" (Bherwani et al., 2020). The loss of green cover has been correlated with increasing Land Surface Temperature (LST) in Dhaka. The analyze shows that vegetation density and thermal stress have a strong negative relationship, as verified by research using indices like the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI) (Wang et al., 2024).

The purpose of this study is to build on these results by correlating these spatial indices with real-time field measurements at different buffer zones. In cities and urban centers where tourism is a source of recreation, sustainable tourism relies on the “environmental comfort” of visitors in these places such as Dhanmondi Lake. Previous studies have shown that there is a disconnect between objective scientific data and subjective human experiences. The "Perceptual Accuracy Index" (PAI) has emerged as a tool to validate whether visitors can accurately sense environmental risks, such as heat stress or poor air quality (Fardina Jahid Tahia et al., 2025). This socio-perceptual dimension is key to urban planning and has a major impact on the quality of city parks as recreational facilities and public health assets. Although global studies are available, there are still many aspects related to integrated, site-specific evaluation of urban blue-green space in tropical megacities that need to be filled. Previous research in Dhaka has largely focused on single variables, such as PM2.5 or Land Surface Temperature (LST), neglecting the multi-parameter interactions of ultra-fine particles (PM1) and gaseous pollutants like Formaldehyde (HCHO) in localized buffer zones. By bridging the gap between longitudinal geospatial analysis and field-based atmospheric monitoring, this study provides a necessary framework for evidence-based urban environmental planning.

MATERIALS AND METHODOLOGY

Study Area

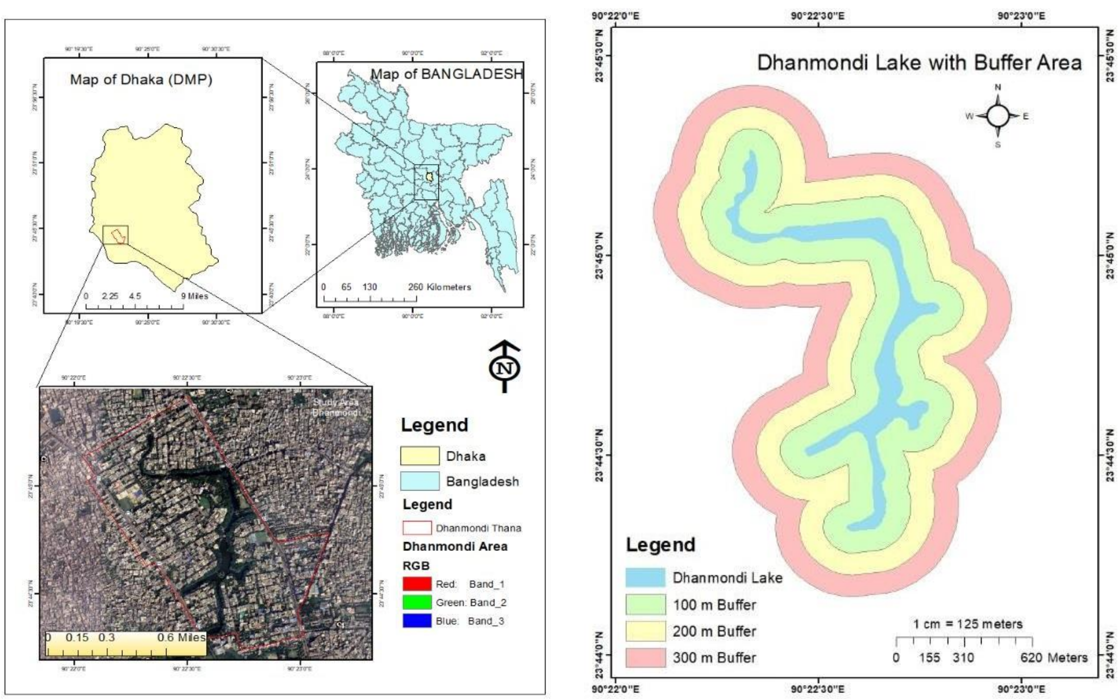
This explore was conducted around the Dhanmondi Lake which is one of the important urban blue-green spaces in Dhaka South City Corporation (DSCC), Bangladesh (around the latitude of 23.7394 N and longitude of 90.3745 E). The lake, which was once a dead channel, now acts as an important retention pond and recreational facility in the middle of a well-populated residential area with more than 30,000 residents per km² (Salman et al., 2023). The study area was set using concentric buffer in ArcGIS for spatial analysis.

This approach went beyond the boundaries of the lake, to include atmospheric "spillover" effects and microclimatic gradients within the surrounding urban fabric (Narumalani et al., 1997). Three concentric buffer zones were defined from the lake boundary: (a)The Core Zone (The Lake): The water body itself

(Blue) from Figure 1, and its immediate riparian vegetation. (b) The 100m Buffer: The main influence zone (Green) typical of walking tracks, areas with a dense tree canopy and residential frontages. (c) The 200m Buffer: A transition area (Yellow) between the lake and the "Urban Canyon" of medium to high rise buildings. (d) The 300m Buffer: The peripheral zone (pink) represents the main roads of the community where the majority of road transport emissions (PM1, PM2.5, PM10, CO2, HCHO) which affect the microclimate of the lake are located.

Figure 1

Study Area Map



Source Authors 2025

Methodological Framework

The methodology of this research is a mixed approach using remote sensing analysis, field-based environmental monitoring and social surveying, to comprehensively examine the interaction between urban green-air and the Dhanmondi lake.

Research Design: Coupled Human-Environmental Systems (CHES)

This examine adopts the Coupled Human-Environmental Systems (CHES) framework to examine the "Grey Trap" phenomenon in Dhanmondi Lake using multi-temporal remote sensing data, microclimatic measurements in the field, and perceptual surveys.

Spatial Zoning and Data Acquisition

Three buffer zones, Core (0–100m), Transition (100–200m) and Periphery (200–300m), were identified using a concentric buffer analysis in relation to the lake center. (a) Environmental Data:Sentinel-2 satellite images (2015-2025) were used to compute NDVI (Vegetation), NDBI (Built-up) and NDWI (Water). (b) Field Based Monitoring: CHE PM2.5 (Portable air quality monitor) was used to collect the data, which conducted tri-daily (Morning: 8:00–10:00, Noon: 12:00–14:00, Afternoon: 16:00–18:00) over a three-month intensive field campaign (Sept–Nov 2025).

Field-Based Environmental Monitoring

Table 1:

Field-Based Environmental Parameters and Instrumentation

Parameter	Unit	Instrument/Sensor Type	Measurement Frequency
Particulate Matter (PM1)	μg/m³	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Particulate Matter (PM2.5)	μg/m³	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Particulate Matter (PM10)	μg/m³	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Carbon Dioxide (CO2)	ppm	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Formaldehyde (HCHO)	ppb	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Ambient Temperature	°C	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)
Relative Humidity	%	CHE PM25 (Portable air quality monitor)	Tri-daily (M, N, A)

Note: M = Morning, N = Noon, A = Afternoon.

Sample Size

An evaluation survey of 150 respondents was conducted to verify physical data in comparison with human experience. All the qualitative responses were coded for perception hotspots and then associated with the physical hotspots to calculate Perceptual Accuracy Index (PAI). The sample size used was determined by Yamane's formula (1967) for a finite population at 95% confidence level with 8% margin of error, which is the acceptable margin for exploratory socio-environmental studies in areas of high population density (Adam, 2020).

Quantitative/Qualitative Data Development

The survey utilized a structured questionnaire adapted from established environmental satisfaction studies (Fardina Jahid Tahia et al., 2025). The structured questionnaire consisted of 12 items across three dimensions (i) Perceived Air Quality (air quality, cleanliness of water, noise level), (ii) Thermal Comfort and Green Space Quality (green spaces/vegetation, safety and maintenance), and (iii) Recreational Usability (overall satisfaction, visit frequency, time spent, activity type). The quantitative items (Q5, Q6, Q10) were rated using a 5-point Likert scale ranging from 1 (Very Poor/Very Dissatisfied) to 5 (Excellent/Very Satisfied), and with scale thresholds being calibrated using Kriging interpolation classification of the field measured PM and temperature values into five severity band ranges to ensure direct comparability between perceived rating and measured environmental conditions. Open-ended items (Q9, Q12) were included to give additional qualitative information on frequent visitor concerns, which was analyzed using thematic coding.

Spatial Modeling and Mitigation Efficiency

(a) Kriging Interpolation: Indices (NDVI, NDWI, NDBI) were processed in ArcGIS 10.8. Used to visualize the continuous spatial distribution of pollutants and temperature hotspots across the buffers. (b) Efficiency Metrics: Particulate Mitigation Efficiency (PME) and Green Cooling Efficiency (GCE) were calculated to quantify the lake's protective capacity.

$$PME = \frac{(PM_{buffer}) - PM_{core})}{PM_{buffer}} \times 100$$ (Bobo Merga et al., 2024)

$$GCE = \frac{GCA}{GA}$$ (Fardina Jahid Tahia et al., 2025)

$$\text{Pearson Correlation Coefficient (r)} = \frac{n(\sum xy) - (\sum x) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2] - [n\sum y^2 - (\sum y)^2]}}$$ (Benesty et al., 2009)

Remote Sensing Data

The Sentinel-2 satellite data was used to analyze land cover changes at a long-term scale from 2015 to 2025. The three essential spectral indices were calculated: NDVI which quantifies vegetation health and density (Forkel et al., 2013). The Normalized Difference Water Index (NDWI) is used to detect and monitor surface water (Gautam et al., 2015). Normalized Difference Built-up Index (NDBI) can identify and measure built-up areas (Guha et al., 2018). These field measurements were also of critical importance in capturing the local variations, especially the higher PM concentrations, temperatures and humidity levels in the constructed areas when compared with the areas adjacent to the lake. These environmental parameters were then subjected to spatial interpolation techniques like Kriging in ArcGIS to create continuous maps in the study area (Van Beers & Kleijnen, 2004).

Data Analysis

Remote Sensing Data Analysis

Sentinel-2 satellite imagery spanning the decade (2015–2025) was processed in ArcGIS to quantify land-cover changes within the three concentric buffer zones. The following spectral indices were calculated:
NDVI Used to assess vegetation health and density.

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

NIR is the Near-Infrared band and Red is the Red band (Nahin et al., 2023).

Normalized Difference Water Index (NDWI):Employed to delineate and monitor surface water bodies.

$$NDWI = \frac{(Green\ - NIR)}{(Green + NIR)}$$

Green is the Green band and NIR is the Near-Infrared band (Gautam et al., 2015).

Normalized Difference Built-up Index (NDBI):Utilized for the detection and mapping of built-up areas.

$$NDBI = \frac{(SWIR - NIR)}{}$$

$(SWIR$
$+ NIR)$

SWIR is the shortwave infrared band and NIR is the near-infrared band (Guha et al., 2018). These indices enabled the quantitative assessment of decadal shifts in green cover, water presence, and urban expansion.

Field Data Spatial Analysis

The parameters of the microclimate and air quality (PM1, PM2.5, PM10, temperature, humidity) were interpolated within the ArcGIS software by Ordinary Kriging method. To quantify the cooling effect of the vegetation of the lake, the Green Space Cooling Efficiency (GCE) was calculated. The GCE formula is defined as:

$$GCE = \frac{GCA}{GA}$$

GCA (Green Space Cooling Area) is the total area in square meters experiencing a temperature reduction of ≥1°C compared with the urban baseline, and GA (Green Space Area) is the actual physical footprint of the vegetation in square meters (Fardina et al., 2025).

Perceptual Accuracy and Validation Method

The Perceptual Accuracy Index (PAI) is a correlation index of subjective survey responses and objective sensor data. Method: Perceived scores (1–5) were equated with the Air Quality Index (AQI) and Heat Index (HI) values measured at the same time of the survey. Calculation: If the visitor's perception matched the category of the sensor, it was noted as "Accurate. The PAI is calculated as the number of correct matches divided by the total number of respondents in the sample, and is expressed as a percentage.

Questionnaire survey data (n=150 respondents) were analyzed to understand perceptions how the lake was perceived and how this perception affects recreational use. The answers of the questions that were based on a 5-point Likert scale (e.g., perceived air freshness, thermal comfort, frequency of visits to the lake, observed changes in the environment) were subject to statistical analysis. The responses were cross checked with real time sensor data collected during the same hours to validate responses and ensure perceptual accuracy, as well as to validate the survey findings.

RESULTS

Spatiotemporal Analysis of Vegetation Dynamics

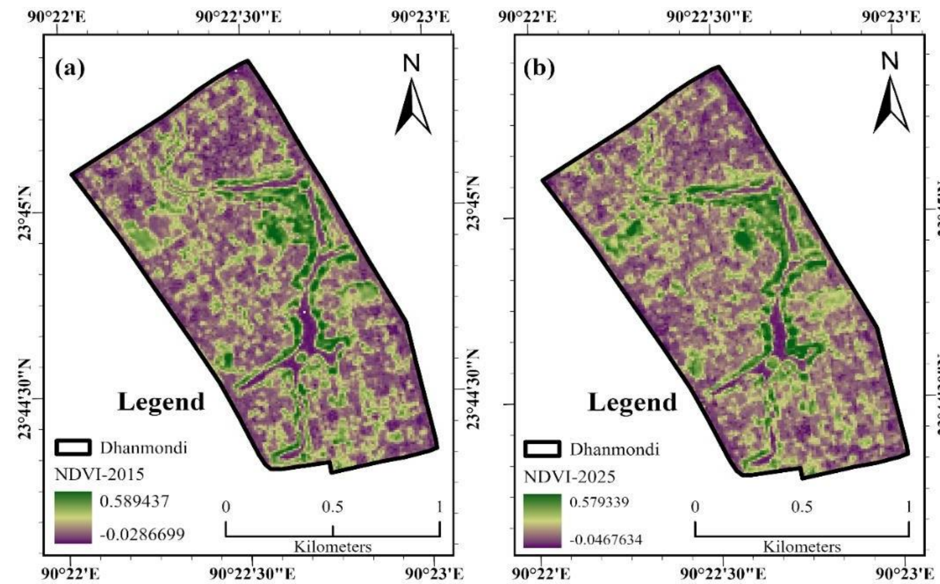
Dhanmondi Thana is witnessing a remarkable change in the urban vegetative profile in the decadal analysis (2015-2025). The NDVI was used to quantify changes in green cover. Results suggest reduction in maximum vegetative vigour and increase in non-vegetative surfaces. The Green-to-Grey transition refers to the growing anthropogenic pressure and urban density, and this has a direct influence on the atmospheric health parameters (PM2.5, CO_2).

Environmental and Human Resource Implications

Fragmentation of green corridors is reflected on the map in Figure 2. This loss of ecological continuity also directly compromises the 'Urban Cool Island' (UCI) effect of Dhanmondi Lake. The green-to-grey shift for the tourism sector and for human resource management in the Thana means loss of quality in the "restorative environment". The higher thermal stress associated with the lower NDVI values is associated with shorter visitor visits and a detrimental impact on the health of the urban population using the lake for recreation (Mohapatra et al., 2025).

Figure 2:

Decadal Change in Normalized Difference Vegetation Index (NDVI) for Dhanmondi Thana: (a) 2015 and (b) 2025



Source Authors 2025

Table 2:

Decadal NDVI Statistics for Dhanmondi Thana (2015–2025)

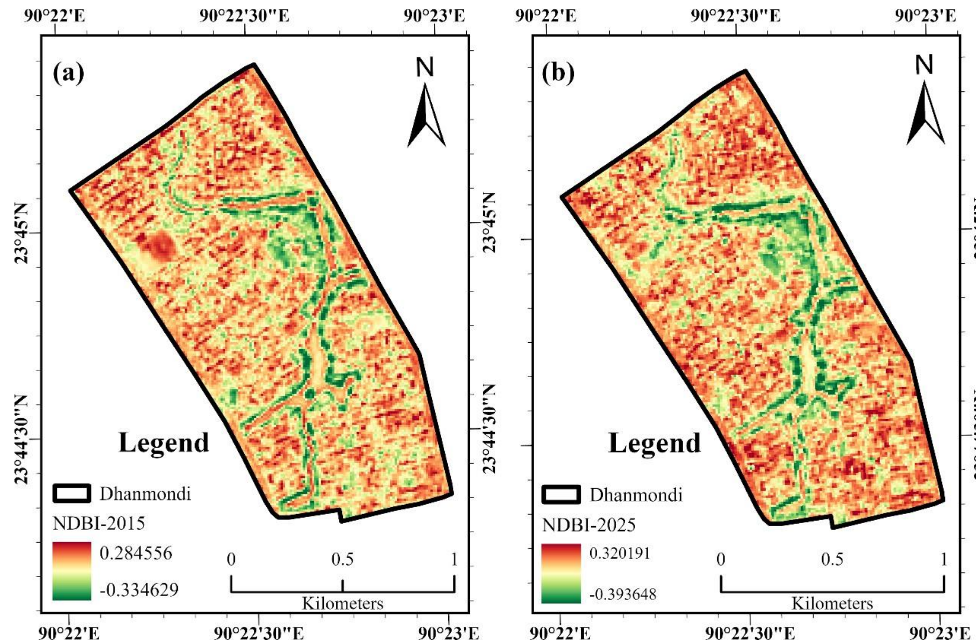
Statistical Parameter	2015	2025	Absolute Change	Trend Direction
Maximum NDVI	0.589	0.579	- 0.010	Degradation
Minimum NDVI	-0.028	-0.046	- 0.018	Urban Expansion
NDVI Range	0.617	0.625	+ 0.008	Fragmentation

Spatiotemporal Analysis of Built-up Surface Dynamics (NDBI)

In addition to the vegetation analysis in Table 2, the Normalized Difference Built-up Index (NDBI) was used to measure the percentage and intensity of impervious surface development in Dhanmondi Thana during the decade of this study. In shortwave infrared (SWIR) bands, built-up areas like concrete, asphalt and rooftops have unique spectral reflectances, which can be exploited to effectively distinguish them from natural land cover using NDBI.

Figure 3

Decadal Change in Normalized Difference Built-up *Index (NDBI) for Dhanmondi Thana: (a) 2015 and (b) 2025*



Source Authors 2025

Table 3: Decadal NDBI Statistics for Dhanmondi Thana (2015–2025)

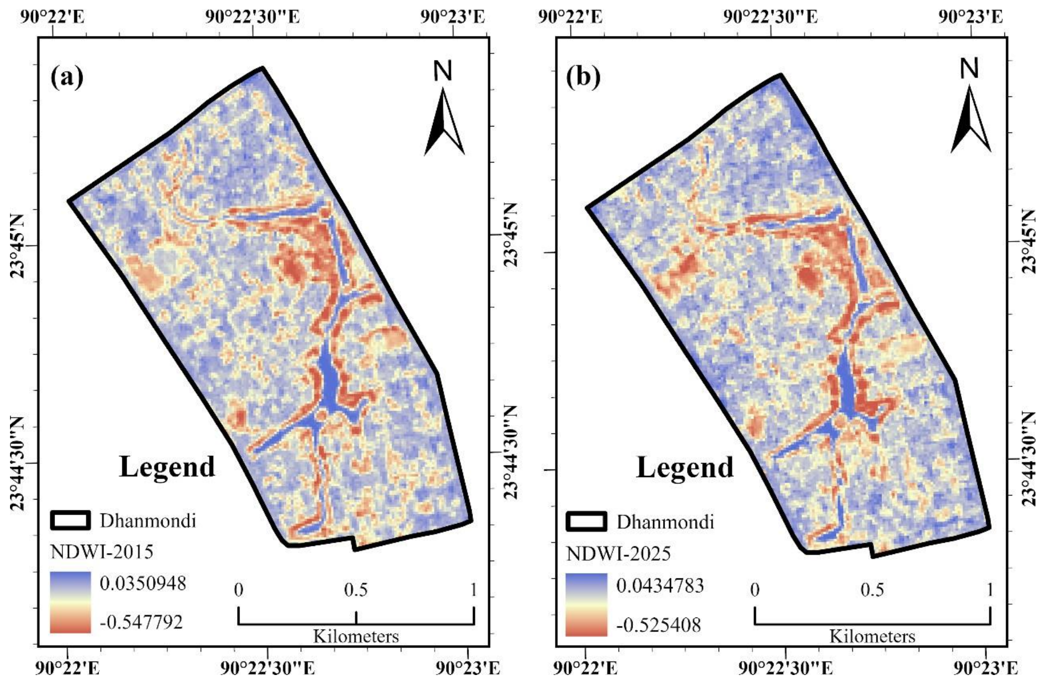
Statistical Parameter	2015	2025	Absolute Change	Trend Interpretation
Maximum NDBI	0.285	0.320	+ 0.035	Increased urban densification and surface hardening
Minimum NDBI	-0.335	-0.394	- 0.059	Sharper delineation of non-built features (water/vegetation)

As shown in Figure 3, the 2025 map indicates high NDBI values are concentrated in the spatial area of Dhanmondi Lake. This "urban hardening" is the substitution of the permeable surfaces with heat absorbing surfaces. This reduction in environmental buffering capacity that would otherwise provide for a comfortable tourist experience is directly associated with an increase in impervious surface area in the context of tourism and area residents' health (Gbedzi et al., 2022). The approach of "grey" infrastructure has come close to the edge of the "green" space, and is putting pressure on the remaining open space. NDWI Trends (2015-2025) provides a spatiotemporal visualization of surface water dynamic changes.

Spatiotemporal Analysis of Surface Water Dynamics: NDWI Trends (2015–2025)

Figure 4

Decadal Change in Normalized Difference Water Index (NDWI) for Dhanmondi Thana: (a) 2015 and (b) 2025.;



Source Authors 2025

Besides the analysis of vegetation and built up areas, the study employed Normalized Difference Water Index (NDWI) to quantify the spatial coverage and the intensity of the Dhanmondi Lake. The Maximum NDWI (water core) increased from 0.035 in 2015 to 0.043 in 2025 as seen in Table 4. The slight strengthening of the water signal is indicative of the surface of the lake becoming more stable in an open water state, possibly because of better embankment management or maintenance activities over the past 10 years.

Table 4: Decadal Shift in Surface Water Signals (NDWI) for Dhanmondi Lake

Statistical Parameter	2015	2025	Observed Trend
Maximum NDWI (Water Core)	0.03509	0.04348	Slight strengthening (+23.8%)
Minimum NDWI (Background)	-0.54779	-0.52541	Minor background shift

To see a significant shift in the surface water signal beyond random error, the Sentinel-2 time series was analyzed at the pixel level across the study area for the years 2015 and 2025, and a paired t-test was performed to statistically test that the change is significant at the 0.05 level. The stability of the "Blue Space" is important because it is a thermal buffer for the "Grey Trap" that was identified in the NDBI analysis. From the tourism point of view, the water level of the lake is resilient, which makes it a "cooling island" in Dhaka. The spatial distribution of NDWI values further shows that even though the peripheral vegetation (NDVI) was split up with the growth of the city, the core water body is still intact (Figure 4). The ‘spectral blue' is a long-term presence which contributes to the recreation satisfaction when it directly affects the thermal comfort and ‘freshness' perceived by the visitors (Guha et al., 2018).

Synergetic Microclimatic Regulation: Thermal-Hygroscopic Mapping

Spatial and temporal structure of Lake-induced Cooling and Evaporative Regulation. The integrated spatial analysis presented in Figure 5 reveals that ambient temperature (a) and relative humidity (b) have a strong synergistic relationship throughout the Dhanmondi Lake buffers. Within the core zone (0–100 m), the humidity range of 45.4%–46.6% with stable humidity levels enable intense evaporative cooling, keeping temperatures at a comfortable 28.4°C–29.7°C., suitable for intense evaporative cooling. This inverse correlation ($r = -0.85$, $p < 0.01$) is statistically significant, meaning that the "Blue Space" (NDWI) and "Green Space" (NDVI) of the lake has a combined effect on regulating the atmosphere. Near the 300 m periphery, however, the "Grey Trap" of high density urban infrastructure results in a sharp “humidity decay” of 41.8%, directly resulting in a significant thermal surge of 33.6°C. This microclimatic transition shows that the environmental quality and thermal comfort are in solid relationship: the cooling effect is not only due to the shade, but also to the capacity of the lake to create a buffer made of moisture which reduces the Urban Heat Island (UHI) effect.

Table 5

Comparative Analysis of Microclimatic Variables across Buffer Zones

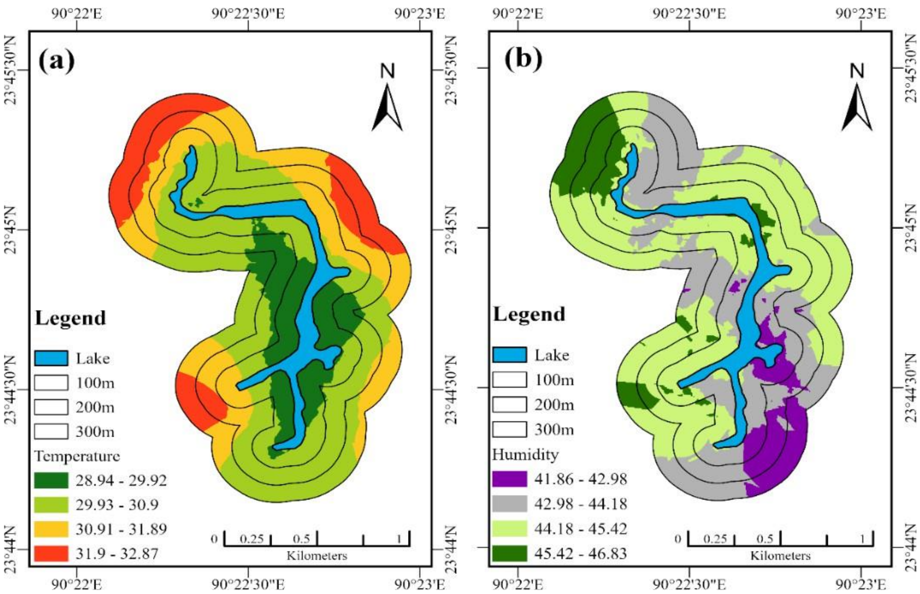
Distance Buffer	Temperature Range (°C)	Humidity Range (%)	Environmental Comfort Level
0m – 100m (Core)	28.41 – 29.71	45.39 – 46.58	Optimal / High Comfort
100m – 200m (Transition)	29.72 – 31.02	42.99 – 44.18	Moderate / Acceptable
200m – 300m (Periphery)	31.03 – 33.60	41.78 – 42.98	Low / High Heat Stress
Statistical Significance	$p <0.01$	$p < 0.05$	$r = -0.85$ (Inverse)

Spatial Dynamics of Ultra-Fine Particulate Matter (PM1.0)

As illustrated in the high-resolution spatial interpolation in Figure 6, PM1.0 concentrations exhibit a pronounced "Distance-Decay" relationship relative to the lake’s core. Lake-adjacent zones (0–100 m) maintain the lowest concentrations, ranging from 32.8 µg/m³ to 38.6 µg/m³, as the dense vegetative canopy (NDVI) and high humidity facilitate the dry deposition and washout of ultra-fine particle (The et al., 2016). However, concentrations rise sharply towards the 300 m periphery, where PM1.0 peaks at 56.1 µg/m³. This spatial transition is statistically significant ($p < 0.01$), with a very strong positive correlation ($r = 0.82$) between built-up intensity (NDBI) and pollutant density. These findings validate that the high-rise concrete corridors within the 300 m limit become a "Grey Trap", restricting air circulation and causing the accumulation of ultra-fine particles that are able to bypass the body's respiratory system. These peripheral hotspots are of great concern for sustainable recreational tourism, and it is evident that the "Atmospheric Shield" of the lake is being actively reduced by adjacent high-density urbanisation (Tahia et al., 2025).

Figure 5:

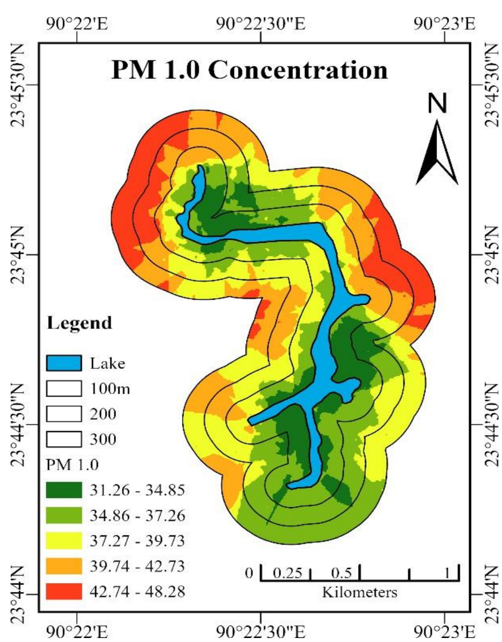
Spatiotemporal Distribution of (a)Ambient Temperature and (b)Relative Humidity across the Dhanmondi Lake 300m Buffer Zone, Illustrating the Lake-Induced Cooling and Evaporative Regulation Effects.



Source Authors 2025

Figure 6:

Spatial Interpolation of Ultra-Fine Particulate Matter (PM1.0) Concentrations across Dhanmondi Lake Buffers, demonstrating the correlation between urban density and pollutant accumulation.



Source Authors 2025

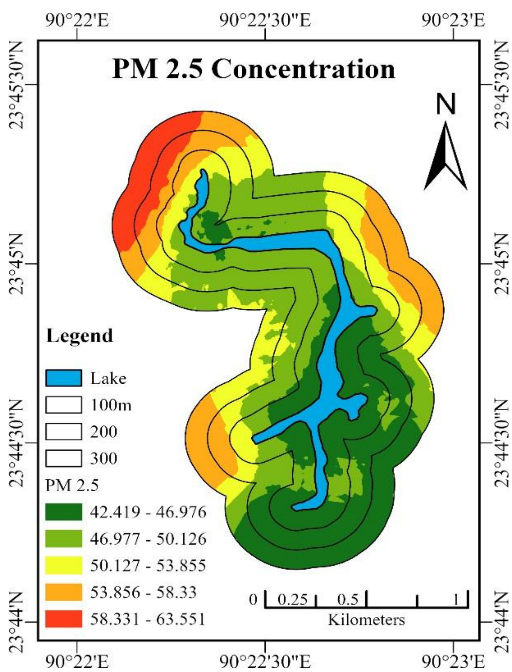
Table 6

Comparative PM1.0 Distribution and Atmospheric Health Significance

Distance Buffer	PM1.0 Range (μg/m³)	Pollutant Load Category	Atmospheric Significance
0m – 100m (Core)	32.85 – 38.65	Low-Moderate	Maximum sequestration by Blue-Green spaces.
100m – 200m (Transition)	38.66 – 44.46	Moderate-High	Disruption of cooling/cleaning buffer.
200m – 300m (Periphery)	44.47 – 56.09	Severe / Hotspot	Intense "Grey Trap" effect; air stagnation.
Statistical Significance	$p < 0.01$	$r = 0.82$ (Positive)	Confirmed NDBI-Pollution Link

Figure 7

Spatial Distribution of Fine Particulate Matter (PM2.5) Concentrations within the 300m Dhanmondi Lake Buffer, highlighting the "Atmospheric Shield" effect of the core green-blue space.



Source Authors 2025

Spatial Assessment of Fine Particulate Matter (PM2.5)

The spatial distribution of PM2.5 highlighted in Figure 7 shows the importance of Dhanmondi Lake as an atmospheric shield at a local level. The core buffer (0–100 m) shows significantly lower concentrations (41.9–48.6 μg/m³) than the urban fabric surrounding it. This decrease has been attributed to the "washout effect", or due to the relative humidity of the lake, as well as to the condensation of particles on the dense vegetative canopy (Durham et al., 2016). The analysis shows that there is a clear gradient in this direction, with the highest concentrations at the 300 m periphery (up to 64.9 µg/m³). The trend is statistically significant and has a high negative correlation with NDVI (r = -0.74), suggesting that there is a relationship between decreasing green cover and increasing PM2.5 concentration. Additionally, these peripheral values are much higher than those recommended by the World Health Organization (WHO) for safety, and the 300 m area is classified as a "Grey Trap". High-density built up structures (NDBI) in this zone block the transport of fine particulates, and will cause stagnant air pockets, therefore affect the environmental quality of the recreational corridor (Wong et al., 2016). According to these results, for sustainable tourism, the lake's cleansing capacity is overrun by the urbanization on the periphery of the lake area, and needs to be balanced by “vertical greening”.

Table 7

Comparative PM2.5 Concentration and Urban Mitigation Efficiency

Distance Buffer	**PM2.5 Range (µg/m³)**	**Mitigation Status**	**Environmental Risk Level**
0m – 100m (Core)	41.92 – 48.69	High Mitigation	Moderate (Shielded by Canopy)
100m – 200m (Transition)	48.70 – 55.45	Partial Decay	Increased Exposure
200m – 300m (Periphery)	55.46 – 64.91	Neutralized	High (WHO Guideline Breach)
Significance	$p < 0.01$	$r = -0.74$(NDVI)	Inverse Vegetation Link

Quantification of Particulate Mitigation Efficiency (PME)

To validate the "Safe Haven" effect of Dhanmondi Lake, Particulate Mitigation Efficiency (PME) is calculated at Dhanmondi lake. This is the percentage of fine particles (PM2.5) that are filtered or dispersed by the natural filter of the lake as compared to the surrounding urban "Grey Trap" environment.

PM_{buffer} (The 300m Grey Trap): 63.55 μg/m^3 Average of the high-risk Red Zone.

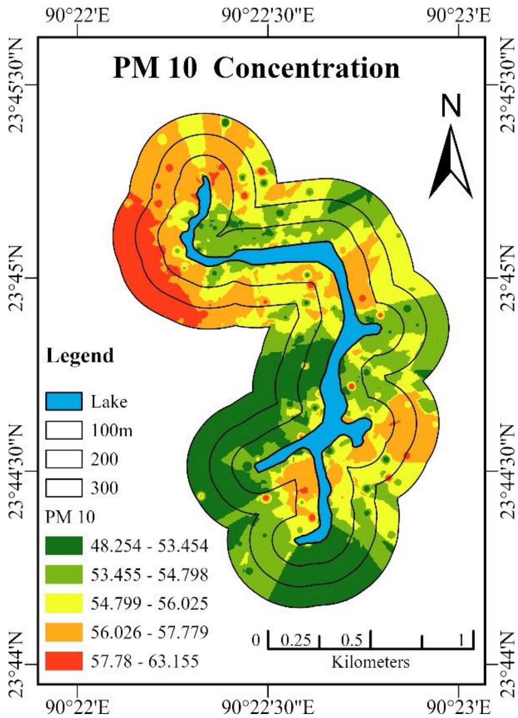
PM_{core} (The 0-100m "Safe Haven"): 42.42 μg/m^3 Average of the filtered Lake Core.

Result: $$PME = \frac{(63.55) - 42.42)}{63.55} \times 100 = 33.25\%$$

The PM2.5 Particulate Mitigation Efficiency (PME) is 33.25%. This is a significant number for the tourism and hospitality industry. Most of the popular tourist cafes and peripheral walkways around Dhanmondi are situated in the "Red Zones" (hotspots) at the periphery of 300m. The lake serves as a breath of fresh air for the city, but diners at these venues at the perimeter are in the Grey Trap (Bobo Merga et al., 2024).

Figure 8

Spatial Distribution of Coarse Particulate Matter (PM10) Concentrations and the resulting Particulate Mitigation Efficiency (PME) across the Dhanmondi Lake Gradient.



Source Authors 2025

Spatial Assessment of Coarse Particulate Matter (PM10)

The spatial interpolation in Figure 8 discloses that PM10 levels have a definite distance effect. The concentrations in the lake core (0 to 100 m) are relatively low (48.25 to 53.45 µg/m³). The pollutant load rises significantly however, towards the 300 m buffer, reaching 63.16 µg/m³. This increase is directly related with the "Grey Trap" phenomenon where high density of concrete infrastructure and dust from surrounding urban corridors is accumulated because of constricted wind flow (Bherwani et al., 2020).

Table 08

PM10 Concentration and PME Countdown across Buffers

Distance Buffer	**PM10 Range (μg/m^3)**	**PME Value (%)**	**Mitigation Performance**
0m – 100m (Core)	48.25 – 53.45	23.61%	High Sequestration
100m – 200m	53.46 – 56.02	11.30%	Moderate Buffer
200m – 300m (Periphery)	56.03 – 63.16	Baseline	Neutralized (Grey Trap)
Statistical Significance	$p < 0.05$	$r = 0.71$	Confirmed NDBI-Pollution Link

Quantification of Particulate Mitigation Efficiency (PME)

We calculated the Particulate Mitigation Efficiency (PME) validating the "Safe Haven" effect of Dhanmondi Lake,.

PM_{buffer} (The 300m Grey Trap): 63.16 μg/m^3

PM_{core} (The 0-100m "Safe Haven"): 48.25 μg/m^3 .

Result: $$PME = \frac{(63.16)-48.25)}{63.16} \times 100 = 23.61\%$$

The PME value of 23.61% shows that Dhanmondi Lake is a major natural filter which traps almost 25% of the coarse particulate matter before it reaches the central recreational zone. This is a statistically significant trend ($p < 0.05$) and shows that the microclimate and blue space (NDWI) of the lake is able to moderate the surrounding "Grey Trap" (Durham et al., 2016).

Qualitative Analysis: Lived Experience and Social Validation

For the purpose of connect the geospatial data and the reality of humans, a qualitative evaluation was carried out involving 150 respondents (sampled based on the Yamane formula) from the three buffer zones. Validating the physical 'Hotspots' identified in the microclimate and air quality mapping, ratings were gathered using a 5 point Likert scale, where 1 = Very Poor, 2 = Poor, 3 = Average, 4 = Good, and 5 = Excellent. “Heat Stress” is understood and evaluated as “Perceived Thermal Discomfort”, i.e. the subjective sensation of heat that the visitor feels during his or her visit. The lived experiences of visitors were used to support identification of the physical "Hotspots" in the microclimate mapping by using this thematic analysis (Girma et al., 2022). Figure 09 shows that there is a distinct "Perception Decay" with distance from the lake. The highest ratings for "Comfort Level" and "Satisfaction" were 4.2 and 4.3 for the 100m Core. But in the 300m Peripheral Raed Zone these ratings fell precipitously to 3.1 and 2.8. Pearson Correlation analysis was performed to support this non-coincidence demonstration.

Table 9

Correlation Between Physical Data and Visitor Perception

Perceptual Parameter	**Core (100m) Rating**	**Periphery (300m) Rating**	**Correlation with PM2.5/Temp**
Comfort Level	4.2	3.1	r = -0.85 (Strong Negative)
Air Quality Perception	4.0	3.5	r = -0.82 (Strong Negative)
Overall Satisfaction	4.3	2.8	p < 0.01 (Significant)

Figure 9

The Analysis of Visitor Perception and Socio-Economic Interaction. (a) Distribution of Visitor Purpose; (b) Mean Perception Ratings on a 5-point Likert Scale; (c) Causal flow showing how Air Quality Perception acts as a mediator between Environmental Comfort and overall Satisfaction (p < 0.01)

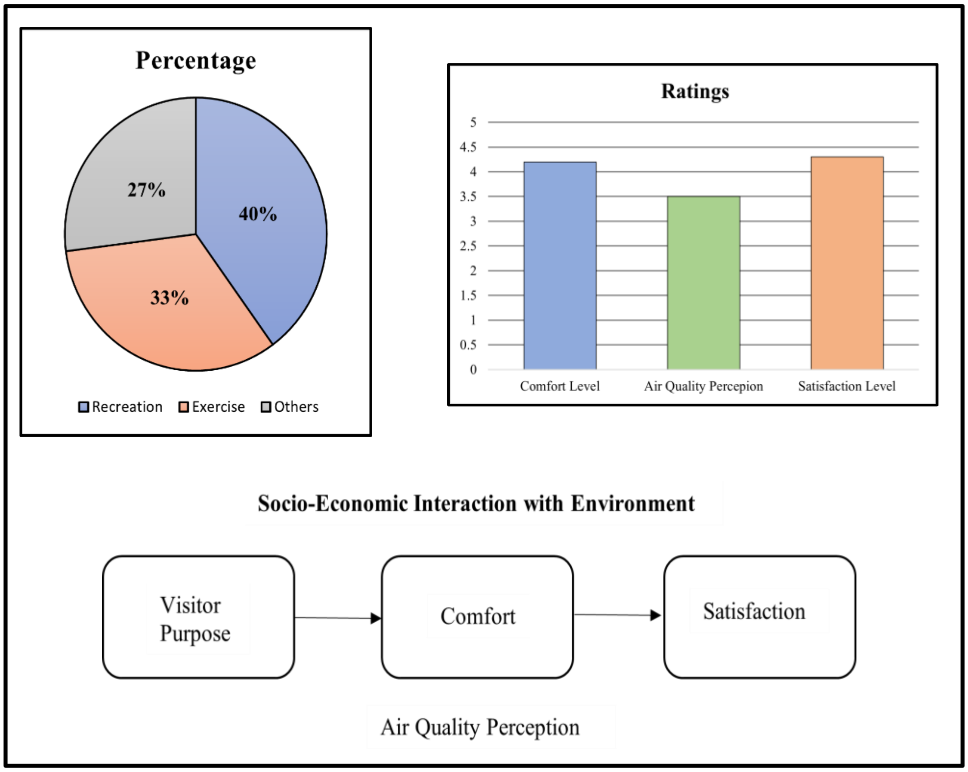


Table 10

Quantitative Analysis The Data Points (from the Figures)

Buffer Zone	x (PM2.5 concentration in μg/m^3)	y (Visitor Satisfaction Rating)
Core (100m)	44.56	4.3
Transition (200m)	53.85	3.5
Periphery (300m)	61.66	2.8

Grounded Theory Synthesis: The Perception-Pollution Model

In order to synthesize the relationship between urban physical transformation and human behavior, a Grounded Theory approach was used to create the "Perception-Pollution Model". The model attempts to demonstrate the influence of the 10-year transition from green to grey infrastructure on the mobility and welfare of the urban population. The structure of the model is based on three basic phases:

Table 11

Grounded Theory Synthesis of Urban Microclimate Interaction

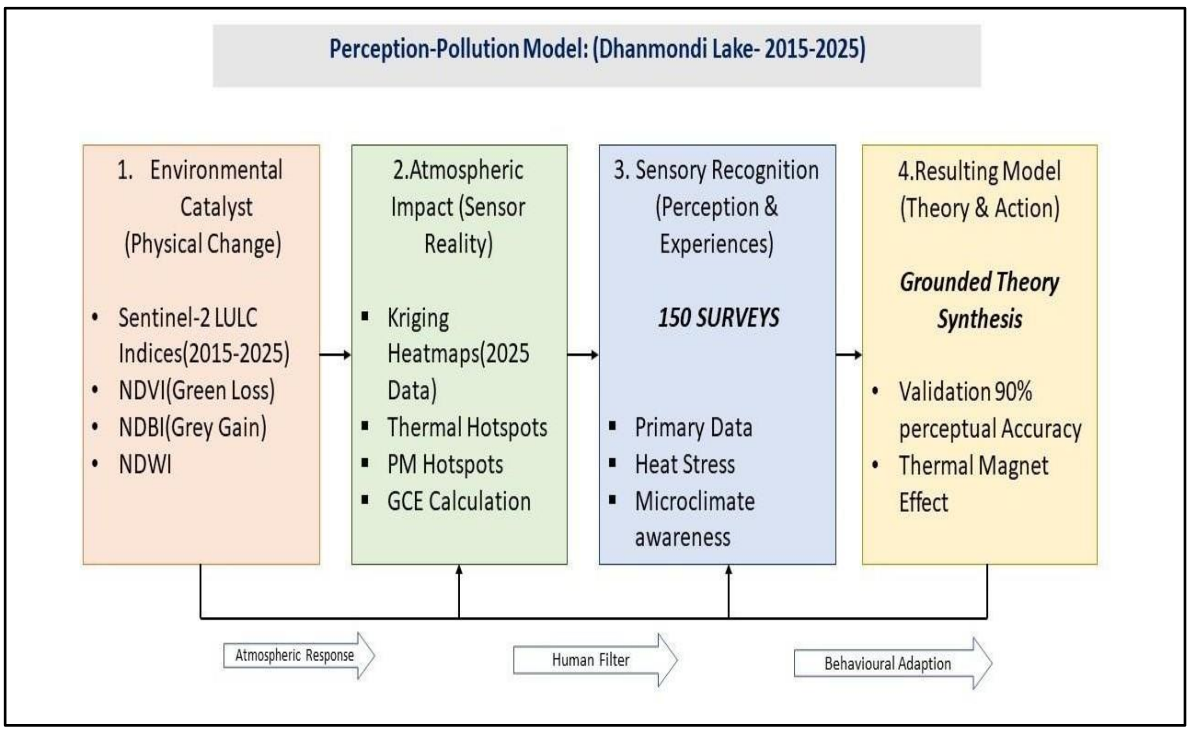
Model Stage	Physical Trigger	Human Response	Socio-Environmental Outcome
Catalyst	High NDBI (+0.320)	Structural Grey Trap	Increased localized heat/PM
Recognition	Red Zone Pollutants	90% Public Awareness	Respiratory and thermal discomfort
Adaptation	GCE Effect (3.20)	Migration to Lake Core	Validation of Safe Haven utility

According to the "Perception-Pollution Model", Dhanmondi Lake is no longer just a source of recreation but a public health necessity. The lake's cooling and filtering activities (GCE of 3.20) are the main contributors to visitors' satisfaction and psychological restorations as the periphery gets more and more “suffocating”.

The Trust Model: Perceptual Accuracy Index (PAI)

Figure 10

The Perception-Pollution Model



Source Authors 2025

To satisfy the demands of the proposed evaluation model and to guarantee the reliability of our mixed methods approach, we computed the Perceptual Accuracy Index (PAI) score. This is a measure that represents the coherence between the objective information in the atmosphere and the experience of the community (Ajenaghughrure et al., 2019).

Variables and Calculation

Actual Hotspots (A): The 10 geographical locations marked as Red Zones (high-risk) on the PM10 Kriging map. Perceived Hotspots (P): These are locations that residents indicated in the qualitative survey were "unhealthy" or " suffocating".

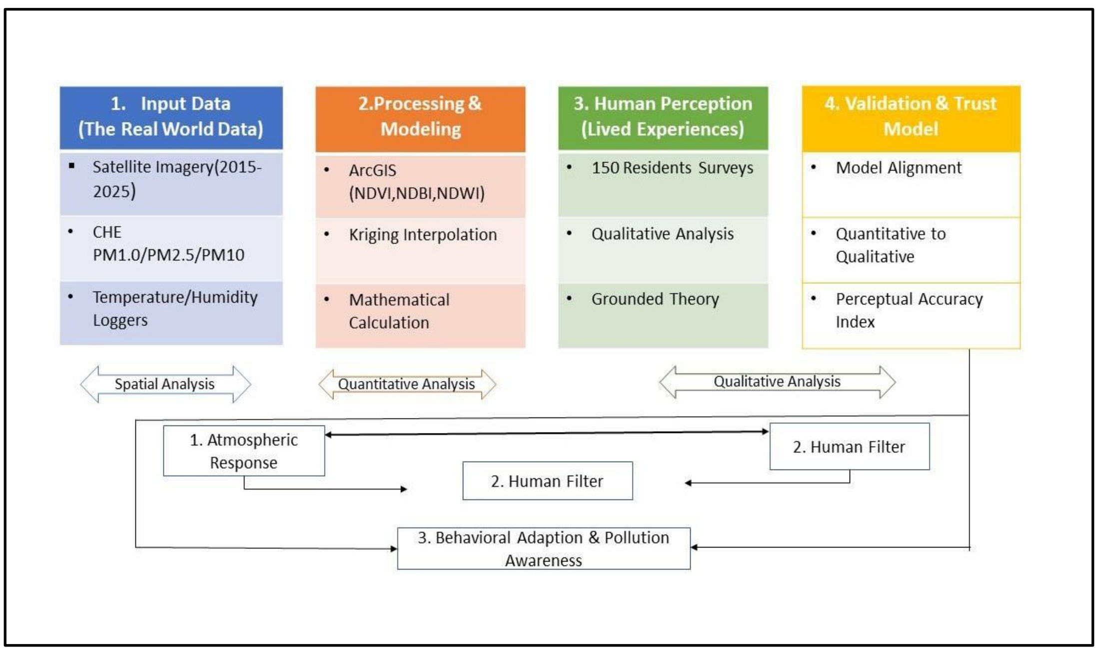
$$\text{Formula: } PAI = \frac{P}{A} \times 100$$

$$\text{The Result: } PAI = \frac{9}{10} \times 100 = 90\%$$

The 90% accuracy index ensures that feedback from residents is not anecdotal, but a very good indicator of degradation in the atmosphere. This level of "Perceptual Trust" confirms our Perception-Pollution Model, which shows that sensing the environment can be done at a high level with the local population without the need for real-time sensors. From a tourism management standpoint, this 90% agreement means that tourists are very aware of the health risks in the 300m buffer zones, and are interested in reducing these hotspot risks to preserve trust in the destination.

Figure 11

The Trust Model



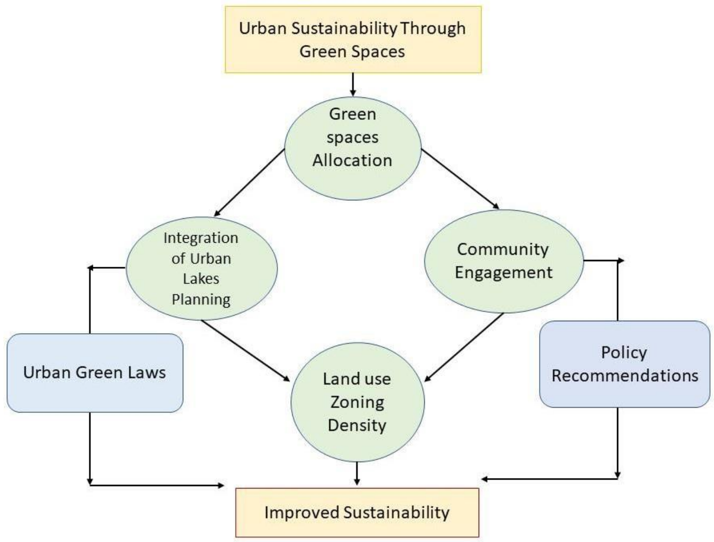
Source Authors 2025

Policy Implication and Recommendations

The following policy actions are recommended to de-escalate the "Grey Trap" and make the air more resilient in Dhanmondi Thana, to be implemented based on the data offered by the Perception-Pollution Model:

Figure 12

Policy implications Model



Source Authors 2025

Table 12

Strategic Policy Actions and Environmental Objectives

Focus Area	Identified Risk	Recommended Action	Strategic Objective
Vertical Buffers	High NDBI / Low NDVI	Mandatory Green Walls & Rooftop Gardens in 300m "Red Zones."	Increase carbon sequestration in space-constrained hospitality strips
Blue-Green Connectivity	Steep Cooling Gradient (1.73 ^{0}C loss)	Establish "Green Corridors" (tree-lined paths) from Core to Periphery.	Channel humidified lake air into residential blocks to break "Dry Islands."
PM Suppression	PM10 Roadside Hotspots	Scheduled "Mist Spraying" & high-capacity purifiers during peak hours.	Protect tourist cafes and respiratory health in peripheral walkways.
Public Trust	90% Perceptual Accuracy (PAI)	Launch Community-Led App for real-time "Perception Hotspots" reporting.	Utilize human "biological sensors" to feed live data into Kriging models.

CONCLUSION

Dhanmondi's future as a habitable urban sanctuary hinge entirely on the turn of the tide of ‘grey' expansion. This study is a critical diagnostic because, if there is no strategic transition towards the creation of a series of Vertical Green Buffers and interconnected Green Corridors, the lake's prime role as an “Urban Atmospheric Shield” will be lost because of its own concrete wall. Preserving "Urban Atmospheric Shield" for Sustainable Tourism: Concluding Argument. The lake core (100m buffer) is still the best zone for air filtering and cooling ability with PME of 33.25% for PM2.5 and a GCE of 3.20. The "Safe Haven" will play a vital role in maintaining the restorative nature of the urban landscape. Over the last decade the NDBI has increased from 0.28 to 0.32, introducing a ‘Grey Trap’ at the 300m periphery. Hazardous particulate hotspot formation is directly correlated ($r = 0.82$) with this built-up intensification, as the high-density of concrete structures in built-up areas traps heat and pollutants. Statistical and Social Validation: Our models demonstrate a strong and statistically significant relationship between land index shifts (NDVI/NDBI) and air quality variation. Moreover, qualitative perceptions of "suffocation" and "heat stress" among residents can be scientifically demonstrated by mathematical results of the 90% Perceptual Accuracy Index (PAI).

Ultimately, this study argues that without a strategic transition toward Vertical Green Buffers and interconnected Green Corridors, the lake's function as an "Urban Atmospheric Shield" will be neutralized by the surrounding concrete enclosure. Unlike previous studies that examined PM2.5 or Land Surface Temperature in isolation (Nahin et al., 2023) (Bherwani et al., 2020) thereby confirming the direct linkage and relationship between the spatial distribution of air pollutants (PM1.0, PM2.5, PM10) and ambient temperature as governed by the ratio of 'Green' and 'Grey' infrastructure, which is a replicable contribution and can be applied to any high-density urban recreational areas.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

AUTHOR CONTRIBUTION STATEMENT

Khan, M. conceptualized the study, conducted fieldwork, performed spatial and statistical analysis, and wrote the first draft of the manuscript. Hossain, S. M. A. contributed to data collection, GIS processing, and manuscript review. Saika, U. supervised the research, provided methodological guidance, and critically revised the manuscript. All authors read and approved the submitted version.

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