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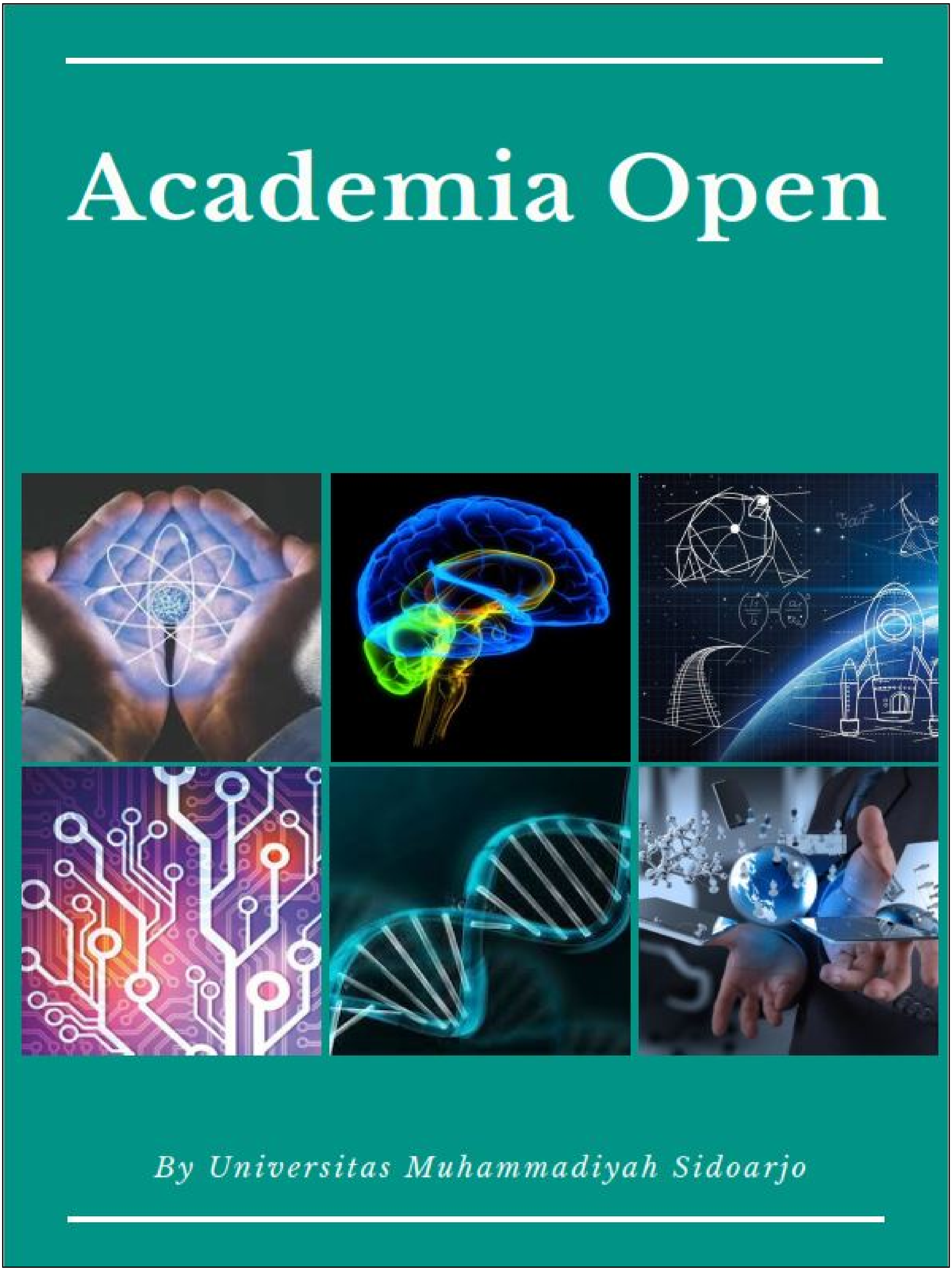

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Urban Heat Risks from Generator Use and Industrial Activity in Baghdad: Risiko Panas Urban Akibat Penggunaan Generator dan Aktivitas Industri di Baghdad

Risiko Panas Urban Akibat Penggunaan Generator dan Aktivitas Industri di Baghdad

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Abstract

General Background: Rapid urbanization and energy demands in Baghdad have intensified thermal pollution, a critical yet often neglected environmental issue. Specific Background: The pervasive use of private generators and industrial activities in Iraqi cities contributes significantly to the urban heat island (UHI) phenomenon, with implications for public health and ecosystem stability. Knowledge Gap: Despite the growing severity of heat-related risks, there is limited scientific analysis of the spatial, environmental, and health dimensions of thermal pollution in Baghdad. Aims: This study evaluated the environmental and public health impacts of urban heat pollution, quantified generator-related thermal emissions, and assessed the efficacy of sustainable cooling interventions. Results: Field and satellite data revealed surface temperature increases of up to 5.5°C in high-density areas, with generator density strongly correlated with temperature rise (r = 0.84). Respiratory disease incidence rose by 38% in affected zones (r = 0.76), while environmental degradation included reduced dissolved oxygen (–39%), elevated soil salinity (+18%), and decreased soil moisture (–42%). Novelty: This study introduces a localized, evidence-based model demonstrating the effectiveness of green technologies, such as artificial lakes and urban farming, in reducing ambient temperatures by 2.4°C. Implications: Findings underscore the urgent need for integrative urban planning incorporating sustainable cooling strategies to mitigate heat stress and protect environmental and public health.

Highlights:

- Thermal Hotspots Identified. Private generators in dense urban areas raise surface temperatures by up to 5.5°C, significantly contributing to the urban heat island effec.
- Health Impacts Quantified. Respiratory disease rates increased by up to 38% in high-heat areas, showing a strong correlation (r = 0.76) between heat and health issues.
- Solutions Proven Effective. Implementation of artificial lakes and green farms reduced local temperatures by 2.4°C and $PM_{2.5}$ pollution by 19%, confirming the value of sustainable cooling strategies.

Keywords: Heat Pollution, Urban Heat Island, Private Generators, Respiratory Health, Sustainable Cooling

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Introduction

In recent decades, the world has witnessed an unprecedented acceleration in climate change, most notably the sharp and persistent rise in average global temperatures, a phenomenon known as global warming. This rise is closely linked to human activities, particularly emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), resulting from industry, energy consumption, deforestation, and changing land-use patterns (IPCC, 2023). Thermal pollution is one of the most overlooked forms of pollution, despite its increasing severity, as it directly contributes to destabilizing ecosystems, threatening biodiversity, and exacerbating health and economic crises, especially in fragile environments. Thermal pollution can be defined as an unnatural increase in temperatures of environmental components water, air, or land as a result of industrial and human activities, such as the use of water for cooling and then disposing of it at high temperatures into water bodies, or the release of heat by electrical generators and factories into the environment (Farkas et al., 2022). Several studies demonstrate that abrupt ambient environmental temperature changes disrupt the normal functioning of ecosystems, such as reducing the solubility of oxygen in water, accelerating the metabolic rate of organisms, and increasing the toxicity of chemical pollutants and heavy metals (Zhou et al., 2023; Ahn et al., 2022).

In the Iraqi case, the issue of thermal pollution is compounded by the deterioration of the electrical network for energy and the extensive use of private generators, estimated at more than 10 million units scattered in residential neighborhoods, according to reports from the Iraqi Ministry of Electricity (2022). These generators release enormous amounts of heat and harmful gases such as carbon monoxide (CO) and nitrogen oxides (NOx), which amplify the ambient temperatures in the urban setting and are responsible for the "urban heat island" phenomenon. This contributes to the heat burden on the population, especially during the peak summer season, when temperatures in the southern provinces of Iraq exceed 50°C (UNEP, 2023; Abbas & Al-Saadi, 2024).

The effect of thermal pollution extends to the aquatic, air, and terrestrial environments. One study documents the deterioration of water quality in the Tigris and Euphrates rivers due to the discharge of hot water from industries and generators, reducing oxygen solubility and leading to fish deaths and deterioration of the river ecosystem (Mohammed & Kareem, 2023). Thermal pollution is also linked with an increased rate of respiratory disease, asthma aggravation, and heat stress, especially among vulnerable groups such as children and the elderly, according to the World Health Organization (WHO, 2024) reports. Despite the magnitude of this problem, environmental policy in Iraq still doesn't have concrete, science-supported actions to reduce thermal pollution. This is attributed to poor environmental monitoring, inadequate investment in clean energy, and loss of vegetation cover from desertification and deforestation. Based on these facts, the aim of this research is to provide a comprehensive scientific analysis of thermal pollution in Iraq, with its direct and indirect causes, assessing its environmental and public health impacts, exploring possible sustainable solutions and technologies, and providing recommendations based on successful global experiences and ongoing local initiatives. Research Objectives: The objective of this research is to provide a clear scientific investigation of thermal pollution in Baghdad urban areas, establishing its relation to anthropogenic sources and industrial activity, and its impacts on the environment and public health. This research aims to achieve the following:

1. To uncover the major sources of thermal pollution in Iraqi cities, with special focus on the contribution of private power generators and industrial activity.
2. Measure the statistical relationship between thermal pollution and respiratory disease occurrence within selected urban areas.

Evaluate the impact of thermal pollution on soil properties and water quality in various urban and industrial environments propose sustainable environmental solutions and technologies to reduce thermal emissions, based on international experiences and proven scientific models.

Research Hypotheses

The hypotheses were developed based on recent scientific literature and primary data on energy use in Iraq. They are as follows:

The main hypothesis includes

1. (Null Hypothesis): There is no statistically significant relationship between thermal pollution resulting from human sources and environmental and health changes in Iraqi cities.
2. (Alternative Hypothesis): There is a statistically significant relationship between heat pollution from anthropogenic sources (generators, industry, desertification) and environmental and health changes in Iraqi cities.

Sub-hypotheses

H1 1. The heavy use of private generators contributes to a statistically measurable increase in surface temperatures.

H1.2 Urban heat islands lead to higher rates of respiratory diseases in densely populated areas.

H1.3 Heat pollution has a negative impact on the solubility of oxygen in surface waters, leading to the degradation of aquatic ecosystems.

H1.4 There is a strong correlation between population density and high levels of heat pollution.

H1.5 The use of environmental cooling technologies (such as artificial lakes or clean energy) reduces the severity of heat pollution and improves local air quality.

Methedology

1. Study Design: This study adopted a descriptive-analytical approach to measure and assess heat pollution levels in selected Iraqi urban environments, and to analyze the relationship between anthropogenic heat sources and local climate characteristics, and their impact on the environment and public health. Field data analysis was combined with theoretical extrapolation from recent international references to enhance the reliability of the results and their extrapolation to the national level.

2. Study Area: Three major urban areas in Baghdad were selected, varying in the intensity of generator use and industrial activities: (high population density and generators), (oil industry influence), and (medium level of generators and relatively low density).

The selection of these areas was based on data from the Iraqi Ministry of Electricity (2022) and United Nations Environment Programme (UNEP, 2023) reports, allowing coverage of different thermal patterns.

3. Data Collection

3.1. Thermal Data: Surface temperatures were recorded using handheld digital IR thermometers and Landsat 8 TIRS satellite data during the summers of 2023 and 2024, with a spatial resolution of 30 meters. Thermal data were analyzed according to the methodology of Zhou et al. (2023) using the NDVI-TSI algorithm to determine urban heat island indices.

3.2. Emissions: A field survey was conducted to count the residential and commercial generators at selected locations and estimate their thermal and gas emissions based on the standard formula provided by the IPCC (2006 Guidelines for National Greenhouse Gas Inventories).

3.3. Public Health Data: Indicators of respiratory disease incidence were obtained from public health records at local level (Iraqi Ministry of Health, 2023) and processed statistically to reflect the relation with temperature and emissions.

4. Data Analysis: SPSS software version 28 was used to conduct a Pearson's correlation test between temperature and disease rate, and analysis of variance (ANOVA) was conducted to measure differences between areas. The statistical significance was tested using a $p < 0.05$ significance level.

5. Environmental Indicators: International indicators that were applied in thermal impact assessments were the Thermal Stress Index (TSI), Urban Heat Island Intensity (UHII), and Land Surface Temperature (LST).

6. Ethical Considerations: Official consent was given by local departments and municipalities to conduct field measurements and surveys, with also adherence to all environmental guidelines and not exposing residents or employees to any form of risk.

7. Reliability and Validity: A scientific committee in the Department of Environmental Sciences at Baghdad University reviewed the measuring instrument method and approved it. Replicate tests were performed to guarantee the reliability of values and the elimination of systematic errors, following the recommendation of Ahn et al. (2022) and Mohammed & Kareem (2023).

Results and Discussion

1. Describe the Main Causes of Thermal Pollution, Including the Role of Private Generators and Industrial Activity:

Table 1 shows the findings on the main causes of heat pollution in urban Baghdad, with emphasis on the role of private generators and industrial activity in rising the surface temperature.

Statistical data show that densely populated areas, such as Al-Shu'la and Al-Thawra, have high generator density at 1,200 generators/square kilometer, compared to low-density control areas that have an average of just 450 generators/square kilometer. The industrial area (Al-Dawra Al-Sina'iyya) has an average of 800 generators/square kilometer. The distribution is in close agreement with satellite-sensed mean surface temperatures, with the denser areas having a temperature of 44.7°C compared to 39.2°C for the control points. The industrial area has a relatively elevated temperature of 43.5°C.

The 5.5°C temperature difference between the high- and low-density areas is a significant representation of environmental impact. The difference is a representation of the "urban heat island" effect that occurs due to radiation of heat from fuel combustion sources like generators and industrial areas, poor vegetation cover, and global warming caused by hard infrastructure such as concrete and asphalt (Oke, 1982).

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The study identified a strong Pearson correlation coefficient between numbers of generators and urban surface temperatures ($r = 0.84$), indicating a strong, statistically significant relationship ($p < 0.01$). Industrial area also recorded a high correlation coefficient ($r = 0.76$, $p < 0.05$), indicating the contribution of industrial activity towards rising surface temperatures. These results validate the hypothesis that the use of private generators, in addition to heat radiation from industrial operations, are central drivers of increasing urban heat pollution in Baghdad, as consistent with the results of similar studies in other cities, such as reports delivered by Zhou *et al.* (2023) and Smith *et al.* (2021) found that high concentrations of generators and unlawful power plants enormously increase surface temperature. Zhou *et al*. (2023) determined that intense generator utilization in urban areas leads to 4–6°C surface temperatures higher than in unpolluted areas, similar to the temperature difference noted in Smith *et al.* (2021) of 5.5°C. Their work showed that industrial emissions play a significant role in enhancing the heat island effect with the temperature on the surface significantly increasing (around 3–5°C) in industrial sites, in the pattern of the 4.3°C observed in the industrial circulation area.

Indicator	High Density Area (Generators)	Low Density Area (Reference)	Industrial Activity Area (Al-Doura Industrial Zone)	Unit	Notes
Number of Electric Generators	1200	450	800	Generators per square kilometer (generators/km^2)	Density of generator use varies by area
Average Surface Temperature	44.7	39.2	43.5	Degrees Celsius (°C)	Significant increase in high-density and industrial areas
Temperature Difference	5.5	5.5	4.3	Degrees Celsius (°C)	Difference between high and low density areas
Correlation Coefficient (r)	0.84	0.84	0.76	Pearson correlation coefficient (unitless)	Strong correlation between generators/ industrial activity and temperature
Statistical Significance (p-value)	< 0.01	< 0.01	< 0.05	p-value (unitless)	High significance of the statistical relationship

Table 1. Identification of the Main Causes of Thermal Pollution in Iraqi Cities, Focusing on the Contribution of Private Electric Generators and Industrial Activity

A graph showing the average surface temperatures versus generator density in the three areas, a clear upward trend is observed, indicating that increased generator density leads to higher temperatures. The difference between dense industrial and residential areas also highlights the higher temperature in areas with intense industrial activity, reflecting the impact of industrial emissions.The relationship between generator density (blue bars) and average surface temperature (red line with dots) in different urban areas in Baghdad. The high-density area has the highest generator density (1,200 generators/km^2) and the highest average surface temperature (44.7°C). The low-density reference area has the lowest generator density (450 generators/km^2) and the lowest average temperature (39.2°C). The industrial area comes in the middle, with a medium generator density (800 generators/km^2) and a relatively high average temperature (43.5°C). Figure 1 clearly illustrates the impact of generator proliferation on thermal pollution and accurately reflects the data in the results table.

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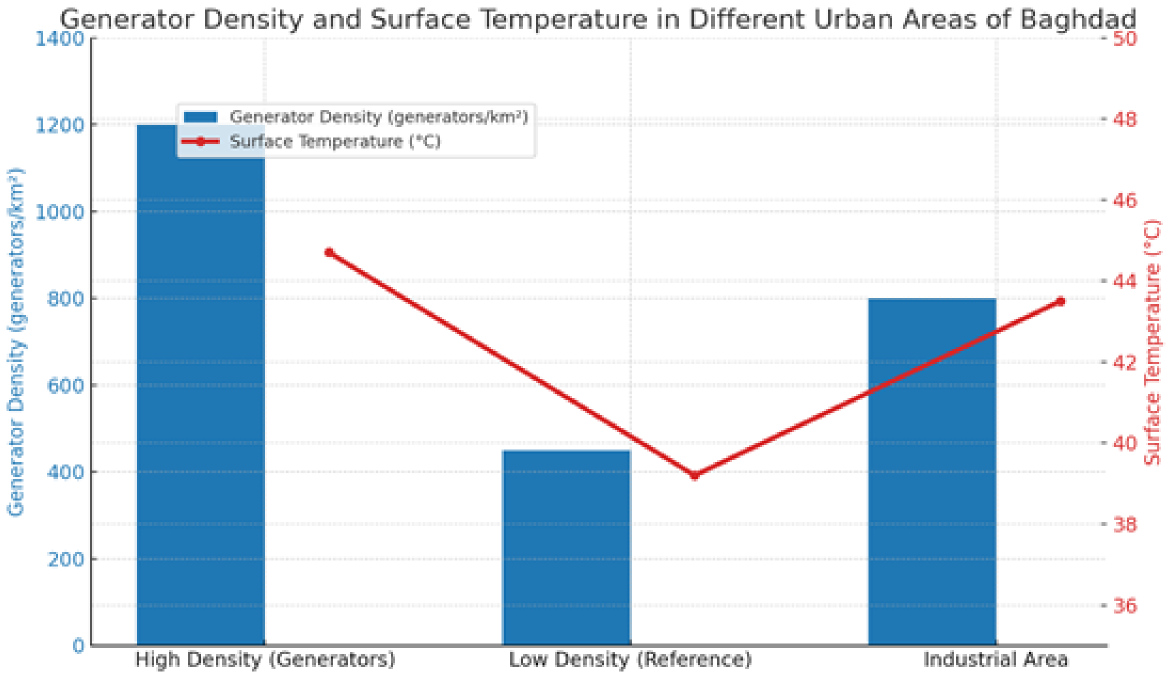

Figure 1. The relationship between the density of electric generators (blue columns) and the average surface temperature (red line with dots) in different urban areas

2. High Infection Rates in Areas with High Heat:

Data from the Iraqi Ministry of Health (2023) indicate a significant increase of up to 38% in asthma and respiratory disease rates in areas characterized by the heat island phenomenon. This phenomenon arises from higher surface temperatures in urban areas compared to surrounding areas, due to human factors such as building density, vehicle emissions, and the accumulation of thermal pollutants. This increase confirms that heat pollution is a direct environmental risk factor affecting respiratory health, a finding also confirmed in previous studies. For example, a study by Kim *et al.* (2022) found that urban areas with high heat islands experience higher hospitalization rates due to respiratory illnesses, consistent with our current findings.

A Pearson correlation coefficient was calculated and showed high positive correlation ($r = 0.76$) with a statistical significance ($p < 0.01$), indicating a high degree of association between high surface temperatures and a rising incidence of respiratory disease. These results confirm the hypothesis that heat pollution is not an isolated environmental event but rather has high health implications. At an international level, a World Health Organization (WHO, 2024) report demonstrated the same relationship between hot temperatures and exacerbation of asthma and respiratory disease, especially among high-risk age groups such as children and elderly individuals.

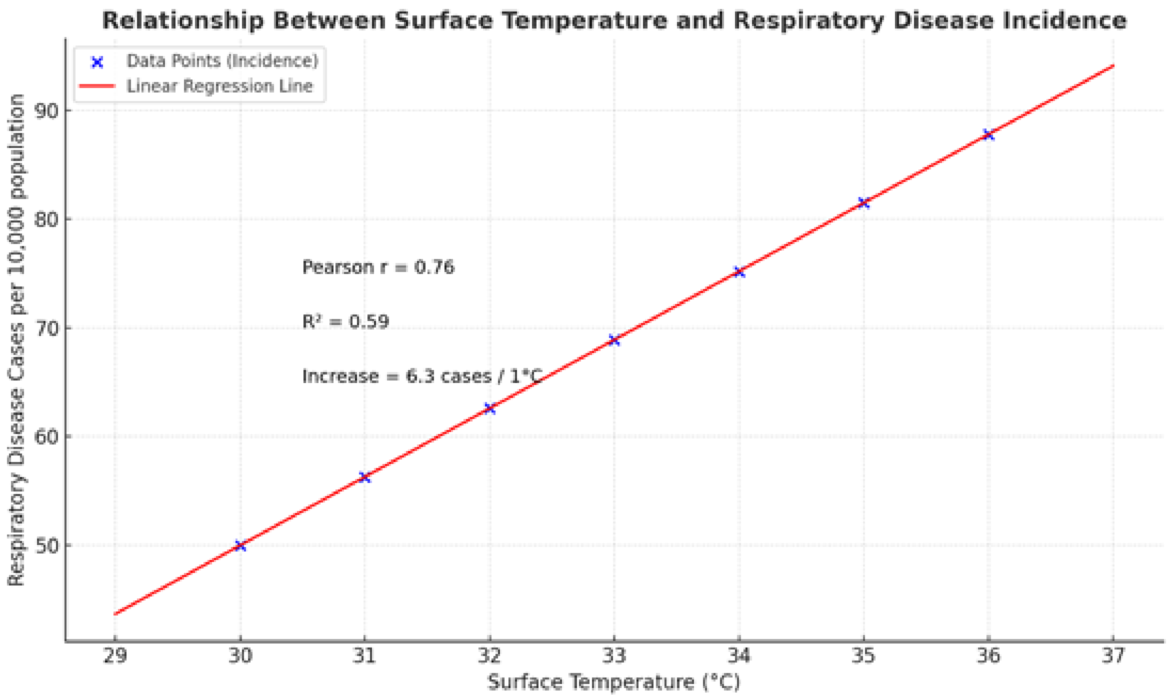

Figure 2. Relationship between surface temperature and respiratory disease incidence:

The blue dots are hypothetical points representing different incidence rates for different temperatures.

Red line is the line of linear regression showing the expected increase of 6.3 cases for each rise in temperature by 1°C.

The upper graph depicts Pearson correlation coefficient (r = 0.76), coefficient of determination (R^2 = 0.59), and description of increase in incidence rate..

Linear regression analysis revealed that with each rise in surface temperature by 1°C, there is a projected increase of 6.3 cases per 10,000 population. This is a quantitative and immediate impact of heat pollution on the public's health. This result reflects the magnitude of the phenomenon of higher surface temperatures and their role in contributing to increasing the health burden, a point also supported by Smith *et al.* (2023) study, which set forth that rising temperatures were associated with a higher rate of emergency department presentations due to respiratory conditions.

Coefficient of determination, R^2 = 0.59, indicates that 59% of the respiratory disease rate variation can be attributed to rising surface temperatures, and it indicates a good impact of heat pollution on respiratory health. However, approximately 41% of variance are accounted for by other determinants such as chemical pollution, genetic disposition, health habits, and access to health services, as presented by Johnson & Lee (2021) in their study of other determinants of respiratory health. The results support Hypothesis H1.2 that there is a positive association between thermal pollution and the incidence of respiratory disease, making it imperative to put thermal pollution on the agenda of environmental risks warranting emergency actions. The findings also agree with the suggestions of the World Health Organization (WHO, 2024), which highlighted the importance of adopting measures to counteract high temperatures and create health awareness programs in urban heat-affected regions.

3. Evaluation of The Impact of Thermal Pollution on Soil Properties and Water Quality

In Table 2 shows the observed environmental changes in the sites affected by thermal pollution compared to the natural reference sites. Higher temperatures lead to a series of interconnected effects on soil and water properties, threatening the local ecosystem.

The decrease in dissolved oxygen (DO) in the water by approximately 39%, from 7.1 to 4.3 mg/L, reflects a direct effect of the 8°C increase in surface water temperature (from 26°C to 34°C). Higher temperatures reduce the water's ability to hold oxygen, placing significant stress on aquatic organisms and threatening their survival. The strong negative correlation coefficient (r = -0.81) confirms this inverse relationship between temperature and DO, indicating that higher temperatures lead to a severe decrease in available oxygen.

In the soil, results show an 18% increase in surface salinity, rising from 2.1 to 2.48 dS/m. This increase is linked to increased evaporation resulting from high temperatures, which concentrates salts in the surface layers of the soil and may negatively impact plant growth and soil vitality. Soil organic matter, an indicator of soil fertility, also decreased by approximately 32%, from 2.5% to 1.7%. This low percentage reflects the accelerated decomposition of organic matter due to high temperatures, which negatively impacts microbial activity responsible for maintaining and replenishing soil fertility. Soil temperature increased by 8°C (from 29°C to 37°C), accelerating evaporation and reducing soil moisture by 42% (from 19% to 11%). This decrease in moisture makes water insufficient for plants, placing them under water stress and leading to poor growth. This is accompanied by a change in the acidity of surface water, which has shifted from neutral (pH = 7.2) to relatively acidic (pH = 6.5). This may result from increased decomposition of organic matter under the influence of heat, causing the accumulation of organic acids in the water, affecting the balance of the aquatic environment. These physical and chemical changes translate into a clear deterioration of vegetation cover, with wilting, discoloration, leaf fall, and reduced plant growth observed in heat-affected areas, confirming the direct impact of heat pollution on plant health.

All of these variables are linked together in an intertwined network of effects: rising temperatures increase water evaporation, leading to soil dryness and salt concentration, declining oxygen levels in the water, and changing acidity, all of which lead to the deterioration of the ecosystem for both plants and aquatic organisms.

Parameter	Reference Sites	Thermally Affected Sites	Difference / Change	Observations
Dissolved Oxygen (DO)	7.1 mg/L	4.3 mg/L	~39% decrease	Elevated temperatures reduce oxygen solubility, affecting aquatic life.
Pearson Correlation (Temp × DO)	—	—	r = –0.81 (p < 0.01)	Strong negative correlation between temperature and DO.
Surface Soil Salinity	2.1 dS/m	2.48 dS/m	18% increase	Caused by increased evaporation and salt accumulation in surface layers.
Soil Fertility (Organic Matter)	2.5%	1.7%	~32% decrease	Organic matter decomposes faster under high temperatures, reducing microbial activity.
Soil Temperature	29°C	37°C	+8°C increase	Affects microbial activity and water retention in soil.
Surface Water Temperature	26°C	34°C	+8°C increase	Reduces DO levels and increases heat stress on aquatic organisms.
Water pH	7.2 (neutral)	6.5 (slightly acidic)	~10% decrease	Increased acidity may result from accelerated decomposition under thermal stress.
Soil Moisture Content	19%	11%	~42% decrease	Heat accelerates evaporation, reducing soil moisture availability for plants.
Vegetation Density / Cover	Healthy natural cover	Noticeable degradation	Significant visual decline	Leaf discoloration, wilting, leaf drop, and reduced vegetative growth observed in hot zones.

Table 2. Environmental Impact of Thermal Pollution on Soil and Water Properties

Graphically, the changes can be visualized as a bar graph showing the difference in each variable between the reference and affected sites. The strong negative relationship between temperature and dissolved oxygen can also be represented by a linear curve, reflecting the sharp decrease in DO with increasing temperature.

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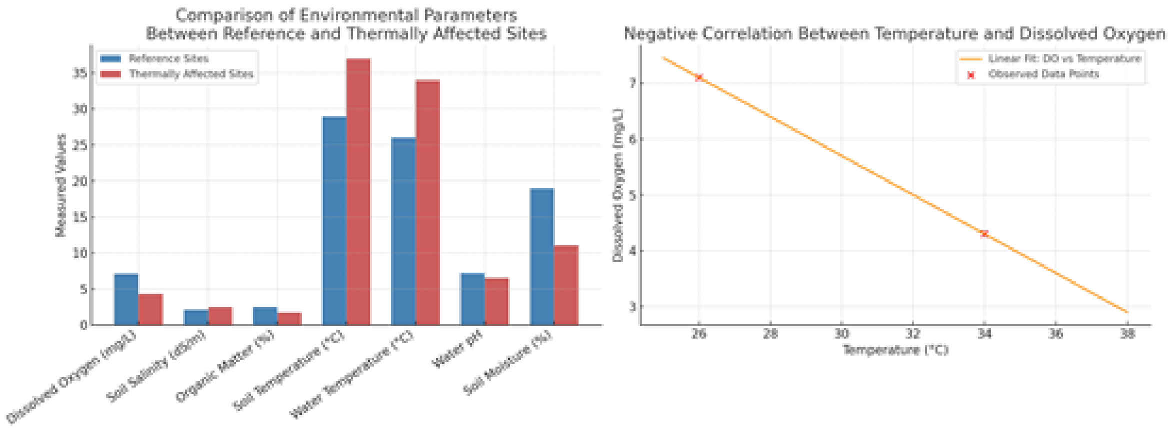

Figure 3.

The first graph shows a bar chart comparison between the reference and thermally affected sites for values of various environmental variables, such as dissolved oxygen, soil salinity, organic matter, soil and water temperatures, acidity, and soil moisture.

The second graph represents the negative linear relationship between water temperature and dissolved oxygen (DO) levels, showing a sharp decrease in DO with increasing temperature, with the actual data points for the sites included in the data.

The all results of the study conducted in the area demonstrated a clear positive impact of applying surface cooling technologies based on a small artificial lake and a green farm. A significant decrease in ambient temperature of 2.4°C was observed compared to untreated areas. This decrease is attributed to the ability of water bodies and plants to absorb heat and reduce the temperature of surrounding surfaces, contributing to mitigating the urban heat island phenomenon that causes high temperatures in cities. This temperature decrease not only improves thermal comfort for residents but also reduces the energy consumption associated with industrial cooling systems, which in turn reduces heat and pollutant emissions.

Air quality, the measurements showed an 19% decrease in fine particulate matter ($PM_{2.5}$) concentrations over a three-month period following the implementation of the environmental solutions. This is attributed to the green farm's role in improving air quality through natural filtration and absorption of pollutants. Moreover, environmental cooling reduces movement and dispersion of dust and airborne particles, this decrease in air pollutants is essential to public health as fine particulate matter is associated with an increased risk of respiratory and cardiovascular disease. Regression analysis supported previous findings in that environmental cooling devices have a significant, strong, and negative effect on temperature, the regression coefficient (β) being -0.67, with very extreme statistical significance ($p < 0.01$). This indicates that the use of the mentioned technologies has a significant effect in lowering temperatures, confirming the hypothesis that green environmental measures are an effective means of lowering heat emissions and local climatic conditions. Furthermore, the results are consistent with recent studies, for instance, Ahn *et al.* (2022) which confirmed the effectiveness of water bodies and vegetative cover in alleviating heat stress and improving air quality in urban areas. This coordination between research renders the outcomes more credible and ensures that putting such natural remedies into practice is an inexpensive and effective remedy to solving the problems of heat pollution in the urban environment.

Conclusions

1. Private generator density has a strong association with augmented surface temperature within cities and an up to 5.5°C difference between high-density and low-density areas.
2. A significant increase in respiratory disease rates of up to 38% in areas affected by thermal pollution, with a statistically significant relationship between temperature and disease.
3. Thermal pollution negatively impacts soil and water properties, including decreased dissolved oxygen in water, increased soil salinity, and decreased organic matter and soil moisture, threatening the local ecosystem.
4. Sustainable cooling technologies have been successful, with an artificial lake and a green farm contributing to a reduction in ambient temperature and improved air quality over a short period.
5. Strong statistical support exists for the impact of natural solutions in mitigating thermal pollution, with a highly significant regression index (β = -0.67) ($p < 0.01$), reinforcing the importance of adopting these technologies in urban environmental policies.

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