Monitoring and assessment of Tehran heat islands using multidimensional cellular grid-based modeling

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Abstract

This paper is an attempt to detect urban heat islands created through a set of criteria involving defined activities, certain types of land use, population and infrastructures. Multidimensional cellular grid-based modeling is a powerful technique for the management of urban heat islands, since creating heat islands involves multiple dimensions and aspects of the environment, including location, time and uncertainty. Since air pollution and local heat islands are the most serious environmental challenges to the public health, effective robust control strategies constitute the most urgent topic in the study of urban development challenges. Moreover, multidimensional cellular grid-based models are used to visualize the results of implemented control strategies for the mitigation of the predicted pollution and the generated heat islands. The use of multidimensional cellular grid-based models allows decision-makers to demonstrate that the chosen strategies have effectively mitigated the reported pollution and local heat islands in all the specified macro zones and that maintaining clean air for long durations of time is also possible.

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Introduction

The increasing rate of urbanization and city expansion has led to tangible changes in atmospheric parameters close to the surface of the earth, including changes in the air temperature, humidity, evaporation, visibility, surface energy fluxes, anthropogenic heat generation and air pollution [1]. All the detected changes in urban environmental quality are defined by concentrated human consumption of energy and natural resources [2]. The poor air quality and the local heat islands caused by the rapid growth in population density and the development of industrial and production activities have turned into a huge challenge for urban managers and decision-makers. Tehran metropolis has grown and spread over 750 square kilometers, and its climate conditions have made no permanent marks on the mitigation of air pollution or the formation of local heat islands. The prevailing dry semi-arid climate and the constant lack of humidity, rainfall, wind and the poor air circulation at local or regional levels have made the management of the Heat
Island Centers (HICs) formed in Tehran more complex and thus exacerbated the hazardous impact of these destructive phenomena [3]. Today, many residential areas in Tehran are in critical conditions in terms of the standards of urban green and open spaces to counteract the identified heat islands in all of the study zones, the trend of reducing green surfaces and increasing pollutions or heat-generating hard surfaces thus persists [4]. Urban environment managers have defined heat islands as a set of areas across the city identified to exhibit unusually higher surface temperatures, higher levels of pollution and lower air movement given their prevailing environmental-physical and behavioral fabric and typology compared to their so-called neighboring spaces. The management of urban HICs is a highly complex matter and requires a precise knowledge of random environmental spatial-temporal factors. Spatio-temporal data sets comprise information for the location of HICs detected zones and other related urban features at a specific time [5]. The need to include several urban beneficiaries, decision-makers and planners further complicates the implementation of these processes [6]. There may be several reasons for the higher ambient temperatures in these centers, including climate conditions, time, topography, wind, air pollution, urban uses, population density, industrial and human activities and the permanently dense traffic in urban access networks that manifest themselves as heat island centers [7].

Urban HICs have increased the need for environmental cooling and the reduction in energy loss in neighborhoods; they have also led to a double-effect and the accelerated spread of air pollution at micro and macro levels, and have multiplied the sustained levels of pollutants and their destructive effects [8]. Given the asymmetric and irregular surfaces of urban spaces and the events shaping them, HICs follow irregular and sometimes complex or unexpected patterns [9]. The rapid urban motorization and the expanding commercial-economic activities have been recognized as the main causes of the increasing the development of HICs in many developing metropolises. The "transformation of urban open spaces into hard and dense spaces, the deformation of neighborhood fabrics from low-density or low-activity areas to areas of movement and constant activity, the dense residential population in single locations”; have made the control and management of the main sources of the formation of HICs more difficult and have increased their destructive effects on urban health and the environment. As the main modulators of breathing space and agents for reducing the heat formed in urban zones, aquatic and green urban covers are diminishing every day and are being replaced by hard artificial covers such as road asphalts and concrete blocks with a high capacity for the absorption and multiplication of environmental heat, which, in a way, exacerbates the problems caused by urban heat generation [10]. In the majority of polluted cities across the world, devising plans for the development of
greenways or open and extensive breathing spaces such as man-made lakes or urban forests has been completely neglected and lost among the others urban development priorities. The purpose of greenways or connecting forest patches is to create a system of local or regional access and movement networks dedicated specifically to non-motorized traffic or green vehicles, so that they can provide citizens with access to different urban zones by claiming a major share of the daily urban traffic and the utilization of natural resources free of thermal patches [11]. Sources of pollution emission and local HICs are simulated for monitoring and assessment as separate inventory layers such as showing the dispersion and density classification of heat patches in industrial, commercial, administrative and educational zones and urban traffic networks and high-density neighborhoods. These zones may be considered the main potential sources causing heat patches and air pollution in the environment with direct and indirect destructive effects on the health and environment in urban neighborhoods. Assessment of HICs requires an integrated and seamless system that is able to find appropriate sustainable solutions for the complex and multidimensional nature of HICs in urban zones [12].

Defining effective sustainable control strategies requires tools that display and analyze the processes of the formation and propagation of HICs in each study zone. The identification of the dominant typologies in each urban neighborhood, the classification of each urban zone’s level of vulnerability and the assessment of the sources of the formation of HICs can be used for defining or choosing effective robust control strategies [13]. HICs inventories and their simulation by Multidimensional Cellular Grid-Based (MCGB) modeling help urban environment decision-makers in the assessment and monitoring of HICs formation, development patterns and behaviors which enable them to assess how the HICs identified in each urban zone interact with their environment and vice versa. Furthermore, monitoring HICs inventories using MCGB models provides managers with a tool for identifying, defining and predicting the spatial-temporal and condition patterns for the formation and development of urban HICs. They can then use time series data in defined periods of time as a basis for defining the predicting scenarios for the assessment of urban HICs in planning and selecting robust strategies [14]. Each adopted strategy should be able to mitigate pollution levels and the range of HICs’ impact effectively and sustain clean air conditions for a long period of time. HICs patterns are modeled to predict the development of HICs and assess their environmental impacts; to complete the assessment process, the results of the implementation of HICs control policies and the assessment of the impacts of developing high-activity urban spaces such as commercial or industrial spaces or expanding highways on HICs in the study urban zones are also modeled. The multidimensional simulation of HICs patterns and behaviors across the study zones enables urban decision-makers
to define sustainable strategies for controlling these patches. Multi-Criteria Decision Analysis (MCDA) is a method that should be used for the accurate weighing and technical classification of the chosen strategies. As an MCDA and multi-purpose method, the Analytic Network Process (ANP) allows the comprehensive and practical consideration of all the intended criteria and objectives in the process of assessment which provides a powerful tool in complex multi-criteria decision-making [15]; the present study uses this method for the final weighing, prioritization and classification of the adopted strategies. Decision trees and related support systems including functions and variables based on propositional and MCDA procedures have been the method of choice for environmental strategies assessments [16]. In the comprehensive and accurate analysis of HICs, integrated seamless MCGB models classify and weigh the most relevant subjective layers such as urban land use, urban transport infrastructures, classified demographic data, point and non-point pollution and heat sources and other heat-rising or adjusting factors in the form of separate thematic maps and perform the simulation of management decision-making according to the outputs extracted from the overlaying of layers of geographical data. Using powerful grid-based spaces and weighing in the smallest-scale units of virtual micro-zoning, MCGB models can conveniently finalize stages such as overlaying layers of data, risk analysis and assessing destructive environmental impacts, comparing criteria and determining the compliance of the adopted strategies with the objectives and the environmental conditions, performing geo statistical analysis and simulating the results of the decisions made for sustainable improvements in the quality of the environment.

Materials and Methods

The growing air pollution and urban HICs are major challenges threatening the public health in Tehran and complicating the unresolved issue of urban management. HICs are mostly formed when natural vegetation is replaced by heat-absorbing surfaces or when low-activity zones are converted to high-density areas with a different land use involving extreme daily functions, such as parking lots, highways, high-rise buildings and commercial centers. The main problems that HICs pose are caused by the density of the high energy-consuming sources identified, particularly high-traffic network nodes, high residential densities, high-activity zones and industries. Linear and area pollution sources, areas with high density population, specific land uses and crowded urban spaces with high activities and movements and lacking appropriate air quality plans were detected as the main local non-point sources of HICs formation in Tehran Air Quality specific Zones (TAQZs) (Fig.1). Identifying all the local HICs sources in each macro zone and defining the most appropriate solutions to solving and compensating the negative impacts of the identified problems lead decision-makers to selecting the most suitable strategies
for their pertinent TAQZs (Fig. 1). MCGB models simulate all the negative and positive aspects of TAQZs for determining the most suitable strategies based on their limitations and strengths. By evaluating the classified spatial layers, all the aspects of HICs-related subjects were simulated both spatially and temporally. All the appropriate strategies were fine-tuned until an acceptable air quality was achieved and HICs formation and development was mitigated in all the TAQZs. Measuring the rates of resilience and vulnerability in each macro zone enhances the precautionary steps that decision-makers are required to take. The most appropriate pollution control strategies were selected based on the specific opportunities and qualifications identified for each macro zone. The opportunities identified for each macro zone measured the vulnerability rates, hazardous impacts and positive opportunities that arose, which were weighed spatially on MCGB models. For example, the spatial detection of urban vacant lands, natural corridors, large green areas and regional parks, convertible land use and effective urban recreational or open spaces could be simulated by MCGB models to counteract urban heat patches as part of UGOS (Urban Green areas and Open Spaces planning and design) strategies. The selected clusters of strategies were finally defined as the main TAQZs’ air quality and HICs control programs.

The MCGB models used for the monitoring and assessment of the impacts of HICs on the defined TAQZs simulated various thematic data layers such as sensitive land resources and areas, geo-statistical buffer zones, hazard-prone lands, vulnerable urban spaces such as hospitals or elementary schools, urban green spaces and recreational zones, high density settlements, high-activity urban spaces, land uses demanding many local or regional daily trips, industrial and main urban-concentric zones, and commercial, administrative and educational spaces, etc. MCGB models were used as zoning techniques for the monitoring and assessment of air pollution patterns and the local and regional dispersion of HICs by spatial-temporal subjective
layers. Due to the complexity of urban systems, the management of air quality and HICs in these areas is still a serious challenge. The dispersion of population, activities and land uses in Tehran does not follow the usual pattern that affects the informal forms of HICs dispersion directly among the specified macro zones.

Figure 2. Time series spatial layers (2011–2014) that simulated monthly pollution and HICs averages

Most high-density, high-activity and high-pollution zones are located in the central and southern parts of the city, while most lower-density, green and vacant spaces are located in its northern parts. The northern part of Tehran helped identify the dominant patterns of HICs formation in Tehran in the regional simulations; however, for micro-zoning the HICs patterns, other alternatives were simulated by MCGB models. Urban vulnerability rates were classified based on the demographic data available, the land use patterns detected and the identified HICs. The density of the HICs was simulated by weighing the MCGB models that marked the most critical regions with a darker color to enable comparison with the other TAQZs cells. The time-position MCGB models detected the main patterns of HICs formation, development and their impacts by the space and time dimensions (Fig. 2). The time series layers simulated both air pollution and HICs dispersion spatially among all the TAQZs. The spatial monitoring of the past and current patterns of air pollution and HICs sources and their measured impacts were simulated on time series MCGB models for ERAP (Expected Rates for Air Pollution increase) prediction through Artificial Neural Network (ANN) analysis. Time series layers were simulated for predicting future pollution and HICs sources patterns and assessing the results of the adopted control strategies for mitigating the detected HICs among the defined TAQZs. To perform a temporal modeling of the ERAP, time series data on the factors that had affected the formation of the HICs and that helped visualize the monthly average of the reported pollution
were simulated for four consecutive years (from 2011 to 2014) in all the **TAQZs** using **MCGB** layers.

![Image](linear_polygonal_point_based_hic_spatial_detection.png)

**Figure 3.** Linear, polygonal and point based HICs’ spatial detection and impact assessment

Industrial, commercial and green areas, convertible-land-use spaces, transportation and demographic movement patterns and other land uses that affect urban activities were classified and modeled based on their potential for generating pollution and heat (Fig.3). By modeling the average pollution and the **HICs** detected spatially on the **MCGB** models, vulnerability rates were classified for all the **TAQZs**. **MCGB** models simulated the pollution and heat islands generated by residential, commercial and industrial land uses and vehicular traffic spatially as classified thematic layers. Industrial zones were given high scores as the most critical areas in terms of pollution and thermal shaping. Residential and green spaces were simulated interactively on **MCGB** models with a low and very low weight for **ANN** predicting matrices.

The main infrastructures used for building compact cities were examined through promoting the planned **LOSCE** (Level Of Services adequately defined for all urban neighborhood Centers), which reduces the demands for unnecessary local movements emphasized through **LUTA** (Land Uses renovating and Transportation system revised for accessing highly Attractive urban spaces) strategies, or through planning for the development of virtual technologies such as electronic governments or e-services described by **TV** (Technology and Virtual infrastructures development policies) strategies. Combining **LUTA** and **TV** strategies as two similar and synergetic policies thus helped achieved a maximum reduction of local trips and thereby a successful mitigation of local **HICs** formation and development. A spatial model for specifying the useful functions and suitable accessibility of urban key services, which is discussed here in the form of the **LOSCE** policy, was implemented using spatial analyst tools as buffering procedures and also through geo-processing analysis. Site selection modeling used for **P&R** (Park and Ride) stations and the simulation of the **LOSCE** policy helped decision-makers find
suitable zones for implementing the LUTA strategy that is simulated spatially by MCGB models as classified and overlaid grid cells (Fig.5). Various complex thematic layers such as demographic analysis results, subjective layers of urban infrastructures, land use classification layers, transportation cluster layers and thematic output results such as accessibilities, activities and behavioral patterns were used for modeling the site suitability analysis of the P&R stations. MCGB models simulated these planning approaches as spatial decision-making procedures for LOSCE allocation and P&R site selection. For instance, buffer zones were used to analyze the impact range of HICs sources or to measure the circle of influence for the defined P&R stations.

**Figure 4.** The simulation of the identified multidimensional HICs and the proposed HIC counteracting factors by MCGB modeling

Simulating the radius impact of local HICs by measuring their proximity influences demonstrates what control policies and their hazardous conditions require. Planning for the behavioral patterns of urban transportation models and affecting enhancements for NEUTS’ (Non Engine Urban Transport Systems) and HOVS’ (Heavy Occupancy of public Vehicles Systems) public trends comprise the main subjects of UTMP (Urban Transportation and Movement patterns Planning) and BP (Behavioral Pattern policies) strategies that can enhance the mitigation power of the control strategies when integrated as synergetic policies. The spatial detection of the best patterns for combining all the vacant lands, green spaces, parks and green belts in order define effective heat-counteracting spaces was carried out using the MCGB...
models for the select strategies such as **UGOS**, **UCT** (Urban Corridors and Topographically useful space planning and design) and indirectly for the **UTMP** strategies. Effective systems were promoted for identifying public transportation patterns that have the least ability to form **HICs**, such as **P&R** local stations, **HOVS** and **NEUTS** programs and their related infrastructures planned by **UTMP** strategies, through simulations on **MCGB** models. **UGOS** strategies were focused on the macro zones that delivered greater green spaces or relevant opportunities and that provided adequate sources of urban recreational or open spaces to define adequate urban soft patches. By making improvements in the **LOSCE** and **P&R** stations in all the **TAQZs**, linear **HICs** decreased rapidly in number. Reducing local trip requests, promoting **NEUTS** and **HOVS** programs and defining the main role of air-friendly policies in subjective urban plans were accomplished by the strategies specified as **TV**, **ET** (Economic and Technological policies development) and **LR** (Law and Rules for air quality control) and by the devising of comprehensive urban master plans enhanced by **UDCP** (Urban Designs and Comprehensive Plans revised by implementing the urban clean air friendly policies) strategies. Designing heat-counteracting zones for eliminating the impact of **HICs** and conserving the natural conditions may comprise the most crucial control programs defined as **UCT** and **UGOS** strategies (Fig. 4). Revising the comprehensive urban plans devised for re-arranging industrial, high-density, residential areas and commercial zones as the main sources of **HICs** formation and development could be another important control program defined properly by **UDCP** and **ET** strategies.

![](image)

**Figure 5.** Park & Ride stations’ site selection and their efficiency operations assessment

Comparisons were made between the current **HICs’** patterns and the conditions after the implementation of the defined strategies. The comparisons were then fully simulated by **MCGB** models for all the **TAQZs**. The various overlaying spatial layers, such as the demographic
programs used for **HICs** control, including **DD** (Demographic Detection pattern) strategy layers, transportation classification layers, urban land use pattern layers, structural and infrastructural layers, categorized urban activity layers and environmental layers, made up the foundation of the geo processing analysis and the **ANN** modeling of the **ERAP’s** and **HICs**’ spatial simulations. The final outputs of the **ANN** matrices were fixed spatially to their related cellular grid-based layers as various thematic maps. The creation of local **HICs** depends on location, time and uncertainty dimensions. Determining hazardous zones based on the identified **HICs** and pollution sources helped define the most suitable policies for mitigating the impact of **HICs**. **MCGB** models allow for an integrated modelling and mapping of multidimensional cellular grid-based zones with **ANN** forecasting matrices and the strategies classified by **MCDA** procedures, which ultimately help evaluate the outcomes of the implemented strategies in terms of mitigating the impact of local **HICs** in each **TAQZ**.

![Figure 6](image-url)

**Figure 6.** The monitoring and assessment of multidimensional decision support systems for urban **HICs** by **MCGB–ANN** models and a customized prediction software

**MCGB** models present all the measured values of **MCDA** or **ANN** databases by smart geo referenced maps that are used in overlaying procedures for **ERAP** and final **HICs** mitigation prediction results. The prediction of the impact of the strategic actions taken for mitigating the
identified HICs hazard zones were simulated by ANN matrices and MCGB overlaying procedures. MCGB models visualized the implementation results for each selected control strategy and determined the most suitable strategies for mitigating the negative impacts of the identified local HICs and improving the positive factors related to the macro zones for sustaining ideal conditions (Fig. 6). MCGB models spatially identified which characters of each macro zone should be conserved or enhanced by suitable synergetic strategies and which ones should be removed or completely changed to sustain clean air quality and mitigate HICs. Each selected strategy has its own HICs control potential evaluated by MCDA and ANN matrices and is ultimately visualized by cellular grid-base layers. MCGB models support the control and management of HICs through their precautionary abilities, which fully convert the traditional reaction programs that seek only to delay critical conditions.

Results and Discussion

Various environmental impacts of atmospheric pollutants and HICs on local dwellers quality of life are a major concern in new urban challenges [17]. Most megacities are considering the development of controlling strategies to mitigate HICs negative impacts, which firstly beginning with monitoring their spatio-temporal thematic maps [18]. Air quality and HICs monitoring provides a means to assess the contamination levels and continuously measuring the controlling strategies results [19]. The prioritized objectives of the Tehran municipality strategic plan have been set as creating an efficient transportation system, a green city, a highly cultured city, a dynamic city, the integration of modernism with the Islamic-Iranian identity and ultimately a clean city with all sources of pollution fully under control. The last objective, however, was neglected rather than becoming the focus of all the proposed urban policies. These heat-counteracting open spaces are hard to find in the Tehran megalopolis. In addition, the dry conditions caused by the regional climate and the past decades’ lack of attention to environmental planning have turned Tehran into a densely-positioned structure that is chaotically full of asphalt. Although the municipality has made great efforts to add to the open green spaces during the past few decades, the present conditions are still far below the norms and the international standards.

The urban commuting patterns have been identified as the main culprit in the formation of linear HICs in Tehran, and the lack of effective green technologies and greenways as well as advanced industries and technologies that enable the use of clean renewable energies compared to similar metropolises that do possess these facilities suggests the destructive influence of poor management in the development of these problems [20]. Reducing the number and length of motorized trips through changing the spatial structure of the city, decreasing the number of
private vehicle trips through increasing the share of public transport in the city’s daily trips and
decreasing the emission of pollutants and the formation of linear HICs should be the main
priorities in the Tehran municipality strategic plan. Concentrating complementary urban services
and facilities in one location reduces the length and number of daily trips and results in the less
formation of HICs in the defined TAQZs. Understanding the Structures of urban parameters is
important for prediction of the future evolution of HICs [21]. The selection of accurate locations
for transformation into industrial zones and replacing large impoverished factories with a high
emission of pollutants with modern, high-tech and clean industries can have an immediate effect
on the urban air quality and the formation and development of HICs. Due to the multiple causes
of HICs formation, defining control strategies based on only a few connected departments may
not result in an effective mitigation of pollution and heat. Implementing integrated policies
developed by all the involved governmental or private sectors should be the main goal of these
plans. Urban HICs management requires an integrated approach that is capable of detecting the
most serious problems, measuring feasible solutions such as industrial planning, utility
management, traffic control and environmental control in households and defining strategic
policies for a sustainable mitigation of the local impacts of heat.

Urban strategies, legislation, investment and taxation should be emphasized as the objectives
of air quality management and control. Defining programs to limit the use of private cars and
encourage the use of public transit as the main means of urban transportation and developing
electronic services for urgent yet routine activities are parts of the solution to an effective air
quality control. Drafting control legislations such as traffic policies, industrial development
policies, energy development policies and land use planning can help improve the control
strategies set for accomplishing a sustainable mitigation of HICs zones. Spatial, temporal and
uncertainty dimensions must be integrated into sustainability urban environment programs [22].
The management of urban sources of HICs formation requires the synergetic efforts of pertinent
governmental and private sectors for redefining urban activities. By typical grid cells simulation
several variables can be evaluated including, HICs and particle dispersion, hard and soft surfaces
parameters [23]. Creating a seamless management system for sustaining clean air, establishing a
proper cooperation among all pertinent governmental departments and local authorities as one
consortium and introducing Tehran municipality office as the main agent responsible for urban
HICs management are some other prerequisites to a sustainable clean air.

Conclusion
MCGB models were implemented to assess dynamic and uncertainty urban features, conditions and actions in different hazardous events for the robust control of local HICs. Simulating the HICs control program assessment consisted of three main parts: (1) detecting pollutants and HICs formation sources; (2) defining vulnerable and hazardous urban zones; and (3) simulating the results of control policies set for mitigating the impact of HICs on all the TAQZs. The selected strategies should cover all the aspects of sustainable development, such as social, economic and environmental preservation and improvement in all the TAQZs. Enabling the access of all the defined neighborhoods to local facilities and key land uses was accomplished through the allocation of the best site to P&R stations and a suitable LOSCE site selection as part of the LUTA policies. The LUTA policies decreased unnecessary local trips and mitigated linear HICs formation in the related TAQZs to a good degree. Public transit systems (such as the subway and the bus) were developed as part of the HOVS policy with a focus on reducing the public tendency to use private vehicles and were simulated using value-based ANN matrices and spatial cellular grid-based layers as part of the UTMP strategy. The study also discussed the establishment of procedures for the multidimensional assessment of spatial, temporal and uncertainty dimensions for evaluating the economic, social and environmental aspects of urban HICs management, and the results of the proposed control strategies were simulated as a decision support system for making robust policies. HICs assessment models should predict major sources of heat generation, analyze time series, evaluate urban conditions and measure the results of control strategies in all parts of a megacity. The evaluation of the environmental, social and economic aspects of the urban features influenced by the mitigation or control of the detected HICs can help prove the effectiveness of the selected strategies simulated by MCGB-ANN models. A sustainable development requires the integration of multiple dimensions to help develop robust strategies. Shifting point source pollutions from inside the city to other areas, greening cities and creating a green-belt to integrate all urban green patches inside and outside the city, improving fuel quality, providing public transit options for all the TAQZs, developing clean technologies in pertinent subjects, expanding subway lines, improving the access to key local services by the NEUTS and P&R stations, revising fuel and energy prices, re-arranging high-density urban spaces, creating intelligent transit systems and emphasizing subjective air-friendly urban plans should be defined as the main objectives of urban programs.

Predicting indirect urban evidence that affects the expansion of HICs can help define the precautionary programs introduced in this study as MCGB-ANN simulating procedures. The lack of comprehensive urban plans for air quality improvement and the multiple sources of
HICs formation with no proper local or regional control strategies in place in Tehran indicate that HICs management will be the first challenge in urban environment management. Land use conflicts, poor infrastructures, the lack of clean technologies, haphazard stationary and dynamic pollution sources, economic and social conflicts and the lack of comprehensive air-friendly urban plans and regulations can further add to this challenge. The rapid land use conversions for the development of greater administrative or commercial urban zones introduce a new challenging subject to the management of air quality and HICs distribution. Urban spatial structure and municipal objectives should both emphasize the promotion of subjective plans that aim to merely ensure a sustainable clean air in all the local areas. Controlling urban activities, land use, infrastructures and movements in order to prevent the expansion of HICs should comprise the most important objectives of Tehran municipality for achieving a sustainable clean air. Through the implementation of control strategies and decreasing the formation and development of heat islands, communities can learn to better manage their energy demands and effectively sustain a desirable urban air quality. Assessing different situations and strategies through MCGB-ANN simulations led to the emergence of the main threats and opportunities in each macro zone for the effective mitigation of the identified HICs. Simulating the results of integrated strategies showed that they were more able to decrease the formation and development of HICs compared to when isolated programs are implemented without first predicting their combined effects.

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