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Type:
Original research

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Keywords:
decision support system, Air Quality Management, Pollution Predicting
A multi-dimensional decision support system for air quality management in the metropolis of Tehran

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Abstract: The present study used an integrated modeling approach involving spatio, temporal, uncertainty decision support systems using multi criteria decision analysis and an artificial neural network for the virtual simulation and strategy assessment of air pollution. The main objective of the study was to define a specific method for air quality assessment in the metropolis of Tehran using a spatio-temporal and uncertainty decision support system. Multi dimensional decision support systems can be efficient tools for urban air quality decision-making process, since sources of air pollution and associated pollution control strategies are dependent on location, time and uncertain variables. Urban air quality management and decision support systems should predict future air pollution levels, take proper actions and present control strategies. A multi dimensional decision support system can thus help develop comprehensive tools for the monitoring and assessment of current and future local pollution conditions and predict the results of implementing the selected strategies. Multi criteria decision analysis and an artificial neural network as the database parts of the multi dimensional decision support system were used for modeling decisions.

Keywords: Decision Support System; Air Quality Management; Robust Strategy; Pollution Predicting

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Introduction

The metropolis of Tehran currently houses more than 15% of the permanent and floating working population of the country, thus exacerbating the problem of imploding centralization caused by the unique prevailing administrative, educational and commercial structures of the region (Habibi et al., 2006). The increasing tendency to migrate and live in Tehran's satellite suburb cities has been hastened by the centralized government structure and the advanced welfare services, job opportunities and extensive access networks as well as the diverse lifestyles and social behaviors that the metropolis offers, so that we now witness more than 8 million permanent population and 3 million floating travelers commuting into the city from satellite suburb cities on a daily basis. In addition, the concentration of more than 40% of the country's macro industrial, economic and policy-making activities in Tehran has created the need for various spectrums of data and seamless spatio-temporal data for the analysis of the entire issues related to the metropolis of Tehran (Bertaud, 2003).

Air pollution is studied as the accumulation of natural and synthetic matter and particles such as solid, liquid, or gas particles that directly and/or indirectly threaten and harm human health (Franek et al., 2004). The phenomenon of urbanization has been transforming the natural landscape and
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habitat of Tehran for years, changing its human activity and lifestyle and having caused various types of damage to its natural resources at local and regional levels, including breathable air and climate changes (Wai et al., 2012). The various sources of air pollution (including point and non-point, fixed and moving) available in the region have created countless complex and multidimensional problems; identifying their complex structures and assessing their irreversible effects require tools that can measure the entire spatio-temporal and uncertainty dimensions in one stroke. Air pollution management is comprised of a set of strategies used for mitigating pollution levels and protecting the public well-being and health. The defined strategies should be assessed and implemented in a coherent and comprehensive program so as to facilitate a sustainable, long-term and acceptable urban air quality (Cofala et al., 2010). An effective air pollution management program should integrate all the required practical strategies in a way that their positive synergies create robust solutions for a fair and sustainable mitigation of air pollution across the metropolis.

Urban policy-makers should therefore work out the environmental costs of economic development and, in the path toward the realization of sustainable development, take account of the values required for the preservation of the environment as well as socioeconomic values (Lu et al., 2011). The different models developed for assessing air pollution aim mainly to help managers realize where, when, to what extent and how pollution mitigation strategies should be combined and used to achieve a standard-quality and healthy urban air without the need for impeding economic development or public satisfaction. Most air quality models are able to effectively predict the time and place of the occurrence of increased pollution based on the recorded variables and time patterns, and can accurately guide decision-makers in assessing the current and future air quality in various urban zones for further planning and decision-making (Fischer et al., 2011). Many factors affect the propagation of pollutants. A sustainable strategic planning requires Multi-Dimensional Decision Support Systems (MDDSS), a variety of expert systems, machine learning processes and virtual simulation systems to help accurately predict the air quality under different conditions at determined times and locations (Elbir et al., 2010). The main features of the process of decision-making in MDDSS and its most decisive roles rely on the prioritization and choosing of the most fitting decisions based on a set of predetermined priorities and objectives for the optimal achievement of the desired status from the current status. Adding prioritization features and an option of choosing among the more essential criteria to visualization features and spatial data make MDDSS more powerful. Decision-making and the choosing of the best solutions from the existing clusters of strategies for sustainable pollution mitigation will definitely play the most crucial role in the management of urban environmental hazards. The use of multidimensional simulations or MDDSS in the management of air quality leads to a better understanding of the spatio-temporal variables and uncertainty conditions that affect air pollution in each of the urban macro zones and provides assessors with the opportunity to identify and study the main causes of the development
and propagation of air pollution based on the analytical reports extracted from recorded time series and to also predict the likely patterns of the spread of pollution under similar spatio-temporal conditions (Rahmatizadeh et al., 2004). Advanced air quality management models require volumes of data for their simulation, evaluation and prediction processes, including data on the climate, air quality, urban use and pollution propagation from sources of pollution including both fixed and moving and point and non-point sources and demographic data among others (Afshar et al., 2007).

The process of data analysis is essential to the collection and classification of data. Data analysis is used for analyzing, clustering, classifying, predicting and creating time series patterns and can be used according to various specialized and technical methods such as statistical methods, Artificial Neural Network (ANN) models, decision tree analysis, genetic algorithms and fuzzy logic theories (Li et al., 2004). The ability to manage the properties of air pollution variables, including spatio-temporal and uncertainty conditions as the constituent dimensions of the environment, is the main prerequisite to lasting decisions. Multi Criteria Decision Analysis (MCDA) techniques have demonstrated their capabilities in situations where the best decision has to be made from a multitude of criteria according to a set of objectives and pre-existing conditions and when the selected criteria also require to be weighed and rated in terms of their importance in meeting the goals and conditions that match those of the decision (Farahani et al., 2007). MCDA techniques and ANNs increase the capabilities of MDDSS in decision-making about urban air quality, since, according to analyses, not only do they account for geographical and temporal variables in the final decisions, but also include priority ratings and the selected criteria based on expert opinions. Assessing the effect of pollutants and pollution patterns in different seasons and times and in local and regional zones requires long-term monitoring. The dominant behavioral and physical patterns of pollution can be identified at different times and locations, so that their results can help the implementation and execution of the modeling stages associated with the evaluation and prediction of pollution (based on spatial thematic layers, time series data and uncertainty scenarios).

Emission Inventories enable assessors to assess the development and propagation of pollution and to address the root cause of the incidence and rise of pollution, and to also carry out a visual study of the reciprocal effects of pollutants on the surrounding environment and on the identified macro zone and to also examine the role of environmental factors in increasing or decreasing pollution levels using spatial-temporal data layers (Kanevski, 2011). Monitoring emission inventory layers using multidimensional layers of data causes the patterns of pollution development and distribution to be identified under the intended spatial and temporal conditions. Overall, the success and efficacy of the selected strategies can be evaluated according to MDDSS simulation results; in a way, the success and capabilities of each selected strategy can be assessed virtually and in the form of decision support models so as to determine the share of each strategy in mitigating the
recorded pollution in each macro zone based on the capabilities of the chosen strategic plan and the prevailing conditions of the macro zone. Emission inventory layers display and control all high-density industrial, commercial and residential points and other urban land uses causing pollution and linear sources of pollution such as road networks. An advantage of stochastic interpolation methods is their ability to provide the necessary conditions for the estimation and prediction of uncertain factors according to spatial interpolation predictions. In other words, they are interpolators and display the values estimated for the prediction of spatial behavioral patterns of pollution (Li et al., 2008). Uncertainty modeling and probability scenarios are developed using ANN matrices, spatio-temporal and uncertainty MDDSS, based on which the maximum probability of accidents associated with pollution dispersion can be determined and the results of air pollution management strategies can be assessed. The developed management scenarios should be assessed according to various ratings under different conditions of internal and external factors and the pollution mitigation capabilities of each should then be calculated and cross-compared (O’Hara et al., 2009).

Materials and Methods

Spatio-Temporal and Uncertainty Decision Support System (STUDSS) enables the identification of the least and most efficient requirements for sustaining air quality in every macro zone and is based specifically on detecting its structural complexity and activity impacts. Total Suspended Particulates (TSPs) were identified as the main problem with the air quality in Tehran and were selected as an air quality indicator for the simulation and modeling of a Spatial Cellular Grid Layers (SCGLs) inventory in each defined macro zone. All classification definitions for positive and negative factors were simulated by specific values abbreviated as COBRO (Costs, Opportunities, Benefits, Risks and Obligations) matrices and decision models were then executed using an ANN database. The measured values were assigned to spatial cellular grid layers for assessing the pollution impact and the outcomes of the compensating strategies. To achieve the air quality objectives set for the macro zones discussed in the present study, COBRO matrices distinguished between the challenges and the opportunities. In general, COBRO matrices review the spatial characteristics of a set of macro zones separately and distinguish all the spatial issues related to the proposed objectives of air quality control. MDDSS enables data collection, management, manipulation and analysis and the presentation of the results in both graphic and report forms, with a particular emphasis on preserving and utilizing the inherent characteristics of spatio-temporal data (Peckham et al., 2010). MDDSS simulate negative or positive cumulative impacts through modeling urban features and the related alternatives that have direct or indirect positive or negative impacts on pollution. The location of air pollution sensing stations and the other data required for the development of spatial data infrastructures are identified in MDDSS on
SCGLs as the reference location. Next, a descriptive database and the results of analyses based on the evaluation and modeling matrices are overlaid on their corresponding spatial layers and stored as location and spatio-temporal data analysis and decision-making processes then begin in accordance with the spatial data layers. Spatial data analysis involving data overlap, buffering and zoning are formed, so that decisions can be made according to the environmental decision support system. The mitigation of air pollution accounted for by the executed strategies was calculated and simulated by MCDA–ANN matrices as well as SCGLs for each defined macro zone. To calibrate the defined clusters, measure their weights and rate them, COBRO – Delphi – MCDA and ANN analysis matrices were used, simulating the air quality decision making processes (Fig.1). The calculated scores and matrix outputs were ultimately visualized on spatio–temporal layers and utilized for uncertainty scenario modeling using the STUDSS method.

Tehran settlements were divided into specific macro zones depending on their emission conditions, dominant typologies, related urban features, structures, infrastructures and activities, the COBRO matrices’ results, land use and demographic characteristics, as per Tehran Air Quality Zones (TAQZs) (Fig.3). The value definition for the classification of the weight of the strategies was first carried out by expert comments using the virtual Delphi method and then by a pair wise comparison in the MCDA; all the defined scores were categorized technically and attached to their related cellular grid layers. A virtual ad-hoc committee was held for weighing the selected strategies as the most vital part of the decision making process using online Delphi questionnaires, which collected the experts’ opinions through the website www.hse21.ir and held virtual training and cluster classifications (Fig.2). The experts’ opinions were gathered through the designed questionnaires in three sections, including a general section (72 questions), an expert section (24 questions) and final section (14 questions). After categorizing the most similar responses, the initials value of the priorities and weights were determined. To carry out a comparison of the technical weightings, MCDA was used to define the final weights obtained for the selected
strategies. All the measured scores were then visualized spatially by SCGL simulations for all TAQZs. The final results gathered on the experts’ opinions were used for the primary categorization and definition of the priorities for the selected strategies, which were then weighed in MCDA software as the next steps (Fig.5). All the measured values were ultimately spatially attached to the thematic cellular grid layers.

Strategies should be selected based on their compatibility with the macro zone characteristics, requirements and disasters. The number and type of the selected strategies were modeled based on their suitability, abilities and compatibility with their corresponding macro zones and the defined COBRO conditions of TAQZs. For determining the causes of air pollution and selecting the best solutions to the problem, three specific approaches were defined: 1. Monitoring the current conditions using spatial layers, 2. The interpretation of time series geo maps for training neural network as memorial part of the system, and 3. Simulating multi dimensional urban spaces by ANN matrices and SCGL models (Holnicki et al., 2010).

The rated weights were quantified in ANN matrices and colors were used to qualify the classifications on SCGL, determining which strategies had achieved the highest scores for their corresponding TAQZs and could thus be deemed the most suitable. The measured COBRO matrices visualized by SCGLs determined the detected positive and negative aspects of all the macro zones and their correlations and defined the functions and overlaps to achieve the determined outputs.
The final clusters of strategies were defined as the main TAQZs for air quality control programs for making a decision tree and evaluating the priorities and scores using the Delphi method and MCDA. All the scores calculated for the strategies were attached directly to their corresponding SCGL models. The final spatial MCDA analysis results specified the 14 rated strategies as: PSP (Point Sources Pollution control programs), LSP (Line Sources Pollution control programs), LR (Laws and Rules), ASP (Area Sources Pollution prevention programs), LUTA (Land Use renovating and Transportation system revised for access to sites of Attraction programs), DD (Demographic Data for preparing and developing air-friendly programs), USS (Urban Spaces and Structures for air-friendly planning and design), BP (Behavioral Pattern policies), UTMP (Urban Transportation and Movement pattern Planning), UCT (Urban Corridor and useful Topographical spaces planning and design), UGOS (Urban Green areas and Open Spaces planning and design), TV (Technology and Virtual electronic services development and planning), UDCP (Urban Designs and Comprehensive Plans revised by implementing clean air-friendly policies in urban areas), ET (Economical and Technological policy development) (Fig. 4). These scores simulated all the measured weights spatially using SCGLs.

**Figure 4** The final decision tree of the selected pollution control strategies and the main decision-making criteria

For simulating time series layers of local air pollution dispersion, the location of Tehran air quality monitoring stations were first determined on thematic SCGLs, and specific attribute data and matrix outputs were assigned to the spatial objects, and the primary STUDSS was ultimately prepared for spatio-temporal uncertainty analysis.
The air pollution dispersion levels were simulated using geostatistical tools such as the Kriging model. The spatial simulation of 48 monthly time series layers of air pollution in TAQZs (2011-2014) demonstrates an iterative process with similar repeated operations of air pollution development and expands the spatial and temporal conditions for the similar macro zones. This process helped in predicting the simulations using ANN tools based on periodical pollution patterns and in detecting the main sources of pollution and their related factors, thereby helping determine the most suitable strategies for mitigating their impacts. The spatial visualization of the air pollution distributed across four years was simulated by separate 12-month SCGLs based on the average air quality index reports of each local station and the Expected Rates of Air Pollution (ERAP) models were ultimately defined for each TAQZ (Fig.6).

Under normal conditions known as UFO (Uncertainty Functions by Ordinary scoring), all related factors are under normal conditions, under which the strategies suiting each macro zone
enhance the positive aspects of the related factors and mitigate the negative conditions detected for each TAQZ. The possibility of enhanced pollution or an evidence of sudden forces of pollution reduction such as rain or wind are considered the main uncertainty factors that affect pollution patterns. STUDSS thus simulated two other uncertainty scenarios of UFMA (Uncertainty Functions by MAximum scoring for the worst possible conditions) and UFMI (Uncertainty Functions by MInimum scoring for the most optimistic forecast and positive conditions).

For rating the strategies and situation modeling in UFMA, the highest values were taken based on a lack of self-filtration in the macro zones and while expecting the worst possible situation with the highest degree of emission for most of the specific TAQZ. The maximum number of synergic strategies for compensating for pollution was defined effectively using the most pessimistic approach. The lack of self air purification in the macro zones as dictated by their dominant characteristics (environmental and structural characteristics, activities and infrastructures) and as per the COBRO evaluation matrices, to predict the worst conditions and factors for air pollution enhancement, the decision-makers had to use the maximum number of suitable strategies for effectively mitigating emission at all TAQZs.

In UFMI, all the defined scores were as low as possible, given the highly positive conditions at the macro zones and the lower emission of pollutants based on time series evaluations, the COBRO evaluation matrices and the best urban conditions predicted. In the UFO predicting model, all the selected urban features and defined factors simulated the normal conditions measured spatially by evaluating time series layers and other alternatives of ERAP models for all TAQZs. Pollution simulations were created using the data collected from multiple air quality monitoring stations spread throughout the defined macro zones, and the ANN air pollution matrix enabled SCGL models to estimate the level of pollution based on the predicted scenarios (UFMI, UFO and UFMA) and geostatistical Kriging procedures. The final integrated overlay maps were simulated by SCGL, reflecting the weights of the defined criteria obtained from the Delphi, COBRO, MCDA and ANN matrices. SCGL helped monitoring the pollution locations, sampling the pollution patterns and the duration and frequency of pollution emission for each defined macro zone. The final integrated strategies selected for each macro zone had to ensure that no irreversible hazardous pollutions were to occur again under any possible condition.

**Figure 7** Artificial neural network analyses for “ERAP” and “ERAPM” predicting simulations
For calculating and modeling the final scores of ERAP in each macro zone and for measuring and predicting the final values for the Expected Rates of Air Pollution Mitigation (ERAPM), specific alternatives were defined, including the PSPD (Point Source Pollution Density factors), the LSPD (Linear Source Pollution Density factors) and the LAIR (Landuse Impact classification Rates). These three complex clusters simulated the constant factors of ERAP and ERAPM modeling as identical to the Kplla (K values for Pspd + Lspd + LAir) constant factors. Five quantitative factors were used as the main variables for estimating the ERAP and ERAPM values modeled in the present study as the Vhaape inconstant (the variable values measured through modeling the “Hidr + Aidr + Asdr + Pdr + Eii” factors) modeled by ANN predicting matrices (Fig.7). These factors included the PDR (Population Density Rates), which measure the rates of population density and the impact of public activities on air quality, the HIDR (Heat Islands Density classification Rates), which simulate the distribution of hazardous thermal patches with harmful effects on public health, the ASDR (Accepted clean air urban Spaces Density Rates), which represent specific weights for anti-thermal urban spaces such as open green spaces, the AIDR (Accepted air-friendly urban Infrastructures classification Density Rates) and the EII (Environmental Impact Index simulations), which demonstrate the role of environmental factors such as the climate, rain, wind, topography and other environmental alternatives that contribute to the increase or reduction of pollution. These factors were used in predicting the scenarios; for the UFMA scenario, the maximum weights were considered as the maximum controlling factors required by the Vhaape alternatives; for the UFMI scenario, the minimum weights were defined and spatially attached to the spatial cellular grid layers and used in overlaying the modeling procedures; and for simulating the UFO scenario, the average mode and mean values of the measured scores were used in the Vhaape database, which simulated the scenario using both the ANN software and STUDSS virtual environments (Fig.8).

Time series modeling was used for predicting the ERAP values at the UFO situations; however, for the ERAP quantities at the UFMI and UFMA scenarios, other variables such as the Vhaape alternatives were simulated. Moreover, for predicting ERAPM using tripartite forecasting scenarios, other parameters such as the Kplla and the scores given to the strategies were used specifically for each defined macro zone. Time series data, Kplla and Vhaape alternatives were used for the ERAP predicting models and, through integrating the control weights given to the strategies with the calculated ERAP values, the amounts of ERAPM was simulated spatially using the macro zones’ cellular grid layers.
Results and Discussion

The main element of air pollution modeling is analysis of the trends of the past and forecasted changes which support environmental decision making (Kobus, 2015). MDDSSs are developed to support assessments of decisions pertaining to urban environmental management so they should be able to detect a wide variety of time-space conditions (Cortés, 2001). Uncertainty modeling based on the defined predicting scenarios could have a major role in robust decision-making due to the complexities and the multidimensional aspects of urban air pollution. The defined tripartite scenarios help decision-makers in simulating the probable impact of the main spatio-temporal and stochastic variables on pollution dispersion in the specific macro zones. Uncertainty scenarios were defined by UFMA, UFMI and UFO, which determined the suitability and the number of requirements for the strategies based on the simulation of the specific scenarios. The strategy selection continued until the amount of ERAP modeling by ANN and the final spatial values of the overlaying cellular grids were mitigated for each specific macro zone and when they reached the standards set for normal air quality. For the predicting scenarios of UFMI (best possible conditions) and UFO (normal conditions), the overlaying models revealed that, after implementing the selected strategies, the amounts of ERAPM met all the requirements for clean air based on ANN and SCGL values measured in all of TAQZs during all seasons. However, in the predicting scenario of UFMA (worst possible conditions), pollution continued during the winter in spite of implementing the selected strategies in macro zones TAQZn12 and TAQZn13 (Fig.9).
Figure 9 The ANN results for predicting air pollution in each of the macro zones after implementing the control strategies defined by uncertainty scenarios and the SCGL overlaying models. 

The air quality in most megacities of the world shows that vehicular and industrial air pollution play an important role in deteriorating this index; however, these two sources of pollution are not the only ones detected in many of the defined macro zones. Land use conflicts, poor urban infrastructures and cleaning technologies, haphazard stationary and dynamic pollution sources, economic and social conflicts and the lack of comprehensive air-friendly urban plans and regulations induce air pollution. Urban air pollution models simulate space contamination morphology evolution under various scenarios by assessment the most influential variables such as structures attributes, socioeconomic status and the effects of complex local environment interactions (Liao, 2016). Decision subjects involve multiple and comprehensive criteria so defined MCDA supports environment managers in robustness decision making (Gettinger, 2013). Decision-makers should be able to demonstrate that the selected strategies can effectively mitigate the reported levels of pollution and maintain the standards for clean urban air for long durations of time. To achieve a sustainable clean air in megacities, defining comprehensive air-friendly plans is necessary. These plans can present guidelines and principles for meeting clean air goals alongside programs for urban development and provide a basis for presenting plans for economic, social and environmental development as well. Multi dimensional simulations of air pollution, support assessing of defined controlling strategies for sustainable urban air quality (Filip, 2015). The management of air pollution sources requires synergetic efforts on the part of several organizations.
within the governmental and private sectors aimed at redefining and modifying relevant activities. An integrated council should be established in Tehran for air quality management in order to facilitate the design and implementation of seamless urban air purifying strategies in all the responsible sectors of the government and the society; this council should have a high authoritative power in setting clean air legislations and pollution control agenda. STUDSS enables comparison of defined scenarios in terms of their impacts on pollution mitigation, which is essential to be taken into account in robustness decision making (Gschwind, 2014). STUDSS can play a significant role in this respect through summarizing and modeling all the relevant information to be used in the development of appropriate micro zone air quality planning and policy-making alternatives in affected cities such as Tehran. Moreover, STUDSS can identify whether the assumptions of the selected strategies for each macro zone are ideal and correct and can also help provide sustainable air quality conditions for future developments and propose plans for environmental change or urban programs.

Conclusion

STUDSS modeling can measure the final ERAP values based on complex alternatives such as time series data used as memorial part of ANN that benchmark the periodical motif of spatio-temporal pollution patterns and constant factors used as KPLLA alternatives and VHAAPE variables modified based on predicting scenarios. ANN matrices executed the comparisons made between the selected strategy outputs and detected the mitigation results of each selected individual or synergetic strategy that helped the decision-makers select the most appropriate array of strategies under different conditions. The number of ANN matrix neurons in the input layers was equal to the number of input variables for the sample ERAP and ERAPM alternatives, urban environmental features, infrastructural conditions and clusters of strategy scores. The spatial output ANN layers announced the predicted pollution level and the expected amount of contamination reduction through executing the selected strategies. All the values measured for the selected strategies, including ERAPM quantities, and for the predicted pollution, including ERAP values, were visualized spatially by cellular grid layers modeled for the second time through the overlaying procedures. Although the defined weight of each strategy was distributed fairly among all the cellular grids, the selection of the most suitable strategies for TAQZs depended on other parameters modeled by ANN functions. The integration of spatial, temporal and uncertainty decision support systems with MCDA and ANN matrices was carried out for the purpose of the visual simulation of the predicted air pollution before implementing the control strategies and for the final results to be determined for the macro zones’ air quality after the execution of the selected plans. The prioritized strategies and the proposed weights of them were defined depending on the existing pollutants detected and the main requirements and opportunities for all TAQZs.
STUDSS models implemented a proactive interaction between spatio-temporal and uncertainty databases with visualization levels that assessed specific strategies for all the micro zones. Spatio-temporal analysis helped assess and predict the impact of pollution and identify the best pollution control strategies for the affected zones based on multidimensional decision-making models.

Through the spatial simulation of the hazardous zones and the vulnerable spaces, the requirements for the selected strategies were determined at each specific TAQZ.

Acknowledgements

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Figure 2
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Table 1: Cross-tabulation results.

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Figure 3
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Figure 5

Time series air pollution simulations by spatial modelling of monthly reported of average pollution from air quality stations (2011–2014)

48 spatial layers which detect the main pollution patterns of each TAGEZ

Maps legend:
- VLP, Very Low Pollution
- LP, Low Pollution
- MP, Moderate Pollution
- HP, High Pollution
- VHP, Very High Pollution

Scale: 1:2,600,000

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