Measurement and Modeling of the Spatial Distribution and Temporal Variation of Ambient Particulate Matter

A Method Developed for the Example of Buenos Aires

Von der Fakultät Energie-, Verfahrens- und Biotechnik der Universität Stuttgart
zur Erlangung der Würde eines Doktors-Ingenieurs (Dr.-Ing.)
genehmigte Abhandlung

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Marselina Arkouli

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Stuttgart, October 2011 Marselina Arkouli

Abstract

Particulate matter (PM) is a component of air pollution that presents a threat to public health and environment in several countries. Latin America is the most urbanized region of the developing world with 75% of its population living in cities. As a result of the rapid urban development, growing population densities and traffic increase, PM pollution is becoming a rapidly growing problem and of higher concern. Buenos Aires city is part of the Metropolitan area of Buenos Aires which is one of the most populated cities of the world and the third in Latin America. In comparison to other cities, the coastal location and terrain flatness of Buenos Aires city is considered to favour the air quality by facilitating the dilution of pollutant concentrations. However, the spatial distribution of the pollutant concentrations in the city has never been quantified due to the lack of motoring networks. The city has only two stations and only one of them measures PM.

The objective of this thesis was to provide a cost-effective methodology for the estimation or prediction of PM concentrations in the urban air of Buenos Aires city and integrate the non-linear relationship of the factors affecting PM concentrations. Firstly, the proposed methodology consisted of an analysis of the results of the measurements performed during one year in Buenos Aires city within the framework of the international project BARUCA. With the evaluation of the measurement data a thoroughly understanding of the main factors affecting the behavior and levels of PM concentrations was gained. As a result, neural network models were proposed which contribute to determine in a reliable way the spatial and temporal distribution of PM in Buenos Aires city. In the field of air quality neural network models have been used mainly because of their ability to model and learn any complex relationship between different variables. Given the importance of the selection of the input data for the training and learning of the neural networks, an analysis of the influence of the input parameters on the targets (PM concentrations) was also done. A model for the determination of the PM spatial distribution was developed which combined the measured PM concentrations at 67 sites and variables such as traffic categorization, land use (residential use, commercial use and green areas), population density and UTM-coordinates. Furthermore, two additional models were proposed to estimate the temporal variation of PM at two monitoring stations for the periods when no measurement data were available. The models combined measured PM data from the permanent monitoring site and meteorological parameters (wind speed, wind direction, temperature and humidity).

Based on the correlation coefficients, it was found that each neural network learns the relationship between the input data and the measured concentrations and the results demonstrate a comprehensible interpretation of the influence of the input data to the networks' outputs. With the proposed models, better and more information about the PM pollution is obtained. In this way, appropriate actions can be taken in order to reduce PM levels and consequently protect the population's health and environment.

These models provide an effective tool, based on land use maps and temporal measurement campaigns, which can be used to assess PM pollution for urban areas like in the case of Buenos Aires city where air quality monitoring networks are limited.

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Zusammenfassung

Die Luftverschmutzung, insbesondere durch Feinstaub, stellt in den Großstädten der Welt ein ernsthaftes Gesundheitsproblem dar. In dieser Arbeit wurde im Rahmen eines Gemeinschaftsprojektes deutscher und argentinischer Universitäten die Feinstaubbelastung in Buenos Aires, der Hauptstadt Argentiniens untersucht. Das Ziel dieser Arbeit war dabei die Entwicklung einer kostengünstigen Methode zur Bestimmung der räumlichen Verteilung der Feinstaub-Konzentrationen sowie der Einflussfaktoren auf diese Konzentrationen.

Im Rahmen des Projektes BARUCA (Buenos Aires Research on Urban Climate and Air Pollution) wurden ein Jahr lang, von März 2006 bis März 2007, in der Stadt Buenos Aires Messungen von Luftverunreinigungen und meteorologischen Parametern durchgeführt. Durch die Auswertung dieser Messungen wurden Kenntnisse über die Haupteinflussfaktoren auf die Feinstaubbelastung gewonnen. Damit wurden Neuronale Netz-Modelle entwickelt, mit denen auf zuverlässige Weise die räumliche und zeitliche Verteilung der Feinstaubkonzentrationen berechnet werden konnte. Das Modell für die Bestimmung der räumlichen Verteilung von Feinstaub wurde mit Feinstaubmesswerten an 67 Punkten und Variablen wie Verkehr, Bevölkerungsdichte, Landnutzung und UTM-Koordinaten trainiert. Weiterhin wurden zwei Modelle entwickelt, mit denen die zeitliche Verteilung von Feinstaub an zwei Orten für Perioden, während derer keine Immissionwerte verfügbar waren, berechnet werden konnte. Diese Modelle wurden mit Feinstaubmesswerten und meteorologischen Parametern (Windgeschwindigkeit, Windrichtung, Temperatur und Luftfeuchtigkeit) trainiert. Die Korrelationskoeffizienten zeigen, dass jedes Modell den Zusammenhang zwischen Eingabe und Messdaten gelernt hat. Außerdem ergeben die Ergebnisse eine plausible Interpretation des Einflusses der Eingangsdaten auf die Ausgangdaten.

Mit den entwickelten Modellen wurden mehr und bessere Angaben über die Feinstaubbelastung in der Stadt von Buenos Aires erhalten. Sie sind somit geeignet, gezielt Maßnahmen zur Verminderung der Belastung vorzunehmen und somit die Gesundheit der Bevölkerung und die Umweltqualität zu verbessern. Die entwickelten Modelle stellen ein brauchbares Werkzeug dar, das auf Landnutzungskarten und temporären Messkampagnen basiert, und generell zur Bestimmung der Feinstaubbelastung in Städten wie Buenos Aires, wo die Anzahl von Messstationen limitiert ist, angewendet werden kann.

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Abbreviation Index

PM	**Particulate matter**
PM_{10}	**Particulate matter ≤ 10 µm**
$PM_{2.5}$	**Particulate matter ≤ 2,5 µm**
$\mu g/m^3$	**Micrograms per cubic meter**
BARUCA	**Buenos Aires Research on Urban Climate and Air Pollution**
EU	**European Union**
WHO	**World Health Organization**
UTM	**Universal Transverse Mercator**
VOC	**Volatile Organic Compounds**
R	**Correlation coefficient**
MSE	**Mean square error**
GIS	**Geographic information system**