Sébastien Rauch · Gregory Morrison
Stefan Norra · Nina Schleicher *Editors*

Urban Environment

Proceedings of the 11th Urban Environment Symposium (UES), held in Karlsruhe, Germany, 16-19 September 2012

Springer

Urban Environment

Sébastien Rauch • Gregory Morrison
Stefan Norra • Nina Schleicher
Editors

Urban Environment

Proceedings of the 11th Urban Environment Symposium (UES), held in Karlsruhe, Germany, 16-19 September 2012

Springer

Editors
Sébastien Rauch
Dept of Civil and Env. Engineering
Chalmers University of Technology
Gothenburg
Sweden

Gregory Morrison
Dept of Civil and Env. Engineering
Chalmers University of Technology
Gothenburg
Sweden

Stefan Norra
Karlsruhe Institute of Technology
Karlsruhe
Germany

Nina Schleicher
Karlsruhe Institute of Technology
Karlsruhe
Germany

ISBN 978-94-007-7755-2 ISBN 978-94-007-7756-9 (eBook)
DOI 10.1007/978-94-007-7756-9
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2013955254

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The 11th Urban Environment Symposium (11UES) was held in September 2012 in Karlsruhe, Germany. The UES series is run by Chalmers University of Technology and the 11UES was organized in collaboration with the Karlsruhe Institute of Technology.

UES was initiated by Professor Ron Hamilton at Middlesex Polytechnic (now University) in the early 1980s and had the title "Highway Pollution". The initial aim was to measure and assess challenges in highway pollution, with a strong emphasis on urban photochemical smog, ozone formation and particle release. After the first symposium, the emphasis on air pollution issues continued through to Munich in 1989 where diesel particulate issues and the relevance to health through measurements of PM10 emerged. The focus on air quality issues was also strengthened by the co-organisation of the symposium with Professor Roy Hamilton at the University of Birmingham from 1986 to 1998. In parallel, the symposium started to receive an increasing number of scientific contributions from the area of urban run off, indeed to the extent that the title of the symposium was changed to "Highway and Urban Pollution". Also at this time the importance of science in support of policy was emerging as a key aspect of the symposium.

The 8th edition of the symposium was held in Nicosia, Cyprus in 2006 and was hosted by the Cyprus Institute. For this symposium, we decided to evolve the name of the series to "Highway and Urban Environment" to provide a positive view of our common future looking to a positive environment. That said, paper addressing pollution issues in the highway and urban environment remain a central part of the symposium as they help to raise awareness around issues to be solved. The 8th symposium was also marked by an organizational change with Chalmers University of Technology taking over the organization of the symposium series. For the first time, the proceedings were published as a book by Springer. The following symposia were held in Madrid, Spain and Gothenburg, Sweden. The 10th symposium was marked by a further name change with the term "highway" being dropped.

For 11UES we aimed at continuing to provide a forum for exchange and discussion on all aspects of the urban environment. Presentations covered air, soil and water contamination, pollution control technologies, management and mobility, urban ecosystems, urban climate and climate change. The symposium was opened by Peter Fritz, Vice-President of KIT, and Gisela Splett of the State Government of Baden-Württemberg. Plenary presentations were given by Jean-Louis Morel from the University of Lorraine, France; Stefan Emeis from KIT, Germany; Christiane Weber from the University of Strasbourg, France, and Timon McPhearson from the New University, USA. The best poster prize was awarded to Lucas Reid of KIT.

The following facts provide a background of 11UES:

90 delegates from 26 countries
138 abstracts accepted for papers and posters
95 oral and poster presentations

We would like to take this opportunity to thank all who have contributed to the success of 11UES. We would especially like to acknowledge Andrea Friedrich at KIT whose organizational skills were essential to the success of this symposium. Cecilia Rossing is acknowledged for editorial work on the proceedings. The Organizing and Scientific Committees thank the following partners for financial support: PALAS, the Stadtwerke Karlsruhe, the KIT Center for Climate and Environment, the Ministry of Traffic and Infrastructure of Baden-Württemberg, and the Karlsruhe Municipality. Finally we would like to thank the delegates for the many valuable contributions and a highly enjoyable symposium.

Göteborg, Sweden

Sébastien Rauch
Associate Professor
Chalmers University of Technology

Göteborg, Sweden

Greg Morrison
Professor
Chalmers University of Technology

Karlsruhe, Germany

Stefan Norra
Professor
Karlsruhe Institute of Technology

Karlsruhe, Germany

Nina Schleicher
Researcher
Karlsruhe Institute of Technology

Contents

Contributors

Paulo Rui Anciães London School of Economics and Political Science, London, UK

M. F. Andrade Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG), Universidad de São Paulo, Rua do Matão, Brazil

Carlos Alberto Arias Department of Civil Engineering, Aalborg University, Aalborg, Denmark

Giles Atkinson London School of Economics and Political Science, London, UK

Sophie Ayrault Laboratoire des Sciences du Climat et de l'Environnement, UMR 8212, CEA-CNRS-UVSQ/IPSL, Gif-sur-Yvette, France

Douglas Baker Science and Engineering Faculty, School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia

Kristýna Bartůňková Institute of Atmospheric Physics, AS CR, v.v.i., Czech Republic

B. Bergmans Institut Scientifique de Service Public, Rue du Chéra, Liège, Belgium

Olof Bergstedt Water Environment Technology, Chalmers University of Technology, Gothenburg, Sweden

Göteborg Vatten, Göteborgs Stad, Box 123, 424 23, Angered, Sweden

Philippe Bonté Laboratoire des Sciences du Climat et de l'Environnement, UMR 8212, CEA-CNRS-UVSQ/IPSL, Gif-sur-Yvette, France

Hans Brix Department of Bioscience, Plant biology, Aarhus University, Aarhus C, Denmark

M Callen Instituto de Carboquímica (ICB-CSIC), c/Miguel Luesma Castán, Zaragoza, Spain

Amanda Silveira Carbone Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo, Brazil

Kuang Cen Chinese Research Academy of Environmental Sciences, Beijing, China

Fahe Chai Chinese University of Geosciences, Beijing, China

Institute of Urban and Regional Atmospheric Sciences, Chinese Research Academy of Environmental Sciences, Beijing, China

Hao Chen Chinese Research Academy of Environmental Sciences, No.8, Dayangfang, Anwai Beiyuan, Chaoyang District, Beijing, China

Yizhen Chen Chinese University of Geosciences, China

Yuan Chen Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Germany

Yizhen Chen Institute of Urban and Regional Atmospheric Sciences, Chinese Research Academy of Environmental Sciences, Beijing, China

P. Comte AFHB, University of Applied Sciences, Biel-Bienne, Switzerland

Alexander Cotte Poveda Department of Economics, University of Göttingen, Göttingen, Germany

Faculty of Accounting and Administration, University of La Salle, Bogotá, Colombia

Silvana Audrá Cutolo Av. Dr. Arnaldo, 715, São Paulo, Brazil

Departamento de Saúde Ambiental, Faculdade de Saúde Públic, Universidade de São Paulo, São Paulo, Brazil

J. Czerwinski AFHB, University of Applied Sciences, Biel-Bienne, Switzerland

Mari Bryn Damsgård Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Ås, Norway

Les Dawes Queensland University of Technology, Brisbane QLD Australia

Cheryl Desha Queensland University of Technology (QUT), Brisbane, Australia

Sylvain JM Desmoulière Instituto Leônidas e Maria Deane, Fiocruz, Amazonia, Brazil

Paulo Roberto do Nascimento Departamento Prática de Saúde Pública, Faculdade de Saúde Pública—Universidade de São Paulo, São Paulo, Brazil

Nigel Downes Department of Environmental Planning, Brandenburg University of Technology Cottbus, Cottbus, Germany

Ahmed Khaled Ahmed Elewa Department of Architecture, faculty of Fine Arts, Helwan University, Cairo Governorate, Egypt

Stefan Emeis Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Garmisch-Partenkirchen, Germany

Joachim Fallmann Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Garmisch-Partenkirchen, Germany

Renata Ferraz de Toledo Faculdade de Educação, Universidade de São Paulo, São Paulo, Brazil

Jaroslav Fišák Institute of Atmospheric Physics, AS CR, v.v.i., 1404 Boční II, 141 31 Prague 4, Czech Republic

Renate Forkel Institute of Meteorology and Climate Research—Atmospheric Environmental Research (IMKIFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

A. Fornaro Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG), Universidad de São Paulo, São Paulo, Brazil

Juliane Gaviolli Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

Leandro Luiz Giatti Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

R.M. González Department of Meteorology and Geophysics, Faculty of Physics, Ciudad Universitaria, Madrid, Spain

Kevin Grönmeier Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

M. L. Guardani São Paulo State Environmental Regulation Agency, São Paulo, Brazil

Asbjørn Haaning Nielsen Department of Civil Engineering, Aalborg University, Aalborg, Denmark

Doug Hargreaves Queensland University of Technology (QUT), Brisbane, Australia

Charlie Hargroves Curtin University, Perth, Australia

Lene Sørlie Heier Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Ås, Norway

Ida Helgegren Water Environment Technology, Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden

Sascha Henninger Department of Physical Geography, University of Kaiserslautern, Kaiserslautern, Germany

Malte Hermansson Department of Cell and Molecular Biology, Microbiology, University of Gothenburg, Gothenburg, Sweden

Thomas Hillenbrand Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe, Deutschland

Paul G Höglund Transforsk-Transearch, Solna, Stockholm, Sweden

Andreas Holbach Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Karlsruhe, Germany

Sarah-Madeleine Hönig Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Wei Hu Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Karlsruhe, Germany

Thorkild Hvitved-Jacobsen Department of Civil Engineering, Aalborg University, Aalborg, Denmark

Sorin Ilie University of Pitesti, Pitesti, Romania

R. Inoue Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG), Universidad de São Paulo, São Paulo, Brazil

Jirina Bergatt Jackson IURS-Institut pro udržitelný rozvoj sídel o. s., Ostrava, Czech Republik

Nathalie Jean-Baptiste Helmholtz Centre for Environmental Research-UFZ, Leipzig, Germany

Inge Jentsch Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

R. San José Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid, Madrid, Spain

Sigrun Kabisch Helmholtz Centre for Environmental Research-UFZ, Leipzig, Germany

D Kramer Department of Industrial Ecology, Faculty of Biotechnology and Industrial Ecology, Mendeleev University of Chemical Technology of Russia, Moscow, Russian Federation

Kjersti Wike Kronvall Environmental Assessment Section, Norwegian Public Roads Administration, Oslo, Norway

Anna Kühlen Institute for Industrial Production (IIP)/French-German Institute for Environmental Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Christian Kuhlicke Helmholtz Centre for Environmental Research-UFZ, Leipzig, Germany

Graciela Landaeta Institute of Architectural Research, Universidad Mayor de San Simon, Cochabamba, Bolivia

PROCASHA Foundation, Cochabamba, Bolivia

Rubens Landin Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

Murray Lane Queensland University of Technology, Brisbane, Australia

Carmen Ledo CEPLAG, Universidad Mayor de San Simon, Cochabamba, Bolivia

Simon Leib Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

F. Lenartz Institut Scientifique de Service Public, Liège, Belgium

Mei Li Queensland University of Technology, Brisbane, Australia

Pierre Le Pape Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France

Laboratoire Interactions des Environnements de Surface, UMR 8148, Univ Paris Sud-CNRS, 91405 Orsay cedex, France

JM López Instituto de Carboquímica (ICB-CSIC), c/Miguel Luesma, Zaragoza, Spain

Julia Loskyll Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Carlos Machado de Freitas Centro de Estudos de Saúde do Trabalhador e Ecologia Humana, Escola Nacional de Saúde Pública, Fiocruz, Rio de Janeiro, Brazil

Environmental Assessment Section, Norwegian Public Roads Administration, PO Box 8142 Dep, N-0033, Oslo, Norway

Mikael Mangold Water Environment Technology, Department of Civil and Environmental Engineering, Chalmers University of Technology, 41296, Gothenburg, Sweden

S. Manorama Department of Botany, Kongunadu Arts and Science College, Coimbatore 641029, Coimbatore, India

A Mastral Instituto de Carboquímica (ICB-CSIC), c/Miguel Luesma Castán, Zaragoza, Spain

Lachlan McClure Science and Engineering Faculty, School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia

Lotfi Medhi Laboratoire Image, Ville et Environnement (LIVE) UMR 7362–CNRS, Faculté de Géographie et d'Aménagement, Strasbourg, France

Sondre Meland Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Ås, Norway

Environmental Assessment Section, Norwegian Public Roads Administration, Oslo, Norway

Eve Menger-Krug Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe, Deutschland

C. Mentink Center of Sustainable Environment, Heerlen, The Netherlands

R. M. Miranda School of Arts, Science and Humanities, Universidad de São Paulo, São Paulo, Brazil

Gabriela Mitran University of Pitesti, Pitesti, Romania

Caroline Mayer Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

A. Mayer TTM, Niederrohrdorf, Switzerland

Paulo Nascimento Departamento Prática de Saúde Pública, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

Peter Newman Curtin University, Perth, Australia

Jutta Niederste-Hollenberg Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe, Deutschland

T. Nogueira Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG), Universidad de São Paulo, São Paulo, Brazil

Stefan Norra Institute of Geography and Geoecology (IfGG), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Clara Inés Pardo Martínez Faculty of Administration, Universidad del Rosario, Bogotá, Colombia

S. Paulsamy Department of Botany, Kongunadu Arts and Science College, Coimbatore, India

J.L. Pérez Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid, Madrid, Spain

P.J. Pérez-Martínez Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG), Universidad de São Paulo, São Paulo, Brazil

Sustainable Economy of Natural Environment Group (ECSEN), Universidad Politécnica de Madrid, Madrid, Spain

Thomas J.R. Pettersson Water Environment Technology, Chalmers University of Technology, Gothenburg, Sweden

William Alfonso Piña Faculty of Science Policy and Government, Urban development and management – Ekística – Universidad del Rosario, Bogotá, Colombia

Cindy Rianti Priadi Laboratoire des Sciences du Climat et de l'Environnement, UMR 8212, CEA-CNRS-UVSQ/IPSL, Gif-sur-Yvette, France

Environmental Engineering Study Program, Civil Engineering Department Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia

Sebastien Rauch Water Environment Technology, Department of Civil and Environmental Engineering, Chalmers University of Technology, 41296, Gothenburg, Sweden

Angela Reeve Queensland University of Technology (QUT), Brisbane, Australia

F. Reutimann BAFU, Bern, Switzerland

Steffen Rothardt Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Klaus Schäfer Institute of Meteorology and Climate Research—Atmospheric Environmental Research (IMKIFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

Nina J. Schleicher Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Karlsruhe, Germany

Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Stefanie Schrader Institute of Geography and Geoecology (IfGG), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Institute of Meteorology and Climate Research—Atmospheric Environmental Research (IMKIFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

Frank Schultmann Institute for Industrial Production (IIP)/French-German Institute for Environmental Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Julia Seimetz Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

M. Severijnen Province of Limburg, Maastricht, The Netherlands

Helena Siltberg Water Environment Technology, Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden

Lindis Skipperud Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Ås, Norway

Mellini Sloan Science and Engineering Faculty, School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia

Zbyněk Sokol Institute of Atmospheric Physics, AS CR, Czech Republic

Ekaterina Sokolova Water Environment Technology, Chalmers University of Technology, Gothenburg, Sweden

Juergen Spielvogel Palas® GmbH, Karlsruhe, Germany

Anna Starzewska-Sikorska IETU-Institute for Ecology of Industrial Areas, Katowice, Poland

Diana Agnete Stephansen Department of Civil Engineering, Aalborg University, Aalborg, Denmark

Harry Storch Department of Environmental Planning, Brandenburg University of Technology Cottbus, Cottbus, Germany

Peter Suppan Institute of Meteorology and Climate Research—Atmospheric Environmental Research (IMKIFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

Ion Tabacu University of Pitesti, Pitesti, Romania

Wael Ahmad Taha El-Garhy Environmental Studies and Researches Institute, Minofia University, Minofia, Egypt

Giuliana Carolina Talamini Departamento de Saúde Ambiental—Faculdade de Saúde Pública, Universidade de São Paulo, Brazil

Bolsista CAPES—Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Guiqian Tang Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), Beijing, P.R.China

Mari Thanstrøm Nyheim Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Ås, Norway

I Tikhonova Department of Industrial Ecology, Faculty of Biotechnology and Industrial Ecology, Mendeleev University of Chemical Technology of Russia, Moscow, Russian Federation 125047

Sabrina Tweraser Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Hedda Vikan Tunnel- and Concrete Section, Oslo, Norway

Franziska Villinger Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Heike Vogel Institute of Meteorology and Climate Research—Tropospheric Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Bernhard Vogel Institute of Meteorology and Climate Research—Tropospheric Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Jes Vollertsen Department of Civil Engineering, Aalborg University, Aalborg, Denmark

Guido Waldenmeyer Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Lijing Wang Chinese Research Academy of Environmental Sciences, No.8, Dayangfang, Beijing, China

Shulan Wang Chinese University of Geosciences, Beijing, China

Yuesi Wang Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), Beijing, P.R.China

Shulan Wang Institute of Urban and Regional Atmospheric Sciences, Chinese Research Academy of Environmental Sciences, Beijing, China

Christiane Weber Laboratoire Image, Ville et Environnement (LIVE) UMR 7362–CNRS, Faculté de Géographie et d'Aménagement, Strasbourg, France

Maximilian Weiss Palas® GmbH, Karlsruhe, Germany

Zhengyu Yang Faculty of Built Environment and Engineering, Queensland University of Technology, Queensland, Australia

Jay Yang Faculty of Built Environment and Engineering, Queensland University of Technology, Queensland, Australia

Susanne Ydstedt Scantech Strategy Advisors, Malmö, Sweden

Yang Yu Chinese Research Academy of Environmental Sciences, Beijing, China

Binghui Zheng Chinese Research Academy of Environmental Sciences, No.8, Dayangfang, Beijing, China

Part I
Urban Management and Spatial Planning

Overview of Material and Energy Flows in Water Infrastructures in Context of Urban Metabolism

Eve Menger-Krug, Jutta Niederste-Hollenberg and Thomas Hillenbrand

Abstract Urban water and wastewater infrastructures (UWIS) are an essential part of every city. They manage large flow streams of water, organic substances and nutrients from urban areas. Management of flow streams has a considerable energy demand, while there are large opportunities for energetic reuse of wastewater resources, which are not yet sufficiently exploited. Energetic reuse of wastewater resources can contribute to more sustainable urban energy systems. UWIS are also hot spots for emission of anthropogenic pollutants to the environment. On the way to a sustainable metabolism of cities, restructuring energy systems and reducing emission of anthropogenic pollutants are two important challenges. Both involve UWIS. This paper analyses material and energy flows in UWIS in Germany and explores their contribution to urban metabolism. We conclude by highlighting potential improvements by new technologies.

Background: Metabolism of Cities

Urban futures for a sustainable world is the title of the symposium. With increasing urbanization, a sustainable metabolism of cities is one important prerequisite for a sustainable world. It is the physical base of urban sustainability. The term was coined by Wolman [49] to describe the sum of material and energy flows in and out cities. The urban metabolism is an important feature of urban ecosystems or the astysphere [33]. Today, the flow streams are managed mainly in a linear way, characterized by large resource inputs, e.g. Energy, Water, Food, Products; and large outputs or emissions to the environment. The function depends on resource availability and capacity of (local to global) hinterland to absorb wastes/emissions. The following Fig. 1 shows an illustration of the urban metabolism. For increased sustainability, minimized resource input, maximized on site cycling and minimized emissions to the environment are important steps. Ultimately, the *sustainability* of resource input need to be maximized and the *negative effects* of emissions need to be minimized. The on site cycling should be organized to mirror natural ecosys-

E. Menger-Krug (✉) · J. Niederste-Hollenberg · T. Hillenbrand
Fraunhofer-Institut für System- und Innovationsforschung ISI,
Breslauer Straße 48, 76139, Karlsruhe, Deutschland
e-mail: Eve.Menger-Krug@isi.fraunhofer.de

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_1,

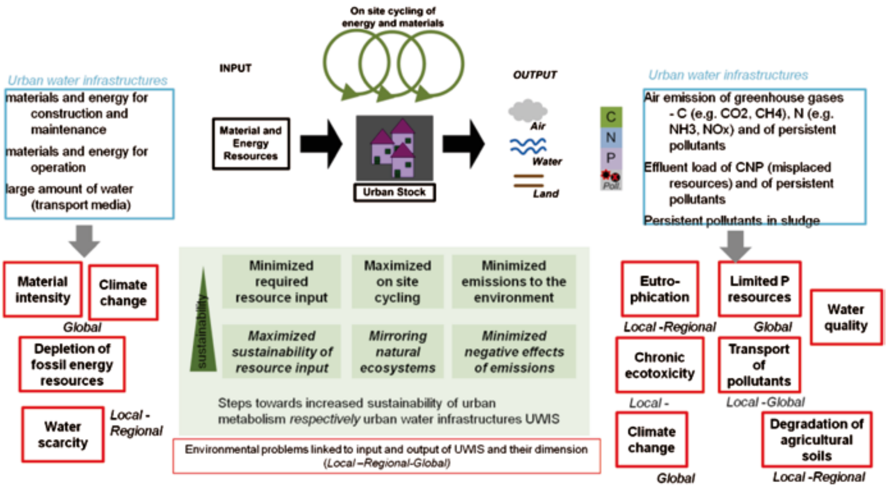


Fig. 1 Urban metabolism with input and output (emission) side, steps towards increased sustainability (*green*), input and output of urban water infrastructures (*blue*) and associated environmental problems (*red*)

tems, which use material and energy in cascades with the flow streams in balance with the surrounding ecosystems. But this is a long way ahead for present cities with their linear metabolism.

Metabolism of Urban Water and Wastewater Infrastructures (UWIS)

Urban water and wastewater infrastructures (UWIS) are an essential part of every cities metabolism. Their main function is to guarantee public health and safeguard water resources. But due to the resource consumption and the emission of UWIS, they are connected to many environmental problems (red boxes in Fig. 1). This includes energy related problems, such as the depletion of fossil energy resources and climate change, as well as water quality and quantity related problems, such as eutrophication and persistent pollutants.

Wastewater flow streams contain large amounts of "resources": Water, Carbon C, Nitrogen N and Phosphorus P. This provides an opportunity for water and nutrient recycling and energy harvesting (reuse of "internal" resources). Currently these opportunities are not fully exploited. There are large non recovered potentials.

Besides the resources, wastewater flow streams also contain a multitude of pollutants. The wastewater pollutant load is a mirror of society: it contains heavy metals and organic micropollutants, such as disinfecting and impregnating agents, flame retardants, pharmaceuticals. Some of them have persistent, bioaccumulative or toxic properties. They are not fully biodegradable with the current technical setup

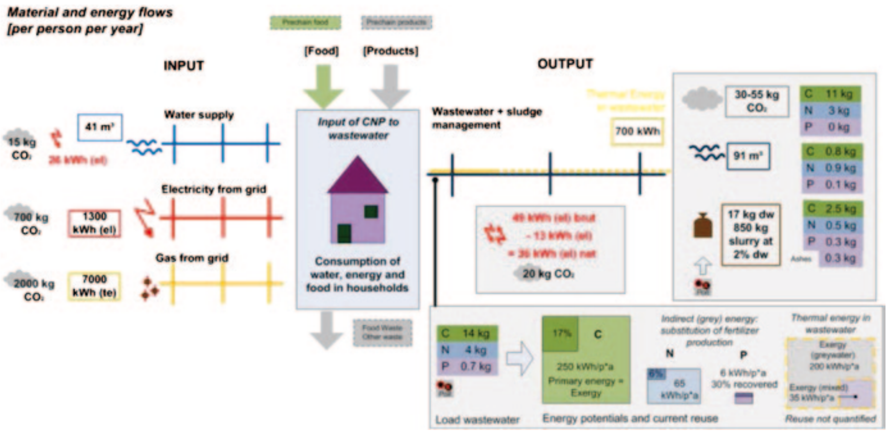


Fig. 2 Urban metabolism: household consumption of water, electricity and gas (thermal energy te) and associated CO2 emissions, energy demand for water treatment (input side); energy demand for wastewater and sludge treatment; material input to wastewater (CNP), energy potentials and current reuse; emission to the environment: generation of wastewater sludge and on site CO2 emissions

employed in wastewater treatment. They are transferred to the environment via effluent, air or stabilized sludge. These are important pathways for many pollutants. The presence of pollutants is a challenge for water and nutrient recycling. Wastewater is also an important pathway for antibiotic resistent pathogens.

On the way to a sustainable metabolism of cities, restructuring energy systems and reducing emission of anthropogenic pollutants are two important challenges. Both involve UWIS.

We now take a closer look at the energy balance of UWIS in context of urban metabolism. For a holistic picture of the current situation of the energy balance, we need to include: direct energy consumption and generation at the different stages of UWIS, as well as an estimate of the internal energy potentials of flow streams, and the proportion which is currently reused *resp.* not reused.

The following Fig. 2 shows the material and energy flows in UWIS in context of urban metabolism. The system boundaries include:

1. The extraction, treatment and distribution of drinking water and the associated energy consumption,
2. Energy use in households: electricity consumption and consumption of gas (thermal energy) for heating and for hot water preparation
3. The transport and treatment of wastewater and the use of biogas from anaerobic digestion, and the associated energy consumption and generation
4. The transport, processing and end use of stabilized sludge generated during wastewater treatment including sludge incineration, and the associated energy consumption and generation.

Extended Energy Balance of UWIS

The inventory and results of the energy balance and associated substance flow analysis is taken from earlier work of the authors [28]. Main data sources for the external energy balance are Haberkern et al. [14], Hansen et al. [15], Agis [1], Lingsten et al. [23], Olsson [34], ATT et al. [3], DWA [10, 11], Houillon et al. [19], UBA [47], MUNLV [31], Stillwell et al. [43], Hong et al. [18], Manara and Zabaniotou [26], for the quantification of TEP: Heidrich et al. [16], Shizas and Bagley [42], Svardal and Kroiss [45] and Olsson [34], Lal [21], Dockhorn [9], Maurer [27]. For the SFA: DWA [10, 11], Ekama [12], Henze et al. [17], Bischofsberger et al. [6], Bengtsson et al. [5], Rosso and Stenstrom [40].

The weighted average of net consumption on the level of UWIS is 62 kWhel/p*a and 7 kWhthermal/p*a. Current reuse covers 18 % of brut electricity demand and 84 % of brut demand for thermal energy. On a primary energy base, net consumption adds up to 189 kWh/p*a (including fuels for sludge transport).

To extend the usual approach to energy balances, we included the theoretical energy potentials (TEP) of resources in flow streams. We base our quantification of the TEP of carbon (C) on a study with bomb calorimeters using freeze dried samples [16]. With 14 kg C/p*a and the derived TEP factor, theoretical energy potential of C resources is 254 kWhprimary/p*a. With 35 % electrical efficiency, 89 kWhel/p*a can theoretically be generated from C resources in wastewater, covering current brut electricity consumption on the level of water and wastewater infrastructures.

Putting current reuse of C resources for electricity generation in relation to TEP gives an average reuse rate of 17 % for Germany. This means that 83 % of TEP of C resources in wastewater is not recovered.

Other than C resources, nutrients in wastewater cannot be used for generation of electricity and heat. But reuse on agricultural lands gains indirect energy credits by substitution of energy-intensive fertilizer production. Fertilizer production via Haber-Bosch requires 60 MJ/kg of N [9, 21]. For P, energy intensity for mining and processing is estimated at 29 MJ/kg P [27]. For N, there are no limitations in resource availability as N2 is abundant in the atmosphere. But P resources are limited and energy demand for processing is expected to rise, as good quality resources decline. For our model, we assume a TEP factor of nutrients of 60 kJ/g N and 29 kJ/g P. This represents the grey energy of nutrient provision.

With 4 kg N/p*a, TEP of N is 66 kWhprimary/p*a, which is lower by a factor of 4 than TEP of C. Again lower is TEP of P with 6 kWhprimary/p*a for 0.7 kg P/p*a. Current energetic reuse of N and P equals the load in sludge applied to agricultural land, taking into account average plant availability. Results of a substance flow analysis (SFA) shows that the weighted average of energy credits for fertilizer substitution is currently 6 % of TEP for N (4 kWh/p*a) and 30 % for P (1.7 kWh/p*a). Energy credits for reuse of N are more than twice as high as for P, despite the lower reuse rate. Fertilizer consumption in Germany is 19 kg N and 1.3 kg P per capita in average (on a elemental base, [8]). 20 % (N) resp. 58 % (P) of this amount can theoretically be supplied by nutrients in wastewater, underlining the importance of nutrient reuse.

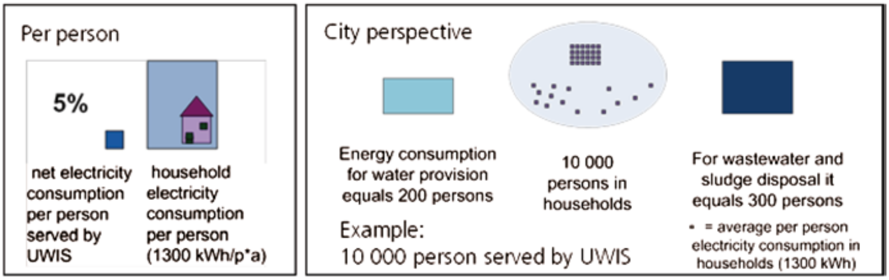


Fig. 3 Electricity demand for UWIS vs. household electricity demand on a per person base and seen from city perspective (10,000 person served as an example)

It is noteworthy, that the non recovered TEPs of CNP add up to 272 kWh/p*a on a primary energy base. This is considerably larger than the current net energy demand of infrastructures with 189 kWh/p*a. C resources in wastewater can theoretically supply enough electricity to cover demand of infrastructures, but currently only 17 % of the theoretical potential is used for electricity generation. By optimizing biogas use and incineration of sludge, reuse can be increased to 43 % of the theoretical potential. Further increase requires minimization of losses occurring during conventional aerobic wastewater treatment. Today, more than one third of C energy is lost at this treatment step. Energy balances of UWIS stand on two important pillars: energy efficiency—reducing external energy consumption; as well as resource productivity—maximizing energetic reuse of internal resources.

It can be seen in the figure above, that energy consumption in households is considerably larger than on the level of UWIS on a per person base. Hot water preparation and heating in households consumes approximately 7000 kWh/p*a [7]. Electricity use averages 1300 kWhel/p*a [41]. Therefore, electricity demand for UWIS equals only 5 % of household electricity demand.

Emission Balance of UWIS

On the output side, emissions to air, water and land need to be considered. Effluent load is mostly in focus of public and politics, as it is a prime goal of UWIS to protect water resources (receiving waters). The effluent load of CNP can cause eutrophication (misplaced resources).

Air emissions from UWIS are also gaining attention. Besides the emissions related to energy use (off site emissions) emissions of greenhouse gases from the flow streams can be considerable. For example, CO2 emissions originating from renewable C in the flow streams (42 kg/p*a) are larger than the off site (fossil) CO2 emissions from energy use of UWIS (35 kg/p*a). The on site CO2 emissions are renewable, as they mainly originate from food and cannot be avoided, as they are inherent components of the flow streams. But their magnitude underlines the importance of energetic reuse of the C resources in flow streams for a minimized CO2 intensity of bioelectricity generation at UWIS.

Other greenhouse gases may also be emitted from the flow streams, e.g. CH4, NH3 and NOx.

Besides the resources, wastewater can contain a multitude of pollutants, such as heavy metals and synthetic organic substances [13, 20, 50]. In general, most of the chemicals used everyday in modern society—flame retardants, plasticizers, disinfection and impregnation agents, pharmaceuticals, and many more—can be found in waste water or sewage sludge. Some of them have persistent, bio-accumulative or toxic properties. Due to their persistent nature, they are not biodegradable with the current technical setup of WWTPs and remain in large parts in effluent and/or sludge or are transferred to air e.g. as aerosols. These micro pollutants are a growing concern for WWTPs: a 4th treatment stage for effluent, as recently introduced in Switzerland, is discussed; sludge use on land has shown a decreasing trend in the last years in Germany due to concerns about soil contamination [47] and air emissions of persistent pollutants from UWIS are also gaining attention.

Energy Balance of UWIS in City Perspective

Even though electricity demand for UWIS equals only 5 % of household electricity demand, UWIS are still an attractive target for measures for improved energy balances, due to the following reasons. Firstly, there are large potentials for energetic resource reuse, as laid out above. Secondly, measures at facilities such as water and wastewater treatment plants, do not affect the users e.g. they require no change in user habits. Also, most companies in Germany are community owned allowing direct political influence. Thirdly, seen from the city perspective, facilities are large single consumers. As shown in the figure below, energy consumption is concentrated there, while households are distributed with different densities over the city area. Taking rather small facilities with 10,000 person served as an example, consumption equals 200 households on the water provision side and 300 households on the wastewater and sludge management side. For the same impact on urban energy balance as a 10 % reduction in external electricity consumption at the wastewater treatment plant, e.g. by increased biogas use, successful reduction measures in 300 households (each 10 %) are required. For larger facilities the value proportionally increases. Often, the wastewater treatment plant is the largest single electricity consumer in a particular city.

Eco Innovations in UWIS: Microalgae Systems for Bioenergy Production

Based on the analysis of the Status Quo of Energy and Emission Balances, we would like to outline a promising approach to improve energetic reuse of wastewater resources, while reducing the emissions of persistent pollutants: Integration of microalgae systems for bioenergy production at WWTPs. The idea of integrat-

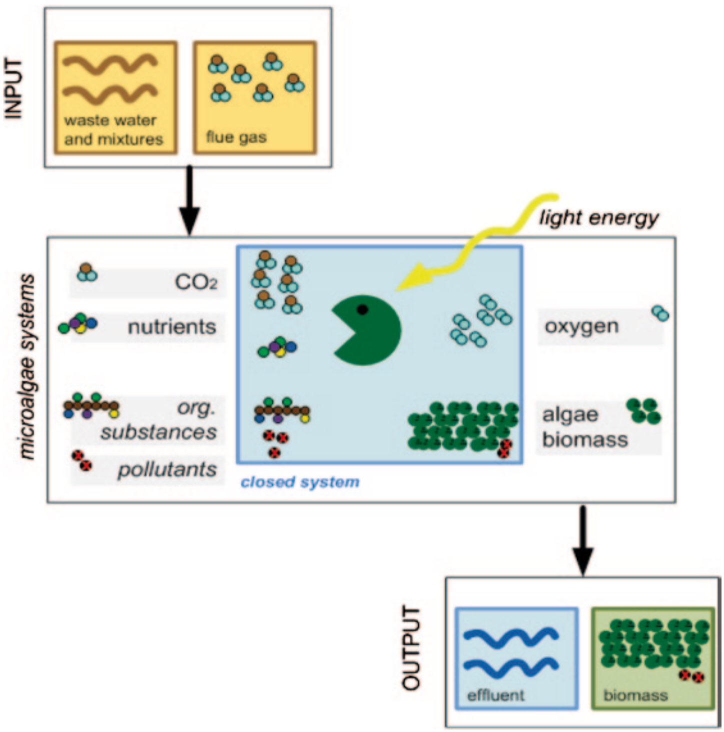


Fig. 4 Substance flows in microalgae systems for bioenergy production at WWTPs

ing microalgae systems and wastewater treatment dates back to the 1950s [35, 36] and offers many potential synergies. In theory, all resources required for algae growth are available at WWTPs (see figure). Wastewater provides a growth medium rich in macro and micro nutrients and CO_2 can be supplied from flue gas on site [24, 46] fig. 4.

Another synergy is the energy offset from (partial) wastewater treatment, as algae remove nutrients from wastewater during growth. Harvested biomass can be used energetically for production of biofuels, or for electricity generation via biogas or direct combustion. Despite these potential synergies, only a few pilot projects of microalgae systems running with wastewater have been described, mainly located in the US [24, 44] and New Zealand [37–39]. They confirm the technical feasibility of the concept.

In an earlier study [29], we proposed a process design for integration of microalgae systems and wastewater treatment, which relies solely on resources from wastewater for microalgae cultivation, with no external input of water, fertilizer or CO_2. Algae grow in flat basins (high rate algae ponds HRAP, [37–39] with CO_2 supply from biogas combustion. For nutrient provision, a mixture of process water (from sludge dewatering) and primary treated wastewater is fed to algae systems.

Harvested biomass is co-digested with sludge. The whole process chain, from cultivation to production of bioelectricity, takes place at the WTP [29].

Integration of microalgae systems considerably improves energy balance of WTPs. With full exploitation of the CO_2 available on site, enough bioelectricity is produced to run WTP energy-neutral during the vegetation season, or even to generate surplus bioelectricity. While effluent quality meets limit values, integration of microalgae systems increases loads of nutrients in effluent, mainly due to the contribution of non-harvested biomass. Important parameters for energy and emission balances are harvesting efficiency and anaerobic digestibility.

To recap, 20 % (N) *resp.* 58 % (P) of fertilizer consumption in Germany can theoretically be supplied by nutrients in wastewater, underlining the importance of nutrient reuse. But besides the resources wastewater can contain a multitude of persistent pollutants. With regard to these pollutants, algae systems offer considerable advantages: On the one hand side, algae systems can be designed in a way to minimize risk of emission of pollutants to the environment, while achieving the same areal productivities as (open) “conventional” bio energy systems (e.g. corn or canola). Microalgae grow in (semi-)closed systems (ponds) and nutrients from wastewater can thus be reused in a safe way. The problem of groundwater pollution and eutrophication, which often accompanies intensive “conventional” bio energy systems, is abolished with algae systems.

On the other hand side, algae systems have the potential to reduce loads of heavy metals and organic micro pollutants in effluent. Processes such as bio-oxidation, bio-sorption or assimilation can remove heavy metals [25] and other persistent organic pollutants [34], supported by a long hydraulic retention time of 4–6 days in aerated environment. Eliminated micro pollutants from wastewater are degraded or transferred to algae biomass *resp.* sludge, making it unsuitable for non-energetic reuse such as animal feed or soil conditioner. Potential to eliminate micro pollutants is well described for laboratory studies, but remains to be proven in pilot projects. If proven in practice, algae systems could provide a cost and energy efficient option to reduce loads of micro pollutants in effluent, while producing energy. This would provide a strong additional incentive for WWTPs to integrate algae systems

Integration of algae systems is interesting for WWTPs striving for improved energy balances, with land resources available in the surroundings. As algae have higher areal energy yields than other energy crops, the area for production of a specific amount of bio-energy can be expected to be smaller [48]. Free digester capacities are available at many WWTPs in Germany, due to safety reserves, and faster digestion in summer. Demographic change with decreasing population, especially in rural areas, contributes to free capacities. Co-digestion of algae biomass to increases biogas production can also move down the threshold for economic feasibility of anaerobic sludge stabilization, allowing smaller plants to switch to anaerobic sludge stabilization.

Conclusion

Energetic reuse of wastewater resources can contribute to more sustainable urban energy systems. Wastewater infrastructures are also hot spots for emission of anthropogenic pollutants to the environment. Integration of algae systems, as laid out above can improve both: the energy balance and the emission balance regarding anthropogenic pollutants.

Besides the energy aspects in focus of the present study, (waste)water infrastructures can contribute much more to a sustainable society. The vision underlying our research is, that eco-innovation in UWIS can contribute to:

1. New sustainable energy systems based on renewables, smart grids and energy efficiency
2. A CO2 neutral and resource efficient society
3. A tox-free society with minimized emission to environment

References

1. Agis H (2001) Detailuntersuchung von 21 Anlagen: Energieoptimierung von Kläranlagen. (Detail analysis of energy demand of 21 WWTPs in Austria). Bundesministerium für Land- u. Forstwirtschaft, Umwelt u. Wasserwirtschaft (Environmental Ministry Austria) http://www.publicconsulting.at/uploads/energieoptimierung_von_klranlagen.pdf. Accessed on 2012-09–02
2. Ahrens L, Shoeib M, Harner T, Lee SC, Guo R, Reiner EJ.Wastewater treatment plant and landfills as sources of polyfluoroalkyl compounds to the atmosphere. Environ Sci Technol. 2011 Oct 1; 45(19):8098-105. Epub 2011 Apr 5.
3. ATT et al. (eds.) (2011) Profile of the German Water Sector. Association of Drinking Water from Reservoirs (ATT), German Association of Energy and Water Industries (BDEW), German Alliance of Water Management Associations (DBVW), German Technical and Scientific Association for Gas and Water (DVGW), German Association for Water, Wastewater and Waste (DWA), German Association of Local Utilities (VKU), http://www.dvgw.de/fileadmin/dvgw/wasser/organisation/branchenbild2011_en.pdf. Accessed on 2012-09–02
4. Behrendt H, Bach M, Opitz D, Pagenkopf WG, Scholz G, Wendland F (2003) Internationale Harmonisierung der Quantifizierung von Nährstoffeinträgen aus diffusen und punktuellen Quellen in die Oberflächengewässer Deutschlands. UBA-Texte Nr. 82/2003. Umweltbundesamt, Dessau
5. Bengtsson M, Lundin M, Molander S (1997) Life cycle assessment of wastewa-ter systems-case studies of conventional treatment, urine sorting and liquid composting in three Swedish municipalities. Report 1997: 9, Technical Environmental Planning, Chalmers University of Technology, Göteborg, Sweden, 1997
6. Bischofsberger W, Dichtl N, Rosenwinkel KH, Seyfried CF, Böhnke B (2005) Anaerobtechnik. Springer Verlag, Berlin, ISBN 978-3-540-06850–06851
7. Destatis (2008) Energieverbrauch der privaten Haushalte 1995 bis 2006. (Energy consumption of private households) Wiesbaden: Statistisches Bundesamt. (Federal Statistical Office) https://www.destatis.de/DE/Publikationen/WirtschaftStatistik/Umwelt/Energieverbrauch-Haushalte2006.pdf?__blob=publicationFile. Accessed on 2012-09–02

8. Destatis (2012) Düngemittelversorgung (Fertilizer supply), Fachserie 4 Reihe 8.2- Wirtschaftsjahr, 2010/2011 Statistisches Bundesamt (Federal Statistical Office), https://www.destatis.de/DE/Publikationen/Thematisch/IndustrieVerarbeitendesGewer-be/Fachstatistik/Duengemittelversorgung J2040820117004.pdf?__blob=publicationFile. (accessed on 2012-09–02)
9. Dockhorn T (2008) Über die Relevanz der Nährstoffe Stickstoff und Phosphat im Abwasser-eine Bilanz für Deutschland (On the relevance of the nutrients nitrogen and phosphate in wastewater-A mass balance for Germany). Müll und Abfall 2008 9, pp. 444–449
10. DWA (ed.) (2007) Schlammbehandlung, -verwertung und -beseitigung (Management of sewage sludge: treatment, reuse and disposal). WasserWirtschafts-Kurse M/4. Oktober 2007 in Kassel, German Association for Water, Wastewater and Waste, ISBN: 978-3-940173-33
11. DWA (ed.) (2011) Leistungsvergleich kommunaler Kläranlagen (Benchmarking of municipal WTPs) (German Association for Water, Wastewater and Waste)
12. Ekama GA (2009) Using bioprocess stoichiometry to build a plant-wide mass balance based steady-state WWTP model. Water Res 2009 May; 43(8):2101–2120
13. Gray SR, Becker NSC (2002) Contaminant flows in urban residential water systems. Urban Water 4:331
14. Haberkern B MW, Schneider U (2008) Steigerung der Energieeffizienz auf kommunalen Kläranlagen. (Improvement of energy efficiency at wastewater treatment plants), German Environmental Agency, ISSN 1862–4804
15. Hansen J, Wu K, Kolisch G, Hobus I, Schirmer G (2007) Ökoeffizienz in der Wasserwirtschaft-Steigerung der Energieeffizienz von Abwasseranlagen. Ministerium für Umwelt, Forsten und Verbraucherschutz Rheinland-Pfalz, Mainz
16. Heidrich ES CTP, Dolfing J (2011) Determination of the Internal Chemical Energy of Wastewater, Environ. Sci Technol 2011, 45(2):827–832. DOI: 10.1021/es103058w
17. Henze M GW, Mino T, MCM vanL (2000) Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. IWA Scientific and Techni-cal Report No.9, IWA Publishing, London
18. Hong J HJ, Otaki M, Jolliet O (2008) Environmental and economic life cycle assessment for sewage sludge treatment processes in Japan Waste Management 29 (2009) 696–703 doi:10.1016/j.wasman.2008.03.026
19. Houillon G, Jolliet O (2005) Life cycle assessment of processes for the treatment of wastewater urban sludge: energy and global warming analysis. Journal of Cleaner Production 13:287–299
20. Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT (2002) Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: a national reconnaissance. Environ Sci Technol 2002, 36(6):1202–1211
21. Lal R (2004) Carbon emissions from farm operations. Environ Int 30(2004):981–990
22. Lazarova V CK-H, P C (eds.) (2012) Water-Energy Interactions in Water Reuse. IWA Publishing, ISBN: 9781843395416
23. Lingsten A LM, Hellström D, Balmer P (2008) Description of the current energy use in Sweden (in Swedish). Swedish Water and Wastewater Association SWWA, http://vav.griffel.net/db.pl?template_file=db_link_pdf.html & link=a & pdf=Rapport_2011-04.pdf (accessed on 2012-09–02)
24. Lundquist TJ WIC, Quinn NWT, Benemann JR (2012) A Realistic Technology and Engineering Assesment of Algae Biofuel Production. California Polytechnic State University: San Luis Obispo, 2010; p 178. http://digitalcommons.calpoly.edu/cenv_fac/188/
25. Mallick N (2002) Biotechnological potential of immobilized algae for wastewater N, P and metal removal: a review. BioMetals 2002, 15 pp. 377-390; DOI:10.1023/A:1020238520948
26. Manara P, Zabaniotou A (2012) Towards sewage sludge based biofuels via thermochemical conversion. Renewable and Sustainable Energy Reviews, 2012, vol. 16, issue 5, pages 2566–2582
27. Maurer M SP, Larsen TA (2003) Nutrients in urine: energetic aspects of removal and recovery. Water Science and Technology, Vol 48, No. 1, S. 37-46 (IWA Publishing)

28. Menger-Krug E Niederste-HollenbergJ, Hillenbrand T (2012a) Extended Energy Balance of the Urban Water Chain in Germany. Submitted to Ecological Engineering September 4th 2012
29. Menger-Krug E Niederste-HollenbergJ, Hillenbrand T, Hiessl H (2012b) Integration of Microalgae Systems at Municipal Wastewater Treatment Plants: Implications for Energy and Emission Balances. Environmental Sciences and Technology, Publication Date (Web): October 10, 2012; DOI: 10.1021/es301967y
30. Müller EA SF, Stodtmeister W, Kobel B (2009) Heizen und Kühlen mit Abwasser-Ratgeber für Bauträger und Kommunen-Energierückgewinnung aus häuslichem und kommunalem Abwasser, Osnabrück: Deutsche Bundesstiftung Umwelt
31. MUNLV (2001) Abfälle aus Kläranlagen in Nordrhein-Westfalen. Bericht zur Umwelt. (Sludge from wastewater treatment in Northrhine-Westfalia, Germany). Ministerium für Umwelt und Naturschutz. Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen. (Ministry for the Environment Northrhine-Westfalia, Germany) Bereich Abfall, Band 5, Düsseldorf, Mai 2001
32. Munoz R, Guieysse B (2006) Algal-bacterial processes for the treatment of hazardous contaminants: a review. Water Res. 2006, 40 pp. 2799-2815,; DOI:10.1016/j.watres.2006.06.011
33. Norra S (2009) Environ Sci Pollut Res Int 16(5):539-45 (2009)
34. Olsson G (ed.) (2012) Water and Energy: Threats and Opportunities. IWA Publishing, ISBN: 9781780400266
35. Oswald WJ, Golueke CG (1960) Biological transformation of solar energy. Advances in Applied Microbiology 1960, 11 pp. 223-242, DOI:10.1016/S0065-2164(08)70127-8
36. Oswald WJ GO, Lynch L (1953) Algae Symbiosis in Oxidation Ponds. Growth Characteristics of Chlorella pyrenoidosa Cultured in Sewage, 1953, reprinted in Sewage and Industrial Wastes 25:1
37. Park JBK, Craggs RJ (2010) Wastewater treatment and algal production in high rate algal ponds with carbon dioxide addition. Water Science and Technology 2010 61, pp. 633-639 DOI:10.1016/j.biortech.2010.06.158
38. Park JBK, Craggs RJ (2011) Algal production in wastewater treatment high rate algal ponds for potential biofuel use. Water Science & Technology 2011, 63 (10), pp. 2403–2410 DOI: 10.2166/wst.2011.200
39. Park JBK, Craggs RJ (2011) Nutrient removal in wastewater treatment high rate algal poinds with carbon dioxide addition. Water Science & Technology 2011, 63 (8), pp. 1758–1764 DOI: 10.2166/wst.2011.114
40. Rosso D, Stenstrom MK (2008) The carbon-sequestration potential of municipal wastewater treatment, Chemosphere 2008, Volume 70, Issue 8, doi:10.1016/j.chemosphere.2007.08.057
41. Schmidt et al. (2011) Erstellung der Anwendungsbilanz 2008 für den Sektor Private Haushalte. Endbericht Februar 2011. Forschungsprojekt der Arbeitsgemeinschaft Energiebilanzen, Berlin. Rheinisch-Westfälisches Institut für Wirtschaftsforschung. http://www.ag-energiebilanzen.de/componenten/download.php?filedata=1302262886.pdf & filename=RWI_Einzelbericht_Anwendungsbilanz_Haushalte.pdf & mimetype=application/pdf
42. Shizas I, Bagley DM (2004) Experimental determination of energy content of unknown organics in municipal wastewater streams. In: Journal of Energy Engineering-Asce, 130 (2), S. 45–53
43. Stillwell AS HDC, Webber ME (2010) Energy Recovery from Wastewater Treatment Plants in the United States: A Case Study of the Energy-Water Nexus. Sustainability 2010, 2(4), 945–962; doi: 10.3390/su2040945
44. Sturm BSM, Lamer SL (2011) An energy evalua-tion of coupling nutrient removal from wastewa-ter with algal biomass production. Applied En-ergy 2011, 88 (10), pp. 3499–3506. DOI: 10.1016/j.apenergy.2010.12.056
45. Svardal andK (2011) Energy requirements for wastewater treatment. Water Sci Technol 64(6):1355–1361
46. U. S. Department of Energy (2010) National Algal Biofuels Technology Roadmap. (05-2010) http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf

47. UBA (ed.) (2012) Klärschlammentsorgung in der Bundesrepublik Deutschland (sewage sludge disposal in Germany). Umweltbundesamt (Federal Environmental Agency), http://www.umweltdaten.de/publikationen/fpdf-l/4280.pdf (accessed on 2012-09-02)
48. Wijffels RH, Barbosa MJ (2010) An Outlook on Microalgal Biofuels. Science 13 August 2010 329 no(5993):796–799. DOI: 10.1126/science.1189003
49. Wolman A (1965) The metabolism of cities. Sci Am 213(3):178–193
50. Zimmerman JB MJR, Smith J (2008) Global stressors on water quality and quantity. Environ Sci Technol 2008, 42(12):4247–4254

Improvement of the Statutory Framework for Construction and Demolition Waste Management exemplified in Germany and Australia

Mei Li, Anna Kühlen, Jay Yang and Frank Schultmann

Abstract Construction and demolition (C&D) waste occupies the largest share of overall waste generation in many countries. However, waste management practices and outcomes may differ between countries. For instance, in Australia, C&D waste recovery is continuously improving during the last years but the amount of C&D waste increases every year, as there has been little improvement in waste avoidance and minimization. In contrast, in Germany, waste generation remains constant over many years despite the continuous economic growth. The waste recycling rate in Germany is one of the highest in the world. However, most waste recycled is from demolition work rather than from waste generated during new construction. In addition, specific laws need to be developed to further reduce landfill of non-recycled waste. Despite of the differences, C&D waste generation and recovery in both countries depend on the effectiveness of the statutory framework, which regulates their waste management practices. This is an issue in other parts of the world as well. Therefore countries can learn from each other to improve their current statutory framework for C&D waste management. By taking Germany and Australia as an example, possible measures to improve current practices of C&D waste management through better statutory tools are identified in this paper. After providing an overview of the statutory framework of both countries and their status in waste generation and recovery, a SWOT analysis is conducted to identify strengths, weaknesses, opportunities and threats of the statutory tools. Recommendations to improve the current statutory frameworks, in order to achieve less waste generation and more waste recovery in the construction industry are provided for the German and Australian government and they can also be transferred to other countries.

M. Li (✉) · J. Yang
Queensland University of Technology, Brisbane, Australia
e-mail: m14.li@student.qut.edu.au

A. Kühlen · F. Schultmann
Institute for Industrial Production (IIP)/French-German Institute for Environmental Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
e-mail: anna.kuehlen@kit.edu

J. Yang
e-mail: j.yang@qut.edu.au

F. Schultmann
e-mail: frank.schultmann@kit.edu

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_2,

Introduction

Construction and demolition (C&D) waste is a worldwide issue due to the rapid growth of towns and cities, and a significant number of illegal dumps [10]. It occupies the largest share of overall waste generation in many countries with their economic growth. The need and importance of C&D waste management and minimization is being recognized around the world. However, the practices and outcomes related to this are different between countries. For example, in Australia, most of the C&D waste (58 %) was recycled [5]. Despite the progress in waste recycling, there has been little improvement in waste avoidance, as the amount of waste continues growing every year [4, 5]. Compared to Australia, the total volume of C&D waste in Germany has remained constant over many years given the steadily growing economy [6]. The waste recovery rate in Germany is one of the highest in the world [3, 6] However, most waste recycled in Germany is from demolition work without much recovery from new construction waste. In addition, specific laws have yet to be developed to further reduce landfill of non-recycled waste.

The practices of waste management and minimization and situations of waste generation and recovery in Australia and Germany are regulated by their statutory framework of the government [13]. This is a common situation in other countries as well. There is the opportunity for different countries to learn from each other about experience and practice of the implementation of statutory tools for waste management.

The research presented in this paper intends to seek solutions to promote waste management and minimization practices through improved statutory framework. Take Germany and Australia as an example, it first provides an overview of the statutory frameworks in Germany and Australia and describes the status of waste generation and recovery in both countries. Then a SWOT analysis is performed to identify strengths, weaknesses, opportunities and threats of the statutory tools, before recommendations are proposed for both German and Australian governments to improve current statutory tools in order to result in more effective waste management and better outcomes of waste avoidance, minimization and recovery.

Statistics and Statutory Framework for C&D Waste Management in Germany

C&D Waste Generation and Recovery in Germany

C&D waste in Germany mainly consists of excavated earth, construction and demolition debris, road construction waste, gypsum-based construction material and construction waste. Table 1 shows the composition of C&D waste and the status of recycling in 2004. It can be noted that most of the waste recycling took place in demolition waste and road scarification and only little in waste generated by new constructions and through excavation.

Table 1 C&D Waste Composition and Recycling in Germany, 2004 [12]

Waste type	Total C&D waste production		Amount of waste recycled
	Million tons	%	Million tons
Demolition waste	50.5	25.2 %	31.1
Road scarification	19.7	9.8 %	18.4
Construction waste	1.9	0.9 %	0.1
Cement	0.3	0.2 %	–
Total (without excavation)	72.4	36.1 %	49.6
Waste from excavation	128.3	63.9 %	9.1
Total	200.7	100 %	58.7

Table 2 C&D Waste Balance 2008 in Germany [7]

		C&D waste [million tons]	Hazardous waste [million tons]	Non-hazardous waste [million tons]
Total		200.52	8.49	192.03
Disposal		24.02	3.71	20.31
Of which	Landfill	22.58	2.67	19.91
	Incineration	0.15	0.05	0.1
	Treatment for disposal	1.29	0.99	0.3
Recovery		176.49	4.78	171.72
Of which	Energy recovery	0.82	0.2	0.62
	Treatment for recovery	175.67	4.58	171.09
Recovery rate %		88	56	89

Regarding the general situation of C&D waste treatment in Germany in 2008 as shown in Table 2, most of the recovered waste was dealt with by "treatment for recovery", which largely avoided high energy consumption in energy recovery. For disposal, most of the waste went to landfill, followed by the "treatment for disposal". Only a small part of the waste was incinerated.

Statutory Tools

In Germany, the statutory tools for waste management are reviewed and the key information of them is presented in Table 3.

Statistics and Statutory Framework for C&D Waste Management in Australia

C&D Waste Generation and Recovery in Australia

In Australia, the largest components of the C&D waste stream and the most commonly recycled materials in Australia are concrete, bricks, asphalt, soil, timber and

Table 3 Statutory Tools for C&D Waste Management in Germany

	Statutory tool	Key information
Legislation and policies	EU Waste Strategy and Waste Framework Directive	Waste prevention Waste handling and hazardous waste management
	Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal	Closed loop recycling Responsibilities of waste producers
	The Law for the Prevention and Disposal of Waste	Transition from disposal to waste management Improvement of waste composition to permit reuse and recycling
	Commercial Wastes Ordinance	Safe and high quality waste recovery Residual waste container for waste disposal
Strategy and guidelines	Strategy for the future of disposal of waste from human settlements	Municipal waste recovery Minimization of landfill
	The Certification of the German Sustainable Building Council	Sustainable building and construction Waste minimization
	Guideline for Sustainable Construction	Sustainable construction throughout the building life cycle Minimization of the use of energy and resources Use of renewable and recoverable materials
Technical instructions	Technical Instruction for Municipal Waste	Treatment and disposal of waste streams Recycling of unavoidable waste Reduction of toxic waste Environmental-friendly waste treatment
	DIN Standards	Regulation of construction and deconstruction work Construction work standards General and contracting construction issues Handling of deconstruction materials
	European Waste Catalogue and Hazardous Waste List	A hierarchical list of waste descriptions A consistent waste classification system
Voluntary commitment	Consortium of recycling management in construction	Until 2011 there had been a consortium of construction industry stakeholders to reduce landfilled construction waste within 10 years by 50%. But at the moment there is no voluntary commitment of construction industry stakeholders

Table 4 C&D Waste Landfilled in NSW Australia, 2006–07 [8]

Waste Materials	Landfill by weight
Paper and cardboard	2 %
Plastic	2 %
Ferrous metals	3 %
Garden organics	4 %
Timber	13 %
Soil and rubble	25 %
Concrete, asphalt, brick and sand	31 %
Other	20 %
Total	100 %

Table 5. Recycling Rates for C&D Waste by Jurisdiction, 2006–07 [5]

Jurisdiction	Recycling Rate
NSW	67 %
VIC	72 %
QLD	30 %
WA	17 %
SA	79 %
ACT	91 %
TAS	Unknown
NT	Unknown

ferrous metals, because they are usually demolished in large quantities and have an existing market for reuse and recycling (e.g. concrete, bricks and asphalt), or they have a relatively high commercial value (e.g. metals) [5]. There is no consolidated data available at the national level about the specific compositions of C&D waste, which is land filled or recovered in Australia, because there are different waste categories used in each jurisdiction. Take New South Wales for example, the largest C&D waste components by weight land filled from 2006 to 2007 were concrete, asphalt, bricks and sand (31 %), soil and rubble (25 %), and timber (13 %), as shown in Table 4.

Although the recovery of C&D waste in Australia has improved significantly in recent years, it varies in different jurisdictions because of the different waste management laws and enforcement. Data in some jurisdictions is even unavailable. The waste recycling rates from 2006 to 2007 achieved by each jurisdiction are shown in Table 5.

Statutory Tools

Information related to the Australian statutory tools for C&D waste management is summarized in Table 6.

Table 6 Statutory Tools for C&D Waste Management in Australia

	Statutory tool	Key information
Legislation and policies	National Waste Policy: Less Waste, More Resources	Resource recovery and waste management Reduction of waste disposal
	National Environment Protection Measures	National objectives to protect the environment Several mandatory national regulations
	The Product Stewardship Bill 2011 (Product Stewardship Act 2011)	A national framework to manage the environmental, health and safety impacts of products Regulated and voluntary activities
Strategy and guidelines	National Strategy for Ecologically Sustainable Development	An integrated approach for waste prevention and minimization Improvement of resource usage and reduction of the impact of waste disposal Avoidance and handling of hazardous waste
	Carbon Pollution Reduction Scheme (CPRS)	Main driver to reduce greenhouse gas emissions Reduction of greenhouse gas emissions through reduction of waste landfill and increased waste recycling
Technical instructions	Green Star Certified Ratings	Reduction of the environmental impact of buildings Achievement of waste recycling, occupant health and productivity, and cost savings Innovation in sustainable building practices
Voluntary commitment	Australian Packaging Covenant	Reduction of the environmental impacts of consumer packaging Avoidance, minimization, reuse and recycling of packaging waste
	Sustainable Packaging Guidelines	Optimization of consumer packaging for efficient resource usage and environmental impact reduction Design, manufacture and end-of-life management of sustainable packaging

SWOT Analysis

SWOT analysis is applied in this research to compare the statutory tools of waste management in Germany and Australia. SWOT is an acronym for strengths, weaknesses, opportunities and threats [11]. SWOT analysis was popularized by [1] It is used to develop four types of strategies, namely SO (strengths-opportunities) strategies, WO (weaknesses-opportunities) strategies, ST (strengths-threats) strategies, and WT (weaknesses-threats) strategies [2, 9].

Through SWOT analysis, the strengths, weaknesses, opportunities and threats of the statutory tools of both Germany and Australia are identified, as shown in Table 7. Strategies indicated by SO, WO, ST, WT are also established and explained in the table.

Table 7 SWOT Analysis of the Statutory Framework for C&D Waste Management in Germany

Germany			
		Strengths (S)	Weaknesses (W)
		Waste prevention and minimization is top of the preference. Most statutory tools include C&D waste section or target on C&D waste. Sustainable construction in the national scope to strengthen understanding and standardise actions in achieving waste minimization. Standard waste classification according to EU waste catalogue. Technical instructions for real practice of waste management	Lack of specific regulatory support for waste minimization from suppliers' packaging on construction site. No voluntary commitments
Opportunities (O)	Increase recycling of (new) construction waste and excavation waste	*SO* Specific regulations and support on increasing construction waste recycling on new construction sites and of excavation waste	*WO* Regulations on minimising packaging. Commitment of the stakeholders of the construction industry with set, high quality targets for waste recycling and reuse
Threats (T)	Most of the disposed waste goes to landfill	*ST* Policies to reduce landfill New technologies of waste disposal to minimise the impact on the environment	*WT* Encourage packaging reuse and new technologies on packaging New technologies of waste degradation Commitment of the stakeholders to prevent landfill and increase recycling of excavation waste

Recommendations

Based on the findings from the SWOT analysis, recommendations are provided for both countries to improve their government regulations to encourage better waste management practices in the construction industry.

Recommendations for Germany

Recommendations drawn from the SWOT analysis for the improvement of German statutory tools for C&D waste management are listed in Table 9.

Table 8 SWOT Analysis of the Statutory Framework for C&D Waste Management in Australia

Australia			
		S	W
		Waste prevention and minimization is top of the preference. Focus on collaborations of stakeholders in achieving waste management targets. Waste minimization and management is nested in broader concepts of resource efficiency, carbon pollution reduction and ecological sustainable development. Specific regulations and guidelines for products and materials packaging from manufacturing industry to assist waste minimization on construction site	Most statutory tools address general waste management rather than C&D waste specifically. No standard classification of waste categories at national level. Lack of technical instructions for C&D waste management in real practice
O	Establish market of recycled materials	*SO* Guidelines for the establishment of recycled materials market Financial support from the government to encourage the use of recycled materials and components	*WO* Technical instructions for construction waste handling, management, transportation, reuse, recycling and sale Develop standards for different recycled materials
T	No consolidated data at the national level Different development of construction industry and waste recycling in different jurisdictions	*ST* Collaboration of different jurisdictions in waste minimization and recycling Develop national waste database to encourage comparison with other countries for improvement	*WT* Develop standard and uniform waste classification system at national level Establish and improve the current statutory tools to address problems related to C&D waste

Recommendations for Australia

Recommendations drawn from the SWOT analysis for the improvement of Australian statutory tools for C&D waste management are listed in Table 10.

Conclusions

C&D waste minimization is an important contributor to the goal of achieving sustainability of the construction industry. In order to regulate C&D waste management practices, governments around the world have established statutory tools to

Table 9 Recommendations for the improvement of statutory tools for C&D waste management in Germany

Statutory tool	Specific issue	Issue description
Financial support for	Newly-construction waste recycling	The government needs to provide financial support to the client and waste management companies to increase waste recovery from newly construction processes
	The development of innovations on waste reduction	The government needs to provide financial support to the construction industry, construction material manufactures and research associations for technological innovations on waste reduction, for instance innovation in material packaging and waste recovery, and alternative options for waste disposal
Legislations for	Reducing waste landfill and reduction of down-cycling	The German government needs to establish relevant legislations for the reduction of waste landfill and material down-cycling, for instance by checking construction waste on site and respective payments
	Waste minimization by manufacturers	It is necessary for the German government to establish material design standard and product stewardship, and develop regulations and policies for manufacturers to recover packaging
Voluntary commitment for	The high quality construction waste recycling and reuse and prevention of landfill	In the past the consortium "Kreislaufwirtschaftsträger Bau (KWTB)" of construction industry stakeholders existed, which made a voluntary commitment with the government to reduce landfilled construction waste (excluding excavation waste) within 10 years by 50 %. A similar voluntary commitment of the industry stakeholders including excavation waste and preventing landfill should be established again

reduce waste generation and encourage waste recovery. The effectiveness of these statutory frameworks has resulted in different waste management status in different countries. Therefore countries can learn from each other about good experience in developing waste management regulations and practices in waste minimization and recovery.

This paper discusses the comparison of different statutory frameworks for C&D waste management by taking Germany and Australia as an example. It firstly outlines the current statutory tools for C&D waste management in both countries and presents their situations of C&D waste generation and recovery. A SWOT analysis is conducted to identify their strengths, weaknesses, opportunities and threats with relevant strategies for improvement. Finally the recommendations are provided for Germany and Australia to improve their statutory frameworks and promote their industry practices of waste minimization and recovery. The recommendations for Germany include financial support for newly-construction waste recycling, legislations

Table 10 Recommendations for the improvement of statutory tools for C&D waste management in Australia

Statutory tool	Specific issue	Issue description
Financial support for	Waste recovery	Government needs to set up financial incentive programs to encourage waste recovery, and to maintain and develop the recycled material market to drive more waste recovery in the industry
Legislations for	C&D waste specific issues	Legislations for C&D waste need to be established for waste minimization throughout the project life cycle by the coordination and collaboration among all the project stakeholders
Technical instructions for	Overall C&D waste management	Technical instructions and guidance on C&D waste handling and hazardous waste management need to be established and reviewed and revised regularly
National system for	Waste classification	Standard and uniform waste classification system needs to be developed at the national level, in order to facilitate data exchange, comparison and benchmarking
	Waste data tracking	A national waste data tracking system should also be established to collect and store a comprehensive range of data on waste generation, disposal to landfill and resource recovery
National guidelines for	Sustainable construction	National guidelines to promote nationally waste minimization and recovery throughout the whole building life cycle

for reducing waste landfill, legislations for waste minimization by manufacturers, and incentive measures for technological innovation of packaging minimization and recovery. For Australia, recommendations are provided including waste legislations specific to C&D waste, technical instructions for C&D waste management, national waste classification system, national waste data tracking system, guidelines for sustainable construction, and financial incentives for waste recovery.

The result of this research will provide a valuable reference for both German and Australian government to improve their current statutory frameworks for C&D waste management. It is also applicable to other countries to review and update their regulatory tools for C&D waste management.

References

1. Andrews KR (1965) The concept of corporate strategy. Dow Jones-Irwin, Homewood
2. Babaesmailli M, Arbabshirani B, Golmah V (2012) Integrating analytical network process and fuzzy logic to prioritize the strategies-A case study for tile manufacturing firm. Expert Systems with Applications
3. European Commission (2010) Being wise with waste: the EU's approach to waste management
4. EPHC (2009) National Waste Overview In: E. P. A. H. Council (ed)

5. EPHC (2010) National Waste Report. Department of the Environment, Water, Heritage and the Arts
6. Federal Ministery for the Environment, N. C. A. N. S. (2011) Waste management in Germany 2011
7. Federal Statistical Office (2010) Waste Balance 2008
8. NSW Department of Environment, C. A. C. C. (2007) Report into the construction and demolition waste stream audit 2000–2005
9. Sevkli M, Oztekin A, Uysal O, Torlak GK, Turkyilmaz A, Delen D (2012) Development of a fuzzy ANP based SWOT analysis for the airline industry in Turkey. Expert Syst Appl 39:14–24
10. Solís-Guzmán J, Marrero M, Montes-Delgado MV, Ramírez-de-Arellano A (2009) A Spanish model for quantification and management of construction waste. Waste Manage 29:2542–2548
11. Skrivastava PK, Kulshreshtha K, Mohanty CS, Pushpanadang P, Singh A (2005) Stakeholder-based SWOT analysis for successful municipal solid waste management in Lucknow, India. Waste Manage 25:531–537
12. Sunke N, Schultmann F (2008) Waste management in Germany. In:CIB Report Construction materials stewardship in selected countries
13. Weisleder S, Nasseri D (2006) Construction and demolition waste management in Germany

Carrying Capacity Dashboard Analyses—Australian Case Studies of Populations Scaled to Place

Murray Lane and Les Dawes

Abstract In a globalised world, it makes sense to examine our demands on the landscape through the wide-angle lens of ecological footprint analysis. However, the important impetus towards a more localised societal system suggests a review of this approach and a return to its origins in carrying capacity assessment. The determination of whether we live within or beyond our carrying capacity is entirely scalar, with national, regional and local assessments dependant not only on the choices of the population but the capability of a landscape—at scale. The Carrying Capacity Dashboard, an openly accessible online modelling interface, has been developed for Australian conditions, facilitating analysis at various scales. Like ecological footprint analysis it allows users to test a variety of societal behaviours such as diet, consumption patterns, farming systems and ecological protection practices; but unlike the footprint approach, the results are uniquely tailored to place. This paper examines population estimates generated by the Carrying Capacity Dashboard. It compares results in various scales of analysis, from national to local. It examines the key behavioural choices influencing Australian carrying capacity estimates. For instance, the assumption that the consumption of red meat automatically lowers carrying capacity is examined and in some cases, debunked. Lastly, it examines the implications of implementing carrying capacity assessment globally, but not through a wide angle lens; rather, by examining the landscape one locality at a time.

Introduction

Effective land-use planning practice involves not only observations of how human behaviour might impact on the landscape, but also methodological remedies responding to those challenges. As such, exhaustive diagnosis, while important, is only half-way towards an effective response. In a planning context, Ecological Footprint analysis has proven itself to be a highly effective tool in ascribing the degree to which current global societal practices reach beyond the sustainable long-term carrying capacity of the planet [13, p. 126]. However, the global scale of analysis means that Ecological Footprinting does not lend itself to on-the-ground

M. Lane (✉) · L. Dawes
Queensland University of Technology, GPO Box 2434, Brisbane QLD 4001, Australia
e-mail: mc.lane@qut.edu.au

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_3,

responses scaled to place. Alternatively carrying capacity assessment more easily accommodates an anticipatory design processes at scales smaller than the global level because it involves the assessment of actual pieces of land, against which future options in human behaviour can be measured. An online simulation tool, the Carrying Capacity Dashboard has been developed in order to facilitate a wider awareness of such issues within in an Australian setting.

Carrying Capacity Assessment Versus Ecological Footprint Analysis

Ecological Footprint is an inversion of the carrying capacity approach. While carrying capacity assessment begins with a specific landscape and predicts the population it can support, Ecological Footprint takes a population and estimates the amount of land they require [21]. Accordingly, it first determines the demands of the population, either at a global or local scale and then calculates the amount of land this set of lifestyle parameters would require. The land requirement however, could be drawn from anywhere on the planet [19], is consequently usually measured in global hectares, and illustrates the condition of ecological overshoot when exceeding the actual land available. Given the globalised nature of modern trade, proponents of this approach argue that Ecological Footprint analysis is thus an accurate representation of existing circumstances [11, p. 6].

In initiating the Ecological Footprint model in the early 1990s, Wackernagel [21, p. 101] divided both consumption and land-use into various categories in order to keep it quantifiably manageable. Consumption parameters comprise food, housing, transportation, consumer goods and services while land-use categories include fossil energy equivalent, built environment, gardens, crop land, pasture, managed forests and non-productive areas [21, p. 103]. While seven of these eight categories are derived from existing land-use data, the fossil energy equivalent is an assumed figure that attempts to translate the use of non-renewable energy sources into equivalent land area requirements. According to the Global Footprint Network [5, p. 13], the amount of land required to perform this function has grown ten-fold in the last 40 years and is now, "the largest contributor to humanity's current total Ecological Footprint."

In contrast to a carrying capacity approach, Ecological Footprint analysis generates nominal rather than geographically-specific land requirements. For example, an analysis of Australia [9] finds that each Australian individual requires about seven global hectares for their resource demands. As the description suggests, these seven global hectares are not necessarily tied to any specific geographic location, but rather, form a generic landmass. Consequently, its originators also referred to the process as "appropriated carrying capacity" [21, p. 121]. This approach is useful in comparing the demands of affluent lifestyles with those less privileged. For instance, at 0.7 global hectares, Bangladesh's Footprint [9] is a tenth of Australia's. Ecological Footprint analysis is also an excellent measure of humanity's ever-increasing demands on the natural environment as a whole [21, p. 85]. However, as a land-use planning tool, its effectiveness can be limited by a focus on the global rather than local landscape. A further criticism levelled against this approach is that it is orientated towards an assessment of existing circumstances [10, slide 8] rather than an exploration of potential alternatives. As its name suggests, Footprint connotes an assessment of what has happened in the past or present, thus a society leaves a footprint. Wackernagel's definition of the Ecological Footprint approach [21, p. 68] seems to reinforce this appraisal when he describes it as, "the land that would be required now on this planet to support the current lifestyle forever." Alternatively carrying capacity assessment more easily accommodates an anticipatory design process at scales smaller than the global level because it involves the assessment of real pieces of land, with actual rather than appropriated attributes, against which future options in human behaviour can be measured. While Ecological Footprint analysis is well suited to the identification of ecological overshoot, carrying capacity assessment is more able to guide a transition away from this societal predicament.

The Global Predicament

Ecological Footprint analysis [9] suggests that humanity requires the equivalent of 1.5 planets to provide the resources and absorb the subsequent waste for its current population with its current lifestyle. The seven billion-strong global human throng is exerting such pressure on our existing societal and environmental systems as to suggest a re-evaluation of existing approaches to the way in which land and resources are managed and to the very structures that allow these problems to escalate. However, at present, most local regions possess neither the tools nor the know-how to assess the productive capacity of their own precincts. To this end, carrying capacity assessment offers a way to assess our resource needs and also determine how best to meet these needs in the future. This process establishes direct causal relationships between a specific landscape, timeframe and people, and inherently links these aspects to systems of land usage and social function.

While carrying capacity assessment offers significant insights into sustainable land-use practices such as highlighting optimal population distributions, efficient resource utilisation and comparing ideal scales for self-sufficiency, to date, this potential has largely been underutilised. Global trade has also made the process of localised carrying capacity assessment problematic because resource production, consumption and waste assimilation are often spread across vastly differing demographic and geographic landscapes. However, given compelling evidence of forthcoming resource depletion [14, p. 8] and the restrictions imposed by climate change, [15, p. 12] the question must be asked: Is it desirable, or even feasible, to perpetuate the existing highly energy-dependant globalised system of trade? If a less energy-intensive, more localised and reasonably self-reliant social configuration was adopted, practical planning methods, such as carrying capacity assessment, could be employed to help guide this transition.

Carrying Capacity Dashboard Overview

A recent innovation in the field of carrying capacity modelling is the launch of an online platform, the Carrying Capacity Dashboard (dashboard.carryingcapacity.com.au) which allows users to test various resource-based parameters for 60 different regions in Australia at three potential scales: national, state and regional. The aim of this openly accessible simulation is to better define and publicise how the process of carrying capacity modelling can operate and to give a broad audience the experience of testing various carrying capacity parameters for their own locations. Carrying capacity analyses, by definition, are reflective of particular pieces of land at a particular time, and any region invariably possesses its own unique physical characteristics, resources and environmental responsiveness. Consequently, the Carrying Capacity Dashboard estimates maximum population thresholds based on the unique biophysical characteristics of specific geographical regions within Australia. The model accounts for various societal and agricultural systems, environmental protection processes and a range of lifestyle choices such as energy, water and food consumption. Given the complexity of the input data, a definitive carrying capacity population number is never likely to be achievable. However, it is possible to offer an approximate figure or range of figures as long as the variables are clearly articulated at the same time. For example, it may be possible to state that the Southeast Queensland region has a carrying capacity of say, two hundred thousand people, assuming that they ate a certain diet and farmed a certain way. The advantage of this approach is that these variables can also be dynamically altered and the impacts on carrying capacity observed. Other analysis derived from this modelling includes estimations of current population over capacity or under capacity, comparisons between regions, impacts of differing food consumption choices including vegetarian and meat diets, impacts of resource wastage and the effectiveness of recycling practices, together with comparisons of organic versus conventional farming, artificial fibre versus natural fibre and biofuel versus petroleum.

Short-Term and Long-Term Parameters

The Carrying Capacity Dashboard gives users the ability to manipulate 17 resource-usage parameters and five land-use types against 60 different Australian regions so the potential to generate a variety of output is considerable. Given the breadth of user-choice, the Dashboard offers two sets of default parameters based on short-term and long-term predictions. The short term parameters are set at current Australian levels. For example, the average Australian diet is made up of about 13 % animal products [4], textile consumption is about 23 kg per person [17], liquid fuel consumption is 2,520 l per person (less than 1 % being derived from biofuel) [1], timber consumption is about half of 1 m^3 per person [3] and there is about 730 m^2 of land required for infrastructure usage [2]. Additionally, about 2 % of Australian agricultural production is estimated to be farmed organically [16] and 12 % of all food is wasted unnecessarily [6] with a negligible amount being recycled back into the food supply. Applying the existing national land-use areas for cropping, pasture, non-agricultural, infrastructure and nature reserve land, the Carrying Capacity Dashboard generates an Australian population capacity of just over 40 million people, almost twice the current population of 22.3 million.

Given the importance of long timeframes in carrying capacity analysis, Fearnside's definition of sustainable carrying capacity as, "the maximum number of persons that can be supported in perpetuity on an area," best describes an ideal approach. However, the concept of perpetuity presents significant difficulties when applying practical application to carrying capacity theory. As Cohen [8, p. 280] points out, carrying capacity predictions relying on indefinite amounts of time are operationally meaningless when it is impossible to confidently predict events infinitely into the future. He argues that, "the precision of prediction declines very rapidly as the horizon of prediction recedes into the future," and so all carrying capacity predictions should be regarded as conditional rather than absolute. However, the fact that accuracy in carrying capacity estimates may diminish over time does not mean that they should be discounted altogether. Rather, it just highlights the importance of making multiple estimates over various timeframes including the long-term. Consequently, Dashboard users are also provided with a set of long-term carrying capacity default parameters in order to more easily choose a configuration reflective of sustainable societal practice. The long-term default option, however, is but one possible future scenario and users are able to alter any of the Dashboard's parameters according to their own visions of the future.

The underlying assumption in the long-term default parameters is the exhaustibility of fossil-fuel based resources. Consequently, the organic, biofuel and natural fibre parameters are all increased to 100 % while liquid fuel consumption is assumed to reduce dramatically. Additionally, the population's diet is realigned with the healthy eat habits identified by National Health and Medical Research Council [7] and includes 7.5 % meat products. Given that many of these changes generally reduce food production, it is thus assumed that food might be valued more highly in the future and every effort made to minimise waste and maximise recycling practices. In the absence of fossil fuels in the production of agricultural produce (as well as in other industries) it is also assumed that the average physical activity level of the population would need to increase to a much higher level than at present, necessitating the consumption of more kilojoules, as muscle-power replaces machine-power. In the absence of artificial fibre production, textile consumption is assumed to decrease while the absence of fossil fuels is assumed to lead to an increase in timber consumption through increased firewood and timber-based construction. Lastly, the Dashboard includes a parameter which estimates long-term climate variability. While not currently accommodating Climate Change, this parameter takes into account the possibility of poor productivity in some years when carrying capacity will be smaller than usual due to factors such as drought and floods. It is important to note that if a society intends to live within the carrying capacity of its productive landscape on a long-term basis, then it will need to limit population not to the expected maximum level of production, but rather the anticipated minimum. In other words, societies must prepare for years with poor yields in order to maintain long term resilience.

An examination of the carrying capacity of Australia's regions under the long-term parameters reveals an even starker picture than under the short-term configuration. Only 13 of the 60 regions are actually under capacity and these are all either in the Murray-Darling Basin or Western Australia's south-west corner. The main reasons accounting for lower carrying capacities under long-term settings is the extra requirements on productive land for biofuel, higher physical activity levels necessitating higher per capita food supplies, and lower yields from climate variability and organic production techniques.

Dietary Protein

The Dashboard parameter entitled meat-eggs essentially adjusts dietary protein, with the uppermost choice, 15 %, indicating a high degree of animal-sourced protein while 0 % reflects a vegan diet. Other significant points within this range include the 1.5 % parameter reflecting an ovo-vegetarian diet, the 2.5 % parameter reflecting an ovo-lacto vegetarian, the 7.5 % parameter reflecting a healthy meat diet [7] and 13 % being current consumption levels. Generally, results from the Dashboard show that diets with less meat require less land. However, there are exceptions to this trend.

For Australia's short-term carrying capacity, the highest meat-eggs option (15 %) results in a carrying capacity of just over 39 million people while the vegan diet results in a capacity of 80 million people. The Dashboard offers another meat-related parameter of a population's diet, which attributes a proportion to white or red meat according to the user's choices. Generally, this parameter transfers the demands on pasture land for red meat animals such cattle and sheep to that of cropping land required for the production of grain for chickens and farmed fish. While the red meat animals generally require more land for meat production than white meat animals the resultant carrying capacity is also dependant on the availability of either cropping land or pasture land. For example, Australia's carrying capacity increases for diets between 0 and 40 % but then decreases for diets with a higher proportion of red meat than 40 % (Fig. 1). The reason for this inflection point is the fact that for diets with more than 40 % red meat, there is no excess pasture land so the model apportions some of the cropping land to the grazing of animals, thus reducing the amount of other food production such as cereals. However, once the red meat component decreases beyond 40 %, an excess of pasture land develops which, according to the model, is unproductive, or alternatively could consist of an excess of food for potential export to other areas (but without increasing the carrying capacity of Australia, in this case). As this unproductive land increases, the carrying capacity decreases. Consequently, if the Australian population wished to maximise its carrying capacity under these circumstances, it would choose a red meat component of 40 % in their

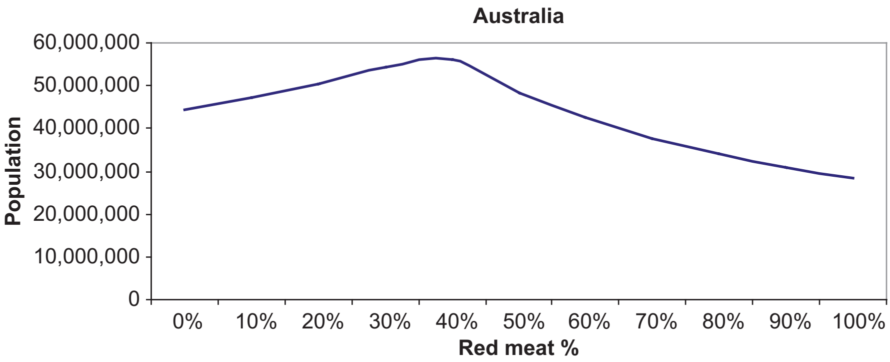


Fig. 1 Carrying capacity of Australia based on short-term default parameters and a range of 0 to 100 % in the red meat parameter

diet. For the purposes of this analysis, it is assumed that much of Australia's land under pasture is unsuitable for the growing of crops. However, if some of the agricultural land currently used for pasture can be converted to cropping land, carrying capacity could be increased beyond the maximum levels indicated by current data.

Localised Production

One of the foundational tenets initiating this research is that societies in the future will need to garner their resources on a more regional basis. This conclusion was drawn partly from the proposition that closer contact with its productive base might engender less environmentally destructive behaviour in the population [20], but also from the viewpoint that fossil fuel depletion will necessitate such a change. For instance, it is questioned whether the current global supply chains, so reliant on cheap and easily-accessible fossil fuel for transportation, will be able to operate as effectively in a post-peak oil world. Using the Dashboard, it is possible to compare the carrying capacities within Australia, based on both small-scale and large-scale resource utilisation, reflecting the open trade of resources at a regional and continental scale.

The carrying capacity of Australia can be calculated in two ways; firstly as nationally self-reliant and also as a collection of regionally self-sufficient entities. It was found that, for Australia, the large-scale capacity (for short-term parameters) is over 40 million, but as an aggregation of smaller regions, it is only about 23 million people. Likewise, under the long-term configuration, findings suggest that if resources are to be utilised at the regional scale, Australia will only be able to support less than 4 million people, whereas it will be able to support more than 9 million if resources are utilised nationally.

The reason for this discrepancy between large and small-scale resource utilisation is the efficiency of land-use in either instance. Under small-scale circumstances there is likely to be more land under-utilised as evidenced by analysis of excess pasture and non-agricultural land. With large-scale utilisation, however, excess land is generated from the usage of all land collectively rather than in small pieces, so the excess portion is likely to be smaller in size overall. As such, large-scale resource usage is generally deemed to be more efficient in land usage than small-scale. It should be remembered, of course, that these projections assume complete self sufficiency within the boundary under question (either national or regional) so excess land is treated as land which does not contribute to the productive nature of the region. This may not always be the case, because land excess to local requirements could, in reality, still be utilised for a population who fall outside the boundary. This dynamic merely reflects the nature of inter-regional trade and could potentially support populations beyond the carrying capacity of their local landscape. Alternatively, local populations could adjust their resource consumption habits, such as their diet, to reflect the productive nature of their local landscapes, although if this meant a dramatic increase in red meat consumption, health implications may also need to be taken into consideration. Of course, while this analysis shows that larger scales may produce higher carrying capacities than small-scales, the problem of continuing to effectively operate the long-distance trade implied by the continental scale in a fossil-fuel depleted future, needs also to be taken into consideration.

Even if the Australian population aimed for national, rather than regional self sufficiency, analysis of the carrying capacity of the continent under the Dashboard's long-term parameters indicates a capacity of about 9 million people while the current population is already more than 22 million and still growing. This disturbing discrepancy poses questions about how a future population might actually support itself. While a downward adjustment of the biofuel component in the model goes some way to making up this difference, it could be assumed that reducing it beyond the 2531 per person level (already only 10 % of current usage) would mean withdrawing significant amounts from agricultural practice, which would probably actually diminish yields (and carrying capacity) further. In any case, even if a different source of fuel was found and biofuel production is reduced to zero in the Dashboard, the restrictions imposed by the other long-term parameters still reduce the carrying capacity of Australia to about 18 million people.

Lastly, it is possible to use the Dashboard modelling to explore the possibility of internal Australian migration in order for the population to reach carrying capacity at a regional scale. While the suggestion of a mass-exodus of populations from Australia's major cities may seem melodramatic, some degree of de-centralisation of the population in the future will be necessary. Prior to the industrialised introduction of fossil fuels to agricultural practice in Europe, for example, only about half the population were able to be supported in non-agricultural activities by the farming population [12, p. 331]). Today, a mere 5 % of the population is able to produce the food for the remaining 95 % [12, p. 376]. However, if fossil fuels are to be withdrawn from this agricultural system, it stands to reason that more human-powered labour will be needed in agricultural activities such as planting, harvesting and weeding. Perhaps future regionalisation might not be as dramatic as pre-industrial levels, but nevertheless, it is likely to necessitate some movement of the population.

If this migration is to occur at the geographic scales analysed in the Dashboard, the Murray-Darling Basin and South-west corner of Australia are regions most able to support increased self-reliant populations. In this case, however, it would be vital that increased population not jeopardise productivity by the building of non-productive infrastructure on good quality agricultural land.

Summary of Analysis

The testing of determinants of self sufficiency at various scales in the Carrying Capacity Dashboard offers much insight into land utilisation and human consumption issues. For instance, it was found that eliminating current unnecessary food wastage in the food supply chain could increase carrying capacity by about 10 million people. Additionally, it was found that meat and animal product consumption accounts for the largest area of food-land requirements by a wide margin. However, red meat, in particular, tends to be produced on land of lesser agricultural quality and in Australia, this makes up the vast majority of the landscape. So, while changes in diet can affect projections of population carrying capacity, the factor determining maximum carrying capacity is often the proportion of cropping land to pasture land within any one region. If an excess of pasture land exists, then changes to diets with less meat do not increase carrying capacity. In fact, such dietary changes may actually decrease carrying capacity.

While dietary changes that necessitate an increase in lesser quality land, such as pasture, can sometimes reduce carrying capacity, this is not the case for the production of biofuels due to the fact that such production competes directly with good quality crop-growing land. Consequently, the Dashboard indicates that biofuel production in any quantity reduces carrying capacity so any redirection of agricultural land usage to fuel production should be considered very carefully.

Some findings generated by the Dashboard modelling seem to suggest planning imperatives of a contradictory nature. For instance, if decisions were merely made on the basis of maximising carrying capacity, then according to the Dashboard, organic agricultural production would be avoided and resources would continue to be produced on as large a geographic scale as possible (on account of national scales producing larger carrying capacities than smaller scales). However, other important systemic issues also need to be considered such as resource depletion, food security, human health and environmental sustainability, so land-use planning decisions need to take place in a context of seemingly divergent priorities. Ultimately, it is the responsibility of all designers of future systems, including land-use planning, to safeguard against potential societal and environmental harms in the context of biophysical constraints. As such, the impetus needs firstly to focus on the identification and measurement of biophysical constraints because, while there is often some flexibility in societal systems, physical limits to population growth are usually not as open to negotiation. For instance, a future shortage of petroleum fuel potentially forms an immovable barrier against which other decisions need to be made. Some may argue that other technologies or transport systems non-reliant on petroleum will be developed to fill this void but in the absence of evidence to suggest that any such technological revolution might be implemented within sufficient time, it seems incumbent on planners to consider strategies of adaptation that necessitate changes to the way we live, where we live, what we consume and the scale of our self sufficiency. In this case, a more localised system of production may help to safeguard food security and societal decisions such as the protection of agricultural land close to urban areas should be made in this context rather than merely assuming business as usual circumstances and maximised carrying capacity outcomes.

It is thus suggested that increased localised self-sufficiency should be a goal of all regions. Findings from the Dashboard suggest that such self-sufficiency, particularly around Australia's large urban centres is problematic, if not impossible. However, full self-sufficiency need not be the aim Australia-wide. Rather, improved food security would suggest that a much larger proportion of a city's food supply should be more accessible to each population, in case possible interruptions to the existing elongated supply chain should leave the over-capacity regions under-resourced.

References

1. ABARES (2010a) Australian energy resource assessment. Commonwealth of Australia
2. ABARES (2010b) Land use of Australia, 4th ed. Canberra, Commonwealth of Australia
3. ABARES (2011) Australian forest and wood products statistics, September and December quarters 2010. Canberra
4. Australian Bureau of Statistics (1995) National Nutrition Survey—foods eaten—Australia. Commonwealth of Australia
5. Borucke M, Morore D, Cranston G, Gracey K, Iha K, Larson J, Lazarus E, Morales JC, Wackernagel M, Galli A (2011) Accounting for demand and supply of the Biosphere's regenerative capacity: the National Footprint Accounts' underlying methodology and framework. Global Footprint Network, Oakland, CA
6. Buzby JC, Wells HF, Axtman B, Mickey J (2009) Supermarket loss estimates for fresh fruit, vegetables, meat, poultry, and seafood and their use in the ERS loss-adjusted food availability data. Washington DC, US Department of Agriculture
7. Byron A, Baghurst K, Cobiac L, Baghurst P, Magarey A (2011) A new food guidance system for Australia—Foundation and total diets. Revised Draft Report for Public Consultation ed., National Health and Medical Research Council
8. Cohen J (1995) How many people can the earth support? W. W. Norton, New York
9. Global Footprint Network (2011) Country trends—Australia. Global Footprint Network, Oakland, CA
10. Gutteridge M (2006) How big is the pond? South East Queensland's Ecological Footprint & Carrying Capacity. Brisbane
11. Lenzen M, Murray SA (2003) The ecological footprint—issues and trends. University of Sydney, Sydney
12. Mazoyer M, Roudart L, Membrez JH (2006) A history of world agriculture: from the neolithic age to the current crisis. Monthly Review Press, New York
13. McManus P, Haughton G (2006) Planning with ecological footprints: a sympathetic critique of theory and practice. Environ Urban 18:113–127

14. McNamara A (2007) Queensland's vulnerability to rising oil prices taskforce report. Queensland Government, Brisbane
15. Moir B, Morris P (2011) Global food security: facts, issues and implications. Science and Economic Insights. ABARE, Canberra
16. Pillarisetti JR (2002) World trade in environmentally sustainable agriculture products: policy issues for Australia. J Econ Soc Pol 7
17. Plastina A (2011) World apparel fiber consumption survey. Washington DC, FAO/ICAC
18. Rees W (1992) Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environ Urban 4:121–130
19. Ritchie J (2012) Bill Rees' last lecture. The Tyee, Vancouver
20. Vail J (2006) Envisioning a Hamlet economy: topology of sustainability and fulfilled ontogeny
21. Wackernagel M (1994) Ecological footprint and appropriated carrying capacity: a tool for planning toward sustainability. School of Community and Regional Planning. University of British Columbia, Vancouver

Contribution of CircUse Approach to Understanding of the Urbanized Land Use Dynamics

Jirina Bergatt Jackson and Anna Starzewska-Sikorska

Abstract The project CircUse (Circular Flow Land Use Management) is financed from the Program CENTRAL EUROPE. Twelve partners have prepared the concept of the Circular Land Use Management, which represents an integrative policy and governance approach. To implement such an approach, a changed land use philosophy is needed in respect of the urbanised land utilization. Such a modified land use philosophy can be expressed with a slogan "avoid—recycle—compensate". This approach is very similar to recycling-based principles, commonplace today for waste or water. The materials' recycling can also serve as a suitable model.

The project partners reviewed key instruments, which have affected the governance, planning, information and organisation, cooperation modes, funding or marketing of already urbanized land in six different countries. Several new instruments designed to strengthen the urbanized land use management were produced by the project. An inventorying tool suitable for a local administration use was developed. This tool helps local communities or urban regions in recording the inner development potential of their urbanized land (brownfields, vacant land, gaps est.). It also helps in recording and considering the available developable Greenfield land. The Integrated Action Plans were prepared for pilot areas in 6 countries to help implementing the CircUse project approach to the Circular Flow Land Use Management. Model proposals for institutional set ups on local or regional scale were prepared and Pilot Projects demonstrating the CircUse project principles were implemented.

This paper describes in further details the project CircUse outputs and it would share various experiences, which partners gained, while implementing the CircUse project common approach of the Circular Flow Land Use Management. It would also comment on efforts in the Czech Republic aiming to promote evaluation of the urbanized land inner development potential and this development potential actual accessibility.

J. B. Jackson (✉)
IURS-Institut pro udržitelný rozvoj sídel o. s., Ostrava, Czech Republik
e-mail: jjackson@iurs.cz

A. Starzewska-Sikorska
IETU-Institute for Ecology of Industrial Areas, Katowice, Poland
e-mail: sta@ietu.katowice.pl

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_4,

Introduction

Land consumption, urban sprawl and brownfields are key urban issues experienced not only in Central European regions. Our existing tools, policies and forms of governance so far failed to prevent ever increasing consumption of land for urbanization. In the Central European area, majority of the urbanised areas increases are not based on population growth, but they are based on increases of urbanised land per head of population. This puts higher demands on our energy consumption and increases the cost of our development externalities, which then reduce our competitiveness. An excessive consumption of land for urbanisation also diminishes the soil environmental services capacity and contributes to global climate problems.

So far, the traditional regulative approaches of spatial planning are failing to deliver the land use sustainability and therefore new integrated land management approaches and policy mixes are needed, to address the stakeholders varied interests in land more comprehensively. New governance approaches are also needed, which can reach above the local authorities' jurisdiction and can protect specific public interest in land from a broader regional level. In the past 5–7 years, a search for an optimum solutions resulted in preparation of new national/regional policies, targets and programs, which were supported by collective efforts of many consultants and research teams [10]. But the actual outcome of these new policies and programs in the Central Europe so far, has not yet delivered the desired goals and targets. The strong concept of subsidiarity principles places most of land use decision in hands of numberless local authorities and regional coordination concerning the local land use is very week or ineffective. Cooperation and coordination between the local and the regional levels is generally insufficient, mostly limited to formal legal requirements of spatial planning, instead of focusing on formats of land use management. The effective and integrated land use management is seldom practised, also due to a fact that the land use management issues usually spread across various departments' responsibilities carrying out strict responsibilities, whereas an effective land use management needs to be focused on cooperation formats, common benefits, goals and concrete outcomes.

From the EU level, there also exists a duality in an approach to the land, which is being perceived not only for its spatial but also for its environmental, biological and geological functions. The soils, soil erosion and soil protection are considered within the EU environmental measures, but the spatial aspects were so far perceived as a national domain and are only indirectly addressed in specific EU policies (Toledo Declaration, Leipzig Charta est.). There is as yet no formal EU pressure on land use effectiveness reporting and land is not being considered as a strategic resource. Even the soil is often treated as an underestimated resource in various environmental assessments (EIA, SEA) and the land/soil is not yet considered a valuable finite resource.

Meanwhile the ever faster occurring changes in climate, demography, land use and other factors represent strong and dynamic forces. These forces are driving changes in national/regional policy requirements and therefore have implications

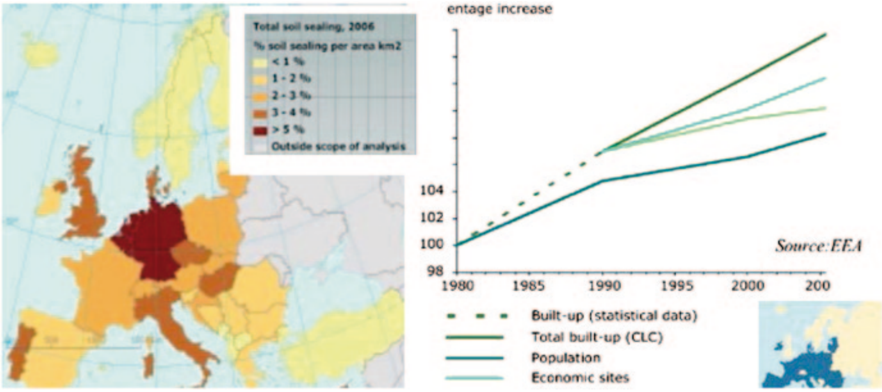


Fig. 1 Level of land sealing and level of built up areas in selected EU countries. [7]

on policy design and they demand new types of tools and policy interventions at all levels. The actual trends in monitored land use dynamics can also show the extent, in which such policies are successful in hitting their targets. But developing multi-level governance approaches for land use adaptation in Europe needs to consider the diversity of formal governmental systems within Europe. Government structures vary, as well as the extent, to which centralized or decentralized approaches are used. These systems can determine the ways in which local, regional and national authorities can act [9]. Within these limits, the multilevel governance approaches, spanning the disconnected levels of various specific jurisdictions and interests of different stakeholders, can support integrated actions, which in turn produce effectiveness and efficiency gains also in the field of the land use management. This support, which can reduce barriers to the new approach adoption, needs to be targeted especially onto the local, the regional and the national levels and it has to be in national languages. Pragmatic models, easy to use new tools, pilot demonstration projects and public awareness actions all illustrating the effectiveness of the land use management should be supported from the EU level funding and programs and also from the national/regional resources. This paper discusses an example of one such an approach [11].

About Project CircUse

The expansion of urbanisation and increases in urbanised land use in the project CircUse partners' countries are causing concerns. Three out of six partner countries (Germany, Czech Republic and Italy) belong to countries with the largest amount of sealed land in EU (Fig. 1). Projects from the Central Europe Program are known for implementing pragmatic approaches to various development issues. There are numbers of projects addressing aspects of brownfields (COBRAMAN, RESOURCE,

Fig. 2 CircUse Process, showing land use as a cycle with three major phases: **a** Zoning new "Greenfields"; **b** Rejection of land not suitable for subsequent use; **c** Activating land potentials (brownfields and empty buildings; gaps between buildings and vacant land; urban renewal and redevelopment sites; sites undergoing planning). The end and the beginning of each phase are crucial decision points. Source: German Institute of Urban Affairs

URBSPACE, TIMBRE, HOMBRE) or soil (SMS), green urban areas (REURIS) or rural land (RUBIRES), but there were so far not many projects, which directly addressed the land use management. Project CircUse (www.circuse.eu) was initiated by the German partners and presented a transnationally valid strategy of land use management based on the methodology of circular flow land use management (Fig. 2). The project CircUse proposed a new policy mix, which pooled together existing and new instruments in the fields of planning, information, organization and co-operation, funding, land utilisation and disposal or marketing. In this context, the approach of an integrated and multilevel land use management promoted by the project CircUse builds bridges between the various stakeholders and governance levels and supports concerted actions, which lead to implementation that is more than the sum of individual measures, and simultaneously avoids processes becoming locked in conflict [8].

Principles of urbanised land recycling "avoid—recycle—compensate", were found as yet not to be fully integrated in the project CircUse partners' countries, thou in legal frameworks and administrative practices in each country were identified useful tools, which could help to improve and reduce the ever increasing urbanised land consumption/head of population [2, 3]. Majority of the project CircUse outputs were aimed at the local/regional and also at a transnational level. For example, The CircUse Strategy illustrated, that common problems and diversity of national and regional frameworks could be faced by a common strategy of circular flow land use management. This strategy recommended that setting up of quantified and qualified land use targets is a necessary requirement for successful implementation of a management strategy according to circular flow land use management—on national, regional and local bases. The CircUse Strategy also identified that a development and application of information instruments and data management tools for registration and monitoring of space oriented potentials, is one of the key activities towards the circular flow land use management. Further analyses of the planning and land management practices in 6 partners' countries have identified that it was mainly on local communities level, where the qualitative data on urbanised land use were missing. This was mainly due to a fact, that the planning was not concerned with the actual economic effectiveness of the land use (vacant buildings, brownfields, gaps est.).

To help this, the project CircUse has firstly unified the urban land use typologies and then prepared a pragmatic inventory tool, focused on the local/regional land use management. This tool can assist local communities to become aware, what is the size of their development potential within their urbanised area. On working with such a data further, analyses of the actual accessibility of this urban development potential can be made and mainly: measures can be proposed to improve the inner urban development potential accessibility. Data gathering can usually help to size up an issue and monitor the situation. But the solution of a more effective land use can be only achieved through a coordinated action, which aims to deliver the good intentions, identified in various policies. As a tool which could achieve this, was by the project CircUse chosen the Action Plan, focused on improving land use effectiveness. Six action plans based on a common template were produced, one per each project CircUse partners' country. A scale of these action plans varied from a site specific (Piekary) to a city based (Asti, Freiberg) to a peripheral regions based ones (Trnava, Voitsberg) to a NUTS 3 based plan (Ústí Region). In the last three plans the multilevel governance approaches and the stakeholders' participation were tested. Some experiences from the preparation and implementation of the Ústí Region plan and efforts to promote more effective land use practices in the Czech Republic are described below.

Based on the analyses of the partners' countries land use practiced, it was also realised that in order to deliver more effective land use management, the existing administrative processes and governance structures need to be modified. Project CircUse is now producing six country reports, all considering optimal management structures, which could facilitate more effective land use management on local or regional levels. Some of these new structures would actually be realised during the implementation of the pilot projects and are also described below.

Case Study: Ústí Regional Action Plan Focused on More Effective Land Use

Czech Land Use Particulars

For many Czech local authorities an increase in size of urbanised area is perceived as a synonym for local growth and attracting new inhabitants and new activities on local Greenfields drives increases to local governments' budgets. Even thou Czech

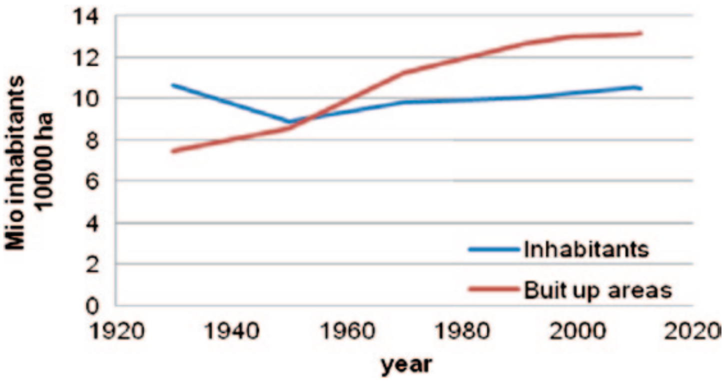


Fig. 3 History of built up areas in relation to population levels in the Czech Republic. Built up areas is one of land use categories registered by the Czech property cadastre. This category includes land under the buildings and land under the courtyards only

spatial planning processes are vertically well integrated—from the national level (PÚR), through the regional level (ZÚR), down to the local level (ÚP) and the sustainability and sustainable land use are declaratorily proclaimed in number of Czech national and regional policies, the actual effect of all this legal framework, integration and policies—an improvement in Czech land use sustainability—is so far missing. For the performance of land use effectiveness in the Czech Republic during the last 80 years see the Fig. 3.

Among all the EU countries the Czech Republic has the fastest growing index of a loss of the agricultural land, also to various development activities. The societal losses of environmental services from the natural land, forest land or agricultural land are still not sufficiently valued or sufficiently compensated for. The Czech planning control system is by pier reviews considered week and the local authorities' independence level is very high. There are a number of other causes, which contribute to decreasing sustainability of the Czech land use. Some of them are:

- an absence of clear national land use effectiveness/sustainability targets,
- no pressure for urbanised land use trends monitoring,
- the Czech planning support information[1], does not as yet focus upon evaluating and monitoring urbanised land use sustainability,
- low level of methodological support to local communities (which would encourage them to focus upon issues related to improving the local urbanised land use effectiveness),
- urbanised land recycling principles are not as yet embedded in planning practise,

[1] Czech GIS based planning support system (ÚAP) was set up by law from 2008. Its implementation is delegated down to 205 local communities (ORP administrative level) and 14 regions. RURÚ—a sustainable land use evaluation is demanded by the law to be repeated each two years for all the Czech communities (cc 6,500 of them). But the RURÚ system as it is set up now is based on 219 consultants' opinion and not on a set of common indicators; hence it is more or less useless.

- an absence of qualitative data describing urbanised land use in Czech communities,
- regionally, there is no reliable data available on the volume, types or categories of brownfield land, vacant urban land, empty buildings, gaps, urbanised land suitable for intensification of use est.
- Czech communities themselves seldom have a reliable and regularly updated data covering the qualitative aspect of the urbanised land use (brownfields, gaps, empty buildings est.),
- none of the Czech communities do as yet consider the inner development potential of their urbanised areas, or are able to evaluate the actual availability of urban inner development potential, or are taking any steps to increase its accessibility,
- to date, there is no data available nationally/regionally on the amounts of residual developable land deregulated for development by the local ÚPs,
- no reliable data on an actual annual uptake of developable land in local ÚPs exist in communities or regional bases.

Regions within the Czech Republic generally feel that the urbanised land use falls more or less exclusively within the local authorities' jurisdiction domain[2]. Such avoidance of urban land use effectiveness issue is putting the regions into a position of failing sufficiently to protect public interests (in land use sustainability terms) from the regional level. Regions are seldom using their regional planning policy documents (ZÚR) to steer the local land use, they are not setting up regional targets for urban land management or demanding local urbanised land use reporting. Regions are also not using their support planning information systems ÚAP and RURÚ to monitor the regional urbanised land use. They do not implement land use monitoring requested by the—National Strategic Framework for Sustainable Development and they do not publish any local land use trends or indicators. In their decision making processes concerning the land take of agricultural, forest or natural land, regions do not insist that applicants (local authorities or local consultants) provide sufficient evaluation of the local urbanised land inner development potential (this would help regions to justify the land take). Also no regional methodology exists on how to compile such an urbanised land inner development potential evaluation.

[2] First regional efforts to protect public interest from a regional level occurred in the Moravskoslezský region planning document ZÚR. However, as the public interest protection in this ZÚR was not supported by suitable data, the local communities, which were being affected by these regional planning demands, appeal to the court and the court removed the objected § form the ZÚR. Since then the region commissioned relevant supporting surveys and there is an intention to return the protection of public interest into the ZUR. See also http://verejna-sprava.kr-moravskoslezsky.cz/upl_01.html.

Table 1 Land use trends in Ústí Region (Czech cadastral categories; adapted from the Czech Statistical Office)

ÚSTÍ REGION	2006	2007	2008	2009	2010
Area (ha)	*533,453*	*533,451*	*533,453*	*533,452*	*533,456*
Agricultural land	*277,117*	*276,779*	*276,367*	*276,138*	*275,921*
Arable land	184,428	183,898	183,487	183,046	182,497
Gardens	8,803	8,830	8,870	8,903	8,908
Orchards	6,178	6,116	6,040	6,006	6,020
Permanent grass land	70,931	71,186	71,223	71,428	71,835
Hop plantations	6,387	6,359	6,356	6,363	6,267
Vineyards	389	390	390	391	394
Non agricultural land	*256,337*	*256,671*	*257,087*	*257,314*	*257,535*
Forests	159,108	159,719	160,207	160,670	161,019
Water areas	10,012	10,270	10,265	10,313	10,292
Built up areas and yards	9,146	9,152	9,241	9,269	9,369
Other areas[a]	78,070	77,530	77,373	77,062	76,856
Population (31.12 of each year)	*823,193*	*831,180*	*835,891*	*836,198*	*836,045*
Built up areas and yards/ head of population (m^2)	*111.10*	*110.11*	*110.55*	*110.85*	*112.06*
Cz built up areas/head of population (m^2)					*124.72*

[a] These areas contain linear transport infrastruction (roads, streets, rail) land reservations strips along this infrastructure, corries, open cast mining est.). Because of the open cast mining the Ústí region has an unusually high level of the “other areas” land use category

Ústí Region Particulars

The Ústí Region (ÚR) is a partner in the project CircUse and this participation has provided an opportunity to support on a regional level activities enhancing development of more sustainable land use in the ÚR. After the Prague, the ÚR is the second most urbanised region in the Czech Republic, but it mirrors the Czech regions with the lowest economic development indicators. The region has a high level of social disparities, nearly stagnating demographic trends, a history of the local populations’ low educational achievements and it faces a number of serious environmental issues. It also has cc 10 % lower built up areas per head of population when compared to national urbanised land consumption. This may be due to the mentioned social disparities, large % of flat dwellers and also may be affected by a vast amount of the open cast mining industry operations, which are recorded in a different cadastral land use category. For the land use trends in the Ústí region see Table 1.

The Action Plan Preparation and Implementation

The ÚR Action Plan (AP, [1]) preparation preceded a concentrated action of both Czech partners of project CircUse to increase regional stakeholders’ knowhow on matters of circular land use management principles. For the ÚR stakeholders' use the CircUse strategy, the CircUse education materials and the land use typologies were translated. The course materials were also adapted for ÚR use by inclusion of regional particulars [6]. Parallel to this action, extensive analyses were performed on the regional and national policies and legal framework, which addressed the regional land use [4]. Similar analyses were carried out for limits of fiscal instruments and programs [5], which may have affected the land use.

These material were opened to the ÚR stakeholders and were followed by a seminar, encouraging stakeholders to share experiences, opinions and barriers, they have encountered in their attempts to steer land use effectiveness. After all this the stakeholders were ready to focus onto the AP preparation. The goals and priorities of the AP were discussed, main activities outlined, commitments to AP were pledged and means how the AP could be financed and implemented were addressed and considered. The AP was from its very start faced with a political instability arising from the autumn 2012 regional elections.

The AP activities can be divided into three main groups. The first group of activities supported local communities with gathering urban land qualitative data and evaluation of the accessibility level of the local urbanised land inner development potential. The second group of activities supported mitigation measures (regional demolition program, proposals for amendments to national legal framework, est.). The third group of activities have focused on increasing public awareness of the issue. As the key source for financing the AP initial activities the INTERREG A Cross Boarder Program Saxony—Czech Republic was identified. Preparation of this new project is now taking place.

Case Study: Pilot Project in Piekary Śląskie

Sustainable development of Piekary Śląskie municipality is connected with redevelopment of the brownfields located in the Brzeziny Śląskie district, which is to result in their economic stimulation and market restitution. It should be emphasized that the project management of degraded areas contain much more elements that are associated with an increased risk compared to a regular project, especially when besides marketing these locations their responsibilities include implementation of corrective actions. That means facilitating comprehensive measures from the design phase, through the supervision of regulatory processes, to creating conditions for granting financial support to new investments.

The Action Plan prepared for this location is an example of implementing the circular land use management in areas of a typical district of Silesian municipality, a district, where the environmental, social and economic problems have succeeded previous intensive industrial activities (with all their negative consequences). The aim of the Brzeziny Śląskie district Action Plan was to restore the natural value of degraded areas, followed by regional economic development, ensured by provision of favourable conditions enhancing the commencement of the new projects as well as assistance in their implementation.

The Action Plan Preparation and Implementation

The process of creation of the Action Plan included several meetings of the Piekary Śląskie Municipality with the potential land use management operator—the Industrial Park—Ekopark. Apart from the initial stakeholders' discussions, resulting in preparation of the Action Plan list of concrete actions, further discussion took place, identifying the required ranges of competencies needed by the implementing management structure. It also was agreed, to limit the Eko-Park competencies to management of brownfields and to transfer the management of Greenfields and other urban areas of Brzeziny Śląskie district back to the Piekary Śląskie Municipality.

When the presentation of the Action Plan draft took place at the meeting with stakeholders' end of February 2012, stakeholders' comments have instigated number of revision to this draft. Within the Brzeziny Śląskie district Action Plan the following categories of activities were therefore included:

- feasibility studies (analyses, research of the ground contamination, detailed stock-takings of the ground),
- analyzes and concept (analyses and concepts of the possible land use management),
- project activity (technical projects relating to communication and territorial development),
- marketing operations (the preparation of offers for potential investors),
- support of investors' activities (advisory),
- investment activities (implementation of the "incubator for the enterprise" project, realization of the pilot project regarding greenfield development),
- activities focusing on social issues and communication.

With regards to the size of the area requiring revitalisation, as well as the financial barriers, which are facing the Piekary Śląskie Municipality and notwithstanding the real possibilities and needs of this location, the following scope for an approach to land use management of this area was adopted:

- step-by-step realization of land use management,
- constant monitoring of already undertaken activities,
- the rationality, innovativeness and efficiency of undertaken activities,
- other, incl. innovative instruments elaborated within the framework of the CircUse project.

The Pilot Project Area Re-Naturalization

An innovative instrument of a compensatory planting model was developed for the Pilot project of Piekary. The model included new procedures, which are to be introduced by the order of the President of the Town. This was achieved by changing a previous procedure, which was closely connected to the national regulation concerning charging for cutting existing urban trees. This regulation required to collect a local fee in any case of such a tree cutting. These payments depended on the type and dimensions of each particular tree (precisely measured). But such payments could be waived, should a sufficient compensation planting be offered on the tree cutting location. The modification of the existing procedure enabled to locally specify, where such a compensatory planting should take place, and also specify the exact type of this compensatory planting. Such a modification in local regulative procedure enabled the Piekary Śląskie Municipality to ensure the long term sustainability of planting trees on the pilot area of the CircUse project in Piekary.

The CircUse Polish pilot project is placed on a highly exposed brownfield site in the Brzeziny district of the Piekary Śląskie Municipality. The size of the pilot area is approximately 14 ha and this Polish investment was planned in the framework of the CircUse project. The Brzeziny district pilot project has focused on a systematic "re-greening" of a part of the post- industrial site and on upgrading of an overall image of the local landscape. The pilot project was set up to demonstrate the innovative example of a possible remediation action, which as an added value has a sustainable financial support for its future maintenance. This is an example that can be easily transferred to other regions, in other countries. The strategy of the land use management within which the investment was implemented also demonstrates an innovative long term thinking of the circular land use, which is the key idea promoted by the CircUse project. This pilot investment is consisting of planting trees and shrubs on the site located in-between an industrial area and a residential area. But two separate functions are being realized by this one action on the pilot area. On one side an insulation zone is being created, shading the neighbouring housing from the industrial site and on the other side a tree belt of public space is being created—a kind of park—which could serve for leisure and recreation activities of the neighbourhood. Figure 4 shows the area for renaturation in Piekary.

Circular Land Use Management Structures

A concept of institutional solutions serving the management of circular land use is another important output of the CircUse project. Here two different approaches were employed: one was based on an existing institution, to which additional or specific tasks and competencies has been transferred. This was the case of the Industrial Park—Ekopark in Piekary or the case of an institutional solution for the Czech regions. Another approach was presented by establishing a new agency specifically

Fig. 4 Renaturation area in Piekary

focused onto the management of circular land use. Such a new agency was actually implemented during the duration of the project CircUse in the region of Voitsberg in Austria. A separate agency was also a preferred solution for the larger Czech towns, plagued by brownfields and low development pressures, as this solution can shade the implementation from the undue pressures of local politics. Both solutions of institutional set ups acting as local operators for management of circular land use can serve as a good practice example for other European towns and regions.

Conclusions

The described two pilot areas of the CircUse project—the Usti Region and the Piekary Śląskie Municipality indicated methodologies and approaches, which were applied in all the six CircUse project partners' countries. Apart from the Czech and Polish locations it was also the Municipality of Asti in Italy, the City of Trnava in Slovakia, the Voitsberg Region in Austria and the region of Saxony in Germany, where the common work of project partners concentrated on application of the CircUse circular land use management principles promotion and dissemination, despite the individual countries differences in scopes and needs specific to their area.

Working together on the CircUse project have led to a number of common solutions and tools, for example a creation of a new commonly applied IT inventorying tool for supporting circular land use management, the Action Plans for each locations, the Institutional Setups Models, or the training materials for various types of stakeholders (from regional experts to secondary school children). Common conclusions and lessons learned from this work were not only related to barriers of the project implementation. They were mainly related to the opportunities and the possibilities, which the project CircUse has opened to all partners. All the partners were during the CircUse project implementation exposed to working with a large number of stakeholders at local, regional, national and international level. They have produced and published in their local languages a large amount of written materials on subject of circular land use management. They were involved in number of round tables, seminars and conferences, where they were explaining and promoting the principles of the circular land use management. When partners' circular land use management understanding and expertise became sufficiently enlarged from being involved on a transnational level, partners became their countries' ambassadors for the circular land use management. They can contribute and some of them are already contributing the more effective land use management in their towns, regions and countries.

References

1. CircUse (2010a) Action plans. http://www.circuse.eu/index.php?option=com_showdown&typeid=12&Itemid=49. Accessed 9 July 2013
2. CircUse (2010b) Strategy. http://www.circuse.eu/index.php?option=com_showdown&typeid=8&Itemid=45. Accessed 9 July 2013
3. CircUse (2011) Circuse possition paper on instruments in Partners Countries. http://www.circuse.eu/index.php?option=com_showdown&typeid=11&Itemid=48. Accessed 9 July 2013
4. CircUse (2011) Analýza strategického a právního rámce s ohledem na udržitelné využívání území v Ústeckém kraji, http://www.urbaninfo.cz/wp-content/uploads/2011/02/Anal%C3%BDza5.1.3.pdf
5. CircUse (2011) Analýza fiskálních a ekonomických nástrojů dotýkajících se problematiky udržitelného využívání zastavěného území http://www.urbaninfo.cz/wp-content/uploads/2011/02/Fisk%C3%A1ln%C3%AD-a-ekonomick%C3%A9-n%C3%A1stroje.pdf
6. CircUse Course information http://www.kr-ustecky.cz/vismo/zobraz_dok.asp?id_org=450018&id_ktg=98838&p1=183826,fileKurzCircusePodkladyUsti.pdf. Accessed 9 July 2013
7. European Commission (2013) Soil sealing guidelines. http://ec.europa.eu/environment/soil/sealing_guidelines.htm. Accessed 9 July 2013
8. European Environmental Agency (2012) Urban adaptation to climate change in Europe. Report No. 2/2012. ISBN: 978-92-9213-308–5
9. Keskitalo ECH (2010) Developing adaptation policy and practice in Europe: multi-level governance of climate change, Springler. ISBN 978-90-481-9324–0
10. REFFINA research program http://refina-info.de/en/refina-veroeffentlichungen/bruessel_2.phtml. Accessed 9 July 2013
11. Verburg PH, van Berkel DB, van Doorn AM, van Eupen M, van den Heiligenberg HARM (2010) Trajectories of land use change in Europe: a model-based exploration of rural futures landscape, pp 217–232, Ecol. 25:217–232. doi:10.1007/s10980-009-9347–7

Environmental Health Indicators for the Metropolitan Region of Sao Paulo, Brazil

Giuliana Carolina Talamini and Leandro Luiz Giatti

Abstract Advances in development and implementation of policies for environmental protection and health promotion have guided the construction of systems of indicators for management processes. The WHO has proposed a model of environmental health analysis framework known as DPSEEA matix (DrivingForce/Pressure/State/Exposure/Effect/Action). The Brazilian government, through the Ministry of Health (MS) have applied this model annually for its 27 states. This paper aims at an approximation of this experience to the Metropolitan Region of São Paulo (RMSP) and its municipalities. The 48 indicators selected by MS, organized into six categories of analysis were found, using data available in public databases online, on the following criteria: relevance, validity, reliability, population coverage, sensitivity, methodological transparency, access, frequency; disaggregated data on population and territory; and comparability of time series. Among indicators consulted, only 28 have been satisfactorily incorporated into the matrix of RMSP, and 8/8 the size of Driving Force, 2/5 of the pressure scale; 8/13 the size situation, 4/5 the size of exposure, 6/8 the size effects, and 0/9 dimension action. In conclusion, despite the large amount of indicators available in the databases consulted, we found limitations in all criteria examined. We highlight the fragility of the environmental indicators. Besides, the need for improvement in the production of environmental information highlights the inadequacy of public policies that do not consider the metropolis as an interdependent system.

Introduction

Today, half of the world population lives in cities, which attract and generate wealth, jobs, investment, and thus are associated with the economic development. The continuous urban growth, especially the growth of the metropolises, goes beyond the

G. C. Talamini (✉) · L. L. Giatti
Departamento de Saúde Ambiental—Faculdade de Saúde Pública,
Universidade de São Paulo, Av. Dr. Arnaldo 715, São Paulo, 01246–904, Brazil
e-mail: giutalamini@usp.br

G. C. Talamini
Bolsista CAPES—Coordenação de Aperfeiçoamento de Pessoal de Nível Superior,
São Paulo, Brazil

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_5,

geographical boundaries of the city. It forms urban agglomerations, where the municipal hub is usually surrounded by peripheral municipalities, away from the infrastructure available and far less integrated into the main dynamics. Thus it causes to emerge an asymmetry among the parts that form the metropolitan area, with different levels of integration among the municipalities. For the institutional structure it is established the difficult task of articulating the exercise of public functions of common interest, such as mobility, transport and road system, environmental management, sanitation, use of the soil and housing, among others [16].

In this context, we live the emergence of systemic risks consisting of large multidimensional problems as part of the physical, social, economic and political dominions. These risks transcend different spatial and administrative scales and they can be characterized by long periods between cause and effect of manifestation, besides offering a wide range of impacts on the environment, the economy, the social conditions and health [9].

The recognition of the complexity of the risks of the urban environment is present in the analyzes of the environmental health, challenging scientific and political processes challenging and stimulating the search for integrated approaches to processes of interdisciplinary and inter-sectoral assessment.

One way of addressing these challenges is to develop a conceptual framework of the system, defining problems, their interrelationships, and establishing principles that sustain the assessment in the environmental health. In this regard, WHO has developed and has been supporting the implementation of a model, known as DPSEEA (Driving Force/Pressure/Situation/Exposure/Effect/Action)—Fig. 1. This model is based on the analysis and the construction of indicators of a given health problem, and their relationship with the environment, exploring causal links from its traction on socioeconomic phenomena, for instance [3].

In Brazil, the DPSEEA model has been applied to the states and major regions of the country by the Health Ministry, through the Health Surveillance Secretariat with the support from the Inter-Agency Health Information Network (RIPSA). The data and secondary selected indicators, generated by different public institutions have been edited and published in a folder format, with an annual basis from 2006 [12–14]. This instrument is part of the strategy of consolidation of the Environmental Health Surveillance in Brazil and aims to promote articulation and coordination among government agencies concerning problems related to environmental health that require an inter-sectoral approach to overcome them.

This study has as starting point this experience with the Health Ministry, applied to the states and major Brazilian regions, and it aims to advance the metropolitan context. It reproduces a methodology in different geographic scales and takes this policy as a basis for selecting and collecting data and indicators in order to offer subsidies to the management of environmental health in the Metropolitan Region of Sao Paulo.

Fig. 1 DPSEEA Framework. Source: CORVALÁN et al., 2000. Adapted by the author

The DPSEEA Model

The WHO model, allows for a comprehensive and integrated understanding of how the "driving forces" of the development processes result in "pressures" on the environment, generating "states" where, in case of human "exposure," may cause "effects" to human health. For each of these categories, indicators and proposed actions are established in a procedure that facilitates the understanding of the problem and visualization of decisions to be made [10].

The environment can be understood as a determinant of health that suffers changes in its state, from social determinants that behave as driving forces and pressures [4]. The model DPSEEA is intended, therefore, to visualize paths or interrelationships to set policies and actions that are directed towards higher levels of causality, as in driving forces and pressures on the environment, approaching and interfering positively in the exhibitions and ultimately in the health effects, but under a policy of sustainability [8].

Smith and Ezzati [18] classify social and environmental determinants into three groups with a spatial scope of the household (poor sanitation, malnutrition, poor housing), the community (modernization of the environmental and exposure to toxic chemicals, air pollution, risks of accidents, occupational hazards) and global ones (inherent environmental impacts on a planetary scale, expressing, for example, in extreme events associated to climate changes). According to the authors, these groups do not exist in isolation, but in different combinations and overlapping exposures, risks and health effects. For it is in urban environments in developing countries that socially excluded population groups often accumulate the highest loads of overlapping risk factors.

The Metropolitan Region of Sao Paulo

In Brazil, where the level of urbanization increased from 36.2% in 1950–84.4% in 2010, according to the Brazilian Institute of Geography and Statistics [6], the population growth and the urbanization have been combined in a process hub since

1970, due to urban-industrial development. The result was the spatial configuration of urban and metropolitan agglomerations, as an extension of the industrial centers in areas of continuous occupation, adding neighboring municipalities in the same relationship complex. In these dense urban areas, the pattern of population growth in the hubs, which selectively undertook more qualified functions, gave way to the high growth of the peripheral municipalities, where the land value was lower. These began to absorb a large number of people with social needs, providing spaces clearly unequal [16].

Cities are therefore the result of their story, their way of relationship between the environment and the society by providing quality of life, which is conditioned by the health situation. While the disease is the effect on the individual, the health situation is a manifestation of the place. Considering the complexity of the urban areas, where networks and connections occur globally, the health situation includes a cadre of emerging and re-emerging diseases, violence, accidents, among others [1].

Founded in 1973, and mentioned in the Federal Complementary Law n.14, the Metropolitan Region of Sao Paulo (MRSP) currently has 39 municipalities. According to the 2010 Census, the total population is 19,683,975 inhabitants, representing 47.7 % of the population of the state of Sao Paulo. The state capital is the city of Sao Paulo, whose population, according to 2010 census is 11,253,503 inhabitants, representing 27.27 % of the state population.

The MRSP grows heterogeneously, with a noticeable decline in population in the central area and an increase in the peripheral zone. However, the quality and quantity of infrastructure, urban services and public facilities, concentration of formal and informal jobs and consumption centers do not follow this dynamic space.

According Maricato et al. [11], both the capital and the MRSP are close to reaching their limits in terms of viability, sustainability and governance. The illegality, irregularity and instability in the production of habitat and land occupation are present in the process of urbanization in this region.

Excluded from the formal city, the population in poverty occupies areas that are of no interest to the real estate market, and they are generally environmentally fragile areas. It can be seen today the expansion of the MRSP, advancing by hills and watershed protection areas. Consequently, the MRSP becomes the stage for recurring urban tragedies caused by floods, flash floods, exposure to contaminated areas, among others, in addition to compromising the quality of natural resources [11].

The history of the economic and social development of this region brought large environmental liabilities as landfills, dumps and areas contaminated with residues from industries, hospitals and from all the urban activities chain. The advance of the territory occupation, previously mentioned, exposes vulnerabilities as exposure and mobilization of contaminants toward the streams and reservoirs. Among the key issues that influence the quality of the environment and the health in the MRSP are the air pollution, the urban mobility, sanitation, involving the water supply, sewage, the urban drainage and solid waste, and the contaminated areas.

And the issue that stands out is the one concerning the water availability, which already has insufficient levels to cover the demand, making them require a major infrastructure and economic investment to transport the resources from neighboring basins. This picture worsens as we recognize the proximity of three major metropolitan areas of the state, the MRSP, Baixada Santista and Campinas, which depend essentially on the same water sources [17]. Regarding the sewage, according to the National Information System on Sanitation [15], 86 % of the territory of the city of Sao Paulo has a network of sewage collection, however, the rate of the treatment of the generated sewage is 50.4 %.

It is also important to highlight the extent and the impact of the metropolitan phenomenon beyond the local level. And it is evident that the issues addressed above include the region as a whole, establishing countless relationships that go far beyond the geopolitical boundaries. The inherent complexity of the processes characteristic of the metropolis is manifested in all spheres of the society and management. And it casts challenges to different areas of knowledge not only in the search for solutions to the problems already made, but also in the search for the sustainability of the metropolitan system.

In this sense, the analysis of the health situation and their interrelationships with social and environmental determinants become a challenge. For, recognizing the metropolis system and the integrated municipalities in their functions is essential for planning and formulating effective public policies, based on the principles of equity and sustainability.

Methodology

The construction of the headquarters of the DPSEEA in the MRSP was based on the brochure published by the Health Ministry in 2008, under the title of "Environmental Health Surveillance: data and indicators selected 2008," which brings together 48 indicators divided into:

1. Driving Force—8
2. Pressure—5
3. Situation—13
4. Exposure—5
5. Effect—8 and
6. Action—9 [13]

The first stage of collection and selection of indicators for the 39 municipalities of the RMSP examined the compatibility with the selected indicators and published in the folder above. The collection of data was performed in online public databases. The initial criteria for the analysis were: availability of the disaggregated data to the municipal level, and relevance of the indicator to municipal and metropolitan context and scale focusing on the environmental health.

This process involved seven workshops with researchers from the School of Public Health of the University of Sao Paulo, in order to discuss, aggregate the experience and the consensus in order to provide a greater consistency to the selection and analysis of indicators for the MRSP.

Table 1. Comparison between the DRIVING FORCE Indicators of the Health Ministry and the Indicators selected for the MRSP.

.	Driving Force Indicators MS, 2008	Selected Indicators for the MRSP
DF. 1	Population	Population
DF. 2	Rate of population growth	Rate of population growth
DF. 3	HDI	HDI -M
DF. 4	Busy economically active population	Busy economically active population
DF. 5	GDP per capita	GDP per capita
DF. 6	Gini Index—Income	Gini Index—Income
DF. 7	Poverty—Households with income per capita until 1/2 of the Minimum Wage (In%)	Poverty—Households with income per capita until 1/2 of the Minimum Wage (In%)
DF. 8	Level of Urbanization	Level of Urbanization

Table 2. Comparison between the PRESSURE Indicators of the Health Ministry and the indicators selected for the MRSP.

.	Pressure indicators MS, 2008	Selected indicators for the MRSP
P.1	Lack of General Services Sanitation	Sanitation. Households without access to the public network (rainwater or sewage)
P.2	Fleet of vehicles per capita	Fleet of vehicles per capita
P.3	~~Land use with crops in~~	Electric power consumption per capita
P.4	Electric power consumption	Production of trash per capita
P.5	~~Manufacturing Industries~~	Household in subnormal agglomerates
P.6	—	Average water consumption per capita

Results

In the Tables 1–5 we compare the indicators selected by the Health Ministry [13] and the indicators selected for the MRSP by category. The indicators that showed no relevance or were not available to the municipal level are shown in the first column in strikethrough format. The indicators adapted or incorporated into the headquarters of the MRSP are shown in bold in the second column.

All the indicators selected by the Health Ministry in the driving force category proved to be relevant to the analysis of the Environmental Health in the MRSP. The search was satisfactory in terms of data availability, mainly because they are known indicators and appreciated in the demographic and socioeconomic sector. The main databases consulted were the Brazilian Institute of Geography and Statistics

Table 3. Comparison between STATE Indicators of the Health Ministry and the indicators selected for the MRSP.

.	State Indicators MS, 2008	Selected Indicators for the MRSP
S.1	Sewage. Households without the sewage collection network service.	Sewage. Households connected to the public network (rainwater or sewage)
S.2	Sewage treatment. Percentage of districts without sewage treatment	Sewage treatment. Percentage of collected sewage that receives treatment.
S.3	Garbage Collection. Percentage of households with direct or indirect regular garbage collecting	Garbage Collection. Percentage of households with direct or indirect regular garbage collecting
S.4	~~Fires and Conflagrations. A number of outbreaks of burning, captured by satellites~~	Landfills Quality Index (LQI)
S.5	~~Risk areas in the urban area~~	Recycling Index
S.6	~~Flood or Flash flood. Percentage of municipalities that suffered flood or flash flood~~	Landfill. Municipalities that have landfills
S.7	~~Use of pesticides. Expresses the intensity of the pesticide use in areas cultivated per kg/ha/year of active ingredient~~	Households with a general Network of water distribution
S.8	~~Percentage of water supply systems without treatment~~	Indicator of Sewage Collection and Treatability of the Urban Population of a Municipality (ICTEM)
S.9	~~Percentage of colletive alternative solutions of water supply without treatment~~	Areas of Fountain Protection
S.10	~~Total Coliforms – Water Quality~~	Number of contaminated and rehabilitated areas
S.11	~~Turbidity – Water quality~~	CO2 Emissions
S.12	~~Free residual chlorine – Water Quality~~	Remaining Vegetation Cover
S.13	Contaminated or potentially contaminated areas	

Table 4. Comparison between the EXPOSURE indicators of the Health Ministry and the indicators selected for the MRSP.

.	Exposure Indicators MS, 2008	Selected Indicators for the MRSP
EX. 1	Population without access to treated water, registered in the Information System for Monitoring of Water Quality for Human Consumption (SISAGUA).	Population without access to water supply network.
EX. 2	Population without sewage installation	Population without sewage installation
EX. 3	Population without garbage collection	Population without garbage collection
EX. 4	Residents in subnormal agglomerates	Residents in subnormal agglomerates
EX. 5	~~Population potentially exposed to chemical contaminants~~	Residents in an inadequate housing.

Table 5. Comparison between EFFECTS indicators of the Health Ministry and the indicators selected for the MRSP.

.	Effect Indicators MS, 2008	Effect Indicators
EF.1	Hospitalization for acute diarrheal disease (ADD) in children under 5 years	Hospitalization for acute diarrheal disease (ADD) in children under 5 years
EF.2	Hospitalizations for Acute Respiratory Infection (ARI) in children under 5 years	Hospitalizations for Acute Respiratory Infection (ARI) in children under 5 years
EF.3	Hospitalizations due to diseases related to inadequate environmental sanitation (DRIES)	Hospitalizations due to diseases related to inadequate environmental sanitation (IES)
EF.4	Proportional mortality due to acute diarrheal disease (ADD) in children under 5 years	Proportional mortality due to acute diarrheal disease (ADD) in children under 5 years
EF.5	Proportional mortality due to acute respiratory infection (ARI) in children under 5 years	Proportional mortality due to acute respiratory infection (ARI) in children under 5 years
EF.6	Proportional mortality due to diseases related to inadequate environmental sanitation	Proportional mortality due to diseases related to inadequate environmental sanitation
EF.7	~~Intoxication with pesticides~~	
EF.8	~~Mortality due to pesticide intoxication~~	

(IBGE), the United Nations Program for Development (UNDP) and the Institute of Applied Economic Research (IPEA).

The PRESSURE category is mainly related to the activities on the land use and the directly or indirectly demand for environmental resources. The search for these indicators involved the IBGE and some specific databases from the National Traffic Department (DENATRAN) and the Energy Company in Sao Paulo (CESP). We found some difficulty in finding disaggregated data for municipal level. Moreover, some of them have been found in specific publications or reports, making it difficult to collect them. In the sanitation sector, indicators on water consumption and waste production, and the number of households in subnormal agglomerates were added, which are also factors that create pressure on the urban environment.

The search for the indicators of the STATE category showed low availability of data at the municipal level, especially when dealing with specific topics. Large surveys are restricted to a few indicators of the environmental or when performed fail to achieve high level of disagreeability. Many of the specific bases consulted do not have enough structure to provide a consistent data yet, especially for the specific need to contextualize specific cities and metropolis.

Besides the difficulty on the collecting process, the data of the PRESSURE and STATE categories are very similar, for, an indicator may be relevant to both categories, as in the case of the sewage theme. Besides the lack of data at the municipal level, when found, they often do not include the totality of the municipalities in the metropolitan system. Some surveys such as the Water and Sewerage Diagnosis of the National Information System on Sanitation (SNIS), rely on information provided by the municipalities or utilities that do not always send their data, or when do, they may not reflect the reality. However, despite the difficulties we reached a total of 12 indicators.

The selection of indicators for the EXPOSURE category reinforced the lack of indicators for the environmental analysis, namely, the available indicators are not satisfactory to meet the determined driving forces and the determined pressures. Besides the lack of indicators, it also stands out the difficulty of translating the same reality. This category demands data that is confined to the number or percentage of people exposed to certain environmental risks. The difficulties of acquiring these indicators were: the lack of technical capacity for data generation; irregularities and methodological difficulties in collecting information, and the non-recognition by the population of aspects of their own house, especially the ones related to sanitation services.

This circumstance also demonstrated, however, that there is no possibility to define population groups exposed to the major groups of environmental risks, and it is even more intangible to identify groups which suffer overlaps of these risks [18].

We also emphasize the difficulty to obtain indicators of population exposed to some types of pollutions that are diffuse, difficult to measure and carrying a transversality under municipal boundaries within the metropolis, as air pollution, which can only be inferred by the EFFECTS category, considering, for example, the number of hospitalizations for the acute respiratory tract infections (ARIs).

The data source EFFECTS category was totally restricted to the Health System Database (DATASUS), a system that offers a great basis, with recent information, good coverage and disaggregability. However, its communication with professionals who are not involved with the health sector is hampered by the large number of subdivisions, programs and projects related to industry and international classification of diseases, as well as loads of categorizations, that are placed as functions in most searches by indicators.

Conclusions

In order to understand the health status of a city or region it is essential to obtain information that will allow the identification of risk factors, and their location, as well as describe their relationships with local contexts and other characteristics of the population [2]. The scarcity of data and indicators and the existence of gaps and uncertainties accordingly limit the adoption of evaluation models and, in turn, complicate the inter-sectoral management needed for the health promotion.

In the process of the application of the DPSEEA Model to the MRSP, the main difficulty was the lack of data related to the characterization of the PRESSURES, the STATE and the EXPOSURE in the MRSP. Thus, there is a greater need in terms of data and environmental indicators, as well as also verified in specialized literature [5, 7, 19, 20]. Despite the large amount of research on the topics of these categories, much of the data does not provide desired quality and frequency analysis for environmental health in the metropolitan context. There is no consolidated database for the analysis of the environmental situation in the MRSP. However, the Environmental Company of the State of São Paulo (CETESB), of the government of the State of Sao Paulo, in their annual reports, generates most of the indicators of environmental quality, playing a major role in the evaluation and monitoring of the territory. Even so, there is a lack of approaches within the metropolitan scope for the production of environmental health data, which makes it difficult the visualization and search for solutions.

It is known that the environmental and the social processes, which are the determinants of the health status, are not limited to administrative boundaries, such as county, state and nation [1]. However, most indicators that are produced and made available by the public sectors are not yet able to reflect the real dynamics of these processes. In this sense, besides the necessity of finding new ways of viewing the indicators, it is fundamental to carry out a systemic analysis of this information, especially when dealing with large interdependent areas as the metropolitan ones.

Acknowledgements FAPESP—Fundação de Amparo à Pesquisa do Estado de São Paulo (proc.n.2010/20899–0); INCLINE—Interdisciplinary Climate Investigation Center/Universidade de São Paulo; and CAPES—Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.

References

1. Barcellos CC, Sabroza PC, Peiter P, Rojas LI (2002) Organização espacial, saúde e qualidade de vida: análise espacial e uso de indicadores na avaliação de situações de saúde. Inf. Epidemiol. Sus 11(3):129–138. doi:10.5123/S0104-16732002000300003
2. Castellanos PL (2004) Análises de situación de salud de poblaciones. In: Navarro FM et al. (Org). Vigilância Epidemiológica. McGraw-Hill/Interamericana, Madrid, pp 193–213
3. Corvalán C, Briggs D, Kjellström T (2000) The need for information: environmental health indicators. In: Corvalán C, Briggs D, Zielhuis G (eds). Linkage methods for environment and health analysis - General guidelines. Geneva: United Nations Environmental Programme/United States Environmental Protection Agency/Office of Global and Integrated Environmental Health of the World Health Organization; 2000; 25–51. doi: 10.4324/9780203479018.ch3
4. Franco Netto G, Freitas CM, Andahur JP, Pedroso MM, Rohlfs DB (2009) Impactos socioambientais na situação de saúde da populaçao brasileira: Estudo de indicadores relacionados ao saneamento ambiental inadequado. Tempus Acta de Saúde Coletiva. 3(4): 53–71
5. Freitas CM, Giatti LL (2010) Sustentabilidade ambiental e de saúde na Amazônia Legal, Brasil: Uma análise através de indicadores. Série Saúde Ambiental 4. Brasília: Organização Pan-Americana da Saúde; 2010
6. IBGE (2010) Censo Demográfico 2010. Available via http://www.ibge.gov.br/home/estatistica/populacao/censo2010/sinopse/default_sinopse.shtm. Accessed 16 Aug 2012
7. IBGE (2008) Indicadores de Desenvolvimento Sustentável. Estudos e Pesquisas Informações Geográficas 5. Rio de Janeiro: IBGE; 2008.ftp://geoftp.ibge.gov.br/documentos/recursos_naturais/indicadores_desenvolvimento_sustentavel/ids2008.pdf. Accessed 17 Aug 2012
8. Kjellstrom T, Friel S, Dixon J, Corvalan C, Rehfuess E, Campbell-Lendrum D, Gore F, Bartram J (2007) Urban Environmental Health Hazards and Health Equity. J Urban Health. 84 (Suppl 1): 86–97. doi: 10.1007/s11524-007-9171–9
9. Klinke A, Renn O (2006) Systemic risks as challenge for policy making in risk governance. Forum qualitative sozialforschung/forum: qualitative Social Research. 7(1). http://www.qualitative-research.net/index.php/fqs/article/view/64. Accessed 17 Aug 2012

10. Maciel Filho AA (1999) Góes Junior CD, Cancio JA, Oliveira MLC, Costa SS. Indicadores de vigilância ambiental em saúde. Informe Epidemiológico do SUS, v. 8, n. 3, 1999. pp. 59–66
11. Maricato E, Ogura AT, Comarú F (2012) Crise urbana, produção do habitat e doença. In: Saldiva P et al. Meio Ambiente e Saúde: o desafio das metrópoles. São Paulo: Ex-Libris Comunicação Integrada; 2010
12. Ministério daS-MS, Secretaria deVemS (2007) Vigilância em saúde ambiental: dados e indicadores selecionados - 2007; V.2(2). Brasília: Ministério da Saúde; 2007. http://portal.saude.gov.br/portal/arquivos/pdf/ambiental_Dados_indicadores_selecionados_2007.pdf. Accessed 17 Aug 2012
13. Ministério daS-MS, Secretaria deVemS (2008) Vigilância em saúde ambiental: dados e indicadores selecionados - 2008; V.3(3). Brasília: Ministério da Saúde; 2008. http://portal.saude.gov.br/portal/arquivos/pdf/folder_dados_08_cgvam_web.pdf. Accessed 17 Aug 2012
14. Ministério da Saúde. Secretaria de Vigilância em Saúde (2006) Vigilância em saúde ambiental: dados e indicadores selecionados - 2006; V.1(1). Brasília: Ministério da Saúde; 2006. http://bvsms.saude.gov.br/bvs/folder/10006002038.pdf. Accessed 17 Aug 2012
15. Ministério dasC (2011) Sistema Nacional de Informações sobre Saneamento. Diagnóstico dos serviços de água e esgotos - 2009. Brasília: MCIDADES, 2011
16. Moura R (2002) Lacuna institucional da metropolização: considerações sobre a Região Sul. Cadernos Metrópole. 2002(8):39-68. http://www.cadernosmetropole.net/download/cm_artigos/cm8_35.pdf. Acessed 17 Aug 2012
17. Silva RT, Porto MFA (2003) Gestão urbana e gestão das águas: caminhos da integração. Estudos Avançados 17(47):129-145. doi: org/10.1590/S0103–40142003000100007
18. Smith KR, Ezzatti M (2005) How environmental health risks change with development: the epidemiologic and environmental risk transitions revisited. Annual Review Environmental Resources 30:291–333. doi: 10.1146/annurev.energy.30.050504.144424.
19. Sobral A, Freitas CM (2010) Modelo de organização de indicadores para operacionalização dos determinantes socioambientais da saúde. Saúde e Sociedade 19(1): 35–47. doi: org/10.1590/S0104–12902010000100004
20. United Nations Environment Program (2012) Global Environment Outlook - GEO5. Environment for the future we want. UNEO, 2012. http://www.unep.org/geo/pdfs/geo5/GEO5_report_full_en.pdf. Accessed 17 Aug 2012

A City-Region in the Forest and its Challenges for Environmental and Health Sustainability

Leandro Luiz Giatti, Sylvain JM Desmoulière and Carlos Machado Freitas

Abstract Manaus, the capital of the state of Amazonas, Brazil, is the most important city in the Amazon region. It has faced very rapid demographic and economic growth whilst at the same time having to deal with a scarcity of essential services and a lack of urban planning. Using the concept of local and regional influence from a large urban area, the aim of this paper is to describe the challenges Manaus faces in relation to sustainability, in terms of the environment and health, taking into account its spatial location in a region of tropical ecosystems. The multi-sectoral indicator analysis proposed by WHO, the DPSEEA matrix, was applied using secondary data from Brazilian public institutions. Interviews were also carried out with public managers, academic experts and representatives of civil society. Results show essential areas to be addressed in relation to the sustainability of Manaus at two different levels: the urban area and its intense relationship with the natural surroundings, resulting in significant health issues where serious infectious diseases due to poor sanitation such as dengue fever, malaria and leishmaniasis predominate, whilst at the same time, there is also an increase in chronic diseases and external causes. In the Amazon region we observed that the prominent role of Manaus, that result of an economic model of incentives to industry, has led to strong economic dynamism, making the city highly attractive to migrants, resulting in rapid and uncontrolled population growth with profound inequalities and an increase in environmental health problems.

L. L. Giatti (✉)
Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo, Av. Dr. Arnaldo, 715, São Paulo, 01246-904, Brazil
e-mail: lgiatti@usp.br

S. J. Desmoulière
Instituto Leônidas e Maria Deane, Fiocruz, Amazonia, Brazil

C. M. Freitas
Centro de Estudos de Saúde do Trabalhador e Ecologia Humana, Escola Nacional de Saúde Pública, Fiocruz, Rio de Janeiro, Brazil

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_6,

Introduction

The aim of this paper is to present the current conditions and trends with respect to socio-environmental issues in the city of Manaus, state of Amazonas, Brazil, taking into account the fact that as well as being an important regional urban centre, it is situated within the Amazon region. Our arguments and discussions embrace a wider view of the driving forces which constitute the main challenges to environmental sustainability and health in this large city in the middle of the forest.

The study was conducted using data and indicators produced by various public sources which are widely available, such as IBGE—Brazilian Institute of Geography and Statistics, the Ministry of Health's Information Department's database—DATASUS—as well as information held by state and municipal (Amazonas and Manaus) public policy departments and SUFRAMA—the Superintendence of the Manaus Free Zone of Manaus.

In order to analyse the socio-economic and demographic processes which affect the region, the environment and human health, we have used methods based on indicators and interviews. With regard to the indicators, we used the DPSEEA matrix (Driving Forces—Pressures—State—Exposure—Effects—Action) proposed by the World Health Organization—WHO [9]. The main advantage of this model over other indicator models of sustainability is that we are able to consider in depth the environmental exposure of human beings in different socio-environmental situations and the effect of this on health. Semi-structured interviews were carried out with public managers, academic experts and representatives of civil society in order to uncover socio-environmental processes and trends and their impacts on health. Our aim was also to identify possible future scenarios, policies and actions which may be conducted in relation to the topics under discussion.

This combination of methods allowed us to understand the inter-relationship between various determining factors within the context of the Amazon region and the policies of the Federal Government, namely, the industrialization model adopted.

In order to analyse the contents of the interviews, the collective subject discourse method [14] was applied to this case, involving the selection of central concepts—a synthesis of social representation about a certain topic—and based on key expressions—a cross-section of excerpts from the interviews which together denote specific central ideas. This selection was conducted using criteria compatible with the objectives of this paper and according to their suitability and complementary nature in terms of conditions and trends revealed by the indicators. The central concepts are presented in this article, listed according to the examples of key expressions which are displayed as footnotes which are English versions made from the original ones in Portuguese. The excerpts of interviews are translated into English from the original Portuguese. The model used in this research allowed us to study the city of Manaus from the point of view of environmental sustainability and health, by applying a discourse rationale in order to analyse the city-region's inter-relationships with its territory [19].

Conditions, Trends and Driving Forces Inherent to the Manaus Context

In the Amazon, the debate around environmental problems is usually circumscribed to the conservation of the ecosystems associated to the Amazon itself, which is the largest tropical biome on earth. However, a large part of the region's population lives in urban environments. In Brazil, the rate of urbanization according to the 2010 demographic census was 84.4 %. In the nine states that make up the so called "*Amazônia Legal*"—occupying 60 % of the Brazilian territory distributed within nine federation states—this rate was 71.8 % [12]. Economically, demographically and with regard to urbanization, the region has grown at a higher rate than the national average, resulting in inequalities and a precarious sanitary situation. In the Legal Amazon the population of cities has been increasing without adequate services and social investments, such as basic sanitation [4, 10].

Manaus, the capital of the state of Amazonas, has been developing rapidly as a result of a Federal Government policy, started in the 1960s, of fiscal incentives to industries, generating significant economic growth [5].

The city of Manaus concentrates around 50 % of the population of the state and 80 % of its GDP. On the other hand, the state of Amazonas has 98 % of its original forest cover preserved [10]. Currently, the main economic driving force identified in Manaus is industrialization. It is promoted by a fiscal incentives policy which is susceptible to risks, since it does not promote a diversified economic model and is disconnected from the economic potential of the region[1]. It is this driving force which attracts investments and industries and also encourages high demographic growth through migration, resulting in an unplanned and extremely unequal process of urbanization[2].

Within the context of the state, the following future trends were identified: development processes in practice in the Legal Amazon which have a high impact on the environment and issues related to inequality to the detriment of the local population's quality of life [10] the continuation of the fiscal incentive policies to stimulate local industrialization and economic growth [17]; the development of the South American infrastructure which aims to turn the Amazon from a peripheral area to become central to the continent [23, 24]; and finally, in the very short term, the selection of Manaus as one of the cities to stage the 2014 Football World Cup.

These should contribute to strengthening the regional importance of Manaus, whilst exacerbating the effects of the driving forces which act upon it.

[1] "…The Industrial Zone of Manaus (…) is the basis of our economy [and also] a big long-term risk (…) It is in our interest to think about the existing chains and how these can be integrated with the forest."

[2] "…this is a history that starts back in 1967, when the Free Trade Zone of Manaus was established, (…) [outside the capital] they used to think that Manaus was an 'Eldorado' where employment was easy to find and everything was easy…".

Interactions Between the Urban and Natural Ecosystems and the Health Situation in Manaus

Since the implementation of the industrial model, the population of Manaus has been growing very rapidly: in 1960 there were 173.703 inhabitants; in 1980, 633.392; in 2000, 1.405.935; and in 2010, 1.802.525 [12]. The economy has proved itself to be very dynamic, with GDP growth of 128.3 % between 2002 and 2009. In 2009, the GDP/capita for Manaus was 60 % greater than the rest of the GDP for the state of Amazonas [1]. Despite rapid economic growth, the percentage of poor people—those who live on less than two US dollars a day—increased from 23.6 % in 1991 to 35.2 % in 2000. According to data from the 2010 demographic census, the percentage of people living below the poverty line in Manaus was 35.5 % [18].

Within a comparative framework of sanitation using data from the demographic census of 2000 and 2010, the percentage of households considered adequate fell from 56.3 to 50.3 %. It is worth noting that the category "adequate" relates to both the availability of water supply through public system and sewage through the public network or a septic tank, and the availability of direct or indirect waste collection [12].

In addition to its precarious urbanization conditions, Manaus is also affected by the natural characteristics inherent to its geography, such as: proximity to the forest, presence of a large quantity of water systems, and high temperature and humidity[3]. This situation results in a particular kind of fragility associated to interference in the ecosystems and environmental services with potential impact on public health.

In addition to the natural characteristics of the region, the conditions brought about by rapid industrialization and urbanization are also linked with health hazards and poor quality of life in situations which are typical of large cities, with problems such as traffic, violence and environmental pollution[4].

Conditions and trends observed in Manaus in this analysis allowed us to identify a scenario which is compatible with epidemiologic transition [21], an increase in chronic-degenerative diseases and external causes, such as violence and accidents. At the same time, infectious diseases remain significant such as dengue, respiratory infections and diarrheic diseases associated with precarious sanitary systems

[3] "…The forest ends and the tarmac begins; on the other hand, (…) [it is] a city that is crossed by many igarapes [streams] and associated to this is the fact that we have a very low proportion of basic sanitation…" "(…) Malaria has become a great concern for the city. There is a high incidence of carriers of the Malaria Vivax in the suburbs (…). Leishmaniasis is another disease which has emerged in large numbers in Manaus (…) [and] illnesses caused by forest viruses, (…) We call these haemorrhagic febrile syndromes, caused by viruses we do not yet know…".

[4] "[migrants from the state] come in their canoes into the traffic, that's why the traffic is chaotic". "[a] city without trees, which does not value the human being, the pedestrian". "…we do not have a public body that can work out how many kilometres of traffic jams there are, analyse the level of pollution in the air, this does not exist, we have not planned for this…". "(…) We need to keep an eye on the advancing deforestation for urban expansion and another eye on the city that is growing in a vertical direction, leading to chronic, cardiac diseases…".

[2], as well as diseases related to the proximity to the forest, such as malaria and leishmaniasis [8].

Thus the superimposition of social and environmental vulnerabilities points towards a very precarious situation among more disadvantaged groups of inhabitants who are exposed to a number of diseases associated to this triple burden of environmental factors [10, 22].

When studying the large cities of India, Chaplin [7] compared local sanitary conditions, especially those found in slums with no provision of basic services, to the rapid and precarious urbanization pattern that took place in England during 19th century which was driven by the Industrial Revolution, creating scenarios which were extremely critical in relation to the superimposition of socio-environmental aspects with marked epidemiological consequences. However, in the English context, urban sanitary reform occurred through the mediation of intense class conflict and the threat of social revolution in which the working class gained an opportunity of inclusion through applying pressure on the political system and the middle-classes.

In India, there are some characteristics which lead to the persistence of a precarious sanitary scenario associated to poverty in the cities;

1. Migratory pressure from rural areas motivated by economic concentration and industrialization in the cities;
2. A middle-class that is spatially concentrated, demanding improvement in sanitation, whilst at the same time, protecting itself through vaccination, antibiotics, modern medicine and sanitary technology;
3. Poor people who are exclusively concerned with providing for their essential needs such as food and shelter. In cases of epidemics of infectious diseases affecting the poorer classes, emergency actions are carried out by the government, thus preventing dissemination and protecting the middle-classes.

Within this context, we can make some comparisons with the situation in Manaus, where there is widespread inequality which is reproduced and accentuated by the constant migratory pressure on the city, leading to social inequalities spatially distributed. This complex scenario leads us to question "*the caricatural and functional view of Manaus as a powerful (industrial) park and nothing else*" [15].

Figure 1 show how urban agglomerations with the lowest income population in the urban area of Manaus are distributed. With regard to issues related to the natural environment superimposed with issues of poverty we observe that the lighter areas—those which are poorer—are particularly concentrated in the more distant suburbs of Manaus, in close proximity to the forest and along streams (*igarapés*), in areas which suffer from social exclusion, far from the reach of government and threatened by floods, landslides and water-borne diseases. It is possible to identify the location of the Manaus urban area in dark colours on the bottom right-hand corner of the map. The light colours show areas of residual forest in the gaps in the urban areas and further into the periphery, particularly in the shape of an arc that stretches from East to West in the Northern part of the city. The Rio Negro river forms a natural boundary to the South of the city and in the North is the Adolfo Ducke reservation (light square). Large areas of forest (in white) remain inside the

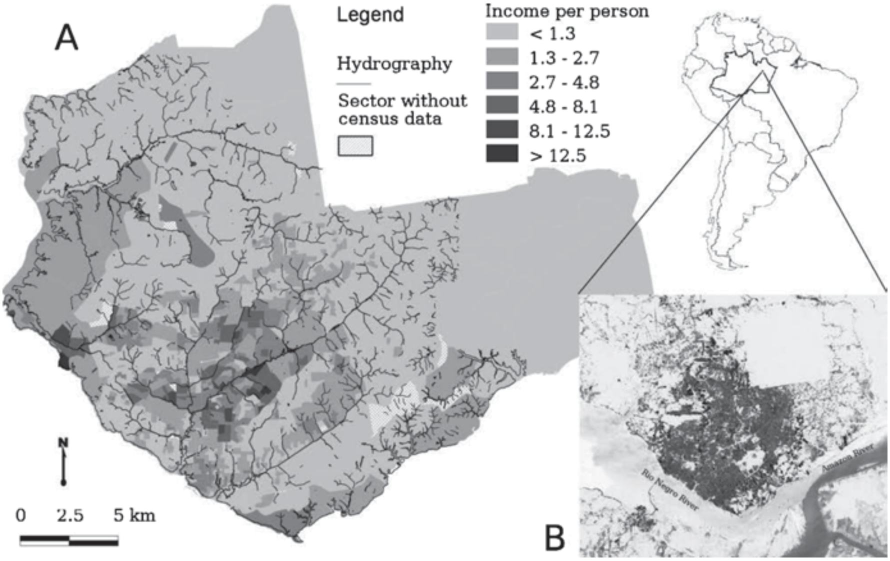


Fig. 1 Income per person resident in Manaus (in n. of minimum salaries)—average per census sector in 2010 (**a**), with delimitation of igarapés (streams). Configuration of the urban area (**b**) August 2011. Source: Census 2010 (IBGE, 2012) (**a**), NASA Landsat mission (**b**). Data available from the 2010 Census (Fig. 1a) according to census sectors and calculated using the total income of the resident population in permanent private households in each sector. The minimum salary base is US $ 306.09 (equivalent to R$ 510.00, conversion rate on 31/12/2010). Urban area (Fig. 1b) is the opposite colour band, on 3 August 2011, TM sensor of Landsat 5 satellite

urban area (university, military area and park) and in the suburbs to the West and East towards which the urban area spreads. In the central part there are some residual forested areas which are steadily declining.

The City-Forest Region

Urban activities are not restricted to cities, but cross over into other territories which go from the centre to the rural areas, making up city-regions. For these city-regions, planning in a wider sense is necessary—the strategic management of environmental, economic and social changes—and is a challenge for a better future for these areas [18].

Manaus considers itself a world city and as the dominant metropolis in the Pan-Amazon region [5]. Its intense urbanization model is in contrast to its surroundings where there is an extreme lack of services and business opportunities [20]. Manaus is situated within the Amazon territory, it is the driving force of the surrounding area and both polarizes changes and is the site of significant impacts itself, bringing together situations of crisis and opportunities for managing its local area and surrounding territory. Within this context, the opposition in relation to the availability of resources is clear: an abundance of environmental services in its surroundings and greater potential for social and economic services in the urban environment.

Since its creation, due to its strategic geographic position, Manaus has been important in terms of connecting the world metropolises with the interior of the Amazon, accessible via the network of waterways. This prominence was at its height during the cycle of rubber exploitation which lasted until the 1950s, when Manaus was an important exporting hub. Today Manaus continues to be significant within these connection networks, but as an industrial complex and in a cycle of influence among national and global metropolises [6].

In relation to the widespread and centralizing influence Manaus has over the Amazon bio-region we apply some of the suppositions presented by Ravetz [18] in order to characterize the Manaus relationship within the wider territory it occupies:

1st supposition: sustainability cannot be considered as fixed or as a new part that is added. Crises and opportunities go hand-in-hand, in that today's solution could be tomorrow's problem.

Firstly, the prevailing sustainability discourse does not operate at a level where it takes into account urban sanitary issues. At this level, the state of Amazonas presents considerable economic growth linked to a positive index of conservation, where only 2.34 % of its total forest area has been deforested up to 2010 [13]. However, this model impacts on the constant demographic growth of Manaus, that is, while the model is positive at the level of the state, there are immense pressures at a city level, associated with an urbanization pattern resulting from industrialization policies which do not correspond to the rate of growth in the demand for basic services and actions that can provide a good standard of living for inhabitants.

Sustainability must be analysed at various spatial and temporal levels. In the case of Manaus, it is impossible to separate out the factors determining its problems without considering actions directed towards the whole of the Amazon region. We note that the industrialization-based development model has been a driving force for Manaus, but has also resulted in a lack of enterprising capacity in the rest of the region[5]. This disparity between the state and its capital has resulted in enormous migratory pressure and a rend of population growth beyond its capacity to provide the services necessary for good living standards[6].

Becker and Stenner [5] argue that it is necessary to take advantage of Manaus' highly enterprising capacity in order to establish productive chains which can spread to the rest of the Amazon, taking into account both the vocation of the region, for example, the exploitation of its biodiversity under sustainable conditions, and the specificities of the whole biome. This can be an important opportunity, consider-

[5] "…Manaus grew tremendously, the rest of the Amazonas state emptied out. In the neighbouring municipalities you can find some types of activity that are directly linked to Manaus, but those which are more distant, they have really emptied out…". "…I think that the [industrial] centre destroyed the enterprising capacity of the rest of the state…".

[6] "…given the speed with which the city grows (…) [the great challenge] is for the public sector to grow in order to reach the same size (…), each year the peripheries grow larger, there are new districts, new urban structures…".

ing the dynamics, global insertion and enterprising capacity of Manaus, within a perspective of establishing a dialogue and direction which relate to the region's potential[7], something that the policy for industrial incentives has not managed to successfully do. Some initiatives have been introduced such as the production of tyres for two-wheel vehicles using rubber from the Amazon region. These alternatives should be part of the agenda for establishing sustainability criteria in Manaus. They should involve situations and processes where the capital city's potential drives opportunities for developing the region and does not merely increase the abyss between a modern and dynamic city and its surroundings, abandoned and deprived in terms of geopolitical processes.

2nd supposition: sustainability is not a goal which can be scientifically measured in terms of quantitative scales. Often there is no single "true" path towards sustainability, but a set of interactions whose results, depending on who is measuring, can be more or less efficient, equitable or lead to protective measures.

3rd supposition: a city-region cannot be an island of sustainability, insulated from the world around it. City-regions can be relatively autonomous, but they are steered in many ways by a global system which requires that national and global actions are connected to local and regional actions, integrating different levels and functions.

It is necessary to promote the importance of the urban context to counteract superficial concepts of sustainability exclusively based on forest conservation. It is, of course, very important to prevent deforestation; this is beyond any doubt at all. The importance of conserving natural resources, biodiversity and ecosystems is widely recognized. Furthermore, changes in the natural pattern of development of ecosystems have been associated to epidemiology, particularly in relation to emerging and re-emerging diseases [16]. This is something that is highly significant in the periphery of Manaus where the action of man on the environment creates conditions which are favourable to the proliferation of malaria and American tegumentary leshmaniasis, and which, in the case of the latter, "spill over" from the forest [8].

However, the social dimension is an essential part of sustainability, health and living standards amongst the urban population and should be part of the agenda for the Amazon region. We hope, therefore, to demonstrate that it is appropriate to discuss sustainability within the network of influences Manaus has on the surrounding region, and it is opportune to think about this network in terms of cities and their widespread influence over their territories, analysing the spatial occupation of municipalities which are associated to the resources of ecosystems and their production capacity.

Historically, the influence of Manaus over its surroundings is associated to the widespread extractive exploitation of the region allied to the ability to navigate extensive water networks which reach beyond the borders of Brazil, to Iquitos in Peru and Leticia in Colombia, for example [23]. Despite the fact that, at present, the major connections between and influence of cities in the Amazon occurs through

[7] "…In terms of the industrial complex, it is in our interest to think about existing chains and integrate them with the forest…".

roads, Manaus continues to be connected mainly through its river networks [20]; however, due to its important position it exerts great influence in the Amazon region as a whole [3].

In fact, thinking about the sustainability of Manaus requires us to consider aspects of the network of influence which the city exerts over the whole Amazon region and its dynamic process of development. An important and timely aspect of the dynamics of the territory is the international process which started in 2000 with the Initiative for the Integration of Regional Infra-structure in South America—IIRSA. Its purpose is to increase the fluidity of goods and people throughout South America by means of axes of integration and development, transforming the Amazon region into a privileged area in terms of flow, and in this way, ceasing to be the 'periphery' of the continent [23]. This initiative will certainly have a significant impact on the already privileged position Manaus occupies, although there are signs of neglect in relation to environmental and urban issues inherent to this process, threatening to exacerbate the weaknesses which are already present [24].

Final Considerations

The position of this large city within the Amazon biome leads to the superimposition of a precarious sanitary situation with environmental problems associated to the urban environment and modernization, including drastic changes to the natural ecosystems and the services they provide. This includes the specific situation of health which strongly interacts with regional dynamics, including growing migratory pressure from other areas of the Amazon region. In addition to this scenario is the specific situation of Manaus in relation to its territory, as it is strongly connected to global economic centres and is very attractive for the regional workforce who originates in areas where there are few opportunities for work and income generation.

In this way, the overall dynamics of the territory contributes to the critical sanitary conditions found in Manaus, where social determinants are superimposed on other risk factors associated to the environment. On the one hand this result directly in problems related to health and the standard of living of local inhabitants and, on the other, in the inability of essential public services to expand at a rate compatible with the growth of the city. It exacerbates the precariousness of services such as sanitation and health care which are not sufficient in face of the growth of Manaus, a major urban centre in the middle of the largest tropical biome on earth. The search for solutions for the sustainability and health of the city of Manaus warrants an analysis of its regional influence, its global connections and current policies, as well as requiring an analysis at different geographical levels such as the Amazon region, the state of Amazonas, the urban areas and the main areas occupied in the territory, their vocation, potential, weaknesses and ecological services.

Acknowledgements Fundação Oswaldo Cruz—Fiocruz (edital 01/2001 "Cidades Saudáveis"); FAPESP—Fundação de Amparo à Pesquisa do Estado de São Paulo (proc.n.2010/20899-0); and INCLINE—Interdisciplinary Climate Investigation Center/Universidade de São Paulo.

References

1. Amazonas (Estado). Sistema de Informações Governamentais do Amazonas (2010) E-SIGA. http://www2.e-siga.am.gov.br/portal/page/portal/esiga2009. Accessed 21 July 2010
2. Barreto ML, Carmo EH (2007) Padrões de adoecimento e de morte da população brasileira: os renovados desafios para o Sistema Único de Saúde. Ciência Saúde Coletiva 12(Supl):1779–1790
3. Becker BK (2004) Amazônia: Geopolítica na virada do III milênio. Garamond, São Paulo
4. Becker BK (2005) Geopolítica da Amazônia. Estudos Avançados. São Paulo 19(53):71–86
5. Becker BK, Stenner C (2008) Um futuro para a Amazônia. Oficina de textos, São Paulo
6. Browder JO, Godfrey BJ (2006) Cidades da Floresta: urbanização, desenvolvimento e globalização na Amazônia Brasileira. 1ª ed. UFAM, Manaus
7. Chaplin SE (1999) Cities, sewers and poverty: India's politics of sanitation. Environ Urban 11:145–158
8. Confalonieri UEC (2005) Saúde na Amazônia: um modelo conceitual para análise de paisagens e doenças. Estudos Avançados, São Paulo 19(53):221–236
9. Corvalán C, Briggs D, Kjellström T (2000) The need for information: environmental health indicators. In: Corvalán C, Briggs D, Zielhuis G (eds) Linkage methods for environment and health analysis—general guidelines. United Nations Environmental Programme, United States Environmental Protection Agency, Office of Global and Integrated Environmental Health of the World Health Organization, Geneva, pp 25–55
10. Franco Netto G, Freitas CM, Andahur JP, Pedroso MM, Rohlfs DB (2009) Impactos socioambientais na situação de saúde da populaçao brasileira: Estudo de indicadores relacionados ao saneamento ambiental inadequado. Tempus, Acta de Saúde Coletiva 3(4):53–71
11. Freitas CM, Giatti L (2010) L. Sustentabilidade ambiental e de saúde na Amazônia Legal, Brasil: Uma análise através de indicadores. Série Saúde Ambiental 4. Brasília: Organização Pan-Americana da Saúde
12. Instituto BdeGeE(IBGE) (2010) Censo Demográfico 2010. http://www.ibge.gov.br/home/estatistica/populacao/censo2010/sinopse/default_sinopse.shtm. Accessed 16 Aug 2012
13. Instituto NdePEspaciais(INPE) (2012) Projeto PRODES—Monitoramento da Floresta Amazônica Brasileira por Satélite. http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php. Accessed 03 Abr 2012
14. Lefevre F, Lefevre AMC (2010) Pesquisa de Representação Social: Um enfoque qualiquantitativo—a metodologia do Discurso do Sujeito Coletivo. Líber Livro Editora, Brasília
15. Oliveira JA, Costa DP (2007) A análise da moradia em Manaus (AM) como estratégia de compreender a cidade. Revista Electrônica de Geografia Y Ciências Sociales 245(30)
16. Patz JA, Daszak P, Tabor GM, Aguirre AA et al (2004) Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environ Health Perspecti 112(10):1092–1098
17. Pereira D (2005) Amazônia (In)sustentável—Zona Franca de Manaus: estudo e análise. 2ª. ed. Ed. Valer, Manaus
18. Programa dasNUnidasparaoD(PNUD) (2012) Portal ODM. http://www.portalodm.com.br. Accessed 10 Jan 2012
19. Ravetz J (2000) City region 2020—integrating planning for a sustainable environment. Earthscan Publications Ltd., London
20. Sathler D, Monte-Mór RL, Carvalho JAM (2009) As redes para além dos rios: urbanização e desequilíbrios na Amazônia brasileira. Nova Economia 19(1):11–39
21. Schramm JMA, Oliveira AF, Leite IC, Valente JG, Gadelha AMJ, Portela MC, Campos MR (2004) Transição epidemiológica e o estudo de carga de doença no Brasil. Ciência e Saúde Coletiva 9(4):987–908
22. Smith KR, Ezzati M (2005) How environmental health risks change with development: the epidemiologic and environmental risk transitions revisited. Annual Rev Environ Res 30:291–333

23. Théry H (2005) Situações da Amazônia no Brasil e no continente. Estudos Avançados 19(53):37–49
24. Vitte CCS (2009) Desenvolvimento, planejamento territorial e integração nacional: Os antecedentes, a gênese e a consolidação da Iniciativa de Integração da Infra-estrutura Regional Sul-Americana—IIRSA. In: Aragón LE, Oliveira JA (eds) Amazônia no cenário Sul-americano. Edua, Manaus, pp 191–215

Metropolitan Environmental Health: Asymmetrical Knowledge and Management in São Paulo, Brazil

Leandro Luiz Giatti, Paulo Roberto do Nascimento, Silvana Audra Cutolo, Renata Ferraz de Toledo, Giuliana Carolina Talamini, Juliane Gaviolli, Amanda Silveira Carbone, Rubens Landin and Carlos Machado de Freitas

Abstract Metropolitan areas have been seen as empty political arenas even though there is a renewed interest in discussing the need for their integrated management. In this context environmental and health issues have come into the spotlight, as political and administrative fragmentation does not assist in dealing with the spread of different pollutants which do not adhere to administrative, or even natural boundaries. This paper aims to explore the São Paulo Metropolitan Region (SPMR), Brazil, encompassing 39 municipalities, taking into account an unequal distribution of knowledge and administrative efforts in addressing environmental health issues. The study was conducted by using secondary indicators provided by public institutions and by undertaking a bibliographical review. São Paulo municipality, as the capital city, concentrates demands for environmental services as well as the need for pollution dispersion, both of which cross municipal boundaries. There is greater concentration of knowledge about the São Paulo municipality, for example the main research effort towards understanding the health impacts of air pollution focuses on its spatial limits. It also centralizes public policies to control atmospheric emissions but these cannot solve the larger, regional problem. In relation to public water supply there is a clear distinction between municipalities that have a greater demand for water and those that produce it, since the latter often present inferior economic and social conditions. This situation reveals extremely asymmetrical relations within the metropolitan space and points to the need to use strategic indicators to induce actions involving health, environment and other public administrative sectors.

L. L. Giatti (✉) · S. A. Cutolo · G. C. Talamini · J. Gaviolli · A. S. Carbone · R. Landin
Departamento de Saúde Ambiental, Faculdade de Saúde Pública, Universidade de São Paulo,
Av. Dr. Arnaldo 715, São Paulo 01246-904, Brazil
e-mail: lgiatti@usp.br

P. R. Nascimento
Departamento Prática de Saúde Pública, Faculdade de Saúde
Pública—Universidade de São Paulo, São Paulo, Brazil

R. F. de Toledo
Faculdade de Educação, Universidade de São Paulo, São Paulo, Brazil

C. M. de Freitas
Centro de Estudos de Saúde do Trabalhador e Ecologia Humana,
Escola Nacional de Saúde Pública, Fiocruz, Rio de Janeiro, Brazil

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_7,

Abbreviations

IBGE	Brazilian Institute of Geography and Statistics
EMPLASA	Empresa Paulistana de Planejamento—São Paulo Metropolitan Planning
CETESB	São Paulo State Environmental Agency
SEADE	São Paulo State Foundation for Data Analysis
SIGAM	Integrated System of Environmental Management, Environment Department, State of São Paulo

Introduction

Given there has been a renewed interest on a global scale in processes of governance in metropolitan areas, a subject which has been out of the spotlight during the last two decades as a result of a greater focus on urbanism [14], socio-environmental and health issues should now gain greater precedence because of their significance for the quality of life of people who inhabit the largest human agglomerations, that is, metropolitan regions, particularly in view of the challenges faced by developing countries [17, 29].

Although there have been a considerable number of academic studies about the management of metropolitan regions and it is acknowledged that there is a need for integration, there is still plenty of scope for establishing effective political spaces for action at a metropolitan level which are capable of promoting integrated management [15]. In Brazil, the lack of integration in terms of management between the different municipalities that make up metropolitan areas stands out. Actions on a metropolitan level are rarely implemented and can usually only be found in sectoral plans. Moreover, it is thought that some urban policies, implemented by one particular municipality, may actually harm other municipalities in the same metropolitan area, leading to conflicts [16].

The São Paulo Metropolitan Region (SPMR), similar to other large Brazilian urban centres, has grown dramatically since the 1950s. This has been accompanied by a multifarious process of peripheralization, where poverty is particularly widespread, leading to an urban fabric that is extremely unequal in spatial terms and where essential public services have not kept up with the speed with which the metropolitan area has been expanding or with the needs of its population [26].

Just as the SPMR is affected by various types of social inequalities, it is also afflicted by environmental problems and a lack of environmental services essential to life. In the region these services, provided in different forms, are distributed within the social environment in an unfair way. Moreover, individual municipal administrations do not necessarily acknowledge the dispersion of socio-environmental phenomena [30] and this represents a significant challenge for managing metropolitan areas when dealing with essential environmental health issues.

The aim of this article is to study the asymmetrical relations between the municipalities that make up the SPMR, focusing on environmental health and, in particular, the problematization and management of atmospheric pollution and issues related to water sources.

Methodological Approach

This article is based on a bibliographical and documental review as well on the collection of secondary data available from public institutions to which the framework developed by WHO—DPSEEA—was applied. It was explored interrelations between the different indicators in a larger chain of causes and consequences and in this way producing environmental health indicators [3].

In relation to the descriptive model applied our aim is to produce an analysis of the SPMR at different organizational levels. In order to do so, we have chosen to use self-organizing holarchic open systems, useful for identifying both ecological and human systems. These holarchic systems are made up of units called holons which can be applied to both the whole and its parts at the same time [13, 31]. In this analogy, each of the 39 municipalities which make up the SPMR is taken as a holon. They form units in themselves and, at the same time, together they constitute another holon, at a higher hierarchical level—the metropolitan region. Given this system configuration, innumerable interrelations are possible, leading to reciprocal interactions in different directions between holons which are contiguous or in close proximity to each other, at the same or at different levels.

A number of metropolitan environmental issues, in particular those associated to atmospheric pollution and water resources, were analysed in this paper as phenomena arising out of the inter-relationships between metropolitan municipalities; therefore, we address the complexity of environmental health situations in a dynamic way. The purpose of this analysis is to demonstrate on the one hand, the transversal nature of problems that cut across the administrative boundaries of each municipality and, on the other, to highlight the differences between these municipalities in relation to the causes of problems, the possibilities of solutions and the different conditions of vulnerability. We seek to demonstrate the relationship structure of the system and the need for integrated action in dealing with the environmental health issues at hand, thus contributing to better management alternatives in order to stimulate and promote a more desirable future [13].

The SPMR has a population of around 19.6 million inhabitants [11] distributed within an area of 7.9 thousand km^2, the largest population concentration in Brazil [6]. Its GDP was R$ 613.1 billion in 2009, that is, approximately 18.9 % of the Brazilian national GDP [19], representing the largest concentration of wealth in the country. The region is an important national and international financial centre and a hub for service provision in the areas of tourism, leisure, health and education, as well as for industrial activities [6]. The central city is São Paulo which concentrates 11.2 million inhabitants [11], besides having the biggest population this municipality exert a strong force under the metropolitan conurbation, its GDP was R$ 389.3 billion in 2009 [10], being the highest municipal GDP in Brazil.

The accelerated economic development of the last decades is reflected in the demography of the region, the demands for environmental services and pressure on the various ecosystems. Between 2000 and 2010 the population in the São Paulo Metropolitan Region grew by 10.1 % whilst the demand for the public provision of drinking water grew by 14.2 %. According to data from the *Plano de Controle de Poluição Veicular* [Motor Vehicle Pollution Control Program] of the State of São Paulo [2], there are around 7.5 million cars currently on the roads in the SPMR.

Exploring the Context and Discussing the Socio-Environmental Problems of the Metropolitan Region

First, with regard to environmental issues, it is possible to observe that the fragmentation of metropolitan regions into separate administrative units does not follow ecosystem distribution and their transition zones, or ecotones, as they are called in ecology. This lack of congruity between natural and administrative systems leads to problems concerning the resilience of urban environments in relation to ecological phenomena. However, the incorporation of concepts which can make municipal administrations compatible with, for example, human ecology concepts, can be extremely important in planning and designing the built environment [30].

Within this context, we can look at the example of rivers and their floodplains, where frequent floods can occur, significantly impacting on environmental health, both in terms of water-borne diseases and the risk of floods, landslides and material losses, as well as other issues directly and indirectly associated to health. Sometimes the river courses mark the boundary between different municipalities and they can also cut across different municipal spaces within the same metropolitan region.

For the SPMR, aggravating issues are regional climatic factors, proximity to the coast, its plateau topography, as well as heat islands which may be causing an increase in daily precipitation in the form of extreme rain. These tend to occur more intensely in the hottest parts of the urban region, that is: in areas of greater population density which are paved and have less green space available [5]. Analysing this peculiarity at a metropolitan level, we can infer that the spatial distribution of heat islands and the predominance of winds carrying humidity are factors which affect whole areas of metropolitan occupation and are not necessarily confined to a particular municipality within the territory.

In the SPMR there is a shortage of water resources to supply the population adequately. The Alto Tietê water basin, a region of river headwaters, which makes up a large proportion of the territorial area of the Metropolitan Region of São Paulo, is faced with conflicting demands which are becoming more and more accentuated. On the one hand, there is an increase in the demand for public water supply, and on the other there is pressure for soil occupation of watershed areas which are ex-

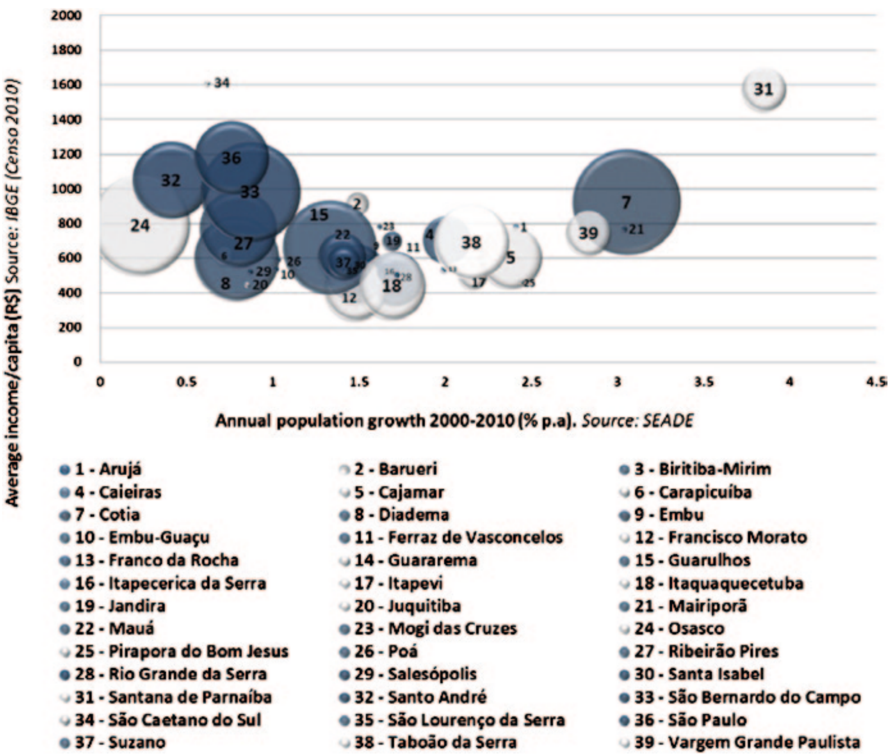


Fig. 1 Distribution of Municipalities in the SPMR by annual population growth rate between 2000 and 2010 (SEADE, 2012) and average household monthly income/capita 2010 [11], with the proportion of households in clusters of subnormal conditions 2010 (*bubble area*, Source: [11]) and the presence of Protected Watershed Areas (*dark bubble*, Source: [28])

tremely important for water provision. The high population growth rate in the area compromises future water production [27].

When analyzing social indicators and the demand for water provision in the SPMR, it is observed that the municipalities with the largest watershed areas, situated in the furthest limits of the region, have the lowest HDIs and the lowest rates of water consumption per capita/day. Whilst the more central municipalities, such as the city of São Paulo, have better HDIs and higher rates of water consumption, they also have a larger population resulting in a much higher demand for water resources [4].The issue of water shortage is also an illustration of the metropolitan dimension and reveals the limitations related to municipal fragmentation. It also exposes the asymmetric relations within the metropolitan region.

Figure 1 illustrates some of the inequalities between municipalities with a large proportion of their territory in protected watershed areas (represented as dark bubbles) and other municipalities in the metropolis. We note that while watershed municipalities are not alone in presenting high rates of population growth during the 2000–2010 period, they have the largest proportion of inhabitants living in clusters of subnormal conditions (largest bubbles). When aggregating this information with the fact that these municipalities have average incomes in comparison with the rest of the metropolitan area, we can infer that watershed municipalities are areas of high social inequality where pockets of poverty prevail.

Another fact associated to the environmental health of the metropolitan area is the emission of atmospheric pollutants, since their dispersion clearly does not respect municipal boundaries. For instance, a municipality which emits more pollutants in the air, soil or water may not be the one with the largest proportion of its residents exposed to these threats.

In the SPMR, an extremely important factor for the dispersion of pollutants is the circulation of air, in particular sea breezes. These are significantly impacted upon by the topography, in particular the Serra do Mar, Serra da Mantiqueira and Serra da Cantareira mountain ridges. However, the islands of urban heat are also very significant in relation to the air circulation dynamics, intensifying convergence points in the centre of the city and other areas affected, where pollutants re-circulate [7].

During the analysis of academic studies related to health and atmospheric pollution a significant number of published articles in international journals relating to the São Paulo Metropolitan Region and the city of São Paulo were identified. For example, when searching on Web of Knowledge [32] and putting terms such as "air pollution" and "health" in the topic box and adding "São Paulo" in the title of articles, a list of 40 publications appeared. When refining our search by adding the term "metropolitan" to the topic box, we found a list of seven articles, as follows: [1, 8, 18, 21, 23–25].

Prominent among these studies is the use of data on atmospheric pollution produced by CETESB, which come from a monitoring network using units spread throughout the most densely urbanized areas of the metropolitan area, in particular, the city of São Paulo and adjacent areas [1].

There were only three articles which addressed the link between pollutants and health [21, 23, 24]. These studies used morbidity and mortality rates referring only to the city of São Paulo. It can be generally inferred that there are a number of difficulties with these types of studies in dealing with the issue on a metropolitan level. It can also be assumed that data in the information systems relating to the city of São Paulo are of a higher quality, thus providing a better opportunity for making a comparative analysis with pollution data. Furthermore, the choice of the central city as the unit of analysis is probably affected by the fact that the state's pollution monitoring network favours this centrality. In any case, it is worth noting that atmospheric pollution is not exclusively confined to the city of São Paulo. Moreover, emissions from other municipalities are also mainly concentrated in the conurbation space between municipalities. It is therefore crucial that public policies address this issue at the metropolitan level.

In relation to the control of atmospheric pollution resulting from motor vehicle emissions, the Resolution by the National Council for the Environment which established the Motor Vehicle Air Pollution Control Program—PROCONVE—was approved in 1986 and resulted in the progressive restriction of new motor vehicle pollution emissions at a national level.

The São Paulo State Department for the Environment established an initiative in the SPMR of rotation of motor vehicle usage for the winter months which is the period more susceptible to higher levels of pollutant concentration. It was first established experimentally in 1995 and was subsequently made compulsory between 1996 and 1998. On a rotational basis vehicles were not allowed to circulate in the designated zone on a specific day. This measure was unpopular and polemical. However, it resulted in the reduction of some pollutants and also in an improvement in the circulation of urban traffic. It could be said that this measure was implemented in a "metropolitan" way, as in 1996 it counted with the participation of ten SPMR municipalities. However, its implementation did not receive strong support at a municipal level [12].

Ribeiro e Assunção [22] argued that even with the constant increase in the total vehicle fleet, this and other atmospheric pollution control measures contributed towards a reduction in the levels of some pollutants such as sulphur dioxide, nitrogen oxide and a decrease in the number of critical episodes of high levels of carbon monoxide between 1975 and 2000. However, these authors stressed the fact that atmospheric pollution continues to be a significant issue in relation to public health in São Paulo.

The latest development with regard to controlling atmospheric pollution from motor vehicles within the SPMR is only being implemented by the municipal administration of the city of São Paulo. This is a motor vehicle inspection and maintenance program which became compulsory in 2010 for all motor vehicles in the city [20]. This measure can be considered to be an important development, but up to 2012 this had not yet been adopted by any other municipalities in the SPMR and therefore cannot be considered an action that is compatible with the magnitude of the problem.

Poverty is an important social determinant of health and it is also associated to environmental degradation and its respective impacts on quality of life. Thus, the process of spatial distribution of poverty within the urban fabric of the SPMR can result in the aggravation of common environmental health problems. For Smith and Ezzati [29] it is precisely the excluded urban population groups in developing countries that suffer from the superimposition of the burden of environmental risk factors. Poor people in the metropolitan region are vulnerable at the level of the household (precarious water and sewage systems, malnutrition and precarious housing), at community level (atmospheric pollution, risk of traffic accidents, occupational risks) and at the global level (within the context of climate change in relation to a greater incidence and seriousness of extreme events associated to disasters as they occupy areas of greater susceptibility, although these risks are not exclusively associated to poverty). Nevertheless, poverty also transcends metropolitan administrative boundaries, that is, some *favelas* (slum areas), for example, cross municipal borders. It is also the case that soil occupation and housing policies in a particular municipality can have adverse effects on contiguous or other municipalities in close proximity [16].

A systemic vision of metropolitan areas is needed to deal with these issues and in order to understand and manage socio-environmental phenomena associated to health. Generally speaking, when analyzing the magnitude of the situation and exploring what lies behind ecological phenomena which determine environmental risks, we are obliged to expand our way of perceiving the metropolitan region, especially in relation to the size of urban areas. At this level, we are able to discuss in a more synthesized and objective way aspects of sustainability in the social, environmental and economic fields.

However, a systemic approach requires greater depth and with regard to the social dimension, for example, it is essential to analyze and take into account political factors, which presupposes giving precedence to administrative, democratic and decentralizing processes.

Therefore, it is not possible to deny that from both a political and democratic viewpoint the separation into different municipalities is a positive step towards autonomy in local management. In view of this, the challenge is to both strengthen municipal autonomy and address metropolitan issues which require integrated intervention on a metropolitan scale, given the fact that socio-environmental issues often transcend and disregard municipal boundaries.

Final Considerations

Socio-environmental and health issues in the SPMR allow us to observe that there is a need for a transversal approach in relation to knowledge production and its application to management. This should be conducted in an inter-sectoral manner, acting across the metropolitan unit as a whole, where its objective should be the health of the population. This approach must be systemic in order to analyse problems and possible solutions, taking into account both the size of the metropolitan area and the fragmented administrative structure of different municipalities. It must therefore overcome various asymmetric relationships which may be identified within this context, such as:

1. The need to focus on monitoring environmental health and the ability to draw up policies and management tools, as shown here in relation to atmospheric pollution in the city of São Paulo. In fact, the asymmetries revealed in relation to the central city must be explored, as its development is based on demands for the resources of surrounding municipalities;
2. In relation to the peripheral municipalities there is less monitoring data available. They also have a lower institutional capacity to draw up policies and management tools, although they may be affected to the same or even a higher degree by environmental and health problems of a metropolitan nature and scope. For example, an aggravating factor is that there is a greater percentages of excluded population in these areas, offering higher vulnerability;
3. The issue of peripheralization of the worst social, and water and sewage indicators, and the recent higher rates of population growth, means that controversially

the municipalities with the worst living conditions provide essential environmental services to the metropolitan area, such as water supply;

4. The polarization exemplified by the municipality of São Paulo and, particularly, the magnitude of its demands, its role in the degradation of ecosystems and services and, most importantly, its institutional capacity to provide answers to problems, means these challenges must be seen as an opportunity for implementing policies and management tools which should be expanded to the entire metropolitan region.

By using a systemic model of analysis, particularly with regard to the loose hierarchical organizational structure [13] of the metropolitan region and its municipal members, it is possible to analyse, for example, the vulnerability of the system: if a particular watershed municipality, let us say Mairiporã, where around 50 % of the water supply for the metropolitan region flows, is affected by an urgent and serious problem of water resource contamination, it could threaten the whole metropolitan region.

Another relevant example is the application of atmospheric pollution control measures, which are only rigorously enforced in the city of São Paulo, thus failing to address the problem in its entirety. Often, metropolitan issues are dealt with in quantitative terms, relative to the size of the population, the size of the urban area, ecological footprints, pollutant emission amounts and so on. Another way of looking at this is to apply a transversal approach to issues of environmental health which must have both a metropolitan scope and, most importantly, allow for and stimulate the integration of municipal management which is conducted in an autonomous manner. Indeed, we are not dismissing the importance of a democratic concept of autonomy, since it can and must be put into practice. However, it must be conducted in an integrated way, taking into account sustainability and according to the complexity of metropolitan problems.

Acknowledgements FAPESP—Fundação de Amparo à Pesquisa do Estado de São Paulo (proc.n.2010/20899-0); and INCLINE—Interdisciplinary Climate Investigation Center/ Universidade de São Paulo.

References

1. Bravo MA, Bell ML (2011) Spatial heterogeneity of PM10 and O3 in Sao Paulo, Brazil, and Implications for human health studies. J Air Waste Manage Association. 61(1):69–77 (Jan)
2. Companhia Ambiental Do Estado De São Paulo (CETESB) (2011) Plano de Controle de Poluição Veicular do Estado de São Paulo, 2011–2013. http://www.cetesb.sp.gov.br/userfiles/file/noticias/PCPV.pdf. Acessed 16 Aug 2012
3. Corvalan C, Briggs DJ, Kjelstrom T (2000) The need for information: environmental health indicators. In: Corvalan C, Briggs DJ, Zielhuis G (eds) Decision-making in environmental health: from evidence to action. SPON Routledge, London, pp 25–55
4. Cutolo SA, Talamini GC, Gaviolli J, Giatti LL (2011) Contribuição ao estudo interdisciplinar de situações e conflitos na Bacia do Alto Tietê. Paper presented at the 3rd International Meet-

ing on Governance of Water: interdisciplinary challenges. University of São Paulo, 07–09 Nov 2011
5. Dias MAFS, Dias J, Carvalho LMV, Freitas ED, Dias PLS (2012) Changes in extreme daily rainfall for São Paulo, Brazil. Climate Change (June) doi:10.1007/s10584-012-0504-7
6. Empresa, Paulista de Planejamento Metropolitano S/A, (EMPLASA) (2011) Por Dentro da Região Metropolitana de São Paulo, 2011. http://www.emplasa.sp.gov.br/portalemplasa/index.asp. Acessed 16 Aug 2012
7. Freitas, ED (2003) Circulações locais em São Paulo e sua influência sobre a dispersão de poluentes. Doctoral Thesis, Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, São Paulo. http://www.teses.usp.br/teses/disponiveis/14/14133/tde-16032006-160700/. Acessed 16 Aug 2012
8. Fundação Sistema Estadual de Análise de Dados (SEADE) (2012) Informações dos Municípios Paulistas. http://www.seade.gov.br/produtos/imp/index.php?page=consulta & action=var_list & tab s=1 & aba=tabela3 & redir= & busca=Taxa+de+Crescimento+da+Popula%E7 %E3o. Acessed 31 Aug 2012
9. Guardani R, Nascimento CAO (2004) Neural network-based study for predicting groundlevel ozone concentration in large urban areas, applied to the Sao Paulo Metropolitan Area. Int J Environ Pollut 22(4):441–459. doi:10.1504/IJEP.2004.005680
10. Instituto Brasileiro de Geografia e Estatística (IBGE) (2011). Produto Interno Bruto dos Municípios 2005–2009. Rio de Janeiro: IBGE, 2011
11. Instituto Brasileiro de Geografia e Estatística (IBGE) (2010) Censo Demográfico 2010. http://www.ibge.gov.br/home/estatistica/populacao/censo2010/sinopse/default_sinopse.shtm. Acessed 16 Aug 2012
12. Jacobi P, Segura DB, Kjellén M (1999) Governmental responses to air pollution: summary of a study of the implementation of rodízio in São Paulo. Environ Urban 11(1):79–88. doi:10.1177/095624789901100117
13. Kay JJ, Regier HA, Boyle M, Francis G (1999) An ecosystem approach for sustainability: addressing the challenge of complexity. Futures 31(7):721–742. doi:10.1016/S0016-3287(99)00029-4
14. Klink J (2010) A reestruturação produtivo-territorial e a emergência de uma nova agenda metropolitana: o panorama internacional e as perspectivas para o caso brasileiro. In: Klink J (eds) Governança das metrópoles: conceitos, experiências e perspectivas. Annablume, São Paulo, pp 7–17
15. Lefèvre C (2009) Governar as metrópoles: questões, desafios e limitações para a constituição de novos territórios políticos. Cadernos Metrópole, São Paulo, 11(22):299–317
16. Maricato E (2011). Metrópoles desgovernadas. Estudos Avançados, 25(71):7–22. doi:10.1590/S0103-40142011000100002
17. McMichael AJ (2000) The urban environment and health in world of increasing globalization: issues for developing countries. Bull World Health Organ 78(9):1117–1126
18. Miraglia SGEK (2007) Health, environmental, and economic costs from the use of a stabilized diesel/ethanol mixture in the city of São Paulo, Brazil. Cad. Saúde Pública (online) 23(4). http://www.scielosp.org/scielo.php?script=sci_arttext & pid=S0102–311X2007001600016 & lng=en. Acessed 16 Aug 2012. doi:10.1590/S0102-311X2007001600016
19. Parlamento Metropolitano (PARLAMET) (2012) Boletim Metropolitano de Conjuntura Social e Econômica. Consultoria Técnica de Economia e Orçamento—CMSP, 2012. http://www2.camara.sp.gov.br/CTEO/Boletim-RMSP08-jan12.pdf. Acessed 16 Aug 2012
20. Prefeitura Municipal São Paulo (2009) Portaria nº 147/SVMA-G/2009. Published at Diário Oficial da Cidade de 18/11/2009, fls. 25
21. Ribeiro H, Assunção JV (2001) Historical overview of air pollution in Sao Paulo metropolitan area, Brazil: influence of mobile sources and related health effects. In: Urban Transport VII: Urban transport and the environment in the 21st Century. Wit Press, Boston, pp 351–360
22. Ribeiro H, Assunção JV (2006) Transport air pollution in São Paulo, Brazil: advances in control programs in the last 15 years. In: Basbas S (ed) Advances in city transport: case studies, 1st ed. WIT Press, Southampton, pp 107–125

23. Saldiva PH, Lichtenfels AJ, Paiva PS et al. (1994) Association between air-pollution and mortality due to respiratory diseases in children in São Paulo, Brazil: a preliminary report. Environ Res 65(2):218–225
24. Saldiva PH, Pope CA, Schwartz J, Dockery DW, Lichtenfels, AJ, Salge JM, Barone I, Bohm GM (1995) Air pollution and mortality in elderly people: a time-series study in São Paulo, Brazil. Arch Environ Health 50(2):159–163
25. Sanchez-Ccoyllo OR, Martins LD, Ynoue RY, Andrade MF (2007) The impact on tropospheric ozone formation on the implementation of a program for mobile emissions control: a case study in Sao Paulo, Brazil. Environ Fluid Mech 7(2):95–119. doi:10.1007/s10652-007-9018-7
26. Santos M (2009) A urbanização brasileira, 5th ed. EDUSP, São Paulo
27. Silva RT, Porto MFA (2003) Gestão urbana e gestão das águas: caminhos da integração. Estudos Avançados 17(47):129–145. doi:10.1590/S0103-40142003000100007
28. Sistema Integrado de Gestão Ambiental (SIGAM) (2012) Secretaria de Meio Ambiente do Estado de São Paulo—SMA/SP. Mapa das Áreas de Mananciais da Região Metropolitana do Estado de São Paulo. http://sigam.ambiente.sp.gov.br/sigam2/Default.aspx?idPagina=5484. Accessed 31 Aug 2012
29. Smith KR, Ezatti M (2005) How environmental health risks change with development: the epidemiologic environmental risk transitions revisited. Annu Rev Environ Resour 30:291–333. doi:10.1146/annurev.energy.30.050504.144424
30. Steiner F (2004) Urban human ecology. Urban Ecosys 7(3):179–197. doi:10.1023/B:UECO.0000044035. 22316.d1
31. Waltner-Toews D (2001) An ecossystem approach to health and its applications to tropical and emergin diseases. Cad Saúde Pública 17 Suppl:7–22; discussion 23–36
32. Web of Science (2012) All databases search (webpage—online). http://apps.webofknowledge.com/UA_GeneralSearch_input.do?product=UA & search_mode=GeneralSearch & SID=4CHJbpe4I19P4aji6Gf & preferencesSaved=. Acessed 17 April 2012

Will there be any Space for Private Parking in our Future City Centers?—The Growing Conflict Between the Human Beings' Desire for Free Mobility and the Politicians' and Authorities' Increasing Wish of Controlling Mobility Management

Paul G Höglund and Susanne Ydstedt

Abstract This paper will deal with what will happen to private parking in the future if the ongoing trend will continue. We are today experiencing an increasing conflict between individual mobility and politicians' and authorities' increasing wish of controlling mobility management. Even if recommendations like in the EPOMM Project (European Commission. EPOMM Project, European Platform on Mobility Management, ongoing project and ECOM, European Conference on Mobility Management, annual meeting event. Brussels, Belgium), to *"make mobility environmental friendly, socially just and economical"*, the general society tends to be more and more reluctant to provide sufficient parking space in cities, both centers and outskirts, than needed for both daily living, working and commercial activities. As conclusion the paper finds it remarkable, that the total amount of cars as well as the private car ownership grows constantly the world over at the same time as the parking possibilities are generally reduced. *Where should we park our cars in the future?*

Introduction

General Problem Description

The paper will discuss the general reduction of Parking Standards and mobility management policy matters, based on a survey made in Sweden by the authors [2] and compare the Swedish domestic situation with international state of the art

P. G. Höglund (✉)
Transforsk-Transearch, Solna, Stockholm, Sweden
e-mail: pghoglund@telia.com

S. Ydstedt
Scantech Strategy Advisors, Malmö, Sweden
e-mail: susanne@scantechab.se

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_8,

and common practice. European Commission Sixth Framework Program Research Projects [3, 4] have dealt with mobility matters as well as specific parking limitations for reducing the free mobility. Also the European Commission White Paper on European transport policy for 2010: time to decide [5] is writing regarding mobility policy matters in a positive way and recommends direct measurements for a balanced future mobility. *"Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel"* and *"Curbing mobility is not an option"*.

Brief Summary and Findings

As conclusion the paper finds it remarkable, that the total amount of cars as well as the private car ownership grows constantly over the world at the same time as the parking possibilities are generally reduced. Where should we park our cars in the future? How will the society handle the human wishes of a free choice of transportation for facilitating all human needs and contact developments, both private relations and an efficient working environment? This contradictory situation will naturally require a lot of parallel measures such as technical development and policies for a more efficient land use. *"Because of using the car is seen as a right and, in some cases, it is a necessity, in a first step to sustainable mobility, any transport policy has to be aware of the sensitivities and the needs of drivers"* [6]. To find a possible equilibrium for parking with maintained freedom of mobility is one of the biggest challenges for the future transportation system at large.

Problem Structuring

Overview and Facts Finding

The magnitude of the total problem area, described in chapter "Introduction" above, is vast. Therefore part boundary definitions and part solutions will be needed. It is essential that useful information with sufficient accuracy for decision makers can be obtained within reasonable cost limits. The specific problems here described require much basic research for finding a possible way of making a synthesis and recommendation for future handling of parking issues with maintained mobility for the society at large.

Legitimate wishes for a general mobility, parking possibilities adjacent to private housing and also an accessibility to activities within the urban areas and city centers, make the balance between the reduction of the totally available parking spaces and the individual needs a very great problem. The most crucial problem is thus *the general wish of authorities to reduce parking standards and minimizing the areas for private parking.*

Because of the lack of existing knowledge and facts as base for the decision making process a lot of research is required. Very parsimonious knowledge exists regarding the various aspects of vehicle parking and environmental effects in the technical field as well as in the social and human behavior aspects. This requires an interdisciplinary approach to this challenging area for research, development and more directly, also practically implemented surveys and field studies.

Specific Problem Description

What is the real problem? If we look upon the issue in a simple and practical way we could make a general problem description as follows:

- To use an own vehicle is not only a practical and easy way of facilitating daily life and necessary
- Transport, but it is also a psychological and emotional issue enhancing the individual feelings of
- Freedom
- Global increase of private car ownership
- Less space in overcrowded cities and less land area to use for open space parking
- Land use problems are increasing because of change in architectural preferences and a more
- Dense city planning

What Happens When Parking Spaces are Reduced?

What will be the real practical result if political interference, mobility management and legislation reduce available parking space? We need a lot more practical knowledge regarding the effects of reduced parking standards and the authorities' violation of already existing and decided parking standards. Most probably we will have an increase of *search traffic* in the street network, and that will have substantial negative effects, such as:

- Traffic delays
- Psychological effects (irritation etc.)
- Increased air pollution
- Public demand for increased infrastructure

There will therefore be a need for more technical studies of the various ways of parking habits and parking establishments. The lack of parking space in central urban areas will certainly also create a demand for parking solutions with a heavy concentration of parking spaces on small horizontal areas, but with a larger spread in the vertical direction, e.g. underground parking garages and parking houses in many floor levels [7].

Table 1 Differences in emissions of CO, NOx, CO_2 and fuel consumption when parking at a given garage compared with curb side parking. The obtained results are from a specific case study under given specific assumptions

	CO g/vhl	NOx g/vhl	CO_2 g/vhl	Fuel cons. g/vhl
Parking in garage	4.00	0.14	149	73
Parking at curb side	6.70	0.25	267	130
Difference in g/vhl	2.70	0.11	118	57
Difference in %	40.3	44.0	44.2	43.3

This special problem area has until now been given little special scientific attention within the international research community as well as among consulting engineers, urban planners and decision making politicians. The main goal with this paper is not to give a description of how to make research of the effects of increased search traffic, but just to try to give an overview and general picture of the problem area.

In order to get the required overview of the here described problem area of a hypothetically increased search traffic it is essential both to obtain existing data and information as well as to use creative thinking and a use of calculating methods and models for e.g. emission and concentration estimations. Also other methods as trip length studies, travel habit surveys and general travel and parking demand modelling could be used. There are nowadays a lot of ordinary network traffic assignment models including micro model description of search traffic for free parking space in parking establishments.

An interesting conclusion here is that the amount of search traffic models and calculating methods for assumed situations are constantly increasing [8–13]. On the other hand real surveys and before and after studies, showing and describing real facts of what happens when parking spaces are reduced are very difficult to find. If it could be proved that search traffic increases in a significant way, if private parking spaces are taken away, it will be an indication that human beings desire for free mobility is definitely in conflict with reduced parking standards. Here we recommend a research area, which would be a balance to all efforts in research concentration on mobility management.

Swedish Study on Curb Side Parking Compared with Parking Garage

Here will only be given a short example of a survey made in 2002 [14] regarding differences in environmental effects from parking in streets compared with parking in a parking garage. The aim of this paper is not to give a detailed description of any particular model or research methodology, but to give a general overview of the air quality aspects within the research area “Parking and Environment”. The survey results were given as an indication of the magnitude of the differences in emission levels, which can be obtained under the given assumptions. The results are site specific, and it was difficult to generalize the result at the stage of the model development.

The crucial part of the modelling is the searching behaviour. The direct emission calculations are done with a sufficient accuracy for comparative emission calculations. For the studied, specific parking garage the comparisons between parking in the garage and parking at the curb side in the neighborhood of the garage are shown in the table below. The calculations are done for the same amount of cars entering a certain area from the same entering points. Calculations are based on individual vehicle driving patterns related to cars, either searching for free parking spaces in distributed parking alongside the streets (curb side parking) or driving straight to the entrance of the parking garage.

The study described above only gives an example of negative environmental effects that can be estimated if the search traffic increases in the streets because of a lack of sufficient parking space. This survey gives a result of modeling a hypothetic situation with given assumptions. It is very difficult to find any research done on real cases, where the effects on search traffic have been studied after a real reduction of the parking standards have been done.

Swedish Study on the Reduction of Parking Standards

Overview of the Swedish Survey and Report

In Sweden it has recently been published a study regarding the present ongoing reduction of parking standards in the three biggest cities Stockholm, Gothenburg and Malmo [2]. When parking issues nowadays are discussed in Sweden it is mostly for actions in order to get fewer parking spaces and not more. Accepted and decided parking standards are neglected when planning for new residential areas and the shopping and commercial activities are moved to the outskirts. This happens at the same time as politicians are speaking about lively and attracting city centres. The parking fees are raising, and the authorities claim that the car use must be reduced because of various reasons. All together there is a very obvious trend against the private use of cars within cities. As a practical reality there is in Sweden today a parking standard of 1.0 parking places per flat, but this is now abandoned, and specific decisions are taken for all new construction areas. The present political reality is that nobody will take the lead for more parking spaces, but there is a great consensus for using the free space for living houses, pavements, bicycle routes etc., i.e. areas with "High Environment Profile" with low Parking Standard (amounts of parking places). The same situation exists in all the larger Swedish cities, such as Stockholm, Gothenburg and Malmo etc.

Parking Standards are sometimes discussed in connection with town and city planning. The opinion of one political side (opposition) is that reduced Parking

Standards give less construction costs. Environment and public transport should have priority before private car use. The ruling political opinion is that parking is a matter totally within the planning monopoly for the different communities. General importance of sufficient parking is not discussed.

On the other hand very seldom the car users themselves are taken in consideration. Here there is a total discrepancy between all statements from the European Commission regarding a free mobility. It is here worth to repeat again, what is said in the Introduction to this paper about the mobility policy matters. European Commission White Paper on European transport policy for 2010: time to decide [5] is writing regarding free mobility and recommends direct measurements for a balanced future mobility. *"Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel"* and *"Curbing mobility is not an option"*.

The Swedish survey finds that the overwhelming amount of stakeholders and actors within this area of parking issues are negative to sufficient parking space. Among those, who are expressing negative views are government organizations such as research institutes, city and town authorities, politicians and also other groups and extremists outside the ordinary democratic decision making procedures. The only stakeholders that are positive to maintained parking space and car use are the commercial and shopping interests.

Politicians are arguing for reducing the car use and traffic within city centers, but they are not so often forbidding car parking in streets. Instead the parking standards are reduced, which leads to a worse parking situation and crowded city traffic. Increased traffic and parking problems then lead to an even more reduced parking standard, and we have then got a real vicious cycle. In Sweden this attitude towards parking is not only a problem within the biggest cities Stockholm, Gothenburg and Malmo, but is also inspiring the smaller cities and towns to act in the same way. Not because it is necessary for traffic congestion reasons, but more for ideological political reasons.

Arguments Against Parking

There are many arguments which are used against parking. Arguments such as "cars are only used by rich people" and that "cars are used by middle aged white men" are not very serious but often used in political debates. Environment issues are not used so often directly against parking, but as a logical chain description. If parking is enough expensive and/or places are difficult to find, less people will use the car, and then it is good for the environment.

Mobility management is often used as a tool for achieving the political goals of reducing parking. Instead of trying to find a realistic balance between wishes of a free mobility and the possible satisfaction of parking needs, mobility management is a very popular way in Sweden for obtaining certain political goals. It is not very common in present political debate to stress the need of private transportation for shopping, taking children to school, leisure travel and use of private cars for a free mobility and facilitating an efficient use of own free time etc. Here the only supporters are Swedish commercial associations, shop owners, owners of parking establishments etc, who feel that their interests are at stake.

We will here try to sum up the more negative aspects and arguments which are used in the general debate regarding parking today. The Swedish survey has found and classified some frequently used argument against parking, which are given as a summary below:

- Social class, sex (gender) and status
- Negative environmental effects
- Mobility management and so called sustainable use of private cars
- Unfair distribution of financial resources
- Congestion and general traffic problems
- Young people cannot afford cars and therefore will housing areas for students be too expensive with high parking standards

Arguments for Parking

There are not as many arguments which are used supporting parking as it is against. There are not many stakeholders involved in the debate who wants to have maintained or higher parking standards. The Swedish survey found that the most used arguments were here the attractiveness of the city centre. A sufficient amount of parking space could increase the attractiveness, growth and also the tourism for the cities. Here again comes the argument against search traffic and thus sufficient parking space could be detrimental for the environment. A few politicians even claimed that the private car will still be a very important part of our total transportation system also in the future. Thus the private car should be given a place within future infrastructural developments and residential areas.

We will here now also try to sum up the more positive aspects and arguments, which are used in the general debate regarding parking today. The Swedish survey has found and classified some more often used argument supporting parking, which are given as a summary below:

- Attractiveness and growth
- The private car is needed, also in the future for satisfying the needs of the human beings
- Lively and interesting, attractive city centres
- Special need for older people, handicapped people, families with children etc.
- Technical development of vehicles makes cars more environmental friendly in the future, but those (electric) vehicles need more parking space for charging stations etc
- Sufficient and balanced parking space will minimize search traffic, traffic congestion and accidents, which is environmentally friendly and promoting general health

Analysis of Survey Results

In Sweden you can generally say that parking is considered a problematic issue. The survey result shows that there are a considerable and overwhelming part of the stakeholders that have this negative approach to parking, and generally all types of parking, which shows that those people are generally against private cars and a free mobility.

This is somewhat extreme in an overall international perspective. Even in USA there is criticism against large parking areas, but that is generally compensated with a positive view for parking establishments in parking garages and parking houses [15]. Parking establishments can here even be discussed from a more sociological perspective where the private parking area is regarded as a demonstration of personal power and integrity [16]. This does not mean, though, that parking in general is considered as negative.

In Sweden it seems that the parking matters are a key issue for politicians, authorities, employees in cities and communities, organizations, institutes, researchers etc., but also for groups outside the ordinary democratic debate. All the people who are really those who should be involved, i.e. the owners and users of the private cars, are very seldom mentioned in this debate and asked for opinions in the ongoing discussions. It seems that this debate is more satisfying the opinions of the people who are leading the debate, and which should have a "higher goal" for the society. The goal definition could here be everything from environment to social class, gender and all kinds of ideological and political opinions.

The general opinion in Sweden seems to be that a reduced parking standard could eliminate the private use of cars, both the real possibilities for car use and also the public wish of using it. Mobility management is here used in a more and more frequent manner for achieving goals without involvement from the care users themselves. The general trend is here to bypass and avoid following already decided parking standards when planning and constructing new private residential areas. Investors and developers of such areas are positive to the decreased amount of parking space they have to provide because of reduced investment costs.

Commercial interests and developers of shopping areas, both in city centres and in the outskirts, are naturally positive to parking areas at streets as well as in parking establishments. But those parking areas should have restrictions for obtaining only short term parking, both high pricing and forbidding long term parking. That eliminates those parking areas for private parking for other reasons than shopping and short timer activities.

The Swedish survey has shown the existence of a more refined way of forcing away private cars from the city centres. The continuing cut of parking standards, and a general reduction of parking space as used in the three biggest cities in Sweden, Stockholm, Gothenburg and Malmo, has been taken as a new standard also for smaller Swedish cities and towns. What is happening and done in the city centre of Stockholm has been taken as a precedent for actions in smaller communities without any real parking problems.

Summing up what is said in this chapter, the politicians in Sweden mostly want to see car free city centers, but they dare not to totally forbid parking in streets. Therefore they try to cut parking standards and reduce parking. In this way they can obtain their goals and intentions. As said above, this will give increased search traffic and traffic congestion and environmental problems. Then this will motivate an even harder regulation of parking and reduction of parking standards. Here we then have got what can be considered a "vicious cycle".

International Comparisons

When you do a literature search regarding the problems this paper is describing, you will find that the major part describes opinions and trend like the result found after the Swedish survey, i.e. that the general opinions are positive to cutting parking standards and reducing parking space for the private car owners. But there are a lot of papers and literature that has a more modified view of parking issues than the present trend in Sweden.

One of the most comprehensive reports regarding European parking issues, Parking Management Strategies and also Mobility Management etc. is the ITDP Report from 2011, Europe's Parking U-Turn: From Accommodation to Regulation [17]. This report gives a very good picture of what is going on in Europe in order to reduce Parking Standards and parking space. The report also gives an overview of many case studies from European cities. As the report contains so much information of relevance to the here presented paper, the Executive Summery will here been given below. Text in Italics is marked by the author to this paper.

"This paper (*the ITDP Report*) reviews *successful parking practices in European cities*. Parking management is a critical and often overlooked tool for achieving a variety of *social goals*. For much of the twentieth Century, cities in Europe, like cities in the rest of the world, used parking policy mainly to encourage the construction of additional off-street parking, hoping to ease a perceived shortage of parking.

In the last few decades a growing number of European cities have led the world in changing the direction of parking policy. European citizens grew tired of having public spaces and footpaths occupied by surface parking. Each parking space consumes from 15 m^2 to 30 m^2, and the average motorist uses 2–5 different parking spaces every day. In dense European cities, a growing number of citizens began to question *whether dedicating scarce public space to car parking was wise social policy*, and whether encouraging new buildings to build parking spaces was a good idea. No matter how many new parking garages and motorways they built, the traffic congestion only grew worse, and as much as 50 % of traffic congestion was caused by drivers cruising around in search of a cheaper parking space.

In the cities reviewed here, parking policy has been reoriented around alternative social goals. Some recent parking reforms are driven by the need to comply with EU ambient air quality or national greenhouse gas targets. Other new parking policies are part of broader mobility targets encouraging reductions in the use of private motor vehicles. While London, Stockholm, and a few other European cities have managed to implement congestion charging to reduce motor vehicle use, more are turning to parking.

Every car trip begins and ends in a parking space, so parking regulation is one of the best ways to regulate car use. Vehicles cruising for parking often make up a significant share of total traffic. Other reasons for changing parking policies were driven by the desire to revitalize city centers and repurpose scarce road space for bike lanes or bike parking. The amount of parking available in a city is heavily influenced by public policy. On-street parking is governed by municipal or district policy, and off-street parking is generally controlled through zoning and building regulations. These are ultimately political questions: how much parking is built in new buildings, and how much public space should be dedicated to motor vehicle parking as opposed to other uses. The impacts of these new parking policies have been impressive: revitalized and thriving town centers; significant reductions in private car trips; reductions in air pollution; and generally improved quality of life. Progress in Europe on parking reform should not be overstated. Most cities still impose minimum parking requirements on developers, and few cities have imposed maximum parking requirements. While a growing number of cities have mandated charges for both on- and off-street parking, they generally charge rates that are too low. The most innovative European parking practices are discussed below as actionable measures that can be applied by any city government depending on their short- and long term goals."

As mentioned before it is difficult to find literature that supports the views and the needs of the private car owners. Mobility Management literature and papers are more easy to find. A few examples will be given here. Mobility Management is often defined as a tool for "promoting sustainable transport by *changing the attitudes and behavior of travelers*, either "Soft Measures" through information and education, or "Hard Measures" by creating new infrastructure, public transport and *parking restrictions*.

One of the most well known Mobility Management Projects is the European Commission MOST Project, Mobility Management Strategies for the next decades [4]. The results and statements from the MOST Mobility Management project are given below. The abbreviation MOST means *MO*bility management *ST*rategies for the Next Decades.

- Being mobile is an essential feature of modern life in Europe. People need to travel for work, for business, to get to school or to go shopping.
- Travelling can also be a leisure activity.
- Yet transport-related problems rank high on the list of concerns among people living in European cities and regions. The way travel is organized needs to be improved, at the individual and regional level.
- Traditional solutions, such as infrastructure improvements and regulations, are not enough to cope with these problems: an integrated approach, that makes use of existing infrastructures, is needed.

- Mobility Management can be seen as a complementary, cost-effective approach to help raise the quality of mobility-related services. It is an innovative demand-oriented approach that establishes new partnerships to provide quality mobility services.
- Its pilot projects in 32 European locations implemented Mobility Management strategies both in traditional (companies, schools) and new thematic sectors (tourism, events and new sites in their planning stage).

The final conclusion for the MOST Project was that it led to improved accessibility and a change in attitudes towards sustainable mobility.

Another interesting paper is the Session Summary from the International Transport Forum 2011, A Delicate Balance: Mobility Rights, Needs, Expectations and Costs [18]. This paper is giving a more balanced overview of the problem area and is stressing that "access to mobility is not equal", and takes up the parking problems for old people, disabled etc. The paper abstract is given below:

"*Mobility is sometimes perceived as a right*, but defining a basic level of mobility provision is not easy. Transport demand is guided by people's needs and aspirations, which are diverse and depend on other choices, such as where people live and work. The cost of transport to individuals is an important factor, and this often differs from costs to society. Societal demands for broad access to transport services come at costs that must be accounted for. These issues converge in the policy debate on *finding the right balance between mobility rights and the costs of providing safe, reliable and sustainable transport systems.*"

Finally, an older report is worth to be mentioned, which gives a very good overview of most parking issues and problems. This is the COST 342 Report from 2005, Parking polices and the Effects on Economy and Mobility [19]. The author of this paper participated to this action as delegate for Sweden. One of the findings, which is relevant for this paper is, that "the elimination of free or unregulated on-street parking and the substitution of paid on-street parking by of off-street parking reduces search traffic". The report also contains many examples of parking policy matters and case studies in Europe.

Summary and Conclusions

Summing up what has been discussed in this paper presented here, it is essential as a first step to mention the difficulties of really obtaining an answer and find solutions to the specific described problem regarding parking standards and activities for reducing and avoiding to co-opting with the given standards. *Is there any possible answer to this question today?* Probably not, as the problem involves a lot of intricate and conflicting areas such as:

- Car user opinions
- General public opinion
- Psychology

- Political goals
- Authority legislation

All those factors will change with time and increased knowledge through extended research and collection of facts.

As conclusion and a summing up of what is written above the following statements will be given. Some of the statements below have been mentioned and commented before in the paper text above.

- The general society tends to be more and more reluctant to provide sufficient parking space in cities, both centers and outskirts, than needed for both daily living, working and commercial activities
- A survey in Sweden indicates that this is the case
- Difficulties to find international practical research which shows the relationship between decreased parking space and negative effects, such as e.g. search traffic
- European Commission Sixth Framework Program Research Projects have dealt with Mobile Management as well as specific Parking Limitations for reducing the free mobility contradictory to e.g. EC White Paper on European transport policy for 2010: time to decide, regarding mobility policy matters and recommendation for direct measurements for a balanced future mobility
- "Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel" and "Curbing mobility is not an option"
- The total amount of cars as well as the private car ownership grows constantly the world over at the same time as the parking possibilities are generally reduced
- How will the society handle the human wishes of a free choice of transportation for facilitating all human needs and contact developments, both private relations and an efficient working environment?
- This contradictory situation will naturally require a lot of parallel measures such as technical development and policies for a more efficient land use.
- "Because of using the car is seen as a right and, in some cases, it is a necessity, in a first step to sustainable mobility, any transport policy has to be aware of the sensitivities and the needs of drivers"
- To find a possible equilibrium for parking with maintained freedom of mobility is one of the biggest challenges for the future transportation system at large

As a final conclusion and open question we can ask, *where should we park our cars in the future?*

References

1. European Commission. EPOMM Project, European Platform on Mobility Management, ongoing project and ECOM, European Conference on Mobility Management, annual meeting event. Brussels, Belgium
2. Scantech Strategy Advisers (2011) Finns det plats för bilen i våra städer i framtiden? (Will there be a place for the car in our cities in the future?) Malmö, Sweden, December 2011

3. European Commission (2006–2009) MAX Project, Successful Travel Awareness Campaigns & Mobility Strategies Management. Brussels, Belgium
4. European Commission (2000–2002) MOST Project, Mobility Management Strategies for the next decades. Brussels, Belgium
5. European Commission (2010) White Paper on European transport policy for 2010: time to decide
6. Wessex Institute of Technology (2002) The sustainable city II. Poblet, M C. The role of parking policy in the long process to sustainable mobility. Southampton, United Kingdom
7. City of Oulu (1988) Substituting curb side parking with multi-storey car parks. Finland 1988
8. Box PC (1999) Curb parking revisited. Urban Street Symposium, Dallas, USA
9. Shoup DC (2007) Cruising for parking, Access 30, 17–22
10. Polak J, Axhausen K (1990) Parking search behavior: a review of current research and future prospects. Oxford University. Transport Studies Unit. 199
11. Kaplan S, Bekhor S (2011) Exploring en route parking type and parking-search route choice: decision making framework and survey design. Department of Transport. Technical University of Denmark
12. Laurier E (2008) Searching for a parking space. Edinburgh Research Archive. 2008
13. Steenberhen et al (2009) An agent-based model for simulating parking search. Sustapark project
14. Hoglund PG (2002) Parking, energy consumption and air pollution. Parking and air pollution research, Model development and pilot studies in Stockholm, Sweden. Transfork-Transerach, Stockholm. 2002
15. Michael Kimmelman (2012) Paved but still alive. New York Times 08/01/2012, p. 22
16. Jakle JA, Sculle KA (2004) University of Virginia Press 2004
17. Kodansky M, Hermann G. (2011) Europe's parking U-Turn: from accommodation to regulation. Institute for Transportation & Development Policy (ITDP), New York. 2011
18. International Transport Forum Annual Summit (2011) A delicate balance: mobility rights, needs, expectations and costs.
19. European Cooperation in the Field of Scientific and Technical Research COST 342 (2000) The elimination of free or unregulated on-street parking and the substitution of paid on-street parking by of off-street parking reduces search traffic

Examining the Critical Factors of Implementing Sustainable Housing in a Multi-Stakeholder Context

Zhengyu Yang and Jay Yang

Abstract Sustainability has emerged as an integral part of the new built housing industry, in response to the devastating global environmental issues. However, the market response to sustainable housing was seen legging behind the shift in public awareness and policymaking. A major challenge of mainstreaming sustainable housing is establishing consensual recognition of each other's roles and opportunities across key stakeholders, and integrating various instruments designed for individual stakeholder's own benefits. The objective of this research is to investigate a vast amount of factors of implementing sustainable housing (FISHs) in a multi-stakeholder context. A comprehensive opinion of the significance and interrelationships of the FISHs are built upon the comparative analysis on stakeholders' various roles through a questionnaire survey and an in-depth interview study. Based on such a platform, a framework is developed with the aid of Interpretive Structure Modelling. It provides visions for systematic implementation of regulative, educational and fiscal instruments based on stakeholder collaboration, which helps break the negative "circle of blame" for under-performance of sustainable housing development.

Introduction

The housing sector accounts for 25 % of the overall carbon emissions, which constitutes a major cause of climate change and position the needs of our future generations at jeopardy [17, 20]. For such reason, building a sustainable housing paradigm with a series of energy-efficient and environmentally-friendly technologies has been a long-term target of Australian housing industry. Despite the potential benefits and technology viability, sustainable housing was seen struggling to find its niche in the mainstream Australian market. For example, Green Star-Multi Unit

Z. Yang (✉) · J. Yang
Faculty of Built Environment and Engineering, Queensland University of Technology, Queensland, Australia
e-mail: zhengyu.yang@student.qut.edu.au

J. Yang
e-mail: j.yang@qut.edu.au

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_9,

Residential was developed by Green Building Council of Australia to benchmark sustainable housing development in terms of energy and indoor environment quality etc. However, by late 2011 this system only endorsed 17 4-star or above housing developments [4]. Similarly, only 33 exemplar projects have been certified by another authoritative organization, Urban Development Institute of Australia, under its EnviroDevelopment scheme [26].

Confronted with such situation, a number of scholars found that the misalignment of stakeholders' perceptions on each other's need was found as another fundamental barrier for sustainable housing development [8, 11, 16, 31]. Under the primarily legislative mechanism, key stakeholders such as developers, builders and consumers do not appreciate the tangible benefits of pursuing sustainability for the businesses of their own, and hardly apprehend the risks of their supply chain partners. Lacking of this mutual understanding, stakeholders often end up falling into a vicious "circle of blame" where responsibilities are shifted to one another for lack of progress, and pioneer motives to step out the traditional unsustainable practices are in turn hindered [7]. The above situation indicates that changes to sustainable housing practices require exploring multiple stakeholders' value gaps and in turn establishing a collaborative approach for implementing sustainable housing. This problem was addressed in a three-year project presented in the current paper.

Establishing the Analytical Protocol

Before empirical study can begin, an analytical protocol needs to be established through upfront review to guide the data collection and analysis. It defines:

1. What are the most recognised factors of implementing sustainable housing (FISHs);
2. Who, according to statute and good practice, could be the key stakeholders in sustainable housing development.

Factors of Implementing Sustainable Housing

Multiple pull and push factors have been identified as influential for stakeholder decision-making towards more sustainable housing [1, 8, 12, 14, 18, 21, 23, 27–30]. For example, Lowe and Oreszczyn [10] argued that insufficient interdisciplinary action among technology, economy and sociology specialists failed to provide reliable lifecycle data of exemplar buildings. Aggravating this situation is the stereotyped additional cost on sustainable features, oftentimes underrated or ignored by policies [28]. As a consequence, sustainable housing experienced psychological ignorance by stakeholders, which reflected on the conservatism nature of construction industry [29]. Van Bueren [27] thus supported the collaborative integration via clear

Table 1 The Two-fold Analytical Protocol

Key factors of implementing sustainable housing (FISHs)	*Technical and design factors*
	T1. Inadequate or untested sustainable technologies or materials
	T2. Lack of professional education and training programs for industry
	T3. Lack of methodologies and tools to consistently define and measure sustainability
	T4. Lack of integrated design for life-cycle management
	T5. Insufficient cost-benefit data from interdisciplinary research
	Economic factors
	E1. Unclear benefits from future legislation, policy and market change
	E2. High investment cost
	E3. Inadequate or inefficient fiscal or other investment advantages
	Socio-cultural factors
	S1. Reluctance of leaving the comfort zone and changing traditional practices
	S2. Insufficient reputation increase, brand recognition and competitive advantage
	S3. Lack of social conscience in climate change and natural resource preservation
	S4. Insufficient demand-side education from media and other channels
	S5. Contested functionality for end users
	Institutional factors
	I1. Lack of collaborative integration
	I2. Lack of inter-stakeholder communication networks
	I3. Inadequate policing of green-washing and unsustainable practices
	I4. Slow and unwieldy administrative processes in certificating and policy-making
	I5. Lack of comprehensive code/policy package to guide action on sustainability
	I6. Duplication and confusion arising from parallel policies/legislation
Key stakeholders in sustainable housing development	1. Government agencies
	2. Developers
	3. Builders
	4. Architects/Designers
	5. Other consultants
	6. Financial institutions
	7. Consumers

leadership and partnership among stakeholders, which could potentially facilitate long-term planning, early agenda-setting and integrated design of sustainable housing. The first fold of Table 1 summarizes the most commonly recognized factors in existing literatures, in order to guide the subsequent data collection and analysis. In reference to Spangenberg's sustainability prism, these factors are clustered under four categories: technical and design factors, economic factors, socio-cultural factors and institutional factors [25].

Table 2 Profile of questionnaire respondents and interviewees

Profile		Percentage (%)	
		Questionnaire respondent	Interviewee
Profession	Government agency	16	15
	Developer	8	15
	Builder	8	15
	Architect/Designer	20	10
	Other consultant	30	25
	Financial institution	8	10
	Real estate agency	10	10
Executive level	Manager/Director	60.4	85
	Other	39.6	15
Geographical spread	New South Wales	16	10
	Victoria	20	20
	Queensland	56	60
	Tasmania	8	10

Key Stakeholders in Sustainable Housing Development

Despite the dozens of stakeholders playing indispensable roles in various stages of housing development, Margerum [13] argued that integrated approaches cannot address all the concerns in a complex environment. Instead, key stakeholders should be focused for their strong linkage with the delivery process of sustainable housing. For example, Robinson et al. [19] found out that governments play critical roles in sustainable building implementation, particularly on fostering collaborative actions, for their roles as a policy-maker, technical consultant, information provider, and funder of on-the-ground actions. Williams and Dair [30] suggested the knowledge barrier and the "comfort inertia" have placed stakeholders like developers and builders in an extremely significant position. This research identified seven key stakeholders from the literature review for their strong linkage with the delivery process of sustainable housing [14, 19, 30]. The second fold of Table 2 lists these stakeholders in sustainable housing development.

Research Methodology

This research aims to investigate and compare the different needs of multiple stakeholders, and in turn identify collective priorities for stakeholder mutual benefits from sustainable housing development. It adopted a threefold methodology, including questionnaire surveys, semi-structured interviews and Interpretive Structural Modelling. The quantitative questionnaire surveys are suitable for extracting abstract and complex perceptions of FISHs and unveil the value gaps among stakeholders, while qualitative interview are appropriate to explain and extend the questionnaire findings by linking FISH significance and interrelations with the diverse stakeholder roles and benefits [22]. The interview study also helps identify the potential practices and solutions to foster each FISH. Interpretive structural modeling transforms complex and random interrelationship of FISH into structural mutual influences (driving force and dependence), which helps provide systematic and collective action guidelines for stakeholders in sustainable housing implementation [2, 6].

Government agency officials, financial lenders, developers, builders, architects/designers, other consultants and real estate agents from 80 organizations were chosen as the questionnaire and interview survey population. It is worth mentioning that real estate agents replaced consumers as survey targets to portray market demand. This is because consumers might have limited ability to provide precise feedback on a good number of survey questions involving technical terms, policies and regulations in the housing development process. Among the 80 targeted organizations, 53 are acknowledged as being at the forefront of sustainability implementation by Housing Institute of Australia and Australia Green Development Forum, and hence will be revealing the motives and barriers of engaging in sustainable housing developments. In comparison, another 27 reputed organizations without strong sustainability focus were also randomly chosen across Australia, to reflect the general trends in housing developments. The cross-referencing selection criteria ensure the valid and representative results from the Australia Housing industry. Before sending out the full-scale questionnaires, six pilot surveys were conducted in September 2010 with two builders, two university professionals and two consultants for to ensure good content validity. 50 valid responses were received out of 163 initial deliveries, which conforms to an acceptable respondent rate of 30.7% for surveys focusing on gaining responses from construction industry practitioners [3, 9].

Following the questionnaire study, 14 questionnaire respondents with robust knowledge and other 6 experts were further selected for in-depth interviews based on their experience in sustainable housing development. As shown in Table 2, both the questionnaire and interview participants spread over four major states of Australia: Queensland, Victoria, New South Wales and Tasmania. 60.4% of the questionnaire respondents and 85% of the interviewees hold a manager or director position in their organization. The wide geographical spread and high level of seniority safeguards the rigor and generalization of the survey results.

Results and Discussion

Overall FISH Significance—The Common Trend

Table 3 shows the amalgamated FISH significance by all seven stakeholder groups in column 2, 3 and 4 (in bold text). Among the four micro categories of FISHs, stakeholders believed economic challenges affect their benefits the most (mean value=4.08). "High investment cost" (E2) (mean value=4.12) is the most signifi-

Table 3 Ranking of the FISHs according to respondent's professional background

FISHs	Overall			Gov		Dev		Bui	
	Mean	Rank	Std. Dev.	Mean	Rank	Mean	Rank	Mean	Rank
Technical and design factors	*3.74(3)*			3.68(2)		3.875(3)		3.33(3)	
T1. Inadequate or untested technologies or materials	*3.35*	*19*	*1.11*	3.00	17=	3.50	18	3.75	3=
T2. Lack of professional education and training programs for industry	*3.82*	*10=*	*1.17*	4.00	3	3.75	15=	3.25	13=
T3. Lack of methodologies and tools to consistently define and measure sustainability	*3.61*	*13*	*0.95*	3.38	13	4.00	8=	3.00	16
T4. Lack of integrated design for life-cycle management	*4.02*	*5=*	*0.95*	3.88	4=	4.00	8=	2.75	17
T5. Insufficient cost-benefit data	*3.90*	*7*	*0.98*	4.13	2	4.25	4=	4.00	2
Economic factors	*4.08(1)*			3.96(1)		4.58(1)		3.89(1)	
E1. Unclear benefits from future legislation, policy and market change	*4.08*	*2*	*0.93*	3.88	4=	4.75	1=	3.75	3=
E2. High investment cost	*4.12*	*1*	*0.86*	4.25	1	4.75	1=	3.75	3=
E3. Inadequate investment advantages	*4.06*	*3=*	*0.82*	3.75	8=	4.25	4=	4.25	1
Socio-cultural factors	*3.58(4)*			3.45(4)		4.125(2)		3.19(4)	
S1. Reluctance to leave the comfort zone and change traditional practices	*3.84*	*8=*	*0.99*	3.88	4=	4.50	3	3.50	8=
S2. Insufficient reputation increase, brand recognition and competitive advantage	*3.37*	*18*	*0.95*	3.00	17=	3.75	15=	3.50	8=
S3. Lack of social conscience regarding climate change and natural resource preservation	*3.57*	*15*	*1.21*	3.63	10=	4.00	8=	3.25	13=
S4. Insufficient demand-side education from media and other channels	*3.59*	*14*	*1.19*	2.63	19	4.00	8=	3.50	8=
S5. Contested functionality for consumers	*3.53*	*17*	*1.14*	3.13	16	4.25	4=	2.50	18=
Institutional factors	*3.84(2)*			3.46(3)		3.83(4)		3.39(2)	
I1. Lack of collaborative integration	*3.82*	*10=*	*0.73*	3.88	4=	4.00	8=	2.50	18=

Table 3 (continued)

FISHs	Overall			Gov		Dev		Bui	
	Mean	Rank	Std. Dev.	Mean	Rank	Mean	Rank	Mean	Rank
I2. Lack of inter-stakeholder communication	*3.55*	*16*	*0.87*	3.25	14=	3.00	19	3.25	13=
I3. Inadequate policing of green washing and unsustainable practices	*4.02*	*5=*	*0.85*	3.63	10=	3.75	15=	3.75	3=
I4. Slow and unwieldy administrative processes in certificating and policymaking	*3.84*	*8=*	*1.01*	3.50	12	4.00	8=	3.50	8=
I5. Lack of comprehensive code or policy package to guide action	*4.06*	*3=*	*0.83*	3.75	8=	4.25	4=	3.75	3=
I6. Duplication and confusion arising from parallel policies/legislation	*3.78*	*12*	*0.96*	3.25	14=	4.00	8=	3.50	8=

cant FISH identified among all, closely followed by another two economic challenges: “Unclear benefits from future legislation, policy and market change” (E1) and “Inadequate or inefficient fiscal or other investment incentives” (E3). An institutional challenge, “Lack of comprehensive code or policy package to guide action regarding sustainability” (I5), was equally ranked the third most significant (mean value = 4.06) with a small standard deviation (0.83), which signified a collective need for a consistent mechanism to systemise available instruments for sustainability, rather than a one-sided energy efficiency mandate. While much research has been switching focus from technical barriers to cultural obstructions in recent years, the results of this questionnaire indicate that the Australian housing industry does not consider the latter to be of great hindrance to stakeholders’ benefits (mean value = 3.58, ranked fourth among 4). “Lack of social conscience in climate change and natural resource preservation” (S3), “Contested functionality for consumers” (S5) and “Insufficient reputation increase, brand recognition and competitive advantage” (S2) were all ranked in the bottom five with a mean value of 3.57, 3.53 and 3.37, respectively. “Inadequate or untested sustainable technologies or materials” (T1) scored only 3.35 and was ranked the least significant challenge among all. It seems respondents commonly acknowledged that the current sustainable technologies and materials are economically viable and do not jeopardize stakeholder benefit.

Individual FISH Significance—Various Perceptions Across Stakeholders Built Upon Their Specific Risks and Benefits

In order to unveil the value gaps across different stakeholders, and in turn seek for possible avenues of achieving mutual benefits through escalated collaboration, this research also examines the FISH value for each stakeholder group (shown from column 5 to column 18 in Table 3). These diverse FISH rankings were further explained via Qualitative Content Analysis based on the interview study, with strong linkage to each stakeholder’s specific roles, benefits and risks in sustainable housing development [5].

In general, government agencies and consumers perceive more benefits than risks than other stakeholders do in the involvement of sustainable housing, and thereby holding higher interest. The interviews found that one common reason for this is their direct benefits of sustainable practices in environmental, economic and social dimensions. For example, more optimistic about the current policy setting (I5) and incentive systems (E3), both of which were ranked 8th as opposed to the overall rank (3rd). This is probably because governments want to address environmental challenges to fulfill national goals and international agreements (e.g. Kyoto Protocol) and meet the needs of the nation’s future generations. They also directly benefit from related environmental tax schemes.

Among all industry practitioners, developers and builders respond the most drastically to contested competitive advantage and perceive this factor as the main reason for their current moderate interest in sustainable housing. For example, developers highly valued challenges regarding rating tools (T3, ranked 8th compared to the overall 13th rank) and cost-benefit data (T5, ranked 4th compared to the overall 8th rank). Builders believe "Fiscal or other investment advantage" (E3) and "Insufficient cost-benefit data from interdisciplinary research" (T5) are the two most important factors for their pursuit of sustainability. This indicates they take the actual technical risk of translating theories to reality and need further rewards to translate increased reputation to competitive advantage at the early stage of sustainable housing development.

The interview results revealed that having a sustainable side can enhance the competitive advantage to a greater extent for architects and consultants. On the other hand, financial institutions and real estate agents were found to have less at stake in sustainable housing development, because they are not directly affected by strong top-down pressure from regulations.

Building the ISM Model for Critical FISHs

Based on the examination of FISH significance with a multi-stakeholder context, 12 critical FISHs were identified as shown in boxes in Fig. 1. The individual interrelationships between each pair of critical FISHs were also identified through qualitative content analysis on the interview study. This research further utilizes ISM to present these contextual relationships, and further transform these complex relationships into the structural and quantifiable mutual influences for systematic implementation [2, 24].

The end product of the ISM is a systematic framework as shown in Fig. 1. The framework highlights four sequential levels of implementation: innovative collaboration; regulatory enforcement; R&D and knowledge diffusion; and market and industry adaptation. Eight specific action guides were synthesized from the interview study for the critical FISHs on the first three levels of the framework. Fostering these higher-up-level FISHs will support sequential FISHs, and systematically guide sustainable housing development [32].

Specifically, the first level is "innovative collaboration". It leads to the creation and communication of mutual benefits for multiple stakeholders at every step along the implementation. As such, it serves as "the prerequisite" for the other eleven factors in the framework. Action guide for this factor highlights a clear stakeholder structure that explicates leadership, as well as individual roles and explains how major stakeholders could ultimately benefit from engaging in a new context of sustainable housing compared to conventional housing.

The second level, "regulatory enforcement", highlights the regulatory and institutional issues, which is the initial driving power of sustainable housing development. It is comprised of an effective regulatory mechanism, an incentive system, reliable cost-benefit data and a consistent nationwide rating tool. In fact, level 2 represents the four essential components of a holistic code for sustainable housing development. It sets the boundaries of the desired outcomes in the market. This

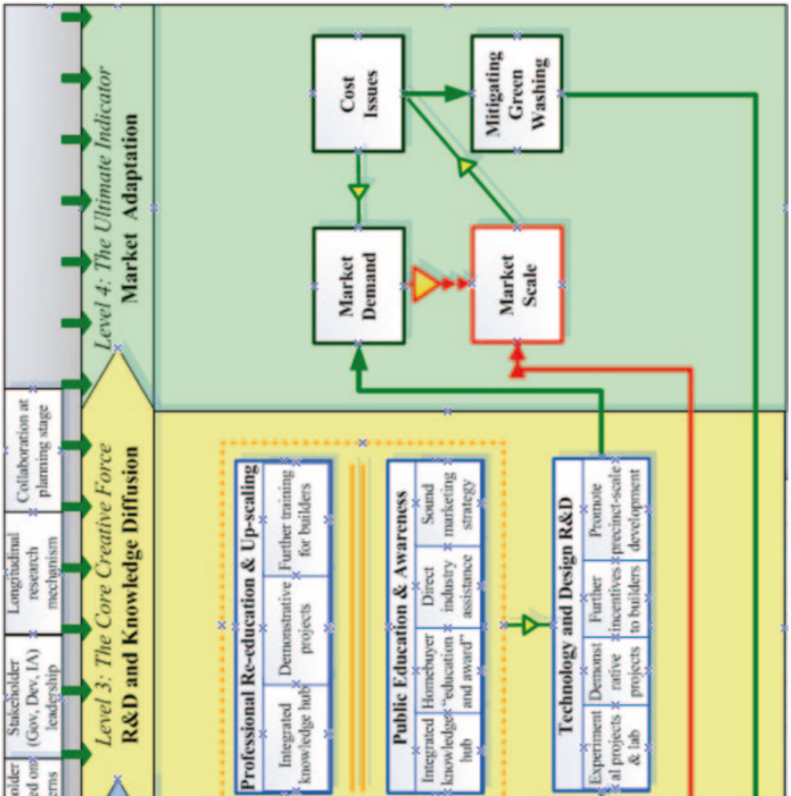


Fig. 1 The systematic frame-work

"managed market" approach is extremely important to assist innovation to grow and become mainstream, particularly for sectors that require substantial upfront capital investment like the housing industry [15].

Level 3, "R&D and knowledge diffusion", includes technology and design R&D, professional re-education and up-scaling and public education and awareness. These three factors are defined as core components because they together manifest the original value-adding process. This process promotes market scale on level 4 and reinforces the cost-benefit data on level 2, which in turn strengthens this level itself. Such a self-enforced loop provides a platform for "economies of scale" in microeconomic terms.

Level 4 includes four dependent yet decisive factors that ultimately indicate the market success of sustainable housing: market demand, market scale, cost issues, and green washing. This market adaptation process has limited creative force itself. However, the process could be driven by higher-up levels, and create momentum to keep circulating towards the market mainstream.

Conclusion

This paper has drawn on comparative quantitative surveys, in-depth qualitative interviews and an Interpretive Structural Modelling in Australia, aiming to promote stakeholder mutual benefits in the implementation of sustainable housing. Through this mixed methods, the significance of the 19 FISHs were examined in light of the various roles, benefits and risks of seven groups of key stakeholders in the housing industry. 12 critical FISHs and their interrelationship were accordingly identified. The end product of this research is a systemic framework of 12 critical FISHs to guide collective stakeholder actions in operational terms. It argues that policies and instruments built around these 12 critical factors could be optimised and implemented on a sequential four-level structure: innovative collaboration; regulatory enforcement; R&D and knowledge diffusion; and market and industry adaptation. More attention should be paid to addressing factors on the higher up levels, so as to lead to the market escalation of sustainable housing. This framework contributes to the knowledge of contemporary collaborative planning and supply chain management. It enables systematic policymaking for government, consumers, and "competitive" industry practitioners upon understanding each other's tension, benefits and responsibilities.

References

1. Adeyeye K, Osmani M, Brown C (2007) Energy conservation and building design: the environmental legislation push and pull factors. Struct Surv 25(5):375
2. Ahuja V (2007) IT enhanced communication protocols for building project management by small and medium enterprises in the Indian construction industry. PhD Thesis, School of Urban Development, Queensland University of Technology, Australia

3. Akintoye A (2000) Analysis of factors influencing project cost estimating practice. Constr Manage Econ 18(1):77–89
4. Green Builidng Council of Australia (2011) Sydney, viewed 01 Oct 2011, http://www.gbca.org.au/project-directory.asp
5. Hsieh HF, Shannon SE (2005) Three approaches to qualitative content analysis. Qual Health Res 15(9):1277
6. Janes F (1988) Interpretive structural modelling: a methodology for structuring complex issues. Trans Inst Meas Control 10(3):145–154
7. Keeping M (2000) "What about demand? Do investors want 'sustainable buildings'?". Proceedings of Cutting Edge 2000 conference, 6–8 September 2000, London
8. Lorenz D, Truck S, Lutzkendorf T (2007) Exploring the relationship between the sustainability of construction and market value: Theoretical basics and initial empirical results from the residential property sector. Prop Manage 25(2):119–149
9. Love PED, Smith J (2003) Benchmarking, benchaction, and benchlearning: rework mitigation in projects. J Manage Eng 19:147
10. Lowe R, Oreszczyn T (2008) Regulatory standards and barriers to improved performance for housing. Energy Policy 36(12):4475–4481
11. Lutzkendorf T, Lorenz D (2007) Integrating sustainability into property risk assessments for market transformation. Build Res Inf 35(6):644–661
12. Lutzkendorf T (2011) How to break the vicious circle of blame? The contribution of different stakeholders to a more sustainable built environment. Res Archit Constr 1 (6). Available at http://www.fec.unicamp.br/~parc/vol1/n6/vol1-n6-LUTZKENDORF.pdf
13. Margerum RD (1997) Integrated approaches to environmental planning and management. J Plan Lit 11(4):459
14. McGraw-Hill Construction (2006) Green Building Smart Market Report. McGraw-Hill Construction, New York, USA
15. Sustainability Victoria (2011) Business models for enabling sustainable precincts. Research report of Sustainability Victoria, Australia. http://www.sustainability.vic.gov.au/resources/documents/Business_Models_For_Enabling_Sustainable_Precincts_Research_Report_v2.pdf
16. Myers G, Reed R, Robinson J (2007) The relationship between sustainability and the value of office buildings. Proceedings of the 13th Annual Pacific Rim Real Estate Conference, 21–24 January, Perth, Western Australia
17. Newton P, Baum S, Bhatia S, Brown S, Cameron S, Foran B et al (2001) Human settlements: Australia state of the environment report 2001, CSIRO on behalf of the Department of the Environment and Heritage, Australian Government
18. Osmani M, O'Reilly A (2009) Feasibility of zero carbon homes in England by 2016: a house builder's perspective. Build Environ 44(9):1917–1924
19. Robinson C, Margerum R, Koontz T, Mosley C, Lurie S (2011) Policy-level collaborative for effective environmental management: lessons and challenges from Australia and the United States. Soc Nat Resour 24(8):1–11
20. Roodman DM, Lenssen N, Peterson JA (1995) A building revolution: how ecology and health concerns are transforming construction. Worldwatch Institute, Washington, D.C
21. Ryghaug M, Sørensen KH (2009) How energy efficiency fails in the building industry. Energy Policy 37(3):984–991
22. Saunders M, Lewis P, Thornhill A (2009) Research methods for business students: Financial Times/Prentice Hall, New Jersey
23. Shin D, Curtis M, Huisingh D, Zwetsloot GI (2008) Development of a sustainability policy model for promoting cleaner production: a knowledge integration approach. J Clea Prod 16(17):1823–1837
24. Singh M, Kant R (2008) Knowledge management barriers: an interpretive structural modeling approach. Proceedings of International Conference on Industrial Engineering and Engineering Management, IEEE, Singapore, 2–4 December, pp 2091–2095

25. Spangenberg JH (2002) Environmental space and the prism of sustainability: frameworks for indicators measuring sustainable development. Ecol Indic 2(3):295–309
26. Urban Development Institute of Australia (2011) Brisbane, viewed 01 Oct 2011, http://www.envirodevelopment.com.au/01_cms/details.asp?ID=57
27. Van Bueren E (2007) Establishing sustainability: policy successes and failures. Build Res Inf 35(5):543–556
28. Vandevyvere H, Neuckermans H (2005) From sustainable housing sciences to sustainable housing policies: challenging the social responsibility of researchers and designers. Paper presented at World Congress on Housing Transforming Housing Environments through Design, pretoria, South Africa, September 27–30
29. Wilkinson SJ, Reed RG (2007) The structural and behaviourial barriers to sustainable real estate development. Paper presented at American Real Estate Society (ARES) Conference, San Francisco, USA, 11–14 April 2007
30. Williams K, Dair C (2007) What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments. Sustain Dev 15(3):135
31. Yang Z, Yang J (2009) Sustainable housing implementation through mutual benefits to stakeholders: a decision making approach. In: Li Q, Yang J (eds) Proceedings of CRIOCM2009 International Symposium on Advancement of Construction Management and Real Estate, The HongKong Polytechnic University, Nanjing, pp 1012–1018
32. Yang Z, Yang J, Eves C (2012) The implementation of sustainable housing through mutual benefits to key stakeholders. In Proceedings of: 4th CIB International Conference on Smart and Sustainable Built Environment—Emerging Economies, Fundacao De Desenvolvimento Da Unicamp, Brazilian British Centre, Sao Paulo, pp 603–610

Part II
Green Cities and Urban Ecosystems

Ecosystem Services Provided by Urban Vegetation: A Literature Review

Christiane Weber and Lotfi Medhi

Abstract Since the blossoming of environmental awareness in the 1970s and the emergence of sustainable development, the interest of development of urban vegetation and green spaces has increased tremendously. New disciplines and approaches, following the example of ecology and urban forestry are emerging in particular to assess the ecosystem services provided by vegetation in urban areas. This research takes place into a large project on Greening spaces in urban areas and especially on the ecosystem services provided by vegetation and the effects upon atmospheric pollutants and air quality. A specific objective has been to identify and characterize these urban ecosystem services over the past decade. Among 200 scientific literature papers, 170 have been selected to identify ecosystem services that are the most studied, according to pre-established criteria a database has been created to identify the predominant characteristics of these studies. No fewer than 55 ecosystem services were identified as the principal focus of the research work or simply mentioned. The effect of vegetation on air quality (pollution) appears to be the major ecosystem services studied during the last decade in various disciplines.

Introduction

Nature's Services, the book directed by [4] and the publication in Nature of Costanza *et al.* publication "*The value of the world's ecosystem services and natural capital*" in 1997 [5] correspond to the publications often noted as important milestones in the emergence of the notion of ecosystem services. Indeed these publications attempt to identify and measure the role of nature and its ecological functions, for both, determine a baseline for the degradation of ecosystem services provided by nature towards society [5], and develop a systemic approach of a "natural capital" into various dimensions [4]. The ecological hypothesis used here, as "the existence of a

C. Weber (✉) · L. Medhi
Laboratoire Image, Ville et Environnement (LIVE) UMR 7362– CNRS, Faculté de Géographie et d'Aménagement, 3 rue de l'Argonne, 67000, Strasbourg, France
e-mail: christiane.weber@live-cnrs.unistra.fr

L. Medhi
e-mail: lotfi.mehdi@live-cnrs.unistra.fr

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_10,

degree of replacement or substitution of such services", appears in fact earlier in the SCEP study (Study of Critical Environmental Problem) in 1970. "Environmental services" was used for the first time in this report, for the UN conference on "human environment" in 1972; it introduced the concept of ecosystem services recognized as a semantic tools to identify the impact of human activities on the biosphere "*The gradual decline in ecosystem function brings with it a decline in services for man*" (p122). The ES concept has been institutionalized acquiring an universal vocation all through the process leading to the publication of the Millennium Ecosystem Assessment (MEA) in 2005 [14]. Later the TEEB study (the Economics of Ecosystem and Biodiversity, 2007) initiated by the UN and European commission focused on the economic consequences of biodiversity erosion and the necessity of protection or conservation of various species. This report claims the integration of economic values of biodiversity and ES provided by ecosystems in territorial decision-making. Since this period Ecosystem Services have been considered mainly through economic values, actually cultural or ethical values are envisioned to complete the evaluation panel.

The increase of urban population and urban sprawl transform definitely the landscape through fragmentation of natural habitats, expansion of imperious surfaces, negative outcomes of human activities etc. inducing strong pressures over environmental systems. Urban ecosystems have been compared [18] to "*parasites in the biosphere*" but they are also part of a global system equally biological, social, built and geophysical. As such the Ecosystem Services (ES) generated by urban ecosystems have a crucial importance for urban quality of life of citizens e.g. providing beside usual maintenance processes (physical, chemical and biological), resources (wood, fiber, air, water), regulation (climate, air quality, soil maintenance, extreme event moderation…) and cultural (traditional knowledge, recreation, tourism, ethical) services. Some of these benefits, such as vegetation's effects on air pollution or on urban pollution more generally, have already been the object of several studies [8, 15, 21]. In fact, an increase of articles from 200 to more than 1000, between 2004 and 2010 in several disciplines shows a strong interest [20]. Another point that might be pointed out is the scale of the ES, locally generated [2] they may provide a solution to deal with local problem such as those due to traffic. This might be considered as a key in local decision-making processes.

Among the urban ES the most often cited by citizen and local authorities in Europe, the vegetation is the one associated to a strong effort done by municipalities. Looking backward throughout the XVIII to the XX centuries, vegetation has been considered in various status: for Victorian philanthropists and humanists ideals vegetation is considered as an integral part of city development process, filling the needs and welfare of citizens (fresh air and refuge to alleviate the consequences of the industrial age). City planners in the XIXe introduced the concentric model of towns establishing the "Green belt" to define cities boundaries, and in the XXe, E. Howard moved further with the "Garden City concept" inducing communities connected with livable residential areas where green spaces are the support of healthy living conditions and social and cultural activities. The Charta of Athens (1933) has amplified the zoning processes towards modern and functional cities, greens spaces being considered as an aesthetical choice accompanying the construction of collective housings.

Thus for several decades, new status have been attributed to urban vegetation without assessing really their impact on ecosystem dynamic or human/natural interactions. At the same time, urban decision, planning design, and management procedures have ignored numerous vegetation functions [6, 8, 9]. Due to the interest of the international community for biodiversity and local aspiration for "nature" in cities, the status of vegetation has changed one more time, becoming a valuable ecological good [13]. It is therefore interesting to deepen the questions related to the role of urban vegetation, requiring research based on relevant information that can be understood and shared by scientists, professionals, and policy-makers [9]. It has indeed to be noted that the engagement of life science or environmental science researchers has appeared rather later than the one of social and humanities sciences [3]. Some domains of interest have been already studied: Health and social realm, ecological and environmental features, and cultural and patrimonial issues. Urban ecology discipline stresses especially the ecological processes within vast urban regions, considered as socio-biophysical complexes.

The objectives of this article through a critical review of scientific papers focused

The identification of the urban ES studied during the last decade by the scientist community and the approaches employed to assess these ES and the determination of the discipline the most involved and the reviews the most concerned;

For the most representative urban ES, an analysis of the benefits has been summarized and some perspectives enunciated. This investigation will provide some insights about the evolution of ES as a concept but also as a driver for the community of scientists and decision makers.

To set up the design of this study no exhaustive list of these services has been compiled, nor have the studies devoted to them or their disciplinary affiliations been elucidated in detail [8]. The difficulty in this type of exercise lies in the ambiguity of the key notions, for their meanings vary from one discipline to another [6, 10].

This article is divided in four sections. The first presents the conceptual framework of the study referring to the ES of urban vegetation; the second describes the methodological and analytic design adopted. The third section presents and develops the results of the analyses. And, the last section is devoted to a discussion of the results and of items to guide both further research into ecosystem services and their consideration by policy-makers.

Conceptual Framework

The concept of ecosystem services has emerged progressively, especially since the 1960s [5]. The definition of ecosystem service used here is the one proposed by Constanza et al. [4] further developed by Bolund and Hunhammar [2]: *ecosystem services are defined as "the benefits human populations derive, directly or indirectly, from ecosystem functions"*. Daily [4] refers to these functions as ecosystem services and defines them as those conditions and processes through which natural ecosystems, and the species that inhabit them, sustain and fulfill human life. More specifically, ecosystem services are defined by their contribution to human well-being, since they are end products of various ecosystem functions such as climate amelioration and recreation because they are enjoyed, consumed or used by humans. Ecosystem goods, a subset of ecosystem services, can be defined as tangible material products such as wood, fuel, or food that results from ecosystem processes [7].

The inventories of urban ES might be gather is several groups according to the number of ES identified: the Millenium Ecosystem Assessment [14], the Ministère de l'Ecologie, du Développement Durable et de l'Energie (France) respectively with 23 and 43 ES. Costanza et al. [4] identified and classified 17 of the principal ecosystem services. Some ES are defined especially for green areas: Bolund and Hunhammar [2] counted 6 ES, Nowak and Dwyer [17] 14 ES, Niemela et al. [15] 16 ES and Dobbs & et al. [8] 13 ES. Thus the number of urban ES is associated to the initial objectives of the studies and the values (financial or cultural) associated to the ES regarding the society references.

Methods and Materials

The global objective of the literature review attempts to catch the evolution of the urban ES concept and the characteristics of this evolution, especially for the ES provided by the urban green areas. A remark has to be done at this point. In the literature the notion of green areas stay rather "poor", since it designs particularly urban trees or urban forests. Few are attached to the singled tree; lawn and bushes are seldom mentioned.

Selection of Articles

To select the most pertinent articles a particular attention was given to keywords. They were intended to choose a representative sample of articles from the work done in this domain, work characterized both by its abundance and its heterogeneity. At the same time, a selection based only on a normative approach might be too rigid to ease the recognition of the functions studied. The "Image, Ville, Environnement" unit (LIVE- CNRS UMR7362) of the University of Strasbourg (France) has free access to various types of bibliographic resources: Databases: Francis, Pascal, Georef, ISI, Scopus, etc; Electronic periodical databases: Science Direct, SpringerLink, Revue.org; Catalogues: UdS[1] libraries catalogue, Sudoc[2], etc.

[1] Université de Strasbourg, http://www.unistra.fr/.

[2] Système Universitaire de Documentation, http://www.sudoc.abes.fr/.

Table 1 Variables used in the multiple correspondence analysis MCA

Variable	Meaning
Ecosystem services provided by urban vegetation	55 ecosystem services were identified. (Appendix 1, 1–16)
Discipline of first author	13 different scientific disciplines have been identified according to the first authors' discipline. We first listed all of the authors' disciplines and then grouped them in more general domains: biology, ecology (including botany), forestry (including urban forestry), geography, the environment (including climate studies, soil science, hydrology, etc.), urban planning and policies, landscaping (including architecture), sociology, agriculture, political science, economics and pharmacy
Year of publication	Most of the articles selected were published between 1999 and 2011. Nonetheless, 12 important articles published before 1999 were included in the data table
Journal	Journals were classified according to the number of their articles listed in the table
Country where first author works	The country of the first author affiliation has been considered

The key words used for this research were: linked to the urban ecosystem components: "urban", "city"/"tree", "vegetation"/"biodiversity" and to the benefices or the impacts of human activities: "pollution"/"well-being", "human health"/"ecosystem services". To refine and enlarge the sample, supplementary key words have been added regarding spatial information: such as "green spaces", "wooded areas", "urban forest"; other key words stamping the disciplines have also be used like "urban ecology", "urban forestry" etc. It is probable that some articles dealing with the topic of ecosystem services used other synonyms for the key ideas mentioned above. To fill this gap, several studies have been selected being identified in the references of the articles already selected to complete the lexical field. For the most part, these articles were published over the past decade [20]. Nonetheless, several earlier publications considered of particular interest were retained (Table 1). It was necessary to examine meticulously all of the elements developed in each article: questions addressed methodology, case study, results, etc. Finally, 170 articles over 200 were selected, including reports, dissertations and book chapters. These initial results allow identifying 55 ecosystem services provided by urban vegetation). According to the type of service chosen, some authors chose to study a single service, while others dealt with several. For this reason, two supplemental criteria were added; the first concerns the articles summarizing all of the services provided by vegetation, while the second considers a combination of variables related to the interaction with air quality only (see Appendix 1, 1–16). As indicated above, the principal constraint here lies in the variability of the meanings of the key ideas, according to the specific discipline considered, title reflecting more or less the content of the article.

Data Analysis

The information collected was dispatched in: scientific domain, country of affiliation of the first author, journal, year in which the article was published.

These choices allowed answering related questions such as: "Which of the ES characteristics are the most studied?" "What discipline is most dynamic in this domain?" "Is any country more active than others?" "What journals are most representative of this field?" "Are there any temporal variations in the appearance, disappearance or emergence of concepts?" To analyze all of the information collected, a multivariate analysis was performed to synthesize them and to evaluate the strong forms that emerged from the overall set. A multiple correspondence analysis [16] was run followed by an ascending hierarchical classification (AHC) in order to identify the groups maximizing intergroup variance. The statistical analyses were performed with Xlstat software (http://www.xlstat.com/).

Critical Review

The results are divided into two packages, one considering an external critical review highlighting the topics, the reviews or the authors and allowing pointing out the major trends, the efforts concentrated in various scientific areas and their evolution, the major reviews and so on. It is a way to envision the evolution and the fluidity of the scientific streams in this domain. The second package deals more about the content of the articles providing: the scientific research results obtained by the community and some operational features promoted in the papers to be transferred to decision makers.

Characteristics of the Selected Studies

Seven main themes came out of the 55 ecosystem services studied and/or mentioned (Appendix 1; the 16 first): air quality; links with soil and water quality; social well-being; landscape quality; economic services *per se*; urban planning; ecological balance and conservation. The preliminary results indicate that the effects of the vegetation on air quality, pollutants or energy are the objects the most detailed topics in the research projects. This may be explained essentially by both, the recent technical advances in this field, which allow deepen analyses and the growing interest in understanding the interactions between vegetation and air to help alleviate the effects of human activities and reduce the impact of emission on climate at various scales. Biodiversity but also green planning covers the remaining part.

Over the past decade, 2 years concentrate the highest numbers of articles published (2002 and 2006) respectively 17 and 24 articles, respectively). This trend is confirmed by the study of Potschin and Haines-Young [8] on general ecosystem services.

Nearly half (44 %) of the authors could be attached to environmental sciences. If we separate the life and earth sciences (environment, ecology, biology, agriculture, and pharmacy) from the social sciences (geography, urban planning and policies, sociology, economics, and landscape), authors from the first category account for at least two thirds of the total. That said, these results must be interpreted cautiously because the disciplinary frontiers remain fuzzy. Finally, *Landscape and Urban Planning* (31 articles) is the journal that has published the larger amount of articles in the field of ecosystem services (nearly 20 % of all article), followed by *Urban Forestry & Urban Greening* (18) and *Environmental Pollution* (14). A little more than a quarter of all the articles were published in journals appearing only once on our list. This last information shows that even if an effort is still to be done in pluridisciplinary approaches, from planning and biology for instance, the reviews chosen privileged to diffuse the results are addressing a large scope of potential readers.

Scientific Results

Improvement of Chemical Air Quality

The studies have attempted to quantify and characterize the process of the elimination and fixation of chemical elements and atmospheric particles by the vegetation cover. Depending on the case studies, they have dealt with species selected in compliance with criteria set in advance (i) often trees and bushes: *Platanus x acerifolia Willd/Platanus racemosa Nutt/Populus nigra L, Pinus needle;* (ii) wooded areas, or (iii) urban green spaces (in their vast diversity). They are based mainly on experiments and measurements taken in the field, comparing plant and environmental data. It is difficult to generalize the results, because the effect of the species studied depends on the biotope in which they develop.

Improvement of the Physical Air Quality for the Well-being of Inhabitants

Numerous authors have tried to understand the mechanisms of the urban atmospheric processes, as affected by vegetation, especially through computer simulation. Some studies have neglected or even excluded from their analyses interactions between species and environmental variables, which may increase the gaps between the simulation results and findings in the field. Vegetation is even sometimes considered as an "inert" physical barrier in relation to urban atmospheric processes, as the built environment and some equipment also are. Other studies have looked at the role of vegetation cover both to diminish urban pollution (noise, smells, microbial germs, etc.) and to improve the well-being of city-dwellers (Fig. 1).

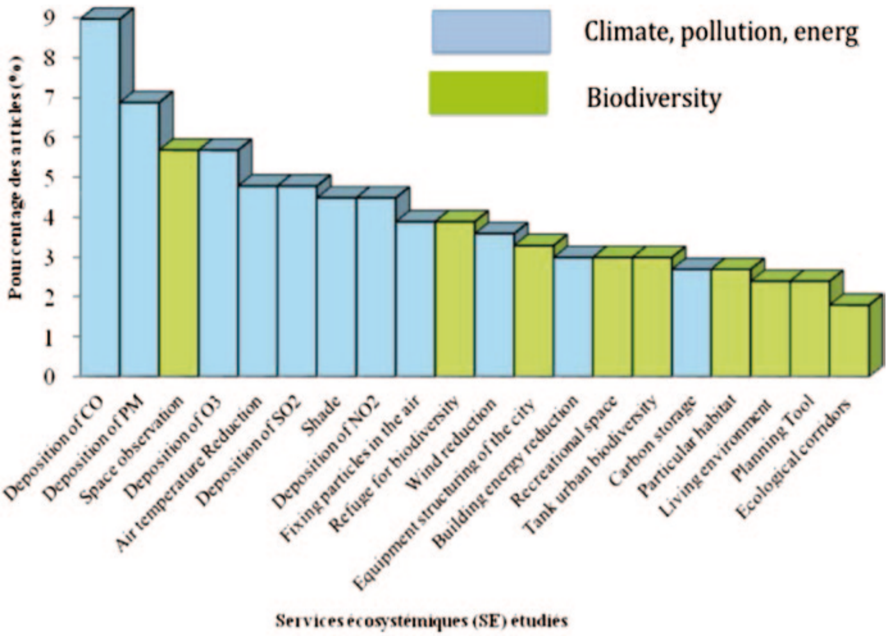


Fig. 1 Preliminary analysis: results of summary table of articles. Distribution of ecosystem services by number of articles in which they were treated or referred

Contribution to Sustainable Development and Ecosystem Conservation

Most of the ecosystem services studied are associated with this category. They are linked to all of the disciplines and journals. In France and Canada, the study of green spaces covers especially the quality of multifunctional public spaces. These articles are published most often in *Environmental Pollution*. On the other hand, looking at the services most commonly discussed in these articles, authors from the United States and the United Kingdom have concentrated on the functions. Most of their articles have been published in *Landscape and Urban Planning* and *Urban Forestry and Urban Greening*. These authors have also developed some guidelines based on sustainable development. A large scope of listed functions is attributed to the urban green belt, from leisure and citizen well-being to protection of biodiversity and fight against global warming.

Operational Results

Some general trends might be illustrated through the results obtained. Lists of vegetation (trees or bushes) have been selected for pollution emission purposes:

- Lists of species that might be more useful (Europe). Regarding particulate matter: bushes like '*Salix incisa*, *Pinus mugo*, *Skimmia japonica* and *Spirea cine-*

rea and trees: *Pinus sylvestris*, *Taxus media*, *Taxus baccata* and *Betula pendula*. Species less relevant are *Acer platanoides*, *Prunus avium* et al. *Tilia cordata*. To reduce ozone concentration Paoletti [19] shows that 2 species of cedar loose less COVs. Silver Mimosa (*Acacia dealbata*) has also a good impact on ozone but produce lot more COV. Another study in Barcelona shows that among ornamental species, 11 contribute positively to the COV emission in urban atmosphere [16].
- Normative index: Some studies allow defining the most resistant species face to pollution and pollutants capture and established normative indexes like the APTI or API (Air Pollution Tolerance Index) or the TBI (Tree BVOC—Biogenic volatile organic compounds—Index) to characterize the plant less productive in COV. The West Midlands metropolitan area, (UK) has also proposed a specific score regarding the impact of various species on air quality.
- Adaptation trend: Species more adaptable to extreme heat event have also be selected like *Gleditsia triacanthos*. [16].

Discussion

This study highlights the principal characteristics of the changes in the approaches linked to urban ecosystem services and allows identifying new trends and research questions.

Trends in Studies Reviewing Ecosystem Services

Over the past decade, ecosystem services studies have been marked by two trends, which developed jointly: the ecosystem services provided by all ecosystems (including urban ones), while others have focused solely on the role of urban vegetation [5] and experimentation and measurements in the field [17, 21].

Moreover, since 2005 (when the Millennium Ecosystem Assessment was published), an emergence of particular interest toward assessment of ecosystem services and their integration in the decision-making process (planning, design and management of vegetation areas can be noticed) [6, 15, 21]. Even if current planning methods continue to draw their references from functional urban studies based essentially on socioeconomic considerations. The articulation between ecological or energetic features like urban vegetation, amount of carbon stored by woodlands, low energy buildings and society values, representations, opinions or perceptions open largely several options of research.

Perspectives

This paper attempts to precise the current knowledge upon urban ecosystems services, mainly dealing with the functioning of urban green areas and their ecosystem services.

James et al., [9] and Bentsen et al. [1] propose innovative and promising avenues in this domain stressing the interest of studying the management of green spaces and the importance of multidisciplinary and interdisciplinary approaches to research like experimental platform for instance, on an international level, to understand the relations between urban vegetation and the well-being of city-dwellers.

Several directions have emerged from this study: the evaluation of the efficiency of the indicators suggested for each of the services. In such a case, the multidisciplinary approach is an ineluctable procedure, especially in its weaving of the associations between the social sciences, life sciences, and earth sciences illustrated by the need of articulation between disciplines using modeling as merging capacities. In the case of urban green ecosystem services, it would be interesting to define bridges according to the objectives of each scale. Gain will come from a real integration of the vegetation characteristics according to the aim and the scale of use.

The results have shown a flagrant lack of knowledge about some ecosystem services, specifically:

- Economic aspects: little work, for example, has been devoted to ornamental production intended to develop green spaces, or to the impact of vegetation on the attractiveness and market value of parks. In some countries (such as Germany), trees have been used as billboards of a sort, to finance their planting and management. Little research has attempted to understand such arrangements.
- Esthetic and cultural aspects: a lack of knowledge has also been observed about the role of vegetation as a landscape component that develops the image of the city or serves as a barrier to protect its citizens' private lives.
- Planning aspects: Many countries apply urban planning practices considering green spaces as real estate can be developed. Species inventories, measurements and generalization in urban area (*in situ*) or experimental plate-forms might participate to better planning practices, where trees or plants are chosen according their biologic capacities instead of just ornamental aspects. Economic, social but also ethic studies might complete, these aspects connecting with inequity or spatial justice issues.

Conclusion

This study has extracted from a literature review a large number of ecosystem services that vegetation is likely to provide in urban areas. Studies on this topic are various in aiming the ecosystem services, their characteristics and the objectives of their use.

Appendix 1 Summary table of key ecosystem services (15 first over 55)

	Ecosystem services	Direct (D) or indirect (I) services	Percentage of articles considering the ecosystem services	Authors most involved	Type of vegetation studied most
	Air quality				
	Air pollution removal				
1.	Deposition of carbon monoxide CO	D	13,53	Nowak D J/and others	Woodland
2.	Deposition of ozone O_3	D	9.41	Nowak D J; McPherson G E/and others	Some species of trees or shrubs—Lawns (herbaceous)
3.	Deposition of nitrogen dioxide NO_2	D	7.65	Nowak D J/and others	Some species of trees or shrubs
4.	Deposition of particulate matter	D	7.65	Nowak D J; McPherson G E/and others	Some species of trees or shrubs—Lawns (herbaceous)
5.	Deposition of sulfur dioxide SO_2	D	8.82	Nowak D J; McPherson G E/and otherss	Some species of trees or shrubs—Lawns (herbaceous)
	Other Services				
6.	Low VOC Emissions	D	0.59	Karl T; Kirstine W	Woodland Lawns (herbaceous)
7.	Air temperature reduction	D	9.41	Akbari H; Shashua-Bar L/and other	Woodland
8.	Carbon storage	D	5.29	Jo H K; Akbari H/and other	Woodland
9.	UV radiation reduction	D	0.59	Hermans C	Some species of trees or shrubs
10.	Low allergenicity	D	6.47	McPherson G E; Nowak D J/and other	Woodland
11.	Wind reduction	D	6.47	Gromke C; Akbari H/ and other	Woodland
12.	Building energy reduction	D	5.88	McPherson G E; Nowak D J/and other	All VUA—Shrubs
13.	Noise reduction	D	6.47	McPherson G E; Nowak D J/and other	Woodland
14.	Odor	D	6.47	McPherson G E; Nowak D J/and other	Woodland
15.	Decrease in the quantity of germs	D	6.47	McPherson G E; Nowak D J	Woodland

The selected articles have underlined three research trends:

- The effect of vegetation on chemical air quality, and pollution impacts;
- Other ecosystem services are less identified and characterized: the well-being of inhabitants, ecological balance, the role of esthetical values, etc. If the interactions between urban climate and vegetation are the major topics for the moment in the research community other types of ecosystem services seem emerge in some articles through multidisciplinary vision enriching our understanding of the ecosystem services provided by types of plant species other than trees.
- Finally, since the emergence of urban ecology the multifunctional aspects of urban green spaces seem to favor an increasing interest. Functionalist urban planning at the beginning of the 20th century attributed to green spaces only social and leisure roles. This trend is being modified, thanks to numerous studies showing measurements enriching a multifunctionality insight of urban green spaces useful in designing and managing public space.

References

1. Bentsen P, Lindholst AC, Konijnendijk CC (2010) Reviewing eight years of Urban Forestry and Urban Greening: Taking stock, looking ahead. Urban forestry and urban greening 4: 273–280. doi: 10.1016/j.ufug.2010.06.003
2. Bolund P, Hunhammar S (1999) Ecosystem services in urban areas. Ecological economics 29: 293–301. doi: 10.1016/S0921-8009(99)00013-0
3. COST Action C11 WG1B (2001) http://www.greenstructureplanning.eu/COSTC11
4. Costanza R, d'Arge R, de Groot R, Farberk S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Suttonkk P, Belt MVD (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253–260. doi: 10.1016/S0921-8009(98)00020-2
5. Daily GC (Ed.) (1997) Nature's services. Societal dependence on natural ecosystems. Island Press, Washington, DC, pp 392. ISBN 1-55963-475–478
6. de Groot RS, Wilson MA, Boumans RMJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecolog Econ 41: 393–408. doi: 10.1016/S0921-8009(02)00089-7
7. de Groot RS, Alkemade RL, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7:260–272. doi:10.1016/j.ecocom.2009.10.006
8. Dobbs C, Francisco JE, Wayne CZ (2011) A framework for developing urban forest ecosystem services and goods indicators. Landscape and urban planning 99: 196–206. doi: 10.1016/j.landurbplan.2010.11.004
9. James P, Tzoulas K, Adams MD, Barber A, Box J, Breuste J, Elmqvist T, Frith M, Gordon C, Greening KL, Handley J, Haworth S, Kazmierczak AE, Johnston MJ, Korpela K, Moretti M, Niemela J, Pauleit S, Roe MH, Sadler JP, WardThompson C (2009) Towards an integrated understanding of green space in the European built environment. Urban Forestry Urban Greening 8:65–75. doi:10.1016/j.ufug.2009.02.001
10. Lamarque P, Quétier F, Lavorel S (2011) The diversity of the ecosystem services concept and its implications for their assessment and management. C R Biol 334:441–449. doi: 10.1016/j.crvi.2010.11.007

11. Lebart L, Piron M, Morineau A (2006) Statistique exploratoire multidimensionnelle, Visualisation et interface en fouille de données. Dunod, Paris
12. Leuzinger S et al (2010) Tree surface temperature in an urban environment. Agricultural Forest Meteorology 150:56–62
13. Mehdi L, Weber L, Di Pietro F., Selmi W (2012), Évolution de la place du végétal dans la ville, de l'espace vert à la trame verte ; to be publsihed Vertigo, Vol. 12, numéro 2
14. Millenium EA (2005) Ecosystems and human well-being: current states and trends. Washington. Island press. http://www.maweb.org/documents/document.358.aspx.pdf. Accessed 28 March 2007
15. Niemelä J, Saarela SR, Söderman T, Kopperoinen L, Yli-Pelkonen V, Väre S, Kotze DJ (2010) Using the ecosystem services approach for better planning and conservation of urban green spaces: a Finland case study. Biodivers Conserv 19:3225–3243. doi:10.1007/s10531-010-9888-8
16. Noe SM et al (2007) Monoterpene emissions from ornamental trees in urban areas: a case study of Barcelona, Spain. Plant Biol 10:163–169
17. Nowak DJ Dwyer JF (2007) Understanding the Benefits and Costs of Urban Forest Ecosystems. In Kuser JE (ed) Urban and Community Forestry in the Northeast, Springer, pp 25-46. http://books.google.fr/books?hl=fr&lr=&id=PCycWgOkZwC&oi=fnd&pg=PA25&ots=nrf9t2pxKS&sig=_AWzfLE_P5IrpmLFWj3wNpFDTtc#v=onepage&q&f=false. Accessed 28 March 2007
18. Odum EP (1971) Fundamentals of Ecology. Saunders, Philadelphia pp. 574
19. Paoletti E (2009) Ozone and urban forests in Italy. Environ Pollut 157:1506–1512
20. Potschin MB, Haines-Young RH (2011) Ecosystem services: Exploring a geographical perspective. Prog Phys Geogr 35:575–594. doi: 10.1177/0309133311423172
21. Young RF (2010) Managing municipal green space for ecosystem services. Urban forestry and urban greening 9: 313–321. doi: 10.1016/j.ufug.2010.06.007

Assessment of Ecosystem Services in Urban Systems for the Example of Karlsruhe

Kevin Grönmeier, Sarah-Madeleine Hönig, Inge Jentsch, Simon Leib, Julia Loskyll, Caroline Mayer, Steffen Rothardt, Julia Seimetz, Sabrina Tweraser, Franziska Villinger, Guido Waldenmeyer and Stefan Norra

Abstract In recent times many studies e.g. "The Economics of Ecosystems and Biodiversity" (TEEB) and the "Millennium Ecosystem Assessment" (MEA) have drawn attention to valuing ecosystem services (ESS) not only in natural environment but also in urban systems [The Economics of Ecosystems And Biodiversity (TEEB) Hrsg. Mainstreaming the Economics of Nature 2010, Infodienst Landwirtschaft – Ernährung – Ländlicher Raum Schwäbisch Gmünd Hrsg. Vergleich der Preiswürdigkeit verschiedener Mineraldünger 2011]. The assessment of ESS is an important part of nowadays economic issues and political decision making, especially in ecological urban planning. In this context, a project was launched at the Institue of Geography and Geoecology, KIT, to locate and valuate ESS for the example of Karlsruhe. Inspired by previous studies like the "Green City Index" (Singapore Index) or "City of Biodiversity" methods of identification, mapping and evaluation of ESS were developed. The mapping of biotope types according to the guideline of the State Ministry for Environment, Measurements and Nature Conservation (Landesanstalt für Umwelt, Messung und Naturschutz Baden-Württemberg (LUBW) Biotoptypenkartierung) was used to identify the different ecosystem types [7]. Five 0.5 km^2 large areas (tiles) were chosen as representative parts of Karlsruhe to provide a general overview on urban ecosystem types. These ecosystem types can be evaluated with respect to the four ESS (provisioning, regulating, cultural and supporting services) mentioned in the MEA [Infodienst Landwirtschaft – Ernährung – Ländlicher Raum Schwäbisch Gmünd Hrsg. Vergleich der Preiswürdigkeit verschiedener Mineraldünger 2011]. Out of these four services urban relevant ES subservices were picked out to be valued with monetary and non-monetary methods. This study aims at localizing urban ESS and developing and summarizing new assessment tools, which can be used as basis for further studies in Karlsruhe or other urban systems. In addition, the results of this research holistically can be utilized to understand and sum up EES in Karlsruhe in follow-up surveys.

S. Norra (✉) · K. Grönmeier · S.-M. Hönig · I. Jentsch · S. Leib · J. Loskyll · C. Mayer · S. Rothardt · J. Seimetz · S. Tweraser · F. Villinger · G. Waldenmeyer
Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany
e-mail: stefan.norra@kit.edu

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_11,

Fig. 1 Investigated tiles (LGL Baden-Württemberg)

Introduction

Ecosystems in urban systems are under high pressure by various development activities and environment pollution. Nevertheless, especially in urban systems, ecosystems provide indispensable basics for a healthy and worth-living environment. More and above that, in urban systems even the most sealed and developed areas form ecosystems of varying effects on the living conditions. The approach of ESS provides a strong tool to assess the value of ecosystems also in urban systems to improve and optimize the structures of urban developments. Within this study, a method was elaborated in 2011/2012 to value the ESS for the example of Karlsruhe.

Methodology

Five 0.5 km^2 tiles were chosen as representative parts of Karlsruhe to give a general overview of ecosystems' types occurring in urban systems. The tiles are arranged along transect from west to east in Karlsruhe and show different land uses (Fig. 1). The mapping methodology of biotope types according to the State Ministry for Environment, Measurements and Nature Conservation (LUBW—Biotoptypenkartierung, [7]) served as a guideline to identify the different types of biotopes. These types were evaluated with respect to the four ESS. Specific urban relevant and important services were identified and evaluated with monetary and non-monetary methods.

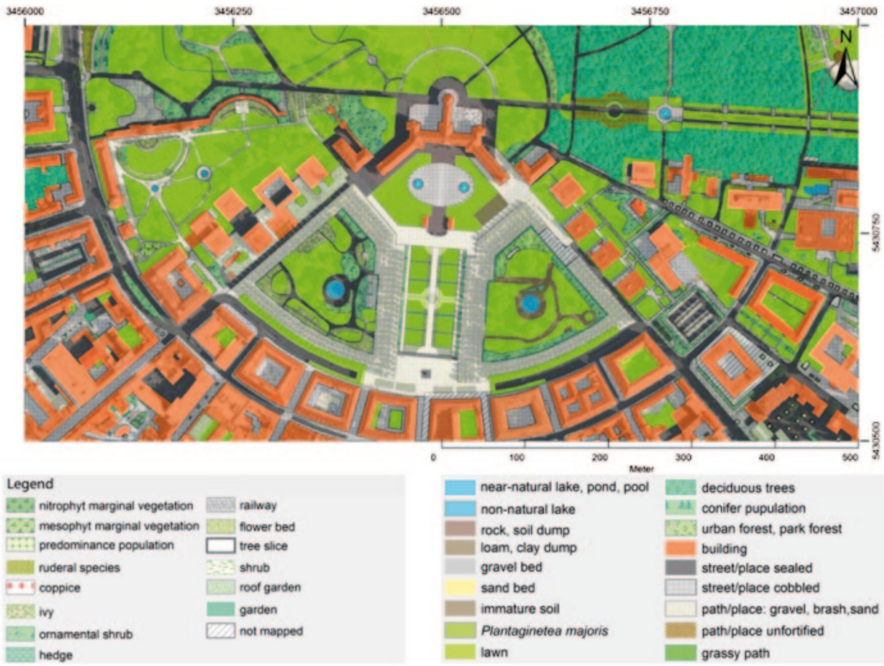


Fig. 2 Biotope types of the city center (tile J10) in Karlsruhe, aerial photo: Liegenschaftsamt Karlsruhe

The research started with mapping biotope types and drawing biotope maps in GIS (Fig. 2). These biotope maps are essential to locate urban ecosystem services. On that basis, ESS were cartographically expressed in maps (e.g. biodiversity Fig. 3), while other are diagrammed. Table 1 shows the used methods for the assessment of EES.

Results and Discussion

Mapping

The land uses of the urban areas are illustrated by the mapped biotopes (Fig. 2).

As an example the map of biotope types and the map of the ecosystem service biodiversity for tile J10 (city center) are presented in Figs. 2, 3.

Table 2 gives an overview over the main biotope types and the usage of the investigated tiles of Karlsruhe.

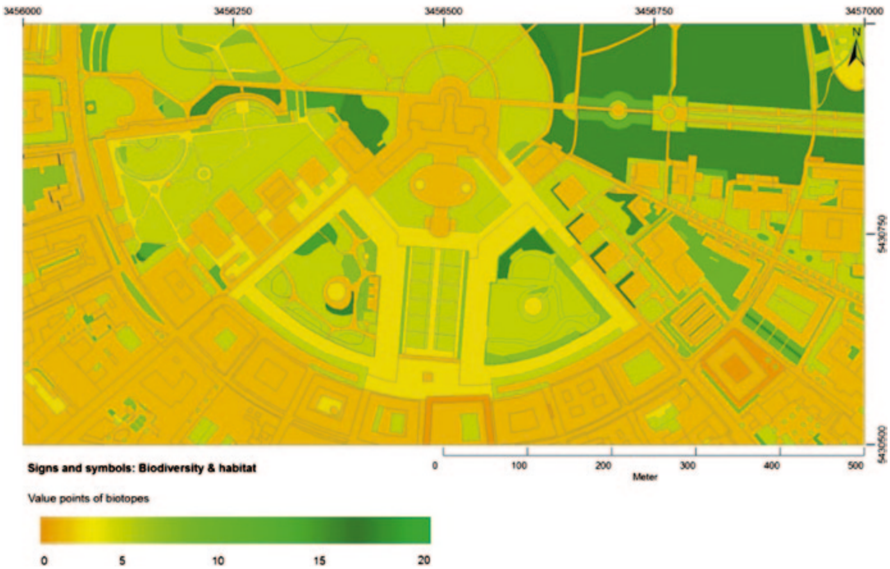


Fig. 3 Biodiversity of the city center (tile J10) in Karlsruhe

Table 1 Methodology of assessed EES

Ecosystem Service	Method
Biodiversity	Value points of biotope value (the higher the points, the more biodiversity), guidance of LUBW [5], non-monetary
Food supply	Price and earnings for agriculture crops
Pollination	Value of bee colony, according to TEEB Case Study [2]
Cultural and spiritual inspiration	Cemetery maintenance costs per m²
Recreation	Costs for maintenance of green areas and allotment
Climate regulation (climatic balance, dust bounding capacity)	Categories of ground cover [7], non-monetary
Groundwater renewal	Grade of sealing, precipitation charges and run-off coefficient
Nutrient element regulation	Estimated by valuing nutrient content in soils (N, P, Ca, K, Mg, S) based on the actual price of fertilizers [5]
Value of trees	Calculating capacity of wood, current price of forestry wood
Carbon storage	Value of carbon storage per ha with carbon certificate [6]

Table 2 Details of mapped tiles

Tile	Biotope types/utilization
J3 (Industry area)	Agriculturally used areas, sealed paths, buildings, lawns, forest and floodplain areas, industrial area (30 %)
J5 (Port settlement)	Buildings, sealed places, cemetery; river Alb (natural biotope type, floodplain-band)
I7 (West City)	Anthropogenic biotope types (90 %), buildings, lawns, gardens, allotments, sport fields
J10 (City Center)	Green spaces, biotope type represents the cityscape (radiate streets around castle) outward, recreation areas, lawns, urban forest, buildings, streets and paths
K16 (Suburban Area)	Buildings (6,5 %), lawn, cobbled streets and squares, gardens (12 %), largest area by agriculture crop research institute "Augustenberg", cemetery

Biodiversity

The conducted assessment of biotopes provides a good overview and a reasonable introduction to the ecosystem service biodiversity. However, it did not take wildlife or connection between biotopes and is based solely on valuing the biotopes by points according to the guideline of the State Ministry for Environment, Measurements and Nature Conservation [7].

Tiles' Details

In tile J3 the transition between rural and urban area becomes evident. Anthropogenic influenced industrial areas directly adjoin more rural biotopes and natural floodplains. A settlement of industrial and commercial areas is rather typical, because the use of riverine areas as a residential area was unthinkable before mosquito control.

Comparatively, tile J5 scores the highest total biodiversity points of all tiles. This is caused by many natural biotopes with a very high rating, though they are not classic city biotopes. While high value points were awarded, biotopes can be further improved (e.g. by containment of invasive species). Nevertheless, by having these high-quality biotopes inside the city of Karlsruhe, it becomes clear that even in cities sufficient natural areas can exist if they are adequately protected and maintained.

As mentioned above, in tile I7 (West City) rather low assessed and anthropogenic influenced biotopes are found. High-quality biotopes are only found on a very small scale, which indicates that urbanization and anthropogenic use shaped I7. Thus, it is not surprising that I7 achieves the lowest biotope value of all the selected tiles. However, this area is enhanced by a high number of trees.

The extremely low values of biotopes in tile J10 (City Center) reflect that this part is strongly influenced by human beings. By a high degree of development and sealing many plant species have been pushed back. The downtown area is heavily affected by non-indigenous or intentionally planted plants. Spontaneous vegetation occurs almost nowhere in this district. For this reason, the mapped biotope types and biodiversity are rather inferior in comparison to the other tiles.

Unlike tile J3 and J5, tile K16 (suburban area) has less dense developed areas, but still the overall biotope value is lower. This is because although a high number of natural biotopes were found, most of them have a low value. The agricultural land on Augustenberg is characterized by monocultures (orchards) and thus has only a poor biodiversity value.

Food Supply

For the evaluation of the ESS food supply the average crop in dt/ha has been used. The applied market rates are from 2010 since market prices for the diverse groceries in the same reference period were not available. In the calculation merely the area of cultivable land was used. Information such as age, quantity and height of the trees or shrubs was not considered. This might affect the results, since especially in orchards the density of trees per area differs. However, the exact recording of these data is extremely time consuming. A specific of tile K16 is that there is a crop research institute and almost all crops have to be abolished, so there is only marginal direct marketing.

Pollination

The evaluation of the monetary value of pollinating service is based on estimations from Switzerland [2]. Several factors, such as location, climate, annual production or world market price can lead to regional and annual fluctuation of the monetary value. For that reason a detailed interrogation of Karlsruhe's beekeepers has to be started to get an advance in this evaluation. However, the chosen evaluation method is adequate for the first approximation.

Cultural and Spiritual Inspiration

As already mentioned in the MEA, these ecosystem services are difficult to map and to evaluate [9]. In the TEEB it is suggested to use "willingness to pay"-surveys, but in the framework of the study, such an investigation was not conducted [3]. It is in common ground that a cemetery is an important green area to the European culture and, moreover, it is easy to map. This is only a tiny part of what this service can offer, but it definitely requires further research in how it could be mapped and valued, before these ecosystem services can be surveyed at the same degree as the others. Annual fees, using rights, funeral expenses and maintenance costs have been used for calculation of the ESS.

Recreation

Green space, especially lawns, is mapped and attributed with recreation in this study. Tiles with many allotments and green space are the most valuable areas. The tile at the city center (J10) hosts the Castle Park, a large recreation area. Tile I7 in the west is rich in allotments, giving both tiles the best results for recreation. For public green maintenance costs were used for ESS calculation, for allotment gardens the respective fees for renting such gardens from for Germany typical allotment garden clubs.

Climate Regulation and Groundwater Renewal

Climate regulation comprised the factors of mitigating the urban heat effect and dust filter capacity. Both are expressed non-monetary as percentage between no heat island mitigation respectively no dust filter capacity and maximum effects of heat island mitigation and dust filter capacity [1, 3, 8]. The ESS groundwater renewal was expressed as monetary value calculated via surface runoff coefficient, respective area and the fee that has to be paid if precipitation cannot percolate and becomes surface runoff. This fee was 5.06 € per 10 m^2 in Karlsruhe in 2012. With this evaluation method of climate control and groundwater renewal it is relatively simple to compare the tiles with each other. However, the assessment results only from the categories of ground cover. Other factors such as climate and surface structure were not considered. For a more detailed assessment measures in these fields are necessary as differences between the surrounding areas (such as cold-air-lanes) are not displayed by this method. Furthermore all studied biotope types (in total 97) are classified in only 10 categories of ground cover and not every biotope type was easy to classify. For the monetary valuation of groundwater renewal all sealed and partly sealed areas were considered. However, the split precipitation charge of Karlsruhe only considers precipitation, which is canalized. Sealed areas without a connection to the canalization were not assessed separately.

Nutrient Element Regulation

The important difference between the investigation areas is the level of sealing of the soil surface. Because of that, the downtown areas are of less value than the peripheral ones. The nutrient contents (N, P, K, Mg, Ca, S) were estimated on the basis of available information on occurring soils and monetarily expressed according to respective fertilizer prices. Including more soil functions and variables important to soil fertility, such as the buffer and filter function of soils, would increase the value of the soil. Additionally, valuing may not be limited just to unsealed areas, because roots can reach underneath sealed areas as well.

Table 3 Ecosystem services of Karlsruhe

ESS	Tiles total	Tile average
Total area	2,500,703 m^2	50 ha
Sealed surface	-	45 %
Biodiversity (Biotope value)	13,662,355 value points	54,634 value points/ha
Food supply	283,978 €/a	1,136 €/(a*ha)
Pollination	1,846 €/a	7 €/(a*ha)
Cultural and spiritual inspiration	4,191,222 €	16,760 €/ha
Recreation	1,282,604 €	5,129 €/ha
Climate regulation		
Dust bounding capacity		26 %
Climatic balance		52 %
Groundwater renewal		
Groundwater recharge		35 %
Precipitation charges	500,249 €/a	2,000 €/(a*ha)
Nutrient element regulation	60,755 €	243 €/ha
Tree value		
Tree value-single trees	376,994 €	1,508 €/ha
Increase of tree value-forests	16,702 €	67 €/ha
Carbon storage		
Carbon storage-single trees	42,376 €	169 €/ha
Carbon storage-forests	8,136 €	33 €/ha

The Value of Trees (Timber and CO_2)

For trees, the diameter in breast height was measured, the height was estimated and the trees were categorized whether they are coniferous or deciduous trees. The volume was calculated according the method described by Nagel (2009) [10]. Average market prices from 2011 were used to calculate the monetary value of timber.

In addition, the amount of stored CO_2 in the trees was calculated. The sample zones do not represent the mean forest area of the city; therefore the extrapolated value for the whole urban area is lower than the one measured by Kändler et al. (2011) [6]. For monetary evaluation the average price for CO_2 at the European Energy Exchange was applied.

All used prices are highly variable over time and are thus not reliable in long-terms. In comparison to the other evaluated ESS, the monetary account of urban trees is comparatively low. It can be assumed that the value would be much higher if all ESS of urban trees (and not only timber and CO_2) would have been considered.

Summary of Ecosystem Services

Table 3 provides an overview over the evaluation of the tiles and the ecosystem services occurring in them. Not for all ESS monetary values could be produced. However, it is noteworthy that the services cultural and spiritual inspiration and recreation are the most valuable ones if expressed in Euro. The transfer of biotope value points into Euro is still under discussion and has not been carried out here.

Conclusions

The localized urban EES and the developed assessment tools can be used as a basis for further studies in Karlsruhe or other urban systems. In addition, the results of this study can be utilized for a holistic understanding and serve as a building block for future surveys on EES. Elaborating the methodology for the assessment of ecosystem services based on biotope type mapping was a main part of this study. Since urbanization is correlated with changes to biodiversity, this is an important aspect when considering EES. Nevertheless some major points could not be considered in this study. For example, the ecosystem service of biodiversity was only conducted qualitatively (non-monetary). Moreover, because the topography of the studied areas was not considered, the actually mapped space is bigger than the GIS based surfaces. Another point is the relatively small extension of the mapped tiles, with only provide an overview and no results for Karlsruhe as a whole. Besides that, “multifunctional biotope types” could be of interest, as overlapping ecosystem services could create a “multi-talented” biotope type by providing e.g. climatic compensation function, recreation and pollination. These “multi-talented” biotope types should be considered even higher in worth.

The whole research results, maps and discussion are unpublished in a report of the Institute of Geography and Geoecology, KIT. The calculated equations and a full list of all references are available on enquiry.

Acknowledgments The authors very much acknowledge the support of Ulrike Rohde (Environmental Agency Karlsruhe). Moreover they thank Silke Wolf (garden and park department Karlsruhe) and Patricia Knebel (district office Karlsruhe) for the data supply.

References

1. Arlt G, Lehmann I (2005) Ökologische Flächenleistungen - methodische Grundlagen: Analyse und Bewertung teilstädtischer Gebiete in Dresden. Dresden. http://www.ioer.de/stadtpotenziale/html/publikat.html
2. Besser T, Hrsg. (2010) TEEB case: Valuation of pollination spurs support for bee keepers; available at www.eea.europa.eu/atlas/teeb/valuation-of-pollination-spurs-support-1
3. The Economics of Ecosystems And Biodiversity (TEEB) Hrsg. (2010) Mainstreaming the Economics of Nature; available at http://www.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf
4. Heber B, Lehmann I (1996) Beschreibung und Bewertung der Bodenversiegelung in Städten. zweiter Beitrag zum Forschungsprojekt Stadtkulturelle Orientierungswerte für die Bodenversiegelung - naturnahe Regenwasserbewirtschaftung in Siedlungsgebieten; Leibniz-Institut für ökologische Raumentwicklung (IÖR); IÖR-Schriften; 15. Dresden

5. Infodienst L-E-LRaumSGmünd Hrsg. (2011) Vergleich der Preiswürdigkeit verschiedener Mineraldünger; Available at https://www.landwirtschaft-bw.info/servlet/PB/menu/1236343_l1_pcontent/index.html?druckansicht=ja
6. Kändler G, Adler P, Hellbach A (2011) Wie viel Kohlenstoff speichern Stadtbäume? - Eine Fallstudie am Beispiel der Stadt Karlsruhe. FVA - Einblick 2/2011; Available at http://www.fva-bw.de/publikationen/einblick/einblick201102.pdf
7. Landesanstalt für Umwelt, Messung und Naturschutz Baden-Württemberg (LUBW) Hrsg. (2009) Arten, Biotope, Landschaft; Schlüssel zum Erfassen, Beschreiben, Bewerten; Karlsruhe; available at http://www.lubw.baden-wuerttemberg.de/servlet/is/60969/arten_biotope_landschaft.pdf?command=downloadContent&filename=arten_biotope_landschaft.pdf
8. Langner M (2006) Exponierter innerstädtischer Spitzahorn (Acer platanoides) - eine effiziente Senke für PM10? In: Meurer, M., Burger, D., Vogt, J.: Karlsruher Schriften zur Geographie und Geoökologie 21, Karlsruhe
9. Millennium E Assessment(MEA) (2005) Ecosystems and human well-being: synthesis; a report of the Millennium Ecosystem Assessment. The Millennium Ecosystem Assessment series;. Island Press, Washington, DC
10. Nagel J (2009) Forest Applets: Volumen von Einzelbäumen. http://www.nw-fva.de/~nagel/forestapplets/volumen/VolumenApplet.html (accessed on 13. 08. 2012)

A Basis for Inquiry into Policy Considerations for Increasing the Application of Biophilic Urbanism

Angela Reeve, Cheryl Desha, Charlie Hargroves, Peter Newman and Doug Hargreaves

Abstract Urban design that harnesses natural features (such as green roofs and green walls) to improve design outcomes is gaining significant interest, particularly as there is growing evidence of links between human health and wellbeing, and contact with nature. The use of such natural features can provide many significant benefits, such as reduced urban heat island effects, reduced peak energy demand for building cooling, enhanced stormwater attenuation and management, and reduced air pollution and greenhouse gas emissions. The principle of harnessing natural features as functional design elements, particularly in buildings, is becoming known as 'biophilic urbanism'. Given the potential for global application and benefits for cities from biophilic urbanism, and the growing number of successful examples of this, it is timely to develop enabling policies that help overcome current barriers to implementation. This paper describes a basis for inquiry into policy considerations related to increasing the application of biophilic urbanism that captures and integrates knowledge from lived experience around the world. The paper draws on research undertaken as part of the Sustainable Built Environment National Research Centre (SBEnrc) in Australia. The paper discusses the emergence of a qualitative, mixed-method approach that captures lived experiences and extends beyond the literature and documented journeys of international cities that have encouraged biophilic urbanism. Stakeholder workshops provide context and scope to research to ensure it is targeted, and a meta-narrative is developed to extract key learnings of relevance.

Introduction

Globally, a convergence of complex and rapidly evolving challenges is likely to force significant shifts in the design and function of cities, including climate change, resource shortages, population growth and urbanization, and financial pressures.

A. Reeve (✉) · C. Desha · D. Hargreaves
Queensland University of Technology (QUT), Brisbane, Australia
e-mail: angela.reeve@qut.edu.au, www.sbenrc.com.au

C. Hargroves · P. Newman
Curtin University, Perth, Australia

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_12,

The scale of change needed to respond to such challenges, and the timeframe available in which to make such change, is unprecedented [5, 6]. With increasingly globalized knowledge transfers, there is also an unprecedented opportunity to learn from international experience to adopt demonstrated approaches to addressing these challenges. For example, the High Line park in New York was inspired by the Promenade Plantée in Paris, and is now inspiring similar developments in St Louis, Philadelphia, Jersey City, Rotterdam and Sydney [3, 4]. New York is considering Sydney's waste management strategy, which was itself based on London's approach [7].

However this process of learning by example has inherent problems, as the Oxford Programme for the Future of Cities notes [7],

> We are now confronted with overwhelming amounts of information about urban life. Ideas and innovations are continually assembled, mobilized and translated within and across cities by means of different networks and gatekeepers… Yet, these processes of learning and knowledge transfer are continuously confronted by the dissociation of mundane and scholarly, policy and technical, lay and scientific.

With these challenges in mind, The Oxford Programme raised two key questions for researchers that are relevant to the focus of this paper:

> How can we prompt methodological advancements that overcome these dichotomies, trace different urban discourses, and promote fruitful learning in and among cities?
> How can these knowledge networks better respond to the governance and socio-economic challenges we see emerging in cities today? [7]

Within this context, this paper presents a basis for a targeted inquiry into policy considerations to increase the application of biophilic urbanism, based on a method developed and refined through a project undertaken with funding from the SBEnrc in Australia. The research team proposed a method combining stakeholder workshops to provide scope and direction, literature review to provide a foundation of base knowledge, an interview series to provide context and capture lived experiences, and the development of a meta-narrative to identify emergent themes and learnings. From this, a practical evidence-base could provide a robust foundation for visioning; gaining public, political and industry support; risk assessment and mitigation; development of specifications and guidelines; and capacity building.

This paper provides context for such an inquiry, highlighting that the challenges facing society today require holistic solutions that address the underlying system failures that have led to this point. The background to the existing investigation is discussed, providing insights into the authors' experience of what is possible when working within the global context of urgent and challenging times. The emergent basis for inquiring into policy considerations is then presented, along with the lessons learnt through this work.

Complex Problems and Synergistic Solutions

Cities are facing critical decisions over how to enhance, replace and repair infrastructure in the face of emerging and serious challenges to provide essential services and ensure urban environments are liveable and functional [11]. Biophilic urbanism is an emerging design principle capable of considering the multi-dimensional and interdependent complexities of urban systems and infrastructure, including stormwater management, electricity demand, urban heat island mitigation, air pollution, food production, biodiversity preservation, congestion management, and place making (see [10]). Through the use of natural design features, biophilic urbanism can meet society's inherent need for contact with nature, and assist efforts to respond to these mounting pressures. The principle directs the creation of urban environments that are conducive to life, and that deliver benefits to a range of stakeholders including governments, developers, building owners, occupiers and the surrounding community [10].

A growing number of cities around the world are developing and implementing mechanisms to encourage and require the use of biophilic elements, although as yet these remain generally *ad hoc* and largely disconnected [8]. However, by learning from these emerging experiences, knowledge can be developed to potentially fast-track implementation of similar policies elsewhere within the necessary timeframes to adapt and build resilience to the rising urban challenges.

Creating a Basis for Inquiry

As part of the SBEnrc project, the research team undertook rigorous, iterative consultation with key stakeholders in Australian government, industry and academia, and identified the following clear needs for the research to provide [10]:

1. An understanding of how biophilic urbanism can be practically applied;
2. Key considerations in design and application and how to mitigate risks;
3. Expected performance, and how to value and compare this performance to conventional approaches to urban design; and
4. How to optimize the process of developing and implementing policies to enable biophilic urbanism so these are effective, timely and well accepted.

It was concluded from this stakeholder engagement that a pragmatic and novel approach was needed to gain a deeper understanding of the emerging experience and knowledge with biophilic urbanism, including insights into the processes of gaining public, industry and government support for biophilic urbanism, experiences in policy development and implementation including risk mitigation, addressing challenges, and what was learnt from aspects that worked well and those which didn't. It was clear that a method to gain such knowledge must extend beyond commonly available information in the literature and the internet.

In the recent UN Habitat Urban Patterns for a Green Economy: Working with Nature publication, this need was confirmed from a global perspective, noting that, "Increasingly, city managers wish to learn by example. Rather than more theory and principles, they want to know what has worked, what has not, and which lessons are transferrable to their own contexts. There is much information available, but little time." [13] As this quote highlights, information is not always useful, nor does it always represent the reality of the situation but rather the interpretation of the party presenting the information. Reports and reviews of case-study cities typically focus on outcomes rather than processes, reporting for example the number of trees planted, square footage of green roofs developed, or the size of the budget allocated [2]. This is of little value to cities elsewhere seeking to understand how to overcome challenges and barriers to achieve similar outcomes, how to reduce the political and financial risks and leverage opportunities, and what policies and programs are most appropriate for their circumstances. Furthermore, cities tend to discuss their successes and not aspects that haven't worked, such that those seeking to use such cities as a model cannot learn from these mistakes through literature alone.

Hence, the project team developed the following method, informed by previous work as part of the Townsville Solar City Program, in collaboration with Townsville City Council and Ergon Energy to create an innovative electricity demand reduction program, that included the study of international case studies of similar programs and interviews with program proponents [12]. The research used a grounded research approach, based on the best existing knowledge and practice in the field, and which continues to evolve as knowledge and experience grow. As shown in Fig. 1 and outlined below, four key phases provide a basis for developing targeted knowledge.

The method shown is designed as a series of layers of inquiry that provide an ever-deepening understanding of the complexity of the relationships between the challenges, the wide ranging benefits provided by biophilic urbanism, and the political, social and economic systems that interplay with each. The method is reflective, considering the broad field and the current state of knowledge and practice, and drawing on the personal experiences and reflections of interviewees, to provide new and important perspectives and insights into the journey towards biophilic urbanism of the city in which they worked. Each of the method phases is outlined in greater detail below.

Phase 1: Develop a Foundation of Understanding

In this phase, the critical literature and knowledge are gathered, as well as details of leaders in the field. This is not just about the 'what' and the 'why', but also the 'who'. It is essential to map the existing knowledge and practice in the field. This establishes the 'what's so' of available tools, technologies, policies and systems, and a vision of 'what's possible' by learning from the experiences of others elsewhere. This is not to suggest that other cities or initiatives are more 'advanced'

Fig. 1 Method for inquiry into policy considerations to increase the use of biophilic urbanism

or sustainable. Rather, as the challenges faced around the world vary, as do the opportunities, there may be an emergence of unique knowledge and practice that can inform strategies for cities elsewhere to respond to new or similar challenges imposed by rapidly changing conditions in the world today.

In the case of the SBEnrc project, this entailed investigating how nature could be integrated as design features into the built environment at various levels, what benefits this provided, and what challenges this presented. Existing case studies, city reports, historical data, industry reports and academic research were reviewed. This provided a detailed mosaic of 'biophilic elements' (specific applications of biophilic urbanism), along with a range of benefits specific to each element and those common to all elements [8].

Phase 2: Identify Specific Challenges and Opportunities

Knowledge of the availability of alternative options is rarely sufficient to cause their actual use. More commonly, an array of challenges prevents their integration into mainstream practice. Uncovering specific challenges and potential opportunities requires considering the perspective of multiple stakeholders, including government representatives, industry practitioners, academics, and citizens or citizen groups. The Collective Social Learning (CSL) methodology developed by Emeritus Professor Valerie Brown for addressing 'wicked'[1] problems in society [1] is proposed as a structure for uncovering perspectives and insights from each stakeholder group, to uncover challenges to be addressed, and key strategies and opportunities to enable this to occur.

The CSL methodology steps workshop participants through four questions, requiring them to consider alternative perspectives of the problem at hand. These steps are described here, as used in stakeholder workshops for the SBEnrc project:

- What should be? Participants share ideals through a visioning exercise of what an ideal biophilic city would look like, uninhibited by existing barriers.
- What is? Participants establish the facts of the current situation, considering the enablers and disablers to biophilic urbanism in Australia.
- What could be? Participants discuss strategies and considerations for bridging the gap between 'what should be', and 'what is'—in this case, strategies and opportunities for biophilic urbanism, including potential components of an economic framework to value the benefits provided.
- What can be? This stage inspires collaborative action from participants, as key stakeholders in the issue. Participants in the workshop developed commitment statements to take actions to further the biophilic urbanism in Australia.

Phase 3: Capture Existing Knowledge

Information readily available about initiatives taken by cities to encourage biophilic urbanism is typically focused on outcomes rather than processes of developing such initiatives, providing little insight to those seeking to learn from these experiences. Further, the challenges and misguided attempts that may have occurred as part of developing the policies and programs are not frequently publicized, yet are vital learnings. Finally, many such initiatives are *ad hoc* rather than systemic and intentional, and stem from contextual circumstances that may not exist elsewhere. This context must be understood as background to a case study and learnings taken from it.

Thus, identifying and gathering critical information must actively engage key actors who can reflect on the processes, challenges, and systems that influenced the outcomes. This critical information includes 'what' (policies, programs and outcomes), 'who' (key actors), 'how' (processes for overcoming barriers, enhancing opportunities, gathering support, and developing and implementing policies and programs), and 'why' (key drivers and contributing circumstances).

[1] A 'wicked problem' has been variously defined by many authors since being comprehensively described by University of California Berkeley scholars, Rittel and Webber in 1973, and can be summarized as a class of problems, which are poorly defined; where the information is confusing; where there are many stakeholders with conflicting values; and where changes to one aspect of the system can lead to unexpected and non-linear change to other parts of the system. There is no clear solution to such problems, they have inter-dependencies and often multi-causalities and are socially complex [9].

Multiple case studies are hence developed using a mixed-methods approach involving desktop review and semi-structured interviews that seek to answer a set of key questions that provide insights into the processes of developing initiatives, that would inform efforts elsewhere key questions include:

- What were the principle drivers for the initiatives, and what contextual factors enabled these initiatives to emerge?
- Were there challenges or barriers to these initiatives, and how were these overcome?
- What opportunities or benefits catalysed these initiatives?
- What policy tools, planning frameworks or legislative measures have been used to underpin the application of biophilic urbanism?
- To what extent was an economic argument used to support or justify the development of these policies and programs? and
- Have there been any unexpected benefits, or consequences?

Interviews are often with policy makers, program leaders, industry representatives, and academics that developed and/or reviewed initiatives.

Phase 4: Develop a Meta-Narrative

Case studies can provide significant insights. However these occur within a specific set of contextual circumstances, defined by factors including climate, population and socio-economic descriptors, governance structures, history, environment, culture, and individuals. Attempting to replicate the processes that have been successful elsewhere is unlikely to produce the same outcomes without contextualisation. It can be valuable to develop a meta-narrative to consider emergent patterns, gaps, and themes across multiple case studies. This can provide an indication of the developing maturity of the field, what new knowledge is needed; identifies patterns in language and practice; and synthesizes common factors and considerations that have contributed to the success or failure of initiatives around the world, under certain circumstances. Links between key challenges faced in various case studies, and the mechanisms used for overcoming these can be identified, and the potential for this understanding to inform efforts elsewhere can be discussed. The process of developing this meta-narrative is qualitative, with the researcher reflecting on the previous three phases of investigation. In the SBEnrc project, the findings from the case studies were viewed from the perspective of application to the Australian context, as described by the stakeholders, to determine what findings are of particular relevance. The process is subjective and reliant on the researcher to observe emerging themes, complex relationships and relevant patterns.

Conclusions

Implications for Policy Development

The emergent method described in this paper provides a basis for a rigorous, efficient and transparent process for investigating and learning from lived experiences around the world. It addresses common issues associated with learning by example, including a need for information on processes, not just outcomes; to investigate failures as well as successes; and to tailor research to give insights into overcoming specific and localised challenges. It requires the researcher to seek to identify emergent patterns, themes and gaps in global knowledge and practice that can inform policy development and application.

Given the scale of the challenges faced and the urgency of addressing these within the coming decades, this method provides a significant opportunity for decision makers to reduce risks and shorten timeframes for developing and implementing policies and programs. Furthermore it connects researchers, practitioners and advocates in the field, allowing for ongoing collaboration and collective learning to further enhance the speed and depth of the cycle of learning and practice.

Beyond Biophilic Urbanism—Implications for Other Challenges

This method has been applied to the context of enabling biophilic urbanism in Australian cities, however there is an opportunity to apply this methodology to addressing similar policy challenges in other rapidly emergent fields, such as structural adjustment for reduced greenhouse gas emissions, responding to peak-oil and other resource shortages, and climate change adaptation. These challenges are similarly complex, or 'wicked', and require policy development to occur within more contracted timeframes than has historically been possible.

Using the presented method to address these challenges may produce the possibility of enhanced global cooperation to find and apply innovative solutions, and change expectations around the timeframes, and scale, of change that is possible. Whilst the method is intended to be flexible and to be adapted to the circumstances of each unique challenge it is used to address, it is anticipated that having a broad framework will provide guidance for a tested pathway to learning from lived experience around the world.

Acknowledgements This paper has been developed as part of the Sustainable Built Environment National Research Centre's 'Greening the Built Environment' Program, led by Professor Peter Newman, and supported by the Western Australian Department of Finance, Parsons Brinckerhoff, Townsville City Council (CitySolar Program), and Green Roofs Australasia. Professor Tim Beatley is acknowledged for his mentoring, and Ms Omniya el Baghdadi is acknowledged for peer contribution.

References

1. Brown V (2008) A collective social learning pattern, EuroPLoP Workshop, Klosters Irsee, Bavaria, July 9-13 2008; Brown, V., and Harris, J. (2012) The collective learning handbook: from collaboration to transformation. Earthscan, London
2. Bulkeley H (2006) Urban sustainability: learning from best practice? Environ Planning A 38(6):1029–1044
3. Davies A (2012) Can other cities emulate the success of New York's High Line? Crikey Media. 16 October. blogs.crikey.com.au/theurbanist/2012/10/16/can-other-cities-emulate-the-success-of-new-yorks-high-line/, accessed 16 November, Australia 2012
4. McKenny L (2012) Raising the bar for Goods Line drawcard, The Sydney Morning Herald, Australia, November 14. www.smh.com.au/nsw/raising-the-bar-for-goods-line-drawcard-20121114-29c5f.html, accessed 16 November 2012
5. Newman P (2007) Beyond peak oil: will our cities collapse? Journal of Urban Technology, Vol 14. Iss 2:p 15–30
6. Newman P, Beatley T, Boyer H (2008) Resilient cities: responding to peak oil and climate change. Island Press, Australia
7. Oxford Programme for the Future of Cities (2012) Research, City-to-City Learning, University of Oxford, Institute for Science, Innovation and Society. www.futureofcities.ox.ac.uk/research, accessed 14 November 2012
8. Reeve A, Hargroves K, Desha C, Bucknum M, Newman P (2011) 'Considering the Application of Biophilic Urbanism: A Sustainable Built Environment National Research Centre Discussion Paper', Curtin University and Queensland University of Technology
9. Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4(2):155–169
10. SBEnrc (2012) Can biophilic urbanism deliver strong economic and social benefits in cities? An economic and policy investigation into the increased use of natural elements in urban design, an industry report to the Sustainable Built Environment National Research Centre, Project 1.5, Greening the Built Environment Program Curtin University and Queensland University of Technology
11. Smith M, Hargroves K, Desha C (2010) Cents and sustainability: securing our common future by decoupling economic growth from environmental pressures, The Natural Edge Project. Earthscan, London
12. TCC (2010) 'Investigation into Existing Community Behaviour Change Programs on Reducing Residential Energy Demand', Townsville City Council and The Natural Edge Project, as part of the Australian Government Solar Cities Program
13. Habitat UN (2012) Urban patterns for a green economy: working with nature, united nations human settlements programme, Kenya

The Impact of Biogenic Isoprene in Dependence on Meteorological Conditions within Urban Green

Sascha Henninger

Abstract It is indisputable that urban green spaces have a positive impact on their nearby vicinity, but also for the residents. Though it does not matter, if it is a positive effect on the local climate or for recreational values. Nevertheless, an awkward planting could lead to an accumulation of air pollutants. From the applied urban climatology's point of view it is necessary to think about planning new vegetation within urban parks. In comparison to a climatic adjusted construction all over the urban area, likewise for new plantings throughout the planning phase the predominantly planted species must be considered in the right way. The analysis of the air pollution situation within different urban park areas in Kaiserslautern, Germany, inevitably revealed that during clear and calm weather conditions biogenic precursors could be emitted by diverse plants. Less atmospheric exchange, high air temperature and solar radiation arrange it so that near surface ozone is formed. Due to the fact that this air quality indicator could be diluted or dispatched the accumulation of it leads to higher concentration. It could be calculated that a wrong proportion of species which emit higher rates of biogenic hydrocarbons and the size of the green area lead to a location-based formation of near surface ozone by e. g. biogenic isoprene. Finally, this ends in a negative assessment of the recreational value of such an area in relation to the benefits which an urban green area should rather have. However, it is possible to react on this. Planning oriented recommendations for action could be given for optimizing the air quality situation. Ultimately, it is frequently only the lack of knowledge that diverse species of the current vegetation stock of an urban green area lead verifiably to an increase of the local near surface ozone concentration.

Benefits and Drawbacks of Urban Green Spaces

Urban areas represent a heterogeneous structure, which has been growing over a long time period. It is an obstacle to the applied urban climatology to create an adequate urban environment with ideally climatic and air quality conditions. Mainly urban green areas have the ability of a cooling effect. Depending on their size and

S. Henninger (✉)
Department of Physical Geography, University of Kaiserslautern, Pfaffenbergstr. 95, 67663 Kaiserslautern, Germany
e-mail: sascha.henninger@ru.uni-kl.de

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_13,

design urban green spaces could have a significant influence on the air temperature and the climatic conditions of their nearby vicinity. Nevertheless, also smaller ones do have a cooling effect and provide a reduction of the thermal load. Even the urban vegetation of an existing stock offers a great cooling potential, however, it is important to regard some facts: From the viewpoint of urban air quality not every tree is appropriate to be lined out within green spaces. The canopy of the trees must be taken into account and attention has to be paid to the assortment of the tree species: Some trees have the ability to affect the local air quality negatively. Lots tree species emit biogenic volatile organic compounds (BVOCs) in different concentration (e. g. isoprene and terpenes) [5]. These could serve as precursors for the formation of ozone near the ground. Indeed, it should not be neglected that there are also some biogenic emissions, which have the ability to react with anthropogenic trace elements and form secondary air quality indicators. One of these is the biogenic hydrocarbon isoprene. It could form ozone due to its great capacity of reaction. Actually, in comparison to anthropogenic hydrocarbons, isoprene could already start a formation with less concentrated O_3. This is why isoprene is one of the precursors, which has to be taken seriously. The rate of emission is dependent on the meteorological conditions (air temperature and solar radiation) and how these affect the stock of vegetation (leaf temperature) [5, 8]. According to this, clear and calm weather conditions with a high solar radiation and high air temperature are best qualified for leading to a high emission rate of isoprene from the plants' leaves. Even for the days with expected high concentration of ozone the amount of additional biogenic hydrocarbon, such as isoprene, may contribute to further formation of O_3, too. This occurs especially within areas like urban parks, where at first sight high ozone levels are not estimated [5]. So near surface ozone has the ability to react with particulate matters (e. g. pollen) to form free radicals of oxygen. As a consequence these could become toxic. This causes inflammations and inspired allergens could increase the risk of a respiratory disease [9]. Therefore, an analysis and assessment of the urban green area air quality could help to make a statement about the recreational effect of these areas in dependence of the leading vegetation and for that matter for the exposure to ozone [5]. So using the calculation of short- and long-term air quality indices can help to describe the air hygienic situation. These results can be used as a guidance of urban planning taking account of the influence of biogenic emission as a function of actual weather conditions [3, 5].

Assessment of Air Quality

For an assessment of air quality within a distinct area there are different standards. However, some facts should be considered for an evaluation:

- a clearly defined purpose concerning the diverse trace elements,
- the type of land usage,
- the side effects of the analyzed air quality indicator on human health as well as on vegetation and materials,
- duration of exposition, and

- the statistical distribution (e. g. exceedance probability).

Taking account of these it is achievable to create a valuation system, which assesses the impact of each air pollutant in consideration of the temporal scale and in dependence of the actual type of land use.

Diverse summary indices can be used to present an assessment of the air quality situation within a certain area and different areas respectively. The advantage of such indices is that not only the concentration of one substance will be assessed, but also the influence of several sources of emission. Referring to Mayer et al. [7] two air quality indices should be distinguished:

- impact-dependent air quality indices and
- impact-related air quality indices.

For this investigation and the assessment of the air quality situation the impact-related air quality index was chosen because it is more useful for these belongings. In contrast to the impact-dependent air quality index it is also possible to evaluate O_3 by the established guidelines of the European Union for the air quality indicator. The calculation of this air quality index enables a temporal reference. It facilitates a direct relation to health impairments, caused by corresponding substances, at a definite time of the day. One result of this is the opportunity to react correctly and at the right time. A further advantage of this valuation standard is the medical coverage.

In consideration of a pay-as-use assessment of urban green areas according to Straßburger [11] some specifics have to be attended:

- the application frequency of the urban green area in dependence of the season and the meteorological conditions,
- the application frequency of the residents in dependence of the time of the day, and
- the duration of stay within the park area.

Taking into account that the aim of this investigation is to analyze the formation of near surface ozone within urban green areas, it was ensured to determine the days during clear and calm weather conditions with high air temperature and high solar radiation. These are the days promising the highest emission rate of isoprene and formation of O_3 as well as the highest visitor frequency, most notably predominantly in the afternoon hours.

Investigation Area

Even if the focus of the investigation is on the formation process of near surface ozone, it is inevitable to fulfill some criteria, which involve the sealed and built-up surrounding areas beside the actual investigation area. The representativeness of urban green spaces and their reproducibility respectively the transferability of these results should hardly be given. Hence, the following facts must be attended:

Table 1 Assignment of trace element dependent emissions into DAQ index value and DAQ index classification and their grades, exemplarily offered for ozone. (Modified by Fröhlich-Nowoisky [2])

O_3 [$\mu g\ m^{-3}$]	Index value	Index classification	Grade
0–32	0.5–1.4	1	very good
33–64	1.5–2.4	2	good
65–119	2.5–3.4	3	satisfactory
120–179	3.5–4.4	4	adequately
180–239	4.5–5.4	5	poorly
≥240	≥5.5	6	awfully bad

- the comparability with an urban green area of the same size and structure within the urban area,
- the comparability with urban green spaces of a similar size and structure within other urban areas,
- the immediate vicinity to highly frequented streets to gauge potential sources of emission,
- the relevance and visitor frequency as an indicator for a nearby recreational area of the urban residents, and
- the question about the typical or characteristic urban park vegetation.

Two urban green areas, the so-called “Stadtpark” and “Volkspark” in the city of Kaiserslautern, Germany (49°14′N., 7°53′E.), were chosen to prove the measuring methodology. These urban green spaces are the two most frequented recreational areas in Kaiserslautern and mainly used for leisure by the residents. Especially, within the “Volkspark” many events act as attraction. But both areas also offer many leisure-time possibilities. With a size of approximately nine hectares the “Volkspark” is coevally the biggest urban green space in the city, whereas the “Stadtpark” is even smaller (3.3 ha). The area of the “Volkspark” is bounded by four-lane streets in the west and south. The “Stadtpark” is embedded within the densely built-up area of the city center (Table 1).

Measuring Methodology

Measurements were taken during clear and calm weather conditions between June and September. Due to these conditions such time periods suited very good and offered a so-called “worst-case-scenario” with wind speed less than 1.5 m s^{-1}, which provides a great potential to accumulate diverse trace elements, midsummery air temperatures by at least >30 °C and an accordingly high solar radiation of Q > 900 W m^{-2}.

Air quality measurements as well as the climatological ones were taken by two mobile laboratories. The aim of this measuring methodology was to determine the diurnal course of the different air pollutants’ concentration in relation to the meteorological conditions within both urban green areas. Thus it should be possible to prove the daily air quality and how it was influenced respectively dependent by different external influencing factors [4]. Besides ozone carbon monoxide, carbon dioxide, nitrogen monoxide, nitrogen dioxide and aromatic hydrocarbons (benzene, toluene, ethylbenzol, m-, o-, p-xylene) were measured. The air quality indicators were determined by a suction device of the mobile laboratory at 4 m above ground level. Additionally air temperature, air humidity, global and solar radiation were measured in 2 and 4 m a. g. l. respectively, wind speed and direction were determined in 10 m a. g. l by a 3-D sonic anemometer. Though it is possible to display the results as a time line or in dependence of wind speed, it is more favorable in dependence of the wind direction. This enables an exact temporal allocation to the potential sources of emission of the specific air pollutants within and outside the urban park area. In addition to the determined 1-min- and 15-min-average mean values for calculating the data in different time intervals, also integrated 1-h-average mean values were detected of the aromatic hydrocarbons [5].

Perceptions

Theoretical Estimation of the Biogenic Isoprene Emission Rate

Immediately after the mapping of the vegetation it was possible to calculate the theoretical rate of isoprene emission in dependence of the occurring species, considering an optimum of meteorological conditions. Indeed, it must be mentioned, that this estimation of biogenic emissions is afflicted with some uncertainties (e. g. phytomass, single or group trees, tanning). Nevertheless, the estimation should not be neglected, because it creates an image of the pattern of emission which is very helpful for the ongoing analysis of the air quality situation within the investigation area [5]. The mapping resulted in a heterogeneous structure of single trees, groups of trees and small forest areas. Altogether within the "Volks- and Stadtpark" there are 701 and 267 individuals respectively, combined with diverse species, whereas at least Aceraceae, Betulaceae, Fagaceae, Malvaceae and Platanaceae placed > 80 % of the total stock for both investigation areas. For measuring isoprene this was an advantage, because the species of plane (Platanaceae), beech trees (Fagaceae) and lime tress (Malvaceae) are considered as potential emitters of isoprene. Exemplarily, an assembly of the dominant groves for the "Volkspark" is shown in Table 2. Additionally the specific rates of isoprene emissions are also offered. The highest rate of emission could be expected for planes (Platanus acerifolia) and oaks (Quercus robur) and had to be identified as "high-emitter"-plants. Likewise the lime (Tilia concordata) and the birch (Betula pendula) must be counted as "high-emitters", too. Attention should be paid to the fact that at least plane and oak trees set > 50 % of all species within the investigation area. Other individuals revealed values less than 2 µg g (dry weight)$^{-1}$ $^{h-1}$ and must be referred as "low-emitter"-plants. Down to the present day there is a number of publications which deal with the analysis of urban

Table 2 Assembly of the dominant groves within the "Volkspark" and their specific rates of isoprene emission plus the rate of emission per tree considering an average leaf mass of 15 kg per individual

Scientific name	Specific rate of isoprene emission [μg g(dry weight)$^{-1\,h^{-1}}$]	Rate of isoprene emission per individual (15 kg) [μg h^{-1}]	Number of individuals	Rate of emission per species [mg h^{-1}]
Acer campestre	8	120	25	3
Platanus acerifolia	883	13,245	22	291.39
Quercus robur	1,405	21,075	310	6,533.25
Tilia concordata	26	390	72	28.08
Betula pendula	25	375	45	16.88
Amount			474	6,872.6
Total park area			701	8,874.05

trees and their potential of forming near surface ozone along roadsides as well as within urban green areas [3, 13]. Since Taha [12] the terms of "low-" and "high-emitter"-plants are used. The consideration of these low- or high-emitting tree species may have a sustainable impact on the emission of biogenic hydrocarbons and thus on the formation of ozone. For the purpose of this investigation the analyzed biogenic plant emission was divided into low- (<2 μg g (dry weight)$^{-1\,h-1}$), mid- (2–50 μg g(dry weight$^{-1\,h-1}$) and high-emitter-plants (>50 μg g(dry weight)$^{-1\,h\,-1}$) to have a more precise description of the specific situation of the vegetation of the investigated green space [3].

Knowing the tree species and their specific amount enables to calculate the total emission. The specific emission rate of isoprene [μg g (dry weight)$^{-1\,h-1}$] must be multiplied with the average biomass [g] of the respective species and the number of appropriate individuals. In reference to Kesselmeier et al. [6] and Straßburger [11] the average biomass was assumed a dry weight of leaves of 15 kg per tree. Exemplarily, for the "Volkspark" it could be calculated that solely the most important "high-emitter"-plants of the investigation area, shown in Table 2, offer a theoretical isoprene emission rate of 6.8 g h^{-1}. All in all this resulted in an biogenic isoprene emission rate of 8.8 g h^{-1} for all mapped tree species of the vegetation stock of this investigation during the day time hours, in dependence of optimal meteorological conditions (Table 2).

By calculating the so-called maximum incremental reactivation of isoprene (MIRi), it is possible to analyze which amount of ozone could be formatted theoretically by the current emission of isoprene [5]. So the incremental reactivation of isoprene is 9.1 [1]. Taking account of the MIRi, the mentioned total amount of isoprene emission within the investigation area of the "Volkspark" (s. Table 2) and the assumption of clear and calm weather conditions, the biogenic isoprene may cause a theoretical O_3 concentration of 90.4 μg m$^{-3\,h-1}$ [5].

Analysis of the Short-time Exposure

As it was mentioned in chapter 5.1 additionally to ozone the primary air pollutants were determined at the same time. Hence, the analysis of the data showed, that neither CO_2 nor the NO_x could be evaluated as pollution to human health. At no time of the day they roughly reach their limit values for emission. But an entirely different result was offered for the near surface ozone concentration. Between 2 and 7 p.m. the so-called MIK-value ("maximum emission concentration") for ozone (120 μg m^{-3}), defined by the German VDI and taken as a basis for the analysis, was exceeded several times (0.5-h-average-values). Also the limit values of emission for protecting human health of the Federal Emission Control Act (180 μg m^{-3}; 1-h-average-values) were passed a bunch of times in the late afternoon hours. Finally, this time period between noon and sundown, the time of the day with the highest air temperature and highest solar radiation, could be signed as polluted by near surface ozone. This negative phenomenon is furthermore exacerbated due to the fact that the highest rate of emission was nearly congruent with the time of the day when potentially the highest visitor frequency within the park area could be expected. In consequence the mentioned daily air quality index (DAQ; s. chap. 2) was calculated to give a statement for the impact-related air quality within the investigation area and its effect on human health. For an adequate validity of the calculation the daily maximum concentration of the 1-h-average values were considered of the O_3. This procedure enabled a better and more precise assessment of the air quality situation because the diurnal course of the air pollutant could be reflected. Thus the hourly average value air quality index for the diurnal course of the near surface ozone could be proven and is shown in Fig. 1.

As a result of the calculation it could be demonstrated that during midsummer days (between noon and 7 p.m.) with clear and calm weather conditions, it must be expected that for this time of the day with the highest frequency of visitors near surface ozone is formed within the urban green space of Kaiserslautern. Due to this situation the calculated impact-related air quality index for the "Volkspark" is not better than "adequately" (3.87, s. Table 1), which shows the significant influence on the air quality of O_3 within this green area and allows conclusions on a feasible pollution of human organism. So this calculation in comparison to the above mentioned specific diurnal course of the isoprene and the near surface ozone respectively offered the possibility to locate the places of the highest O_3 concentration. In dependence of the meteorological conditions, especially in respect of the atmospheric stability of the boundary layer, it could be determined that places with "high-emitter"-plants reveal the highest concentration. These are unfortunately congruent with those places, where it could be expected to find the highest frequency of people belonging to the risk group children (children's playground) and elderly people(seniors playground).

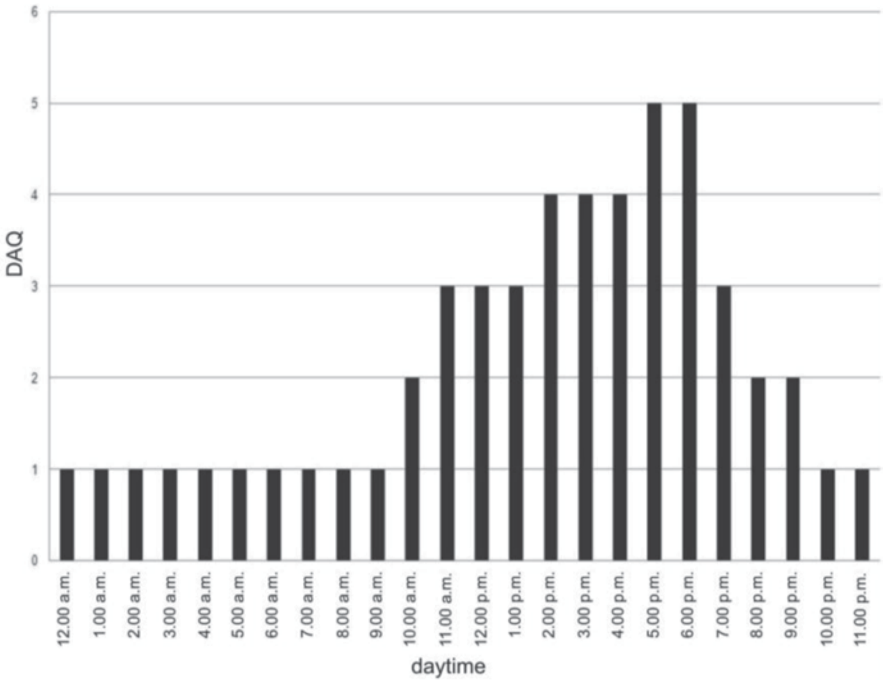


Fig. 1 Mean diurnal course of the air quality classification based on 1-h-average mean values for the investigation area "Volkspark", Kaiserslautern, Germany

Concluding Remarks

It is of course indisputable that urban green spaces have a positive impact on their nearby vicinity. Though it does not matter, if it is a positive effect on the local climate or for recreational values. Nevertheless, it could be shown, that an awkward, particularly, also thoughtless planting could lead to an accumulation of air pollutants. From the applied climatology's point of view it is necessary to think about planning new vegetation within urban parks. In comparison to a climatic adjusted construction all over the urban area, likewise for new plantings throughout the planning phase the predominantly planted species must be considered in the right way. The analysis of the air pollution situation within the "Volkspark" in the city of Kaiserslautern inevitably revealed that during clear and calm weather conditions biogenic precursors could be emitted by diverse plants. Due to the fact that this air quality indicator could be diluted or dispatched the accumulation of it leads to high concentration which obviously exceed the limiting values. This resulted in an air quality classification for the investigation area which was not satisfying. Not least this is ascribed to a vegetation stock with a rate of more than 70 % so-called "high-emitter"-plants [5]. It could be calculated that a wrong proportion of species which emit higher or lower rates of biogenic hydrocarbons and the size of the green

Table 3 Assembly of the dominant groves within the "Stadtpark" and their specific rates of isoprene emission plus the rate of emission per tree considering an average leaf mass of 15 kg per individual

Scientific name	Specific rate of isoprene emission [µg g(dry weight)$^{-1\ h-1}$]	Rate of isoprene emission per individual (15 kg) [µg h^{-1}]	Number of individuals	Rate of emission per species [mg h^{-1}]
Carpinus betulus	33	120	17	2,04
Fagus sylvatica	44	660	8	52,08
Fraxinus excelsior	101	1,515	17	255.85
Platanus acerifolia	883	13,245	1	132.45
Quercus robur	1,405	21,075	7	351.0
Tilia	26	390	39	152.10
Amount			79	647.9
Total amount			267	941.4

area lead to a location-based formation of near surface ozone by 5 to 10 % caused by e. g. biogenic isoprene. Though, by the example of the smaller "Stadtpark", it could be demonstrated that it is crucial to consider the relation between the size, the amount of different tree species and especially these representing high-emitter-plants. Using the above mentioned method of mapping and calculation it was obvious that within this area there are obviously some isoprene sources, much higher than within the "Volkspark" (s. Table 3). But these, in comparison with the species acting as "low-emitters" arrange, that there no abnormalities for the isoprene and ozone concentration as well.

Taking account of the MIRi, the mentioned total amount of isoprene emission within the investigation area of the "Stadtpark" the biogenic isoprene may only cause a theoretical O_3 concentration of ~24 µg m$^{-3\ h-1}$, despite the fact that within the nearby vicinity there are no NO-sources to destroy the formerly created near surface ozone.

However, and this could also be proven, it is possible to react on the problem, especially for the "Volkspark" or for the "Gruga-Park" in Essen, Germany, mentioned by Straßburger [11]. Planning oriented recommendations for action could be given for optimizing the air quality situation. Ultimately, it is frequently only the lack of knowledge that diverse species of the current vegetation stock of an urban park lead verifiably to an increase of the local near surface ozone concentration.

References

1. Carter WPL (1994) Development of ozone reactivity scales for volatile organic compounds. J Air Waste Manag Assoc 44:881–899
2. Fröhlich-Nowoisky J, Pickersgill DA, Despres VR and U Pöschl (2009) High diversity of fungi in air particulate matter. Proceedings of the National Academy of Science of the United States of America 106(31):12814–12819

3. Henninger S (2011a) A mobile measuring methodology to determine near surface carbon dioxide within urban areas. Air quality - Models and Applications:173–194
4. Henninger S (2011b) Urban Green Areas: Lots of Benefits, but some Drawbacks. Paper presented at the 16th International Conference on Urban Planning, Regional Development and Information Society REAL CORP 2011, Essen, Germany 18–20 May 2011:1069–1077
5. Henninger S (2012) Biogenic isoprene and its impact on human health in dependence on meteorological conditions. In: Journal of Environmental Protection, doi:10.4236/jep.2012 published online
6. Kesselmeier J, Staudt M (1999) Biogenic Volatile Organic Compounds (VOC): an overwiev on emission, In: Physiology and Ecology:23–88
7. Mayer H, Kalberlah F, Ahrens D and U Reuter (2002) Analyse von Indizes zur Bewertung der Luft. Gefahrstoffe - Reinhaltung der Luft 62:177–183
8. Pacifico F, Harrison SP, Jones CD and S Sitch (2009) Isoprene emission and climate. Atmospheric Environment 43:6121–6136
9. Shiraiwa M, Sosedova Y, Rouviere A, Yang H, Zhang Y, Abbat JPD, Ackermann M and U Pöschl (2011) The role of long-lived reactive oxygen intermediates in the reaction of ozone with aerosol particles. Nature Chemistry 3:291–295
10. Straßburger A (2004) Analyse atmosphärischer Spurengase zur Bestimmung des lufthygienischen Erholungswertes eines urbanen Parks. Dissertation, Universität Duisburg-Essen
11. Taha H (1996) Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. Atmos Environ 30:3423–3430
12. Young PJ, Arneth A, Schurgers G, Zeng G and JA Pyle (2009) The CO2 inhibition of terrestrial isoprene emission significantly affects future ozone projections. Atmospheric Chemistry and Physics 9:2793–2803

Part III
Urban Planning and Development

Regional Dynamics, Urbanisms and Environment in Colombia. An approach for the Bogotá Region

William Alfonso Piña and Clara Inés Pardo Martínez

Abstract This study evaluates and analyses the regional dynamics, urbanisms and environment in Colombia through studying the Bogotá region to determine the factors that affect the development and conformation of this region showing different trends with respect to other regions localized in developed countries. This analysis is conducted through the use of different methodologies applied in a longitudinal study of Bogotá to characterize patterns of the agglomeration process and concentration trends in this region while taking into account urbanism and environment. The results indicate that in the Bogotá region, the trend of conformation is varied, suggesting that this region has singular patterns of development and consolidation that depend on different features. Geographic possibilities, connectivity, availability of environmental resources and urban services are key factors in the Bogotá region, which have caused higher urbanization, characterized particularly by housing and limited productive chains. All findings of this study are important in the formulation of public policies according to regional dynamics and features found in the Bogotá region.

Introduction

Urban expansion and development have been driving changes in land use and cover and ecological changes in several regions worldwide. Diverse theories explain this phenomenon and suggest that these processes must be evaluated on multiple scales simultaneously to determine the relationship that determines the conformation of urban regions. Several factors such as environmental conditions, economic activities and social structures interact in multifaceted forms to shape urban development

W. A. Piña (✉)
Faculty of Science Policy and Government, Urban development and management – Ekística – Universidad del Rosario, Calle 14 No. 6–25, Bogotá, Colombia
e-mail: william.alfonso@urosario.edu.co

C. I. P. Martínez
Faculty of Administration, Universidad del Rosario, Calle 14 No. 6–25, Bogotá, Colombia
e-mail: cipmusa@yahoo.com

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_14,

on different scales. The regional dynamics worldwide reflect diverse factors of conformation based on several geographic, economic and social conditions.

In the literature, regional dynamics have been studied using different approaches such as computer-based simulations of urban models that are applied to evaluate theories about spatial location and the interaction between land uses and related activities [1]. For example, [13] used logistic regression to model urban growth in Atlanta and found that population density, distance to the nearest urban clusters, activity centres and roads, and number of urban cells are determinants of the urban growth and spatial patterns of the future urban areas. [14] applied an integrated an urban model and the Geographic Information System to analyse regional transportation and land use policies that provided evidence of economic competition among the zones and the projected land uses. Pattern analysis has been used to determine urban dynamics in a different context. For example, [21] quantified urban dynamics by applying temporal remote sensing data with the help of well-established landscape metrics for four decades in Bangalore showing that urban dynamics can be attributed to rapid urbanization coupled with the regional change urbanization. [19] evaluated spatiotemporal features during the urban expansion in Phoenix from 2000 to 2012 according to land use. They determined that the increase in the urban area was caused by the pattern of population growth and the natural environment.

In Colombia, economics-based studies on regional dynamics have worked especially well. For example, [2, 3] analysed the features of interregional completion by applying a Dendrinos-Sonis model and found a low level of integration among the different regions and a high level of competition in Colombia. He also studied the interactions between regional economies in Colombian using a multiregional input-output model and found that the majority of Colombian regions have self-sufficient sectors that should generate regional disparities. [25] evaluated the competitiveness of policies finding disparities in regions and variables such as bureaucracy, corruption, crime and infrastructure that highly impact the productivity in Colombian regions. [22] evaluated the structural interdependence among Colombian departments by applying a regional extraction method and demonstrated that Bogotá has a great influence on the other regional economies through the power of its purchases. These studies show that Colombian regions exhibit differences in trends that have influenced their development and in dynamics that have generated disparities among regions. However, these studies did not analyse the applicability of several methodologies to determine regional development, especially in the case of Bogotá. In addition, the methodologies applied have included sectorial results that do not involve an integral and systemic approach and does not allow strategies to improve urbanisation process to be proposed.

Taking this background into account, this study demonstrates some features of conformation phenomena in urban regions as the result of expansion of Latin-American cities, specifically in the main Colombian city of Bogotá. A large percentage of this city's population is becoming urbanised, which has a high impact on the territory. The main contribution of this analysis is the provision of elements to aid the construction of an integral approach of regional analysis based on different methods including geography, physical and environment planning and social urbanism.

In regional studies, it is important to account for several conditions that allow for, provide and promote the concentration of the population in the urban process and conformations in case studies of the selected Bogotá region, e.g., the multiscalar analysis proposed by [8]. In this study, arguments were based on economic geography to support the relationships between economy, territory, population, environment, management, social and geopolitics conditions using a systemic analysis suggested by the new geography, with the goal of balancing the economic vision and to provide a better knowledge of conformation regions with some limitations.

Hence, this paper presents an analysis of the approximations and approaches used to study the regional dynamics, urbanism and environment in the Bogotá region, with the aim of contributing to the knowledge of territorial conformation of regions in developing countries by identifying the main factors that determine the localization of population in defined areas where studies are limited. Following this section, Section 2 reviews the relevant literature. Section 3 discusses the methodology. The results are analysed in Section 4. Finally, Section 5 concludes the study and offers some policy implications.

Literature Review

Diverse theories have applied regional dynamics from schools of thought in urbanism based on industrial neighbourhoods to analyse sustainable development where urbanism has a direct relationship with the environment. Similarly, geography has been included in studies of urbanism from chorology to regional geographic analysis (see Table 1).

Recently, several researchers have introduced the concept of "new economic geography", beginning with [7], that describes industrial organization and international trade. These studies used the postulates of [18] on three factors that determine the development of industrial zones: knowledge diffusion, the advantages of big markets for specialized techniques and inherent vertical linkages to local big markets. The concept of "new economic geography" shows the relationships between urban economies and is based on a model defined by Von Thunen [10] that integrates economic relationships with spatial features and establishes marketing conditions with respect to land use and localization conditions of economic activities[1]. However, [12] proposed a model on urban systems describing the tension that is generated between external economies related to industrial geographic concentration and diseconomies arising therein whereby it is possible to establish a relationship between the size of cities or regions and the optimal conditions that will benefit the population. These elements are important for new economic geographies

[1] The model of Von Thünen could be applied to almost all physical and human situations where the zoning of a phenomenon occurs. Hence, over the last decades, this model has been validated on several occasions (Garcia, 1976).

Table 1. Development of different theories for urban analysis and regional dynamics

	School of thought in urbanism			Developmentalism school		Strategic planning	Territorial planning and land us	Sustainability
Naturalism	Positivism	Structuralism	Neo positivism	Neo-structuralism (neo-Marxism)				
18th Century	19th Century	Early 20th Century	Mid-20th century	‘60s	‘70s	‘80s –‘90s	2000s	2004s
Chorography	Landscape geography. Region	Physical geography	New geography, Theoretical geography	Radical geography	Structuralism radical geography	Regional geographic analysis	Human geography	New economic geography
Culture associated with the landscape	Environmental determinism	The possible	Hypothetical - Deductive	Speculative and deductive.	Criticism of official geography	General systems theory	Social structure	Economic structure
Historic and political region	Delimitation of physical features, unity characterization, perception key.	Classical geography or regionalist Physical determinist. Historicism	Geographic region	Geography of environmental perception and behaviour. Functionalist analysis	Social and cultural factors	Open territorial system	Economic region	Multiscalar.
Political region	Natural region	Chicago school Urban landscape ecology	Central sites theory Localization theory	Analysis of production patterns and socio-economic spatial formations	Preoccupation by social topics: welfare, marginalization, liberalism	Metabolism of region Conduct, knowledge	Phenomenology, existentialism, idealism, subjectivity, personal experiences	Analysis of new regions
	Ratzel, Mackinder, Herberston	O. Schlüter, C. Sauer, Blanche	Cristaller, Von Thünen	Milton Santos, Doreen Massey, Gottman, Etienne Juillard	William Bunge. D. Harvey	Boulding, Lowenthal, Goodey, Gold	Tuan, Buttimer, Guelke, Harris.	Fujita, Kruger
Travels, notes, reports	Analysis of space conceived	Analysis of space itself	Probabilities, changes and transformations			Images, mind maps.	Sociology of perception	Localization-complementarity

Table 2 Evolution of the Bogotá Region

Period	Features
1954—Municipalities addition	Natural growth in the municipalities. The concept of region does not exist as such. The model implies to advance and integrate close municipalities only to generate a pool of land
1991—The upper basin of Bogotá river	Natural geographic region. Region is a geographic concept such as a land border that is identified by natural features that are common in the territory. Program region comprised by Bogotá and 27 municipalities with an integral management formed by a provincial board and a regional plan for the basin
1994—Metropolitan region	Metropolitan area with functional relationships (band model). Bogotá as a balanced development axis of a metropolitan region from a cooperation framework with neighbouring municipalities. 2.574 km^2 and 20 municipalities
1996—The Cundiboyacense altiplano	Natural geographic region. Region must organize from geographic criteria with zones that have common features in natural environment. This region is formed by the Bogotá savanna, Ubaté and Chiquinquira valley, Tunja, Duitama and Sogamoso Valley and Sumapaz and Fusagasugá zones
2000—Bogotá savanna. The territorial ordinance plan (plan de ordenamiento territorial POT)	Metropolitan area with functional relationships (band model). The construction of a metropolitan structure that allows for the spatial distribution of population and activities in a system of regional centres that preserves functions and essential ecological spaces and interconnections by a network of more efficient equipment. There are two corridors of regional centres: Western cross (transversal de occidente) and longitudinal northwestern (longitudinal nor-occidente). 17 municipalities of savanna
2001—Regional planning	Closed model (lineal, concentrated, decentralized models). Multiple dynamic and complex systems intertwined among them. Permanent flow of people, energy and information characterised by a network of cities that allows for the generation of planned productive and competitive land in the long term led by infra-municipal instances
2003—Central region	Open model. Competitive region that generates projects allowing economic integration, regional planning and competitive international policy. Relationships at a diverse scale that should achieve competitive land planning. The central region is integrated by Boyacá, Cundinamarca, Meta and Tolima leading every region near the central axis such as Tunja, Bogotá, Villavicencio and Ibague
2004—Network of cities. Concept of POT review	From closed model to open model characterised by a network of cities and municipalities integrated to achieve competition to an international level and agreements on diverse aspects of the relationship between Bogotá and its municipalities such as environment and connectivity
2005—Municipalities of edge	From metropolitan area to functional relationships as a band model. To harmonise the relationship of Bogotá with its municipalities of edge discussing sectorial projects as shutdown train. Six municipalities on the edges: Soacha, Mosquera, Funza, Cota, Chia, la Calera y Bogotá
2006—The savanna of Bogotá	From metropolitan area to functional relationships as a band model. Metropolitan area focused on sectorial plans such as the urban regional macro-project of El dorado Airport, and shutdown train. 17 municipalities of savanna

Table 2 (continued)

Period	Features
2008—Sub-region	Open model. Competition worktable as a scenario of public and private agreements that identify, manage and impact projects in every zone or province that transcends the municipal and has an impact on the competition at the regional level
2010—Bogotá capital region	Open model. It decentralises development and consolidates an urban-regional network that guarantees social inclusion and improvement of the quality of life and welfare of the population in the longer term. 117 municipalities (Bogotá Cundinamarca). Central region in the international context

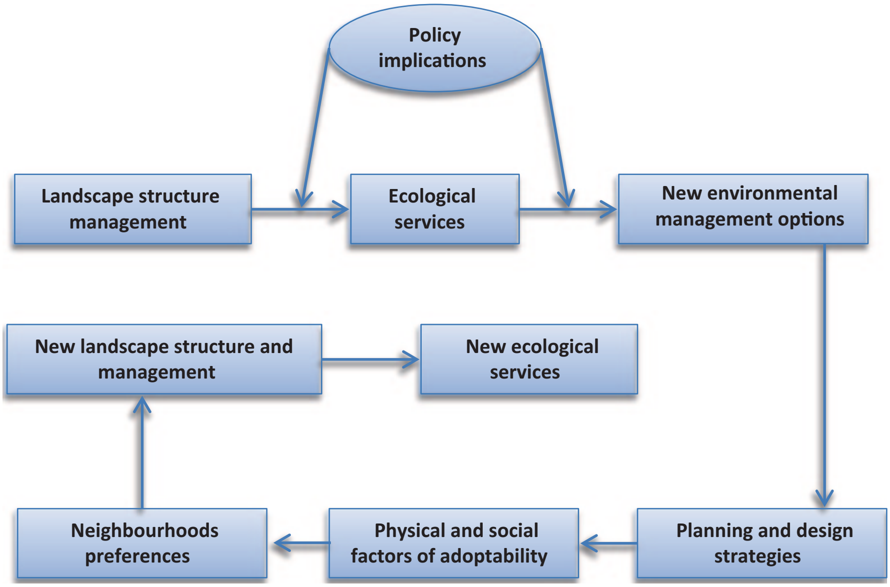


Fig 1 Regional dynamics as an open cycle

showing that cities must specialize in an industry generated by external economies and that the optimal size of a city depends on the role that this plays in the region.

In the case of regional scale, the new geography is emphasised, especially in the regional sciences. The contributions of [6] on central place theory constituted the foundation of the spatial economic theory developed by [8] that analysed the specialisation of economic activities and productive process with the aim of evaluating regional models, urban systems and international models that assessed the same problem although they were on different scales: where and why does economic activity occur? According to [5, 20], trends in regional dynamics can be characterised as an open cycle or spiral where interrelationships exist between policy motivations, environment, physical, management, design, social and democratic states and activities (see Fig. 1).

Methods and Data

To analyse the concrete case of regionalisation of Bogotá and Savannah, different methodologies of regional geographic analysis that have been applied in the Bogotá context are explored that distinguish periods, scopes and emphasis. With these results, various methodologies based on aspects from the multiscalar method proposed by [8] are identified, where an economic geography approach is used to explain diverse agglomeration forms in determined spaces and different geographic levels from three fundamental aspects: increasing returns, transportation costs and the locational movements of productive factors and consumers.

Taking these methodologies into account, this study proposes a model that incorporates other visions of classic geography such as environmental, spatial and human visions while considering different aspects that affect the regionalisation process to define criteria for a better understanding of the prospective trends and scenarios, with the aim of proposing alternative specific interventions in the planning instruments. Hence, the territorial prospective is analysed as a method of spatial assessment that allows the territories to be studied in their own categories by applying several stages to determine dynamic elements in the transformation process of land and with these results, formulating scenarios of future development for territory in the context of sustainability [4]. The description of the regionalisation process in the Bogotá region analyses urbanisation trends and localisation of population and other information while taking into account previous studies. The methods applied in this study seek to develop an integral analysis that links economic, socio-political and institutional elements in an occupied territory, taking into account the appropriation and use of spatial conditions with the aim of achieving an adequate explanation and perspective of these elements as whole delineated region.

Data

The data used in this study to analyse the Bogotá region are mainly from the National Administrative Department of Statistics (DANE), National Planning Department (DNP), the District of Bogota's Planning Secretary, the Governorate of Cundinamarca, Ministry of Environment, Housing and Territorial Development, Geographic Institute Agustin Codazzi, and the Habitat secretary of Bogotá, among others. Additionally, to explain the effects of territorial phenomena in the Bogotá region, the results of the study on the formation of the municipalities' occupation model for Bogotá Savanna were included for the following regions: downtown savannah, west savannah and Soacha (25 municipalities). This study was developed by [11] and evaluates the topics of sub-urbanisation and growth of conurbation generated by population, housing, industrial location and environmental effect in this region.

Results and Discussion

Several studies have demonstrated that Colombia had a different evolution compared with the majority of Latin-American countries principally because urban, industrial and commercial development was not concentrated in only one city and historical period due to the complex geography that kept the regions in relative geographic isolation. Colombia is recognised as a country of regions with dynamics, different vocations, different economic specializations and populations with diverse cultures.

Evolution and Trends in the Bogotá Region

In the recent decades, the evolution of the Bogotá region has been characterised by the addition of several municipalities without the concept of region following an open model with a metropolitan area added to the region concept as a regional urban network (see Table 2).

Population Dynamics and Trends in Land Use in the Bogotá Region

The population of the Bogotá region has increased 8.5-fold in the last 60 years (from 883.412 habitants in 1952 to 7.467.804 habitants in 2011), and the population who previously lived in great rural properties in the municipalities around the Bogotá now lives in urban zones. Initially, the population of Bogotá grew 6 %, whereas municipalities of the Savanna of Bogotá grew 2.7 %. This growth changed progressively between 1993 and 2005. The population of Bogotá grew by 1.9 %, whereas that of the other municipalities grew 3.6 % [16].

Trends in Suburbanization, Infrastructure and Roadways in the Bogotá Region

The Bogotá region moved from three predominant regional ways connected with railway and tram to five regional roads of predominant connection with a private collective system of BRT (Bus Rapid Transit) named the Transmilenio buses of Capital district. Industrial corridors have been appearing in this region that have consolidated by the construction of industrial areas, bodegas, construction for floriculture (sheds and greenhouses) and agro industrial sectors along the main regional and national ways. As result of these processes, the Bogotá region has been occupied by disperse forms generating new neighbourhoods, isolated properties, ways and roads among rural properties without clear rules and regulations, which have fragmented different ecosystems, resulting in soil losses, alteration of areas of environmental interest and altered landscapes.

Table 3 Levels of analysis proposed for regional studies

Lines of analysis	Macro-scale	Meso-scale	Micro-scale
Spatial-ecological-environmental	Features of territory for human settlements	Process, inputs and outputs. The metabolism concept	Eco-tone or eco-cline Micro cycles of materials
Economic process and trends	Global incidence, market and flows	Agglomeration trends, market, complementarity	Clusters, innovation nodes, changes in the land use
Social (cultural and political)	Migrations and localization trends	New urban centres, networks (services, equipment and public space)	Local settlements, neighbourhoods units, daily living conditions and mentalities

Socio-Economic Trends in the Bogotá Region

The Bogotá region contributes 32 % of the gross domestic product (GDP) and generates 31 % of the production in Colombia, which includes manufacturing and services, where 85 % are small and medium enterprises and the majority, almost 85 %, are located in Bogotá. The model of territorial occupation in the Bogotá region shows an oversupply of industrial soil with almost 10,000 h along five corridors such as the Medellín way, North way, North central road, intersection of the Savanna, Mosquera-Madrid and Soacha-Sibate [16, 25].

Market labour in this region is characterised by an unemployment rate below 12 %, where 67 % of the population in the hotel and commercial sectors, 24 % in services and 18 % in manufacturing industries. Poverty and inequality show complex trends, with a poverty level of 22 % and a Gini index of 0.50. However, the statistics of region indicate an imbalance, i.e., municipalities near to Bogotá have poverty levels between 7 % and 13 %, whereas distant municipalities have levels of 70 % due mainly to the lack of basic services and infrastructure [9, 16]. Moreover, these aggregated data in the studies of the Bogotá region are limited to determining the dynamic trend in regional development.

Spatial Features in the Bogotá Region

The main spatial features are the following: i. Geographic-environmental spatial: Geology of the Altiplano characterised by a terrace of lacustrine origin with river-lacustrine deposits and influence of volcanic ash that have contributed to the conformation of soil. The ecological structure and its relationship with areas of environmental importance in the Bogotá region include moors, forest ecosystem, wetland and arid and semiarid zones with potential for ecotourism. Moreover, this region is localised on aquifers and is rich in groundwater and has diverse high-productivity soil; ii. Economic spatial: Attraction to higher markets of the country; and iii. Cultural spatial: primary destination for employment opportunities.

The globalisation process modifies the trends of population agglomeration in cities. In contrast, environmental conditions dominate in the Bogotá region; the great offering of urban services and institutional programs have become key variables for increasing the preferential eligibility of a site for settling by real economic conditions.

In regional analysis, it is possible to integrate different approaches to determine region trends; for example, recent studies have utilised modelling using the Geographic Information System to determine isochrones curves with the aim of establishing travelling times. This information has allowed us to identify that zones with higher travelling times concur with zones of higher urban growth, showing that new populations determine localisation according to Bogotá as the city with higher opportunities and welfare. These revisions explain with more precision the growth phenomenon in sub-regional centres such as north Zipaquira, west Facatativa and south Bogotá.

Model Proposed

Taking into account the results from the recent decades in the Bogotá region as described above, evidence from limitations and restrictions in the description of phenomena and as a transition of planning a strategic model in the framework of sustainability, this study suggests a model of physical system denominated ecology or environmental that can be described as follows: “An instrument directed to plan and to schedule the land use, productivity activities, regulations on human settlements and development of society consistent with the natural potential of the land, to achieve efficient sustainability of natural resources and environmental protection”.

In this context, physical geography as a synthesis science must be the basis of the development of this new planning with a systemic and holistic approach considered as a multidimensional cognitive activity that is complex and dynamic and that can be used as a regulatory element of relationships between social and natural systems. This planning process implies that ecological or territorial regulations are key elements that are related to the socio-economic development of every society, and they are a cultural and political demonstration.

The land planning is oriented by the following factors: *i*. To provide minimal opportunities that guarantee adequate quality of life for the population; *ii*. To conserve and develop natural grounds of life (bio- and geo-diversity, essential ecological process, etc.), and *iii*. To maintain in the long term the potential use of land and natural environmental resources.

This proposal states that the territory be regulated from geography and other disciplines using global and interdisciplinary actions to enhance a balanced development of regions and physical organisation of space based on the sustainability and welfare of the population. Moreover, the regional studies require a multi-scalar approach including a macro-scale analysis for the environment and space, a meso-scale assessment of economic features and, at the micro-scale, a determination of

Table 4 Application of prospective model in the Bogotá region

	Model of territorial development, background and key variables	Hypothetical trends	Scenarios, objectives and strategies for territorial development
Bogotá region (Place—Space)	Hydrological network quantitatively high. High-potential hydrogeology of aquifers. Woodlands in high mountaineous regions. Possibilities to integrate disturbed ecosystems	Positive: Touristic business related to the landscape. Negative: Occupation of reserved zones of aquifers and round rivers. Indiscriminate strip mining. High rate of forest extraction. Disposal of wastewater in river and stream	Possibilities to declare a system of protected areas in Bogotá savanna. Declaration of productive agriculture zones by food security. Integral project for decontaminating Bogotá river and effluent. To establish a system of natural environmental parks
Process (Relationship or agreements among people to exploit a territory)	Large offer of industrial soil and strong market. Increase of urbanisation in soils with high environmental value and agriculture use	Positive: Maintenance of demand of soil for industrial use. Possibilities to generate centres for development in new towns for improving public services. Negative: No planning to locate industrial uses, with low urban standards generating inadequate process of urbanization. The current models of occupation are characterized by co-urbanisation, fragmentation and disperse or diffuse occupation, which generates impacts in the short, medium and long term on the productive capacity of soil and the depletion of resources, especially water	Measures for decentralising employment and locating closer to sub-regions. Search for mechanisms to balance prices of soil promoted by property speculation to recover agriculture activity

Table 14.4 (continued)

	Model of territorial development, background and key variables	Hypothetical trends	Scenarios, objectives and strategies for territorial development
Population (sociocultural)	The region most attractive for population in Colombia is Bogotá, mainly due to environmental conditions, a large market of goods and services, and more productive and dynamic labour. However, the variable with the highest incidence is the culture: Bogotá is the best site for urbanisation	Positive: A higher concentration of population, lower poverty. The concentration of labour should generate higher productivity in the region. Negative: Increase of inequality and segregation in the city. The concentration of the population increases risk and vulnerability by shortage of supplies and natural disasters	New measures for urbanisation processes and new occupations by migration and population growth to improve functionality of settlements. It is important to work on imaginary and rationalities of new habitants to limit proliferation of construction in sub-regions

the social components generating a descriptive and alternative form of transformation for spatial and ambient quality of society, process and society.

These factors should be applied in three dimensions: *i*. Ecological-environmental – the relationship between society and environment; *ii*. Spatial – the interactions between settlements, cities and regions where network plays an important role; *iii*. Political – territory management (see Table 3).

Moreover, the territory is constantly changing, which implies the inclusion of the territorial prospective as a methodology of spatial analysis to investigate the territory based on individual categories while taking into account the dynamics of the transformation process in the territory [4]. Table 4 shows a proposal for the application of the prospective methodology.

Conclusions and Policy Implications

In the cities, to appropriately model the synergy between economic development and social transformation on an environmental basis, it is necessary to include goals of economic growth, social and environmental productivity in the planning process with the aim of achieving regional and local balance. Social and environmental goods and services do not depend on nature or features of the population or demographic dynamics, but they are sensitive to transformation, production and reproduction based on a shared vision of territory. This implies that the recognition and social and environmental valuation of environmental and social goods should be taken into account along with their boundaries and possibilities and the joint construction of a model of territorial occupation.

The challenges of urbanisation in public policy should focus on the reduction of inequality among sectors, regulation of population mobility, economic productivity, and sustainable development in the cities, where the construction of planning with regional dimension and long term is important.

Moreover, it is important to analyse the regions using methods that consider economic factors and include contributions with new, integral and creative approaches to better understand regional dynamics to generate solutions according to the reality of regions and the requirements of population from the point of view of sustainability development, especially in developing countries, as demonstrated in this study in the case of the Bogotá region.

This study recommends that regional studies must be integral to avoid bias in the explanation of territory dynamics and also determines features of sites with the aim of determining programs and plans to improve land interventions for sustainability development and population welfare.

References

1. Batty M (2009) Urban Modelling. Chapter XXX. International Encyclopedia of Human Geography. Editors-in-Chief Rob Kitchin and Nigel Thrift.www.elsevierdirect.com/brochures/hugy/overview.html
2. Bonet J (2003) Colombian regions: competitiveor complementary?. Revistade Economía del Rosario 6, 53–70
3. Bonet J (2005) Regional structural change in colombia: An approach with input-output matrix. Documentos de trabajo de economía regional No. 62. Banco de la Republica
4. Bozzano H (2004) Territorios reales, pensados y posibles. Aportes para una teoría territorial del ambiente. Editorial Espacio, Buenos Aires, Argentina
5. Cadenasso M, Pickett S, Schwarz K (2007) Spatial heterogeneity in urban ecosystems: reconceptualising land cover and a framework for classification. Frontiers in Ecology and Environment5, 80–88
6. Christaller W (1950) Das Grundgerust der raumlichen Ordnung in Europa. Frankfurter Geographische Hefte, 24, s. 1–96
7. Dixit A, Stiglitz J (1977) Monopolistic competition and optimum product diversity. The American Economic Review 67:297–308
8. Fujita M, Krugman P, Venables A (2001) The spatial economy: cities, regions, and international trade. The MIT Press
9. Gamboa L, Garcia A, Otero J (2009) Statistical inference for testing Gini coefficients: An application for Colombia. Working Paper No. 65. Universidad del Rosari
10. Garcia M (1976) Current value of Von Thünen model and two empirical verifications. Revista de Geografía 10, 11–33
11. Gomez J (2009) Formulación de un modelo de ocupación territorial para los municipios de La Sabana. Gobernación de Cundinamarca
12. Henderson J (2003) Urbanization, Economic Geography, and Growth. Handbook of Economic Growth, Volume 1, P. Aghion and S. Durlauf (eds.), North Holland

13. Hu Z, Lo C (2007) Modeling urban growth in Atlanta using logistic regression. Comput Environ Urban Syst 31:667–688
14. Johnston R, Barra T (2000) Comprehensive regional modelling for long-range planning: linking integrated urban models and geographic information systems. Transportation Research Part A 34:125–136
15. Lampis A, Kiku L (2012) Colombia between the local and the global: Regional Insertion within the new global economy. Sociedad y Economía 22, 95–132
16. Lizarazo P (2011) Cuadernos de desarrollo Económico. CUADERNO No. 7. La Integración de la Región Capital, hacia 2038. http://www.desarrolloeconomico.gov.co/index.php/cuadernos-de-desarrollo-economico/
17. Losch A (1940) Die Raeumliche Ordnung der Wirtschaft, Fischer, Jena; 1944, second edition; 1962, third edition, Fisher, Stuttgart; 1954, English translation from German original by W H Woglom and W F Stolper, The Economics of Location, Yale University Press, New Haven, Connecticut.; second print, Wiley, New York
18. Marshall A (1890) Principles of economics. Macmillan and Co., Ltd, London
19. Moquan S, Tian G (2010) An analysis of spatiotemporal changes of urban landscape pattern in Phoenix metropolitan region. Procedia Environmental Sciences 2:600–604
20. Pickett S, Cadenasso M (2008) Linking ecological and built components of urban mosaics: an open cycle of ecological design. J Ecol 96:8–12
21. Ramachandra T, Aithal B, Sanna D (2012) Insights to urban dynamics through landscape spatial pattern analysis. International Journal of Applied Earth Observation and Geoinformation 18, 329–343
22. Salgueiro F, Amaral E, Bonet J, Hewings G (2010) Structural interdependence among Colombian departments. Econ Systems Res 22:279–300
23. Thünen vonJ (1826) Der Isolierte Staat in Beziehung auf Landschaft und Nationalökonomie. Trans. By C.M. Wartenberg (1966) Von Thünen's Isolated State. Pergamon Press, Oxford
24. World B (2007) Colombia: Contributions for politics of sub-regional competitiveness. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2009/10/06/000333038_20091006005302/Rendered/PDF/422690ESW0P10110Box342010B01PUBLIC1.pdf
25. World B (2009) Report on world development. New economic geography. Mayol Editions

The Roles of the Urban Spatial Structure of the Main Cities Slums in EGYPT and the Environmental Pollution

Ahmed Khaled Ahmed Elewa and Wael Ahmad Taha El-Garhy

Abstract The slums surrounding the main cities in Egypt suffer of the environmental pollution indicated by the high disease ratio related to air, water, and soil pollution. There is a relationship between the current urban spatial structure and the environmental pollution.

This phenomenon is clear in the slums that spread rapidly in the last few decades surrounding the out skirts of Egyptian main cities. Those slums have unique local urban characteristics, permanent well structure buildings with infrastructure supply including water and electricity and in some cases sewage system and showed that the main cause of the environmental pollution is not the absence of infrastructure or good construction buildings, but the main cause of environmental pollution is the urban spatial structure.

The study found that the future up-grading plans for Egyptian main cities slums should regard some reviews for the current urban characteristics of those slums.

Introduction

The Egyptian main cities are facing the problem of informal urban sprawl caused the phenomenon of the slums[1]. Although there are various causes of environmental pollution, the urban spatial structure and its characteristics in the Egyptian main cities slums have roles in increasing pollution. These slums are suffering of the bad effects of the environmental pollution, and high ratio of diseases [2].

[1] Within the Egyptian context slums have been known as ‘Ashwa’iyyat’, which literally means ‘disordered’ or ‘haphazard’. It refers to informal areas suffering from problems of accessibility, narrow streets, the absence of vacant land and open spaces, very high residential densities, and insufficient infrastructure and services (World Bank, 2008).

A. K. A. Elewa (✉)
Department of Architecture, faculty of Fine Arts, Helwan University, Cairo Governorate, Egypt
e-mail: ahmedfinearts2007@yahoo.com

W. A. Taha El-Garhy
Environmental Studies and Researches Institute, Minofia University, Minofia, Egypt

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_15,

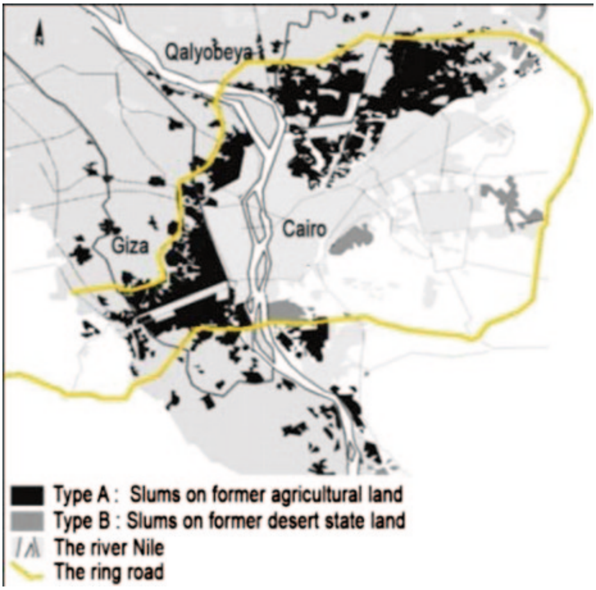


Fig. 1 A map of Greater Cairo which consists of 3 governorates showing the spread of the main two types of slums

Available statistics show that the number of slums in Egypt had reached 1,221 in 2006 in 24 governorates [1], Around 15.7 million people are living in these slums, representing 24 % of total population in Egypt and 40 % of the total urban population.

Slums in some cities reached 77 % of city's urban growth (Bani Mazar – El Minya), they have even reached 87 % of Giza city urban expansions, in Greater Cairo slums surrounding the formal districts consisting more than 40 % of the city urban mass [3], (see Fig. 1)

However these slums are enjoying permanent well structure buildings and the common infra-structure of the formal districts.

The Research Problem

Although these slums are enjoying permanent good structure buildings and in most cases common infra-structure services like formal districts, they are facing the problem of local environment pollution.

The Study Hypothesis

The common local *urban spatial structure*[2] of the main cities slums in Egypt is having urban characteristics which acting several roles have affected the local environment in bad way by causing pollution.

The Main Aim

The main aim is to clarify those roles and how they are the main cause of local environment pollution, this will be important in the making of the future up-grading plans of those slums, and improving the life's quality by decreasing the environmental pollution.

The Methodology of the Study

An analytical study was done on several Egyptian main cities slums, focusing on the urban spatial structure and its characteristics, using SWOT analysis to determine the way they affected the local environment.

The Typology of the Main Cities Slums in Egypt

Although that the main cities slums in Egypt have four types of shared common local urban characteristics, there are two main types forming the majority (about 90 %)[3] of the main cities slums as:

1. Type A: Informal settlements on former agricultural land, this type is very common in the out skirts of the main Egyptian cities in the delta and the valley of the Nile River like in Cairo, Giza, Shobra-elkheima (Qalyobeya), Alexandria, Tanta, Mansura etc.
2. Type B: informal settlements on former desert state land, this type is mainly located in Cairo, the slums are growing on the vacant desert state land whether inside the urban mass or in the outer city skirt such as "Manshiet Nasser" were the garbage collectors are living and practice their activity in collecting, sorting, and recycling the garbage [4], (see Figs. 1 and 2).

[2] Urban spatial structure refers to a cluster of concepts concerned with the arrangement of urban public space, the way that urban public space is arranged affects many aspects of how cities function and has implications for accessibility, environmental sustainability, safety, social equity, social capital, cultural creativity and economics (Wikipedia the free encyclopedia).

[3] The other two types are: Type C: Deteriorated Historic Core (Islamic Cairo) and Type D: Deteriorated Urban Pockets.

Fig. 2 Above are the two mass plans showing the type A of slums; Informal settlements on former agricultural land. Below are the two mass plans showing the type B of slums; informal settlements

The comparisons between the two main types clarify and reveal the main general characteristics of those different types' slums, (see Table 1)

The Local Urban Characteristics that Form the Local Urban Spatial Structure of the Egyptian Main Cities Slums

The two main types of the slums are generally shared common local urban characteristics which form its urban spatial structure.

An analytical study based on field visits was done to describe the slums common local urban characteristics in order to understand the roles of the urban spatial structure of these slums and the environmental pollution.

These Urban characteristics include some different characteristics.

Table 1 Comparison between the two main types of slums in main Egyptian cities

		Type A Slums on former agricultural land	Type B Slums on former desert state land
Where	Position	The edges of the city urban mass, and the outer skirt	Varied positions to the main cities urban mass according to the slum site
	Placement	Agricultural land	Vacant desert state-owned land
	Urban pattern, see Figs. 3–4	Slum on agricultural land-Irrigation patterns forming longitudinal blocks. Geometrical orthogonal street network, with narrow inner streets	Slum on desert state land No specific repeated pattern. Irregular streets network, with narrow inner street
How/What	Construction and material	Reinforced concrete skeleton and slabs, with red brick infill walls	Most of the buildings like type A, beside huts of tin and corrugated sheets Generally worse than Type A
	Final architectural product	Multi-story buildings up to about 14 floors. 100 % plot coverage The typical buildings have only one side elevation, other sides are attached to other buildings (back to back) using light wells for natural ventilation, lighting the inner rooms	Variant types of buildings but the Multi-story buildings like in type A is the major type with average height 6 floors up to 14. Huts of tin and corrugated sheets less than 10 %
	Infrastructure	Basic infrastructure is available including: drinking water, electricity, complete sewage system in some areas, but in most cases depends on septic tanks	Basic infrastructure is available like in type A
	Services	Public services are available but poor	The same like in type A
Who	Activities/Income resources	Professionals and workers Low income, variant workshops (cars maintenance-welding-carpentry,… etc)	Like in type A The same in type A, some slums are specific in a particular activity such as sorting, recycling garbage

Urban Pattern and Land-use Characteristics

However these slums were growing in a random way. The natural and the original urban characteristics of vacant land in the Egyptian cities whether agricultural or desert land, has an impact on the urban pattern that makes a clear difference between the urban pattern of the slums and the formal districts. These slums have the common land-use characteristics of the residential districts, but there are some notable characteristics as the problems caused by the land-use conflict, including

Fig. 3 Slum on agricultural land, Giza *(left)*. Slum on desert state land, Cairo (*right*)

Fig. 4 The clear difference between a slum urban pattern adjacent to a formal district, south of Cairo, east bank of the Nile (*left*). An aerial view from south of Cairo showing that the lack of the public spaces is the main difference between slums and the formal districts (*right*)

residential industrial and socio-economic activities including workshops of metals, carpentry, cars repairing, and many other handcrafts. Some slums depend on informal activities located in the heart of these slums as garbage sorting and partially recycling, causing dangerous conflict between residential and these activities like in "Mancheyet Nasser" in Cairo. The lack and shortage of some essential services and land uses such as the absence of open spaces neither green areas nor vegetation life are found. The only available open spaces are the narrow longitudinal local roads network (see Figs. 3–4), so there is no previous planning providing the public spaces.

Buildings Characteristics

These slums have some unique architectural characteristics as (see Fig. 5):

Fig. 5 The typical type of the slums buildings, permanent with reinforced concrete skeleton and bricks, note the lack of windows as inner rooms depend on light wells

- Permanent buildings of reinforced concrete and bricks. The buildings often covered 100% of the plot, so buildings are attached side to side and back to back forming contiguous blocks. Each building has only one elevation for ventilation and sun light.
- Residential buildings and service rooms depend on the light wells (narrow courts) for natural ventilation and lighting, of bad quality.
- Ground floors are usually used in commercial purposes such as shops, workshops, stores, manufactories etc.

Inner Streets Network Infra-structure

The inner roads are a result of the original site agricultural or desert land forming rectangular strips blocks in the agricultural land, and an organic network of crossed roads in the desert land slums. In both types the inner network is like a maze.

- There is no hierarchy of the inner streets. The width average is between 3–5 m, and usual usually the buildings on both sides with height often not less than the double street width.
- The inner streets are extended to long distances, at times more than 50 m without side exits or cross streets. The dead end streets are very common in these slums.
- The irregular width of the streets which leads to narrow, unpaved and dirt streets and nodes.

The most significant about these slums is that they enjoy the supplies of infrastructure including drinking water supply, electricity, phones and the coverage of mobile networks and internet, using septic tanks for the disposing of sewage or haphazardly by using non-insulated ground tanks and in some cases a complete sewage system [1].

Fig. 6 Networks; the agricultural land (*left*) in comparison to the desert land (*right*)

Analyzing the Slums Urban Spatial Structure Characteristics

Swot analysis is used to determine the weakness of the current urban spatial structure in order to understand direct and indirect roles which affect the environment in these slums (Table 2). The analytical study of the urban spatial structure of the slums in main Egyptian cities showed that the weaknesses are the notable indicator about the current urban spatial structure (see Fig. 7). These slums suffer from a bad quality urban spatial structure with many weaknesses which have negative impacts on the local environment. The availability of the infrastructure and the good condition of the buildings structure emphasize the study hypothesis that the urban spatial structure has roles in the process of the environmental pollution.

The Roles of Slums and Environmental Pollution

The urban spatial structure of the Egyptian slums has roles which affected the environment in bad way; these roles have a catalytic reaction on the process of environmental pollution and, generated of its common local urban characteristics as follows.

The Roles of the Urban Spatial Structure and the Slums Microclimate

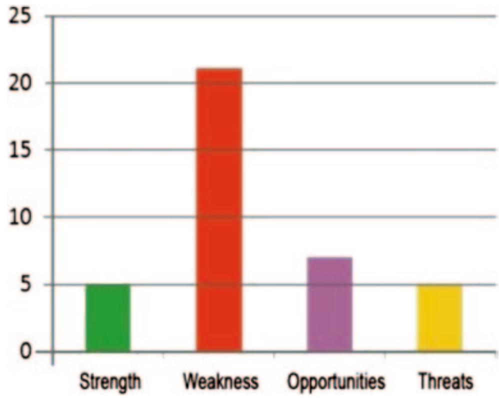
The urban spatial structure caused the changing on the microclimate of the slums in Egypt; this microclimate has unique local characteristics as follows:

- Changes in temperature, the heavily urban areas where brick, and concrete, absorb the sun's energy, heat up, and reradiate that heat to the ambient air resulting

Table 2 Swot analysis of the urban special structure characteristics

Strength	Weakness	Opportunities	Threats	
Each slum is considered as an independence urban unit	The high density of built up area The lack of the open spaces The complexity of the streets network	The clear urban pattern characteristics of the slums facilitate the enclosing of the slums in order to develop urban solutions	The possibility of the future expanding of each slum	Urban Pattern
___	The lack of some of some essential services The mix land-use between residence and the workshops and other industrial, commercial and storage activities The existing of activities causes pollution	The concept of the specialized slum which depends on one main activity could be a base for successful development	The continuing growth of activities causes pollution	Land-use
	The lack and in some cases the absence of open spaces The absence of green areas and trees The using of 100% of the plots area as buildings	The possibility of reutilization of some existing land-uses to compensate the lack of open spaces.	The growth demanding of vacant land for activities	Public Spaces
The good condition of the buildings construction	The architectural problems caused by the contiguous block shape such as bad natural lighting and ventilation The loss of the advantage of the Prevailing winds and the sun lighting directions The using of light wells is causing hygienic problems, as there bottom is used as a place for garbage The hygienic problems caused by the commercial purposes such as: workshops, stores, manufactories…etc. which abuts the residents	The good construction condition making the possibility of applying amendments to the current buildings as group of buildings (blocks) to enhance the natural lighting and ventilation		Buildings Urban Characteristics
In most cases the network is well connected to the main city roads network	The absence of the hierarchy of the inner roads network The complexity of the network The narrow width of the streets compared to the actual needs The problems caused by the long distance of inner streets (more than 500 m) without exits The dead end streets The problems caused by the irregular width of the inner streets The streets became a source of dust and Particulate matter (PM)	The inner streets network could be re-designed to only pedestrian streets and vehicles streets to solve some urban problems	The continuous exploitation and infringement of the inner streets spaces to be used in commercial housing activities	Inner streets network

Fig. 7 Chart showing the SWOT analysis direct results of the current urban spatial structure of the Egyptian slums



urban heat island (UHI) which is a kind of microclimate, slums are generally 2 to 4 °Celsius hotter than the Surrounding areas [5].

- The contiguous blocks made up of buildings which detached side to side and back to back forming large areas of concrete surfaces which have bad thermal mass prosperities and act as a generator of the urban thermal plume[4] over the slum area.
- The stagnation of the air current, as there are no enough public spaces or vacant land, and the only open air areas are limited to the narrow inner streets, and the light wells in the buildings plots which are always shadowed as a result of the heights of the buildings, so there's no open spaces to cause the differences in temperature, pressure by the sun heating, which lead to the meteorological phenomenon of urban dust dome[5].
- The buildings have only one side elevation for natural ventilation and lighting, therefore inner rooms depends on light wells which always deep and narrow as the buildings average height is about 5 floors, at the same time the bottom of this wells is always full of waste and wet (as the drain, water pipes are passing through), These light wells which spread among the urban mass turned into a source of polluted air and the Green house gases (GHGs).

Absence of the Direct Sunlight

As a reason of the urban spatial structure characteristics, most of the residential units and the inner streets are deprived of the direct sunlight, which causing hygienic problems especially in Egypt as the climate is warm and the high humidity

[4] Urban thermal plume describes rising air in the lower altitudes of the Earth's atmosphere caused by urban areas being warmer than surrounding areas (Wikipedia, the free encyclopedia).

[5] Urban dust domes are a meteorological phenomenon in which soot, dust, and chemical emissions become trapped in the air above urban spaces. This trapping is a product of local air circulations. Calm surface winds are drawn to urban centers, they then rise above the city and descend slowly on the periphery of the developed core (Wikipedia, the free encyclopedia).

Fig. 8 Some slums are specialized in sorting and recycling of garbage and waste

in summer. This means that the slums are deprived of the antiseptic properties of the ultraviolet light from the Sun.

Absence of the Vegetation

One of the notable urban characteristics of the Egyptian slums is the absence of the green areas and vegetation life, the urban spatial structure of these slums showed the high density of built up area.

Most of the Egyptian slums have an area not less than 10 acres of buildings and narrow streets. The priority is always for buildings and commercial activities and there are no exist of green areas or trees which absorb light and heat, that building's roof just radiates back into the air, this helps to increase the problem of the UHI.

Generally these slums have no vegetation life and are deprived of the environmental benefit and advantages of the vegetation life.

The Environmental Pollutions Caused by the Land-uses

The types of the land-uses (as urban characteristic) in these slums as well as the conflict between land-uses are causing indirect and direct environmental pollutions as: The types of land uses which is dominated by multi-use buildings and absence of open spaces and green areas can increase the concentration of GHGs in the atmosphere.

The conflict of land-uses in these slums; the workshops of variant industrial activities are contiguous with residential units, as the workshops always located in the ground floor of the residential buildings, these socio-economic activities produce large amounts of GHGs, most notably CO2 as a consequence of these activities. The worse is that some slums are specialized in sorting and recycling of garbage and waste (see Fig 8), including:

- Toxic waste such as pesticide, herbicides, fungicides
- Hazardous waste such as most paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer and containers

These variant kinds of wastes and human activities have air polluting emissions such as:

- Odors from garbage, and industrial processes.
- Particulate matter PM which caused as a result of the workshops generates significant amounts of aerosols, the burning of fossil fuels, and dust of the dirt inner streets, Cairo was the most air polluted city by PM in 2004 [6].
- Carbon monoxide (CO), Carbon dioxide (CO_2), Sulphur oxides (SOx), Nitrogen oxides (NOx).

The Roles of the Inner Streets Network in Polluting the Environment

The inner streets network has direct and indirect roles in the process of polluting the environment as follows:

- Inner streets are always dirt and unpaved, and being used by the residents for their industrial and recycling activities which make them a source of dust and Particulate matter (PM) and lead to the phenomenon of the urban dust dome.
- The streets network is not always accessible for tracks which affected the process of disposal of garbage and wastes to be a source of air pollution notably that the residents used to burn the garbage which cause gases emissions including GHGs and other gases [6].

Conclusion

The study found that the slums environmental pollution problem in the main Egyptian cities is not related to the absence of *infra-structure* and the bad conditions of the residential units.

It was the *urban spatial structure* characteristics which had direct and indirect roles in the process of the local environment pollution; the urban characteristics are causing a microclimate with negative *meteorological phenomenon* which acts as a catalyst and increase the bad environmental effects of the socio-economic activities of the residents.

These socio-economic activities are forming continuous source of GHGs and other emotions which sequestrate in the microclimate system of these slums.

Therefore future studies should concern that the slums urban spatial structure was responsible of the increasing rates of the local environment pollution, there is a need for more studies from another scientific perspective beside the urban perspective to find applicable solutions to mitigate the bad impact of the slums urban spatial structure on the environment.

References

1. Egypt State of the Environment Report (2009), Ministry of State for Environmental Affairs, September 2009, Egypt
2. Fatma E-Z et al. (2004) Greater Cairo Slums, a profile based on the 2003 Egypt demographic and health survey, March 2004
3. IRIN and UN-HABITAT (2007) Tomorrow's Crises Today: The humanitarian impact of urbanization, Chapter 8: Cairo: sheltering the urban poor. Available at: http://www.irinnews.org/pdf/in-depth/TomorrowsCrisesToday-Chapter8.pdf
4. Khalifa MA (2011) Redefining slums in Egypt: unplanned versus unsafe areas. Journal of Habitat International 35-2011:pp. 33–34
5. Rouviere C, Williams T, Ball R, Shinyak Y, Topping J, Nishioka S, Ando M, Okita T (1990) Human settlement; the energy, transport and industrial sectors; human health; air quality and changes in Ultraviolet-B radiation. In: Climate Change: The IPCC Impacts Assessment 1990 Chapter 5. Available at: http://www.ipcc.ch/ipccreports/far/wg_II/ipcc_far_wg_II_chapter_05.pdf
6. The WB (2007) World Development Indicators Chapter 3.13: Air Pollution p. 174–175. Available at: http://siteresources.worldbank.org/DATASTATISTICS/Resources/table3_13.pdf. Retrieved 2010-08–29

Water Vulnerability with Population Growth in Metropolitan Areas of Developing Countries: An Interdisciplinary Approach

Silvana Audrá Cutolo, Giuliana Carolina Talamini, Juliane Gaviolli, Paulo Nascimento and Leandro Luiz Giatti

Abstract This research shows the current situation in Metropolitan Region of São Paulo (MR), the effects of demographic growth, internal migration, and social environmental conflicts and vulnerabilities of water availability and natural resources. We used data of research in water resources based on demographic and socioeconomic data provided by public institutions. Being assessed in relation to the uses of water in the São Paulo MR, seeking to identify areas of conflict arising from urban areas and their impacts on the vulnerability of ecosystems in water availability. São Paulo MR is composed of 39 cities with 19.5 million inhabitants in 7.9 million km^2, of which 25 (64 %) cities are in watershed areas. In 2010, total water demand was 77.2 m^3/sec. São Paulo MR has about 200 m^3/sec of water per person/year, considered a high critical value, demonstrating the lack of water. These values are conflicting regarding the trend of migration to cities and suburbs of the average São Paulo MR, and the conurbation of the Campinas and Santos Metropolitan Regions, in which there is a competition for water uses of Piracicaba river basin near Campinas; and Santos RM, situated on the coastal area and with high groundwater availability. With the prominence of conflict and worse water availability, we consider the high dynamics of the Brazilian economy, with rising incomes associated with increased water consumption per capita in metropolitan areas.

S. A. Cutolo (✉)
Av. Dr. Arnaldo, 715, São Paulo, Brazil
e-mail: cutolosa@usp.br

Departamento de Saúde Ambiental, Faculdade de Saúde Públic, Universidade de São Paulo, São Paulo, Brazil

G. C. Talamini · J. Gaviolli · P. Nascimento · L. L. Giatti
Departamento Prática de Saúde Pública, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_16,

Introduction

The impact of urbanization in developing countries in the natural environment has become in an irreversible due to the chaotic and disorganized growth. Degradation of water quality is a common problem in metropolitan areas of developing countries due to multiple pressures on the excessive uses from urban areas, landfills, septic tanks, sewers and others [8]. As urban water demands increase, cities are beginning to pull water away from agriculture [13]. By 2025, nearly 5 billion people are expected to live in cities. If those projections hold, the urban population will represent 61 % of the global population, up from 46 % in 1996 [13]. The consequences of insufficient water availability can result in degradation to human health, ecosystems, agricultural, and industrial output, while increasing the potential for conflict between regions and countries. In conjunction with increasing demands on water supplies, has been an increase in the concentration of human habitation [9].

The expansion of the metropolitan regions and peripheries can be caused both by the arrival of new migrants and by the sub-urbanization of the middle class out of the central city [2]. In Latin America, the largest cities are considered as Mexico City, Buenos Aires, Santiago and São Paulo with dramatic expansion of economic activities and urban population into regional metropolitan peripheries and beyond the suburbs [8]. A significant part of the population lives in squatter settlements as slums and dwellings are often built in hazardous areas as riverbanks, mountain slopes, areas of watershed protection [18]. Several authors have attempted to the effects of metropolitan expansion on natural environmental areas with illegal occupation of nature reserves, degradation of watershed, lack of infrastructure in sanitation, increasing the risk of areas supply with chemical and organic pollution, contamination of rivers by industrial and diffuse loads from household sewage, floods generated by the urban poor use of space and the inadequate management of urban drainage, and, finally, the lack of waste collection and disposal [4].

Vulnerability of water availability in some Brazilian Metropolitan Regions (MRs) of São Paulo, Campinas and Santos is associated with some risk factors such as:

1. Irregular settlements in protected areas [18],
2. Increase in disposal by diffuse loads in surface and groundwater systems [4];
3. Loss of rainforest biome in a humid tropical region, where are located the as the MRs, in Atlantic Forest with reduced aquifer recharge related to irregular soil occupation with spatial heterogeneity, including fragmentation and differential connectivity of natural ecosystems [12], and
4. Increased transmission of neglected diseases related a challenge of providing safe water and health impacts of lack of access to water and sanitation [14].

Neglected diseases infections are most prevalent in tropical and sub-tropical regions of the developing world where adequate water and sanitation are lacking. Moreover, three million children under five years of age die every year due to diarrheic complications caused mainly because of water contamination in developing countries [13].

Based on this introduction, a global issue remains unresolved: Is it possible to reduce the vulnerability of water availability and conflicts between metropolitan areas with integrated management of water resources and strategic vision for maintenance of ecosystem services? The consequences of insufficient water availability can result in degradation to human health, ecosystems, agricultural and industrial output, while increasing the potential for conflict [9, 13].

The aims of this study are: to assess the current situation of water availability on the conflicts, demands and vulnerabilities in watersheds in MRs, even in a humid tropical region; to draw attention to the importance of governance with a focus on watersheds in the metropolitan, and show the complex relationship watersheds as management of water resources as a basis for promoting an approach to environmental health, ecological and health promotion in MRs of developing countries.

Methodology

The State of São Paulo has 645 cities and is embedded in two large rivers in Brazil: Paraná and Atlantic Southeast. Among the major surface water sources stand out rivers from State of São Paulo: Tietê, Mogi Guaçu, Grande, Pardo, Piracicaba, Paranapanema and Ribeirão do Iguape. Includes up rivers from other states like Parana River, Paraiba do Sul River (State of Rio de Janeiro) and the river Jaguari (Minas Gerais), which flows into the system of Cantareira. It is the largest system of water supply in South America and the source of 50 % of the water that comes into the metropolitan region of São Paulo. The State of São Paulo has a significant number of integrated systems because of the existence of large urban areas, among which stands out the Macrometropole Paulista, where the MRs of Campinas, São Paulo e Baixada Santista are located (Fig. 1). The State of São Paulo is divided into 22 Units of Water Resources Management (UWRM), and MRs of Campinas, São Paulo and Baixada Santista are located in 5th Watershed Piracicaba-Capivari-Jundiaí, 6th Watershed Alto Tietê and 7th Watershed Baixada Santista (Fig. 1).

The methodology of our study is focused considering the watershed within the healthy settings approach by focusing on water as an integrating unit of analysis in an ecosystem context of health and sustainability. Thus, taking as a category of analysis the watershed, while an occupied territory and with their own dynamics, an analysis was systemic view as suggested by Parkes and Horwitz [11]. Watershed can be considered as a territorial unit planning and water management. Constitutes is the set of lands delimited by the dividing water and drained by a main river, its tributaries and sub-tributaries [19].

The data used to verify the actual situation of watersheds and the infrastructure in Metropolitan Regions based on demographic and socioeconomic indicators provided from Instituto Brasileiro de Geografia e Estatística (IBGE), Departamento de Águas e Energia Elétrica (DAEE) are seeking to identify areas of conflicts arising

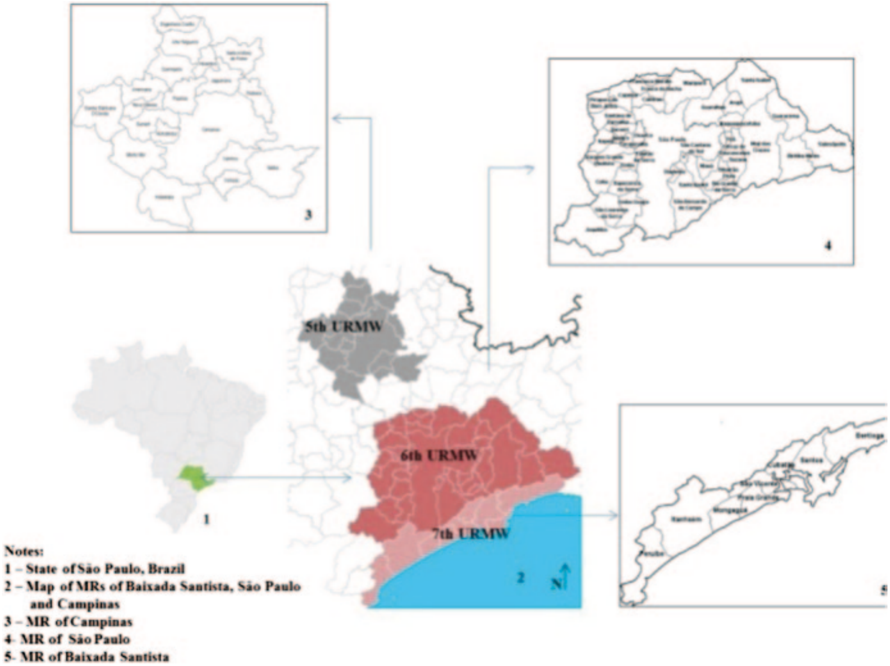


Fig. 1 Map of Brazil and State of São Paulo (1), localization of the Metropolitan Regions (2), MR of Baixada Santista (3), MR of São Paulo (4) and MR of Campinas (5)

from urban areas and their impacts on the vulnerability of watersheds ecosystems. For analysis of data, we design a map with the localization of Metropolitan Regions and the Watersheds with the number of the cities in territory of area of watershed protection areas. Then, we used to synthesize in a frame, leading indicators as total inhabitants, inhabitants/area unit (inh/km^2), Inhabitants subnormal (population that lives in slums, favelas or squatter settlement), Average of Total Water Demand (L/capita/day), Average Flow Rate (m^3/sec) in Metropolitan Regions.

Results and Discussion

Overview of Macrometropole

Specialists on Latin America emphasize that the impact of economic restructuring since the 1980s, including trade liberalization and economic stabilization measures, has been most severe on residents of major cities as a result of reduced public expenditure on municipal services, housing, infrastructure [1]. In the State of São Paulo, the railway network for transportation was developed in the interior to the coast

Table 1 Characteristics of MRs Campinas, São Paulo e Baixada Santista, State of São Paulo, Brazil

	Campinas	São Paulo	Baixada Santista
Watersheds	5th URMW	6th URMW	7th URMW
Cities	19	39	9
Area (Km^2)	3 840	7 947	2 422
Inhabitants (Total density)	2 832 297	19 822 572	1 678 513
Inhabitants subnormal	160.670	596.479	297.191
Average Flow Rate (m^3/sec)	163	80	158
Demand of water (L/capita/day)	178	248	224
Rainfall (mm/year)	1.380	1.450	2.670

of São Paulo, where the port system is located. This transport structure induced the beginning of the industrial occupation of the coast to the interior of São Paulo.

The macrometropole of São Paulo is one of the strategic regions of Brazil with a central role in economic and social development. The boundaries include MRs of Campinas, São Paulo e Baixada Santista and the agglomeration of Vale do Paraíba, Sorocaba and axis of Piracicaba- Limeira. The economic development was established in the macro-region of MRs of São Paulo, Campinas e Baixada Santista. The macro-region has 67 cities in an area of 14 210,724 km^2 and with an estimated total population around of 24 million inhabitants. The State of São Paulo has 22 Units of Water Resources Management (UWRM) and metropolitan regions (MR) are located in a map of Brazil (1), State of São Paulo (2), MR of Baixada Santista in Atlantic Ocean (3), MR São Paulo (4) and MR of Campinas (5) stated in Fig. 1.

In the State of São Paulo, MR of Campinas had about 2.8 million inhabitants in 19 cities with GDP around US$ 45 billion and GDP/capita US$ 16,735 [6, 7]. MR of São Paulo had about 19.5 million inhabitants in 2011, housing more than 10 % of the population in less than a thousandth of the national territory [3], and considered the largest concentration of population and the largest economic center of the country [3] with 39 cities, GDP and GDP per capita were R$ 360 billion and US$ 16,860, respectively [6, 7]. Finally, MR of Baixada Santista had about 1.6 million inhabitants with 9 with GDP and GDP per capita were US$ 39 billion and US$ 13,882, respectively [6, 7]. The characteristics of each MR can be observed in Table 1.

These three MRs of the State of São Paulo occupied about 5.7 % of the area of the state, but concentrated 58.5 % of its population. Regarding Brazil, these MRs came to 0.16 % by area of the country, but reached 12.9 % of the Brazilian population. This concentration was called macrometropole governments of the State of São Paulo [15]. Many of the cities and squatter settlements that make up the macro-region are located in the border area of watershed protection and natural parks with the Atlantic Forest biomes and Cerrado. These areas are suffering a land speculation and irregular occupation, placing at risk the availability of water resources for macro-region. Because human land uses tend to expand over time, forests that share a high proportion of their borders with anthropogenic uses are at higher risk of further degradation than forests that share a high proportion of their borders with non-forest, natural land cover e.g., wetland [21].

Perspective of Water Availability

The present situation of supply and demand of water has led to conflicts and disputes over uses of water. In terms of water vulnerabilities, competition for water from watersheds located in MRs of São Paulo, Campinas and Baixada Santista is increasing with excess of multiple uses and affecting the renewable water resources. The main factors that contribute to increased water vulnerability are:

1. Economic development versus sustainable development
2. Population
3. Per-capita water use
4. Climatic change
5. Allocations for water conservation.

These factors affect urban water use both individually and interactively. According to the UNESCO [19] at least 110 L/capita/day are required for the basic needs of every person. In our results, the values showed a higher demand for each MRs of São Paulo, Campinas and Baixada Santista with 178, 248 and 224 L/capita/day, respectively.

In Fig. 2, we can observe the status of criticality with limiting values of the water availability from MR of São Paulo in Alto Tietê Watershed and Campinas in Piracicaba-Capivari-Jundiaí Watersheds [16, 20].

The critical state of water availability is predominant in the watershed of the Alto Tietê and Piracicaba, comparing the state of Pernambuco, with constant scarcity of water [16]. However, it should be noted that the value refer to the household, and does not take into consideration how much water is used in industrial processes and preservation of life in the urban environment or for other uses. In recent years, the concept of virtual water has been extended to refer to the water that is required for the production of agricultural commodities as well as industrial goods [22].

With increasing population, cities are increasing the water requirements into concentrated areas. Changes to global and regional climates are projected to influence both the total amount and variation of water throughout the globe [9]. In addition, the watersheds require investments to maintain and improve water supplies in MRs. In fact, water quality is the result of urban occupation with a significant proportion of the population living in slums or favelas, occupying areas of risk such as flooded lands, steep hillsides, riparian areas and watershed protection, due to the absence of legal instruments and political planning for the occupation of urban land [4, 17]. We should emphasize that MR of São Paulo removes large volumes of water from the Piracicaba-Capivari-Jundiaí watershed systems located in MR of Campinas, increasing the conflict in a system in collapse. The complex of watershed systems from the macrometropole may be in process of collapse between supply and

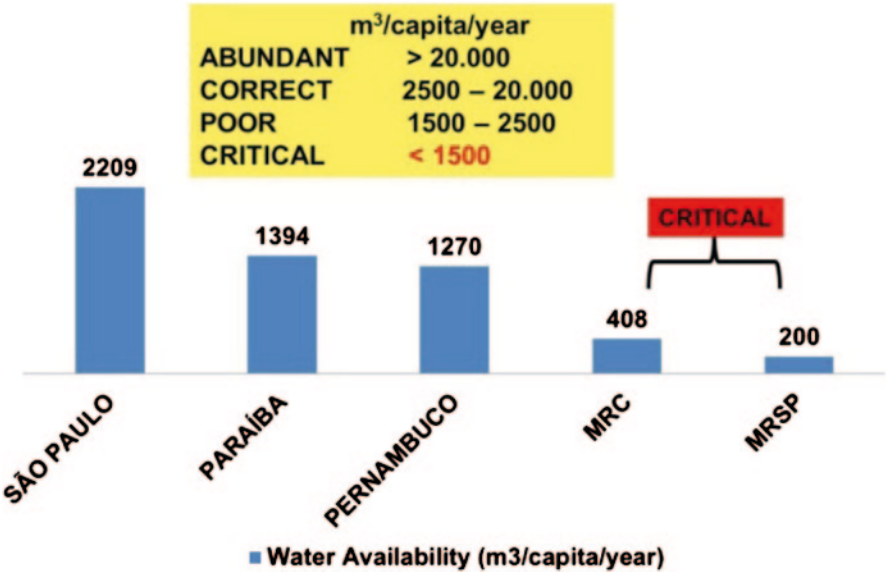


Fig. 2 Water availability in MR of São Paulo (Alto Tietê Watershed) and Campinas (Piracicaba-Capivari-Jundiaí Watersheds) compared with States of Pernambuco, Paraíba and São Paulo, Paraná in Brazil

demand as a result of changes in the hydrological-hydraulic systems, degradation of rivers systems and the overexploitation of both surface water and groundwater. The competition for water from watersheds located in MRs of São Paulo, Campinas and Baixada Santista is increasing with excess of multiple uses and affecting the renewable water resources.

Regarding water availability, but not necessarily with regard to access to water [5], a volume of 700,000 m^3/capita/yr is available in the Amazon region, while in the MR of São Paulo has a volume of about 280 m^3/capita/yr. This disparity brings numerous economic and social problems, especially taking into account the demand of water for human health in the periphery of large MRs of Brazil [5, 14]. Cutolo et al [3] point out that watersheds located in metropolitan regions suffer from water scarcity by poor attention to sanitation and deterioration of water quality from natural resources.

According to the location of the metropolitan areas included in tropical biome and precipitation values, we should make use of technology to use the rainwater to recharge the aquifer as integration of water management and other possible uses.

Unity Resources Management Watershed (URMW)

There are 30 cities in MR of São Paulo that are in a high process of conurbation with cities from MRs of Campinas and Baixada Santista. The complex of watershed systems from the macrometropole may be in the process of collapse between supply and demand as a result of changes in the hydrological-hydraulic systems, degradation of rivers systems that pass through cities with high degradation of water quality and the overexploitation of both surface water and groundwater from watersheds of URMWs: 5th from MR Campinas (Piracicaba, Capivari e Jundiaí); 6th URMW from MR of São Paulo (Ribeirão do Carmo, Ponte Nova, Paraitinga, Biritiba, Jundiaí, Taiaçupeba, Billings, Edgard de Souza, Paiva Castro, Pirapora, Rio das Pedras, Guarapiranga) and 7th from MR of Baixada Santista (Itapanhaú, Itanhaém, Preto, Branco, Cubatão, Moji, Quilombo, Jurubatuba e Guaratuba). Despite MR of São Paulo showing rainfall in the range of 1400 mm per year, the low water availability is also to be located in a region of the headwaters [3] and the rivers are much polluted. The urban area of the watershed occupies approximately 37 % of its territory and in spite of declining rates of population growth; this is not reflected in containing the spread of urban sprawl. The expulsion of low-income population to the periphery of cities contributes to the increasing environmental degradation, in particular the areas of watershed protection and flood plains [11]. These areas present sprawl with the combination of processes of construction of the spaces in poor conditions of urban life and situations of the risks that affect natural areas like forests, protected areas such as watershed protection areas for water supply, in addition, the increase of disease in public health for neglected diseases and chemical contaminants in drinking water [3].

For integration of URMW, according to Parkes et al [10] it is important to apply a tool to support the development and design the projects and programs that address social-ecological systems and health in a watershed context that has a name of the "prism framework". Another tool that is suggested by Parkes and Horwitz [11], includes the design of scenarios with "Adapting Mosaic", that proposed a sense of place and sense of self and reflecting the benefits of participatory, empowering and multi-stakeholder processes.

Water resources have important implications for a range of fields with covering interests in reducing vulnerability, increasing resilience, including community development, ecosystems management, disaster preparedness, sustainability and public health [11].

Conclusion

The concept of vulnerability seems to be related with increasing poverty in hazardous areas such as watershed protection. However, the vulnerability of the waters is a consequence of the lack of planning of the expansion of cities, the lack of public policies, but mainly, difficulties in engagement and social empowerment. Who wants to live away from work? Who wants to live next to garbage dumps and landfills? Who wants to live next to polluted rivers? Who wants to live in slums?

Moreover, there is growing competition for water resources around the MRs of São Paulo, Campinas and Baixada Santista. On this, with the discovery of pre-salt

Santos and the definition of Santos would be the basis for the operations of oil extraction, there is a growing migration and immigration, and there will for sure be a greater use of waters from watersheds located between MRs. Degraded watershed systems are more likely to create conditions that make life difficult for human communities. As a result, the lack of urban planning will lead to an increase of squatter settlements in and around the MRs without access to public infrastructure. However, for integrated water resources management local ecosystem strategies will be required in reciprocal interrelationship with social and ecological context.

Acknowledgments We thank Fundação de Amparo à Pesquisa do Estado de São Paulo- FAPESP for supports: Process No 2012/14160-7 for participation in the 11th Urban Environment Symposium em Karshuhe (DE), 2012 September 16–19; This work is supported by FAPESP (2010/20899-0) coordinated by Pr. Dr. Leandro Luiz Giatti in the research" Indicators of environmental sustainability and health for the Metropolitan Region of São Paulo—An ecosystem approach to study at different holarchic levels"

References

1. Brockerhoff M, Brennan E (1998) The Poverty of Cities in Developing Regions. Popul Devel Rev 24(1):75–114
2. Cohen B (2006) Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technology in. Society 28(1–2):63–80
3. Cutolo SA, Talamini GC, Gaviolli J, Giatti LL (2011) Contribuição ao estudo interdisciplinar de situações e conflitos na bacia do Alto Tietê. 3° Encontro Internacional de Governança da Água. USP: PROCAM,
4. Ellis JB, Mitchell G (2006) Urban diffuse pollution: key data information approaches for the Water Framework Directive. Water and Environment Journal 20, (1): 19–26 DOI: 10.1111/j.1747-6593.2006.00025.x
5. Giatti LL, Cutolo SA (2012) Access to water for human consumption and aspects of public health in the brasilian Amazon. In: Carolina Bilibio; Oliver Hensel; Jeferson Selbach. (Org.). Sustainable water management in the tropics and subtropics. Sustainable water management in the tropics and subtropics. Jaguarão/RS: Fundação Universidade Federal do Pampa/ UNICASSEL/ PGCUlt-UFMA, (3): 613–651
6. IBGE (2010) Censo Demográfico e Contagem da População, IBGE. Available in http://www.sidra.ibge.gov.br/cd/cd2010sp.asp, www.ibge.br. Accessed October 12, 2011
7. IBGE (2010) Produto Interno Bruto dos Municípios (2004–2008). Instituto Brasileiro de Geografia e Estatística. www.ibge.br. Accessed October 12, 2011
8. Iglesias A, Garrote L, Flores F, Moneo M (2007) Challenges to Manage the Risk of Water Scarcity and Climate Change in the Mediterranean. Water Resources Management 21(5):775–788
9. Jenerette GD, Larsen L (2006) A global perspective on changing sustainable urban water supplies. Global Planet Change 50:202–211 . doi:10.1016/j.gloplacha.2006.01.004
10. Parkes MW, Morrison KE, Bunch MJ, Hallströmb LK, Neudoerffer R, Venema HD, Waltner-Toews D (2010) Towards integrated governance for water, health and social-ecological systems: The watershed governance prism Global Environmental Change 20 (2010) 693–704
11. Parkes MW, Horwitz P (2009) Water, ecology and health: ecosystems as settings for promoting health and sustainability. Health Promot Int 24(1):94–102. doi: 10.1093/heapro/dan044

12. Pickett STA, Cadenasso ML (2009) Altered resources, disturbance, and heterogeneity: A framework for comparing urban and non-urban soils. Urban Ecosyst (12):23-44 DOI 10.1007/s11252-008-0047-x
13. Postel SL (2000) Entering an era of water scarcity: the challenges ahead. Ecol Appl 10(4):941–948
14. Rheingans R, Dreibelbis R, Freeman MC (2006) Beyond the Millennium Development Goals: Public health challenges in water and sanitation. Global Public Health: An International Journal for Research, Policy and Practice. 1 (1): 31–48 doi: 10.1080/17441690500443139
15. Ribeiro WC (2011) Oferta e estresse hídrico na Região Metropolitana de São Paulo. Estudos Avançados, 25 (71): 119-133 http://dx.doi.org/10.1590/S0103–40142011000100009
16. Silva TR, Porto MA (2003) Gestão urbana e gestão das águas: caminhos da integração. Estudos Avançados, 17 (47): 129–145, jan.-abr. 2003. http://dx.doi.org/10.1590/S0103–40142003000100007
17. Tucci CEM (2010) Integrated urban water management in the humid tropics. In: Parkinson JA, Goldenfum JA, Tucci CEM. Integrated urban water management: humid tropics. UNESCO: Taylor & Francis. pp. 1–23
18. Tundisi JG (2008) Recursos hídricos no futuro: problemas e soluções. Estudos Avançados, 2008. Avaible in: http://www.scielo.br/pdf/ea/v22n63/v22n63a02.pdf. Access in: 13 ago. 2012
19. UNESCO (2009) Water in a changing world. Available in: http://www.unesco.org/water/wwap/wwdr/wwdr3/. Accessed October 8, 2011
20. UNESCO; WWAP (2003) Water for people, water for life. Barcelona: Berghann Books, 2003. Accessible in http://www.unesco.org/water/wwap/wwdr1/pdf. Acess in 2011 August, 10
21. Wade TG, Riitters KH, Wickham JD, Jones KB (2003) Distribution and causes of global forest fragmentation. Conservation Ecology 7(2): 1–16. URL: http://www.consecol.org/vol7/iss2/art7/
22. Yang H, Wan LG, Abbaspour KC, Zehnder AJB (2006) Virtual water trade: an assessment of water use efficiency in the international food trade. Hydrol. Earth Syst. Sci. (10): 443–454, doi.oai:hal.archives-ouvertes.fr:hal-00305004

Urban Vulnerability Assessment in Flood-Prone Areas in West and East Africa

Nathalie Jean-Baptiste, Sigrun Kabisch and Christian Kuhlicke

Abstract Vulnerability assessment remains central in discourses on global climatic change and takes a more pertinent meaning considering that natural disasters in developing countries continue to deeply affect human settlements. In recent years, severe weather events affected the social and economic asset of local populations and challenged local institutions to adapt in the face of increasing seasonal events and also unexpected larger disasters.

The research project CLUVA 'Climate Change and Urban Vulnerability in Africa' was launched in December 2010 and involves a multidisciplinary team of European and African scientists who investigate the preparedness and adaptive capacities of large African cities. CLUVA is part of a European Seventh Framework Program which aims are to at developing context-centered methods to assess vulnerability and to increase knowledge on managing climate related risks such as floods and sea level rise.

Important features for vulnerability assessment in CLUVA cities are the increasing severity of the physical damages, the shortcoming of social and technical infrastructure, the complexity of land management/market and the limited capacity of local institutions. Understanding vulnerability in this context implies highlighting and interlinking relevant indicators and/or perceptions encompassed in four main dimensions. The social, institutional, physical and attitudinal causes for the production of vulnerability. A combination of tools investigates how households and communities can resist and cope with, as well as recover from floods.

In this paper we present the conceptual approach of our social-science analysis and first empirical research results from Dar es Salaam, Tanzania and Ouagadougou, Burkina Faso. Preliminary findings show that coping capacities are household-centric and encompass short term actions to conserve and consolidate individual assets. These actions occur through local social networks and, communities. Adaptive capacities and the effectiveness of long term recovering interventions are community-centric and involve a web of formal and informal institutions.

N. Jean-Baptiste (✉) · S. Kabisch · C. Kuhlicke
Helmholtz Centre for Environmental Research-UFZ, Permoserstrasse 15,
04318, Leipzig, Germany
e-mail: nathalie.jean-baptiste@ufz.de

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_17,

Introduction

Vulnerability assessment is becoming an integral part of research on global climatic change and continues to be a critical component to understand the processes of affectation and adaptation of individuals, communities and cities to the impacts of climate change. Vulnerability is a contested construct that carries different meaning depending on the perspective from which it is concieved and depending on different research traditions. Yet, it is most often conceptualized as being constitued by elements of exposure, susceptibility and coping and adaptive capacity [5, 9].

The world is currently facing major challenges due to variability and uncertainty of the environment in which urban settlers attempt to pursue their livelihood [15]. The growing urban character of societies, especially those with less-advanced economies, makes them particularly vulnerable to climate change related hazards due to the combination of rapid urbanization, lack of technical infrastructure and limited knowledge and experience in sustaining adaptive strategies to deal with unregulated urban growth onto risky sites [11]. Storm event, rising sea levels and water scarcity are expected to have disproportionate impacts in growing cities.

African cities are experiencing changes at a rate that exceed their capacities to manage the environmental risk they face. In fact severe weather events (drought, flood and windstorms events, change in rainfall patterns, sea level rise and decrease in river basin and water availability are expected to increase in the continent. [15, 20, 22]. They feature a fast growing population which makes them at greater risk from the increased intensity of hazards such as flooding, storms, landslides and heat waves and constraints of fresh water.

Flooding is one of the most frequent and widespread climate change induced hazards, causing substantial losses in terms of human life and economic disruptions. From 1993 to 2002 flood disasters affected more people globally (140 million hab. per year on average) than all other natural and technological disasters put together [7]. Also in Africa, flooding is the most frequent climate related hazard type that results in the highest mortality. Between 1996 and 2005, 290 events were registered in the continent resulting in 8,183 human losses and exceeding mortality caused by windstorms, landslides, tsunamis and earthquakes [19].

Although Africa is considered a continent particularly vulnerable to the effects of climate change, its real impact, particularly on a local scale, is still poorly understood. For this reason, a selected number of African cities were identified to explore the issues of vulnerability, resilience, risk management and adaptation. They are being investigated within a European Seventh Framework Program focusing on assessing vulnerability of urban systems, population and goods in relation to natural and man-made disasters from different disciplinary perspectives. They are referred as CLUVA cities, they are located West and East of the continent and encompass coastal, estuary, inland, and highland characteristics. They feature different weather conditions such as tropical dry, tropical humid and Sub-Saharan climate. The cities selected in the project are Addis Ababa (2.7 million hab.), Douala (2.1 million hab.), Dar es Salaam (3.3 million hab.), Ouagadougou (1.4 million hab.) and Saint

Louis (900,000 hab.). Ranging from medium to large these growing urban areas are confronted not only with increasing weather related hazards but also with the pressure of globalization and development. As urban development demands improved assets, more functional institutional structure and enhanced physical and social infrastructure, it subjects CLUVA cities to continual challenges to adapt to change.

This paper, despite retaining a predominently conceptual character, offers some examples from the cases of Ouagadougou, Burkina Faso in West Africa and Dar es Salaam, Tanzania in East Africa. The next segment describes a conceptual framework enabling the incorporation of local assessment-based factors to evaluate the vulnerability of households and communities.

A Conceptual Framework for Assessing the Vulnerability of African Cities

Approach and Components of Vulnerability

We propose an approach that considers the tightly coupled interdependency between various spheres of urban life and the environment and argue that cities' complexity and the various interconnections of their socio-technical but also socio-ecological systems needs to be considered as central features of urban vulnerability [10]. Exposure describes the physical precondition to be affected [5]. Susceptibility involves the preconditions to suffer harm because a person or a group experiences some level of fragility or disadvantageous conditions. Coping and adaptive capacities refer to individuals or social groups considering their ability to come to terms with stressing, threatening or damaging events by coping with or adapting to them. Thus, urban vulnerability, in our understanding describes a) the degree to which individuals, social groups, local communities, organizations (formal and informal), infrastructures as well as physical assets in urban environments are exposed and susceptible to environmental hazards and b) the capacities of these actors and assets to adapt to and cope with the negative impacts of such hazards. The concept thus aims at deliberately adding a notion of 'the urban'—as the predominant mode of the complex spatial organization of contemporary societies worldwide—to the existing (social) vulnerability discourse. Figure 1 illustrates sequential attributes given to coping and adaptive capacities to flood events in the CLUVA cities.

While applying this idea within an African urban context, there are relevant features for vulnerability assessment to be considered. First, urban population gowth and informal sector dynamics play a role in the degree through which communities interact and also recover from natural events. Second, the attitude and perception of risk in hazard prone settlements influence coping capacities to unexpected and sudden events. Third, the complexity of land management as well as the interactions of formal and informal institutions shape local government responses and long term adaptive strategies. Finally, the conditions of the physical environment particularly

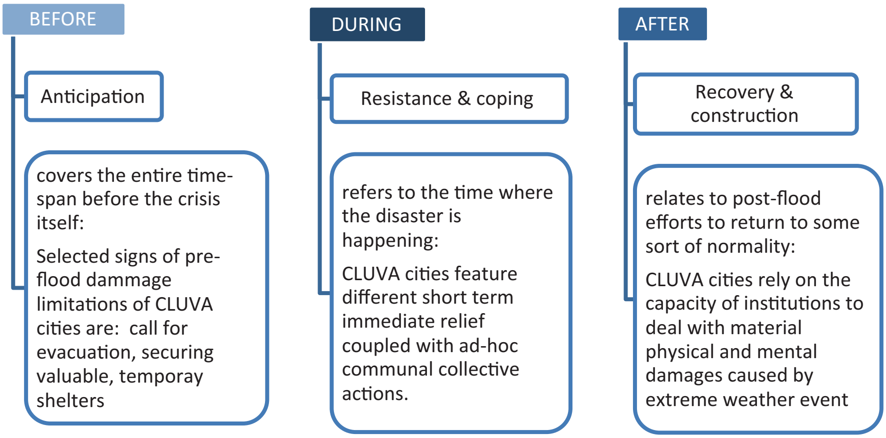


Fig. 1 Evidence of coping and adaptive capacities before, during and after a flood

man-made structures influence the degree of severity of the physical damages reported in recent years. In light of these contextual particularities, we argue that vulnerability assessment in African cities requires highlighting and interlinking relevant indicators[1] and/or perceptions encompassed in four main dimensions [8]:

1. Asset vulnerability encompasses the human livelihood and material resources of individuals and groups
2. Institutional vulnerability refers to the state of local authorities and civil action groups that operate to prevent, adapt or mitigate the effect of extreme weather events.
3. Attitudinal vulnerability conveys the perception and risk management attitude of individuals and groups
4. Physical vulnerability is determined by the characteristics of the land cover may it natural and/or man-made (ibid).

We suscribe to the idea that assessment of vulnerability cannot be studied in isolation from contextual circumstances [3, 23, 16]. It is indeed the context that frames and influences the exposure to climatic changes as well as potential responses. The asset, institutional, attitudinal, and physical dimensions proposed in CLUVA is shown in Fig. 2. This conceptual proposal follows a tradition of analysis based on a "processual and multidimensional view of climate – society interactions" [14]. This approach stems from development studies contributions as well as a conceptualization of vulnerability that regroups the following stand points:

1. Not all individuals or groups are equally vulnerable [17].

[1] A review on exiting vulnerability indicators was conducted prior to the empirical research in which 39 indicators were proposed to facilitate the assessment of vulnerability. These indicators were evaluated and contextualized to the CLUVA cities and integrated in a model fitting to CLUVA (available at: http://www.cluva.eu/deliverables/CLUVA_D2.11.pdf)

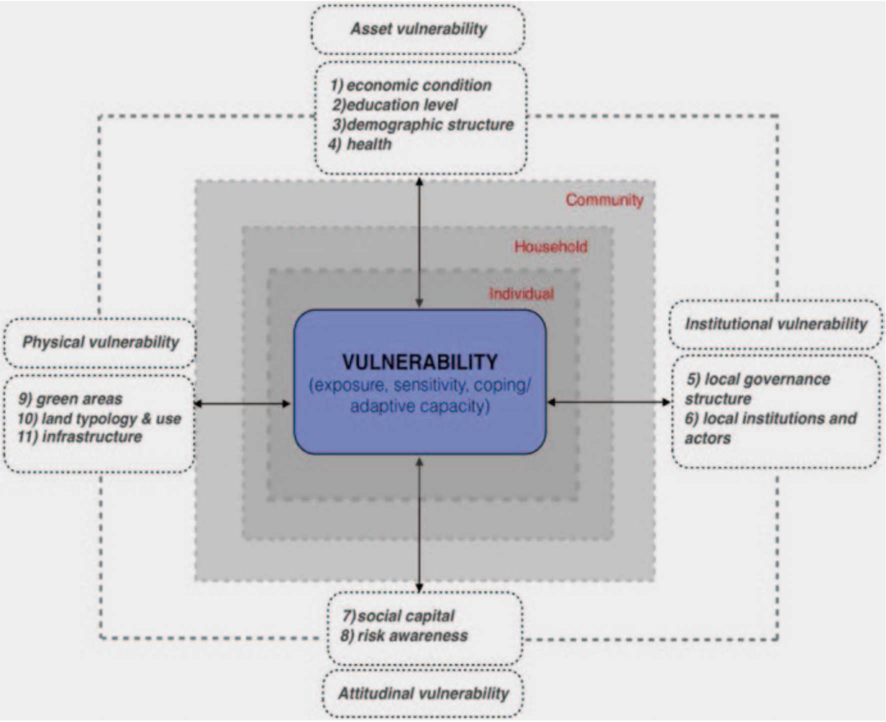


Fig. 2 CLUVA framework focusing on social vulnerability

2. The impact of a disaster may be a product of different spatial realities [4].
3. Vulnerable groups may display patterns of differential losses that they are vulnerable to different stressors [24].
4. Vulnerability causes are not necessarily associated to climatic related such as flood, drought and sea-level rise.

Understanding and Defining the Asset, Attitudinal, Institutional and Physical Dimensions of Vulnerability

Asset is understood as the human livelihood and material resources of individuals and groups. It is seen as the margin of well-being that allows individuals or groups to resist to potential hazards. Asset-based conditions act as stimulus of vulnerability or capacity.[2] These conditions regroup tangible (i.e material possessions) and

[2] Asset based assessments with regard to vulnerability are conducted with the aim at identifying what are the different resources that individuals have [1, 2, 13]. These assessments investigate what the poor possess based on the premise that the more and diverse these assets are the less

intangible (i.e good health and education) resources that influence the degree of resistance of a household or community when dealing with seasonal and/or large scale disasters. In addition to these, economic factors inevitably play a role in vulnerability. Although there is a consensus that a robust economy provides opportunities in case of hazard exposure [3, 21], in African cities, more careful consideration should be given to the dependency of informal sources of revenue. The informal economy represents a large percentage of the income revenue of urban dwellers in the continent. Some East African countries feature a percentage of home–based work higher than 70 %. For instance in Cameroon 80 % of all jobs created in 1992 were in the informal economy [25]. This suggests that informal sector dynamics continue to shape the vulnerability of urban settlers and play a role in the processes of affectation and adaptation to seasonal and extreme events.

Institutions are important factors in increasing and/or decreasing urban vulnerability. Institutional vulnerability considers the state of local authorities and civil groups that operate to resist, adapt or mitigate the effect of extreme weather events. They are central to assess the vulnerability of organizations of entire urban areas. In the absence of institutional capacity there is limited knowledge of an event, poor dissemination opportunities, low emergency preparedness and ability to absorb impact. As a result, any biophysical event has the potential to turn into a serious threat to communities, in particular those located in hazard prone areas. In African cities, the importance of identifying and recognizing the role of formal and informal institutions and actors lies in the fact that these two are intertwined. In CLUVA cities formal hierarchies are linked to legitimate channels of local government whereas informal hierachies are enforced outside legally binding mechanisms.

The attitude to risk is considered important to assess the degree of sensitivity of urban dwellers. How aware people are of the risk they face and whether they consider themselves as being truly exposed and even in a position to mitigate risk? These questions raise arguments that awareness of a hazard leads to prevention of disaster or at least contributes to reducing its impact, and hence serves as a central component of adaptation strategy. In the context of CLUVA, we view risk awareness as the everyday processes by which settlers in flood prone areas perceive risk. Our estimation relates to a certain extent to intuitive awareness of risks based on attitudinal attributes and residents' own evaluation of the consequences of climatic events. In addition, we consider network capital such as family support, access to resources through information, access to help through social ties affects susceptibility.

Physical components such as the urban ecosystem, existing green areas, the use of land as well as the condition of buildings and the infrastructure are important to consider as they are particularly vulnerable to climatic related events. The green

---

vulnerable they are. Since the 1990s a number of frameworks and approaches emerged adding to an already extensive literature on asset and rights and entitlements. For example, the Asset Vulnerability Framework [13] regroups an extensive household asset portfolio distinguishing asset types such as labour, human capital, productive assets, household relations and social capital, which aim at demonstrating how the collection of asset interplay with the concept of vulnerability.

structure is relevant to increase the coping and adaptive capacities of societies as it can protect urban neighborhoods through flood and storm water retention, soil protection and mitigation of heat. However speedy urban zoning initiatives and weak urban planning law enforcement cannot prevent the expansion of settlement into green and/or hazardous areas. In Dar es Salaam it is estimated that 80 % of the city is comprised of informal settlements [12]. Likewise, the rate at which urbanization is growing in Ouagadougou (7 % annual average population growth) and the condition of the buildings found in 'zones non loties' (informal settlement) in pre-urban and rural settlements are important considerations for assessing physical vulnerability.

Methodological Design

Scale of Assessment: Household and Community Level

The level or spatial scale at which vulnerability assessment is being conducted by our social-science approach is at household and community levels. In our view, any inquiries dealing with the condition of individuals require contextualization at the lowest administrative level. A 'household' and 'community' focus enables a better understanding of how and why individuals and groups organize themselves when they face increasing environmental threaths. This approach, in line with an inductive ladder of assessment, can offer signs that are not easily visible at a city scale and allows a deeper understanding of what O'Brien et al. [14] consider as 'human-security framing', meaning the social conditions of the system that enables a hazard to become a disaster.

Criteria for Selecting Areas of Study

Different criteria were used in selecting communities or areas for assessing vulnerability of households and communities among CLUVA cities. They vary from one city to another depending on the type of hazard being studied and the city characteristics. However, commonalities among CLUVA cities are i) the exposure to flood and sea rise levels; ii) the growth and consolidation of informal settlements in flood-prone locations, as well as different institutions and actors that are engaged in coping and adaptive actions. In accordance to the local context, the settlements selected in Ouagadougou are located in water catchment areas or in close proximity to a water canal. In Dar es Salaam the ones selected are located in low lying areas and are exposed to flood hazards; in particular communities experiencing frequent seasonal flooding were selected. The type of building construction or type of housing was also used as a criteria in Ouagadougou contrasting to Dar es Salaam which considered the stage to consolidation of settlements.

Table 1 Key criteria used to identify vulnerable communities in Dar es Salaam and Ouagadougou

Criteria	Dar es Salaam	Ouagadougou
Location in water catchment mark or close to the river		x
Exposure to flood hazard/located in flood prone area	x	x
Mixed (formal/Informal) settlement	x	x
Type of housing/building construction		x
Frequent flood hazards	x	
Existence of local institutions	x	
Stage of settlement development	x	

Table 1 summarises the criteria used for selecting areas of study in these two cities. Based on these considerations, the following settlements were selected:

- Dar es Salaam: Bonde la Mpunga (16,430 hab.) and Magomeni Suna (9,450 hab.)
- Ouagadougou: Dapoya (25,161 hab.),Wentemga (63,180 hab.)

Data Collection Modes

A variety of data collection techniques were used in the areas of study, based on the idea of mixing methods. This allowed stronger inference (i.e. complementary results) and greater diversity (i.e. integration of different views from different perspectives). In Ouagadougou, an explorative household questionnaire covering a horizontal transect across the city investigated the condition of those located in proximity to the water canals. This first inquiry offered some indications on the asset and physical vulnerabilities to flood focusing on the socio-economic characteristic of households, most frequent health conditions and the state of local infrastructure. Additionally, in depth participatory activities such as transect walks and interviews with key individuals were conducted in Dapoya, and Wentemga. These enable us to have a first insight on the institutional arrangements and the interrelations of formal and informal organisations. In Dar es Salaam several group sessions with stakeholders were conducted to explore the role and capacities of different actors and institutions involved in coping and recovery to flood. In addition, structured interviews in Bonde la Mpunga and in Magomeni Suna were developed with the goal of keeping the focus on residents.

Preliminary Results

A preliminary interpretation of the empirical work shows that it is necessary to differentiate between seasonal events and/or unexpected extreme disasters in Dar es Salaam and in Ouagadougou.

Seasonal events have a cyclical character. They are recurring incidences that occur during a particular period. They are for instance consistent flooding during rainy seasons and/or persistent droughts during dry periods. These events are part of the yearly weather-related episodes thus come about with a certain level of regularity and appear to have a gradual impact on the communities assessed. In contrast, unexpected extreme disasters are major events resulting from severe weather pattern and/or anthropological processes. These unpredictable large scale events are punctual and carry a certain level of uncertainty. Ouagadougou and Dar es Salaam have both experienced subtantial damages caused by extreme flooding. The flood of September 2009 in Burkina Faso, affected several sectors (health, housing, production and livelihood, education and infrastructure). The flooding affected 11 of a total of 13 regions and was reported as the worst flood in the history of the country and remains in the collective memory as one of the most damaging events in Ouagadougou. Similarly in Dar es Salaam, 80 % of the houses in the Magomeni Suna area were fully submerged into water during the most recent flood of December 2011. As a result, the community experienced major destruction of buildings, closure of businesses and schools, lack of water, loss of crops, massive evacuation and relocation as well as loss of lives.

Vulnerabilities to seasonal weather events: Indications from Ouagadougou

Ouagadougou, the capital of Burkina Faso experiences seasonal rain between July and September each year and the average rainfall during the wet period is 700 mm. The decomposition of rainfall time series which is based on the data collected from 1940 until 2010, reveals a constant increase of almost 6 mm overtime [18]. This trend exerts particular pressure at the domestic sphere in particular in settlements lacking basic infrastructure for rainwater drainage system. A typical housing compound is composed of one storey units comprising 2 to 3 households as residential parcels are shared by nuclear and extended households or by unrelated neighbors (i.e. landlord and renter) with an average occupant per household is 5.5 persons. In older districts located in the central part of the capital, limited land availability is conducive to dense living arrangements with restricted services which makes these settlements vulnerable to water run-offs. In peripheral settlements, heavy rains represent a continuous treath to the buildings and their occupants due to the fact that residential constructions are traditionally made from earth ‘adobe’ materials that are vulnerable when in prolonged contact with water, as well as water and debris flows during flush flood.

In addition to the physical vulnerability of buildings, we found that the disruption of economic revenues due to seasonal flooding is particularly noticeable among women activities. Indeed, women were found to be more intimately connected to their homes as well as the immediate local environment. Interviews revealed that during rainy seasons they primarily attend their home (e.g. cleaning, removing mud and water, attending children, obtaining clean water) allowing them less time for other income generating activities. The household questionnaire reveled that 44 % of households featured respondents with no instructions. Among them were women which limited access to information affects their coping capacities and thus increases their vulnerability to seasonal events.

In Ouagadougou the effect of periodical flooding increases due to the lack of water retention on the land cover. Damages on housing and public infrastructure intensify as settlements expand without adequate infrastructure. Seasonal flooding affect directly agricultural activities and disturbs local goods trading (i.e. market places, small businesses, selling of fruits and prepared food). Lastly outbreak of diseases are likely to increase during seasonal events due to the increase of favorable conditions for vector animals. Thus, seasonal weather events have a cumulative effect on local communities because of their incremental impact.

Vulnerability to Unexpected Extreme Disasters: Indications from Dar es Salaam

In Dar es Salaam, initial findings show that several networks (cooperatives, associations and groups) serve as self-regulated livelihood support against seasonal weather events. These organizations mostly operate outside any governmental regulatory frameworks and operate by a broader set of values. They are legitimated through social and cultural norms and enforced through traditional and relational mechanisms. Cooperatives are critical for access to loan for (re)construction and education. They also serve as safety nets in case of unexpected events. Such organizations rely and encourage local trust between residents versus a poor level of trust to local authorities due to false promises. Traditional believes "water is afraid of people" perpetuates a false sense of risk, despite the fact that the impact of floods are known.

Responses to Seasonal and Extreme Events

The selected cities illustrate a complex web of actors influenced by community-based experiences to flood. Preliminary findings give evidence that on one hand, actions undertaken by civic groups and communities themselves are important to save the private assets but often remain unnoticed at higher governmental echelons. On the other hand, local government authorities may not always have the opportunity to integrate those able to shape collective action in disaster risk management decision making processes. Thus, a stakeholder analysis at community level offers the opportunity to better understand formal and informal hierarchies and to identify causal settings for institutional vulnerability or capacity. In Ouagadougou, the web of institutions and actors that responds to an unexpected and large event often exceeds the scope of local authorities. For instance, the flood of September

1st 2009, which remains in the collective memory as one of the worst floods in the history of the country, required interventions across all legitimate channels of the local authorities. The same type of interventions was necessary in Dar es Salaam in December 2011.

Conclusion

To assess urban vulnerability in flood-prone areas in West and East Africa the proposed conceptual framework provided a comprehensive approach. First, the sequential attributes given to coping and adaptive capacities to flood events refer to the time before an event in terms of anticipation, during an event in terms of resistance and coping and finally after an event in terms of recovery and construction. Second, the four components of the vulnerability framework—asset, institutional, attitudinal and physical vulnerability—encompass the most important vulnerability dimensions at the community and the household level. These dimensions focus on interaction processes, network support and communication strategies that act as a stimulus for coping capacities. Preliminary observations show that individual and collective interactions serve as organizational buffer that enables resistance and coping capacities. The first findings show the restricted capacities of governmental institutions when dealing with larger-scale event. The assessment of the institutional vulnerability captures the characteristics of those able to shape collective action. In the case of Ouagadougou particular attention is to age-old informal institutions which are not codified however plays a role in sustaining long term implementations.

While coping to ongoing seasonal events imply managing and resisting to shocks in a relative short period of time, adaptive capacity to an extreme event addresses longer-term adaptation measures in the aftermath of an exceptional event—and therefore at the same time taking conscience and planning before the next large scale event. It appears that the margin of well-being of locals barely tolerates the intensity of cyclic rains, coping capacities comprise mostly simple techniques implemented by the communities themselves.

To assess the urban vulnerability in an appropriate manner a differentiation between periodical seasonal flooding and extreme events is necessary. The resistance to periodical flooding is affected by the availability and reliability of sources of revenue. Thus one important consideration is to investigate the human and material resources that influence the degree of resistance of a household or community.

Concerning preparedness to extreme flood events, in particular governmental institutions need advanced techniques and tools. The severity of losses depends on existing social, environmental and institutional conditions. Further research is directed at coping capacities of vulnerable women groups and cooperatives to specify particular resources and potentials as well as limits and constraints.

References

1. Barrett C (1999) On Vulnerability, Asset Poverty and Subsidiarity. Working Paper
2. Chambers R (1995) Poverty and livelihoods: Whose reality counts? Brighton, Discussion Paper No. 347. Institute of Development Studies
3. Cannon T (1994) Vulnerability analysis and the explanation of "natural" disasters. In: Varley A (ed.) Disasters, development and the environment. John Wiley, Chichester
4. Cutter S, Boruff B, Shirley W (2003) Social Vulnerability to Environmental Hazards. Soc Sci Quart 84(2):242–261
5. Government of Burkina Faso, UN, World Bank (2009) Inondations du 1er Septembre 2009 au Burkina Faso. Evaluation des dommages, pertes et besoins de construction, de reconstruction et de releÌvement. Rapport
6. IFRC (2003) World disasters report, Geneva: International federation of red cross and red crescent societies. www.ifrc.org/publicat/wdr2003/
7. Fuchs S, Kuhlicke C, Meyer V (2011) Editorial for the special issue: vulnerability to natural hazards-the challenge of integration. Nat Hazards 58/2:609–619. DOI 10.1007/s11069-011-9825-5
8. Jean-Baptiste N, Kuhlicke C, Kunath A, Kabisch S, (2011) Review and evaluation of existing vulnerability indicators in order to obtain an appropriate set of indicators for assessing climate related vulnerability. CLUVA Deliverable D2.11: CLUVA project (Assessing vulnerability of urban systems, populations and goods in relation to natural and man-made disasters in Africa), Grant agreement no. 265137. Available at http://www.cluva.eu/deliverables/CLUVA_D2.11.pdf
9. Kabisch S, Kunath A, Schweizer-Ries P, Steinführer A (Eds.) (2012) Vulnerability, Risks and complexity. Impacts of Global change on Human Habitats. Hogrefe, Göttingen
10. Kuhlicke C, Kabisch S, Krellenberg K, Steinführer A (2012) Urban vulnerability under conditions of global environmental change: conceptual reflections and empirical examples from growing and shrinking cities. In: S. Kabisch, A. Kunath, P. Schweizer-Ries & A. Steinführer (Eds.), Vulnerability, risks and complexity: impacts of global change on human habitats. Göttingen: Hogrefe (Advances in people and environment studies, 3). 27–38
11. Kebede SA, Nicholls JR (2010) Population and assets exposure to coastal flooding in Dar es Salaam (Tanzania): vulnerability to climate extremes; Report submitted to Global Climate Adaptation Partnership (GCAP), 17 January 2011
12. Kombe W (2005) Land use dynamics in peri-urban areas and their implications on the urban-growth and form: the case of Dar es Salaam, Tanzania. Habitat International 29(1):113–135
13. Moser C (1998) The asset vulnerability framework. Reassessing urban poverty reduction strategies. World Devel 26(1):1–9
14. O'Brien K, Eriksen S, Nygaard LP, Schjolde A (2007) Why different interpretations of vulnerability matter in climate change discourses. Climate Policy 7(1):73–88
15. Parry M, Canziani O, Palutikof J, van der Linden P, Hanson C (Eds) (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate change (IPPC). Cambridge University Press, Cambridge
16. Pelling M (2006) Measuring urban vulnerability to natural disaster risk: benchmarks for sustainability. Open House International 31:125–132
17. Rygel L, O'sullivan D, Yarnal B (2006) A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. mitigation and adaptation strategies for global change, 11(3), 741–764. doi:10.1007/s11027-006-0265-6
18. Tonye E, Yango J, Tsalefac M, Ngosso A, Nguimbis J, Ngohe Ekam S, Moudiki C, Mgaba P, Tamo T, Pancha moluhP, Lindley S, Weets G (2012) Report on climate related hazards in the selected cities. CLUVA Deliverable D5.2: CLUVA project (Assessing vulnerability of urban systems, populations and goods in relation to natural and man-made disasters in Africa), Grant agreement no. 265137. Available at: http://www.cluva.eu/deliverables/CLUVA_D5.2.pdf

19. UN-HABITAT (2007) Profil Urbain de Ouagadougou. UNEP: Nairobi
20. UN-HABITAT (2010) The State of African Cities 2010, Governance, Inequality and Urban Land Markets. UNEP: Nairobi
21. Vincent K (2004) Creating an index of social vulnerability to climate change in Africa. Working Paper No.56. Tyndall Centre for Climate Research, University of East Anglia, Norwich
22. Vordzorgbe S UN/ISRD (2007) Climate change and risk management in Africa: Major issues. Expert background paper for the session on risk management and climate change. World economic forum on Africa. Cape Town, 13-15 June 2007.
23. Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, people's vulnerability and disasters. 2nd edition. Routledge, London
24. Wu SY, Yarnal B, Fischer A (2002) 'Vulnerability of coastal communities to sea-level rise: A case study of the Cape May county, New Jersey, USA' Climate Research 22, 255–270
25. Xaba J, Horn P, Motola S (2002) Employment sector 2002/10, working paper on the informal economy: The informal sector in sub-saharan africa. international labor organization 2002. Geneva International Labor Office Available at: http://www.ilo.org/wcmsp5/groups/public/ed_emp/documents/publication/wcms_122204.pdf

Contextualizing Sustainable Development for Small Scale Water and Sanitation Systems in Cochabamba, Bolivia

Ida Helgegren, Helena Siltberg, Sebastien Rauch, Mikael Mangold, Graciela Landaeta and Carmen Ledo

Abstract Water and sanitation are pressing issues for the urban poor in Bolivia where the lack of safe water and sanitation services contributes to urban poverty. This paper defines sustainable development (SD) in relation to small scale water and sanitation systems in the metropolitan area of Cochabamba, Bolivia. A case study on the water and sanitation systems of two housing cooperatives is performed. By involving all the concerned stakeholders this study aims to identify a contextualized definition of SD, which can be used in order to assess and steer the development of small scale water and sanitation systems in the metropolitan area of Cochabamba. The identified definition consists of the following criteria, referred to as *key issues*: social context, socio-political factors, target group, freshwater resources, economic obstacles, reproducibility, knowledge, management, reliability, water quality and disposal. Three main challenges are identified to have had major influence on the contextualization of the SD concept: which stakeholders that are included, how the differing opinions among the stakeholders are addressed and how active the stakeholders are in the development process.

Introduction

Improved access to adequate water and sanitation services has gained increased attention as a result of the Millennium Development Goals. It is considered as a requirement to fulfil the concept of sustainable development (SD). The lack of access to safe water and sanitation hampers the fight against poverty. The insufficiency has major health implications, especially for children [20]. Bolivia is one

I. Helgegren (✉) · H. Siltberg · S. Rauch · M. Mangold
Water Environment Technology, Department of Civil and Environmental Engineering, Chalmers University of Technology, 41296, Gothenburg, Sweden
e-mail: ida.helgegren@chalmers.se

G. Landaeta
Institute of Architectural Research, Universidad Mayor de San Simon, Cochabamba, Bolivia

PROCASHA Foundation, Cochabamba, Bolivia

C. Ledo
CEPLAG, Universidad Mayor de San Simon, Cochabamba, Bolivia

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_18,

of the poorest countries in Latin America and its water and sanitation coverage is heavily deficient. Despite recent increases in the access to potable water and safe sanitation, large proportions of the Bolivian population lack access to these basic services. In 2001, 62.3 % and 63.3 % of the households had access to piped-in water and sanitation services, respectively, at the household level. In the department of Cochabamba, where the metropolitan area of Cochabamba is situated, the access to piped-in water and sanitation facilities was 53.9 % and 66.7 %, respectively, at the household level in 2001. However, the access to adequate water and sanitation services is higher in the urban areas of the department. In the metropolitan area of Cochabamba, which consists of the following municipalities; Cochabamba, Sacaba, Quillacollo, Colcapirhua, Tiquipaya, Vinto and Sipe Sipe, 64.7 % of the households had access to piped water supply and 83.5 % of the households had a latrine or a waterborne toilet facility, in 2001 [10][1].

SD aims to assure that the present and the future generations have and will have their needs fulfilled. However, the concept of SD has been heavily debated. On one hand, the broad definition of SD has contributed to a relatively free interpretation of the content [11]. On the other hand, the broadness of the concept has been seen as an advantage. Sneddon, Howarth and Norgaard [18] argue that it is necessary to embrace the plurality of the concept in order to achieve sustainable development. SD is not a static concept, but should evolve over time and allow inclusion of different actors at all levels and enable an open dialogue between them. It is important to develop local definitions of SD, which can be used in the work towards its fulfilment [19].

The purpose of this research project is to contextualize SD through stakeholder involvement. It aims to enable assessment and steering of the development of water and sanitation services in the metropolitan area of Cochabamba. Traditionally, water and sanitation projects in developing countries have mostly focused on technical aspects. However, a multi-disciplinary approach is absolutely crucial [12]. This makes SD to a suitable aim, but the concept can in itself be difficult to use as a concrete goal, due to its plurality and broad definition [21]. Hence, it is important to clearly define and contextualize the concept of SD. One way to do this is to decide how the concept should be evaluated and measured [11]. This paper identifies functional criteria for SD that will be used to identify suitable SD indicators for the metropolitan area of Cochabamba. The focus is on small scale water and sanitation systems, since many scholars such as Flores et al. [7], emphasize the importance of these in developing countries, as a solution to the deficiency in access to these basic services. Water and sanitation systems are seen as one system, which is comprised by the provision of water used for domestic purposes and sanitation solutions for wastewater and excreta, including treatment, disposal, transportation of sludge and reuse of residuals and water.

[1] Note that the presented data from the National Institute of Statistics of Bolivia does only consider the existence of a sanitation facility, not how safe it is.

Fig. 1 The structure used to define SD in this study. It is built upon the SD definition of the UN and the *key issues* are to be developed in this paper

Method

The starting point for this research is the SD definition from the UN that includes social, economic and environmental aspects [11]. Under this, a number of criteria, here referred to as *key issues*, are identified through stakeholder involvement. Together the k*ey issues* constitute the contextualized definition of SD, see fig. 1 for visualization. The approach, which involves the division of SD into different levels, is in line with the working procedure of many scholars, such as Hellström, Jeppson and Kärrman [9] and Garfí and Ferrer-Martí [8].

A case study on the water and sanitation systems of two housing cooperatives in Cochabamba has been carried out in this research. The housing cooperatives, which are called COVISEP and COVIVIR, consist of 30 and 12 families, respectively. They are based on a model of cooperative housing, which enables low-income people to access adequate housing through mutual aid, collective property rights and self-management. Together, the member families take loans, buy land, and build and maintain houses that they own collectively. In Bolivia, this model is initiated and supported by the non-governmental-organization (NGO) PROCASHA, which aims at spreading cooperative housing as a means to improve the quality of life for the poor in Bolivia by offering technical advice.

SD requires stakeholder participation, since it refers to all of us. It should not be imposed on people through a top down approach [3, 8, 1]. However, the realization of this is far from easy. There are several aspects that need to be addressed in order for participatory activities to generate high-qualitative results that are representative for the specific area under investigation. According to Rockloff and Moore [15], the following qualities in a participant are desirable: ability to participate actively, competency (skills and knowledge), credibility, perceptiveness for the group identity, capacity to communicate outside of the group, possession of established social networks and ability to function in multiple roles. It is worth to reflect if these demands should be put on the participants and/or on the participatory methods and their execution. No matter of what, the listed desirable qualities illustrate the many challenges that stakeholder involvement imply.

Currently, there are several participatory methods used in research regarding SD. No consensus on what procedure to use and how different participatory methods should be undertaken exist [4]. In this study, interviews, group discussions and input presentations were used to examine the different perspectives on sustainable development of small scale water and sanitation systems. These methods were used because they allow insights in the perspectives of the individuals, as well as the collective thinking. The interviews and group discussions were semi-structured. The informants steered the interviews and the group discussions, but they were guided by the different spheres of SD. The cutting and sorting technique outlined by Ryan and Bernard [16] was applied in the data analysis. The empirics generated from the interviews and the group discussions were used to identify functional criteria and sub-themes, which are referred to as key issues and sub-topics, respectively. These were later on verified through input presentations. The used methods allowed the stakeholders to have a high influence on the outcome. The key issues and sub-topics, which build up the contextualized SD definition, were only based on the input from the stakeholders. The interviews and the group discussions were held until theoretical saturation was achieved, up to no new information was revealed. The input presentations were carried out as the concluding activity and they were held to assure that nothing important was left out. No weighting or prioritization of the key issues and the sub-topics was carried out. However, in order to make the differing opinions among the different stakeholder visible, the percentage of the informants within each stakeholder group that mentioned each sub-topic was calculated.

The concerned stakeholders were identified and divided into the following groups; members of the cooperatives, external stakeholders (supporting NGOs and representatives from the municipalities) and local experts with professional experience within the area. The latter two stakeholder groups were included since there is a danger that the public do not take scientific research into account, which might lead to that different risks and scenarios are exaggerated or underestimated [2]. The inclusion of experts improve the quality of the outcome, since they provide important knowledge that otherwise might be lacking [17].

Results

This paper presents 11 *key issues* consisting of *sub-topics,* which together build up the contextualized SD definition, see Table 1.

Table 1 The identified *key issues* and associated *sub-topics* together with the percentage of the informants within the different stakeholder groups that supported the inclusion of each *sub-topic*

Key issues	Sub-topics	Supporting expressions		
		Members of the cooperatives	External stakeholders	Experts
Social context	Demographic characteristics	0	20%	75%
	Social respect	25%	60%	50%
Social-political factors	Legislation	50%	80%	25%
	Political structure of water organizations	25%	20%	0%
	Municipal support	75%	40%	50%
Target group	Need	50%	50%	0%
	Demand	75%	30%	25%
Freshwater resources	Water availability	0%	20%	75%
	Water use	25%	40%	50%
Economic obstacles	Affordability	100%	60%	75%
	Willingness to pay	50%	20%	25%
Reproducibility	External support	50%	80%	50%
	Collaboration	50%	20%	50%
Knowledge	General awareness	25%	40%	25%
	Associated knowledge	75%	50%	75%
Management	Organization	25%	60%	100%
	Community participation	100%	40%	0%
Reliability	System design	100%	10%	75
	Access	75%	10%	25%
	Maintenance	100%	20%	25%
Water quality	Present state	75%	30%	75%
	Treatment	25%	40%	0%
	Risk of contamination	50%	20%	25%
Disposal	Hygiene	50%	10%	50%
	Emissions	50%	30%	25%

Discussion

In relation to small scale water and sanitation systems in the metropolitan area of Cochabamba this study defines SD through 11 *key issues*. The identified *key issues* and associated *sub-topics* are not expected to comprehensively cover SD, but are an effort to identify functional criteria that enable comparison of different alternatives and systems. The following three aspects have had major influence on the results; which stakeholders that was included, how the differing opinions among the stakeholders were addressed and how active the participants were.

Stakeholder Groups

The high influence that the choice of stakeholders has can be seen in Table 1, which shows that the selection of *key-issues* depends on which stakeholder groups that is included. The stakeholders have a direct impact on the contextualized SD definition. In this study, the inclusion of the external stakeholders and the experts might be questionable, since it is the members of the cooperatives that will use and apply the contextualized SD definition that is decided upon. Is the inclusion of the other two indirect stakeholder groups in line with a bottom-up approach? As Table 1 shows, some of the *sub-topics* would not be included if only the members of the cooperatives were included. However, as mentioned above, the external stakeholders and the local experts contribute with knowledge that otherwise is lacking. For example, the *sub-topics* demographic characteristics and water availability were not mentioned by the members of the cooperatives, despite their obvious importance in order for water and sanitation systems to function satisfactory in the long-run. Beierle [2] argues that participatory approaches can lead to biased results if they only include a small group of people, since the participants might tend to maximize the welfare of the small group rather than the overall societal welfare. Due to this it is crucial to carefully consider what stakeholders to include. However, the selection of stakeholders is not an easy task and the person(s) who does this influence the results. David [6] points out the difficulty to select participants through highlighting that the participants need to be defined by someone, but who is to define that someone?

Differing Opinions

As previously mentioned, the stakeholder groups had different opinions and standpoints, they emphasized different *sub-topics,* see Table 1. This raises the question of the amount of influence that the different stakeholders should have, should the different components in a contextualized SD definition be weighted relative each other? For example, the *sub-topics* affordability and willingness to pay are emphasized more by the members of the cooperatives than by the external stakeholders and the local experts. Consideration of differing opinions is a complex issue, since SD involves both scientific and political dimensions. It is important to consider the power relations among the different stakeholder groups and to bear in mind that weighting implies an indirect valuation of the relative importance of the different stakeholders. Additionally, it is important to reflect around if the key issues contradict each other to some extent and how to deal with that. For instance, in this study, the investment and implementation of water treatment technology improves the water quality, but it increases the cost, and both the *key issues* economic obstacles and water quality are emphasized as important. Despite the difficulties it implies, weighting of different components of SD is sometimes necessary. However, we have chosen to not weight the different *key issues* and *sub-topics* in this paper.

It is not only in the final stage that differing opinions need to be considered in studies like this. The framing of participatory studies implies decisions that limit the scope of the study and thereby also the preferences of the participants. This project includes claims from both the global community and the local stakeholders. The *key issues* are developed according to the views of the stakeholders, but the questions during the interviews and group discussions referred to environmental, economic and social aspects. Hence, the contextualized definition includes all the spheres of the SD concept, see fig. 1 However, should all the spheres of SD be included if the participants do not emphasize them? Should local SD definitions really be guided by the UN definition, which has been criticized for being a top-down approach? In this research, environmental aspects were relatively little emphasized by the stakeholders, so the inclusion of these aspects can be questioned. On the contrary, it can be argued that the concerned stakeholders might not have a complete understanding of the overall picture, as the scientific community aims to have. A common critique against approaches regarding stakeholder-based decisions is that they do not make use of available scientific information and technical resources [2]. The results of this paper can partly be used to support this argument. As previously mentioned, the *sub-topics* demographic characteristics and water availability were mostly emphasized by the local experts. The members of the cooperatives did not mention these *sub-topics*. This might be explained by the fact that the members of the cooperatives are mostly concerned with factors that they understand as direct impact categories. As opposed to experts that are more aware of regional trends that indirectly affect water and sanitation systems.

Active Participation

It was difficult to make the stakeholders participate actively. In general, the participants only had limited input during the interviews, the group discussions and the input presentations. If this was due to lack of interest or knowledge, the execution of the data collection activities or something else is not known. Bell, Morse and Shah [4] state that it is often experienced as difficult to achieve a high level of participation in research regarding SD. Nevertheless, the members of the cooperatives emphasized the *sub-topic* community participation as very important. This indicates that they despite of their low participation in this study consider strong involvement as important. An explanation to the low participation in this study might be the fact that the aim and the results are quite abstract and not directly applicable. Additionally, the stakeholders have not been included in formulating the purpose of this research. This raises the question of when stakeholder involvement should begin. In this case, the involved stakeholders have not asked for this specific study to be performed.

Another explanation to the low level of input can possibly be the confusion regarding the division of the responsibilities for water and sanitation provision, between the individual households and the public sector. The feeling of responsibility functions as a driver for action and change, but this study points out a dual attitude regarding the perceived responsibility for water and sanitation provision. On one hand, the *sub-topic* municipal support was emphasized as absolutely crucial by the members of the cooperatives, especially in the case of sanitation. Hence, the water and sanitation provision is partly seen as the responsibility of the municipality. On the other hand, in practice, the water and sanitation provision is taken care of by the neighbours, not the municipality. The cooperatives are currently members of a community-run water organization, which is not directly linked to the municipality, and they have built their own sanitation system. This indecisiveness between opinion and reality regarding who is to provide adequate water and sanitation services affects how the members of the cooperatives perceive their role in acquiring safe water and sanitation facilities, especially regarding who is to pay for and maintain water and sanitation systems. As well, their participation in activities regarding water and sanitation issues, such as this study, is affected.

Conclusion

Contextualizing SD implies several challenges and some of these are highlighted in this study. The identified *key-issues* and associated *sub-topics* point out that the results depend on what stakeholders that is included and the importance to address and deal with the differing opinions among the stakeholders. Furthermore, this paper highlights the challenge to enable and achieve active participation. In our opinion it is important to use a methodology that considers all these aspects. The demands should not be put on the participants, rather on the approach and the methods. It is crucial to bear in mind that the researchers influence the stakeholder involvement and guide the process.

There are several different methods regarding stakeholder participation, which today can be seen as a requirement when developing local SD definitions. Due to the challenges outlined above, we believe that it would be advisable to develop more detailed recommendations that can be used to guide stakeholder participation. It is neither feasible nor possible to agree upon a methodology that is common practice for all scenarios, due to the need to consider local characteristics. However, in order to guarantee that stakeholder participation generate representative contextualized SD definitions that incorporate scientific knowledge, recommendations regarding good practice would be beneficial.

Finally, it is worth to reflect around why SD is desirable and needs to be contextualized and applied, especially since SD is a highly political topic. The power relations between the different stakeholders affect the content of SD. Who drives the development process of contextualized SD definitions and who benefit from their application?

References

1. Becker J (2004) Making sustainable development evaluations work. Sustainable Development 12:pp 200–211
2. Beierle TC (2002) The quality of stakeholder-based decisions. Risk Anal 22(4):739–749
3. Bell S, Morse S (2003) Measuring sustainability: Learning by doing [e-book]. London: Earthscan Publications Ltd. available through: Chalmers University of technology Library website www.lib.chalmers.se [Accessed 5 10 2012]
4. Bell S, Morse S, Shah RA (2012) Understanding stakeholder participation in research as part of sustainable development. J Environ Manage 101:pp. 13–22
5. Camacho W ed. (2007) Objetivos de Desarollo del Milenio, La Paz: Departamento de Cochabamba
6. David M (2002) Problems of participation: the limits of action research. Int J Social Research Methodology 5(1):11–17
7. Flores A, Buckley C, Fenner R (2009) Selecting sanitation systems for sustainability in developing countries. Water Science Technology 60(11):2973–2982
8. Garfí M, Ferrer-Martí L (2011) Decision-making criteria and indicators for water and sanitation projects in developing countries. Water Science Technology 64(1):83–101
9. Hellström D, Jeppsson U, Kärrman E (2000) A framework for system analysis of sustainable urban water management. Environmental Impact Assessment Review 20:pp. 311–321
10. ESTADÍSTICA INSTITUTONACIONALDE (2001) Censo 2001, Vivienda y Servicios Básicos, Por Provincias y Municipios. (Online) Available at: http://www.ine.gob.bo (Accessed 07 01 2013)
11. Kates RW, Parris TM, Leiserowitz AA (2005) What is sustainable development? Goals, indicators, values, and practice. Environment: Science Policy for Sustainable Development 47(3):8–21
12. Murphey HM, McBean E, Farahbakhsh K (2009) Appropriate technology—A comprehensive approach for water and sanitation in the developing world. Technology in Society 31:pp. 158–167
13. Murray A, Ray I, Nelson K (2009) An innovative sustainability assessment for urban wastewater infrastructure and its application in Chengdu, China. Journal of Environmental Management, pp. 1–8
14. OECD (2002) Policy case study series. Participarory decision-making for sustainable consumption, [pdf] Paris: Organisation for Co-operation and Development. Available at: http://search.oecd.org/officialdocuments/displaydocumentpdf/?doclanguage=en&cote=env/epoc/wpnep(2001)17/final (Accessed 7 10 2012)
15. Rockloff SF, Moore SA (2006) Assessing representation at different scales of decision making: Rethinking local is better. The Policy Studies Journal 34(4):649–670
16. Ryan G, Russell Bernard H (2003) Techniques to identify themes. Field Methods 15(85):85–109
17. Rosenström U, Kyllönen S (2007) Impacts of a participatory approach to developing national level sustainable development indicators in Finland. J Environ Manage 84: pp. 282–298
18. Sneddon C, Howarth RB, Norgaard RB (2006) Sustainable development in a post-Brundtland world. Ecolog Econ 57(2):253–268
19. Wallis A (2006) Sustainability indicators: is there consensus. Int J Environment Sustainable Development 5(3):287–296
20. UNICEF (2012) Water, Sanitation and Hygiene. [Online] Available at: http://www.unicef.org [Accessed 15 05 2012]
21. UNHSP (2004) Urban Indicators Guideline, (pdf) Nairobi: United Nations Human Settlements Program. Available at: http://ww2.unhabitat.org (Accessed 10 10 2012)

Part IV
Air Quality and Noise

Transformations of 2-Stroke Nanoparticles along the Exhaust Gas Way

J. Czerwinski, P. Comte, A. Mayer and F. Reutimann

Abstract Nanoparticle emissions of two 2-stroke scooters were investigated along the exhaust- and CVS-system (Constant Volume Sampling) with closed and with open line (cone). Due to their technology the scooters produce different kind of aerosol (state of oxidation and SOF-content) and in addition to that they were operated with and without oxidation catalyst. The scooters represent a modern technology with direct injection TSDI (two stroke direct injection) and with Carburetor. The tests were performed at two constant speeds of the vehicles (20 km/h and 40 km/h) according to the measuring procedures, which were established in the previous research in the Swiss Scooter Network. The nanoparticulate emissions were measured by means of SMPS (CPC) and NanoMet*). The most important results are:

1. The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe.
2. In the "open" variant of exhaust gas extraction there is a dilution step with unfiltered ambient air directly after tailpipe. This causes a stop of agglomeration, reduction of diffusion loses and increased back-ground NP-concentration. There is also lower postoxidation of CO and HC. In some cases spontaneous condensates due to the temperature drop are supposed.
3. With the "closed" variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enable more intense thermophoresis—and diffusion losses.
4. The NP-concentrations measured with "open" variant are always higher.
5. Most intense oxidation is observed with Peugeot Carb: due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350 °C). With catalyst the temperature.

J. Czerwinski (✉) · P. Comte
AFHB, University of Applied Sciences, Biel-Bienne, Switzerland
e-mail: jan.czerwinski@bfh.ch

A. Mayer
TTM, Niederrohrdorf, Switzerland

F. Reutimann
BAFU, Bern, Switzerland

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_19,

The type of sampling: “open”, or “closed” as well as the sampling position in the exhaust installation have significant influence on the measured nanoparticles emission results.

Abbreviations

AFHB	Abgasprüfstelle der Fachhochschule, Biel-Bienne CH (Lab. for Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, CH)
BAFU	Bundesamt für Umwelt (Swiss EPA)
Carb	Carburetor
CMD	Vount Median Diameter
CPC	Condensation Particle Counter
CVS	Constant Volume Sampling
DC	Diffusion Charging Sensor
DF	Dilution Factor
DI	direction injection
NP	Nano Particulates
PC	Particle Counts
PM	Particulate Matter, Particulate Mass
PSD	Particles Size Distribution
SAS	Secondary Air System
SMPS	Scanning Mobility Particle Sizer
SOF	Soluble Organic Fraction
Sp	Sampling Position
TC	Thermo Conditioner, Total Carbon
TP	Tail Pipe
TSDI	Two Stroke Direct Injection
TTM	Technik Thermische Maschinen

Introduction and Objectives

Laboratories for IC-Engines and Exhaust Emission Control (AFHB) of the University of Applied Sciences, Biel, Switzerland are involved since 2000 in several research projects about emission factors and possibilities of reduction of (nano) particle emissions of 2-wheelers. A special attention was paid to the 2-stroke scooters, which have much higher particle emission, than the 4-strokers.

In an international network project several topics were investigated, [1–7] and the combinations of technical measures to lower the particle emissions of scooters confirmed the expected effects and showed considerable reduction potentials.

In all those previous tests there was a closed passage of the exhaust gas from the tailpipe (TP) of the vehicle to the diluting CVS installation.

Another possibility is to use an open passage with a cone around the tailpipe, like in Fig. 1. The exhaust gas from the vehicle is directly diluted in the cone. In the CVS follows the second step of dilution.

Fig. 1 Minidiluter. Passage of exhaust gas from tailpipe to CVS: closed (*left*), open (*right*)

The different passages of exhaust gas to the CVS have influences on the physical changes of the aerosol like spontaneous condensation, evaporation, agglomeration, diffusion losses and thermophoresis.

Other changes of the exhaust aerosol were introduced in the research by means of two vehicles, each one with different technology and producing different portion of SOF in the exhaust PM (see next section). Finally each of them was operated with active and with inactive (dummy) oxidation catalyst.

Investigated Scooters

The research of emissions was performed on the 2-stroke Peugeot Scooters newer technology: Peugeot Looxor TSDI (two stroke direct injection) and Peugeot Looxor Carburetor (Carb) (Fig. 2).

Both vehicles were profoundly investigated in the previous works, [5] and the differences of the emitted nanoparticles can be characterized as follows: TSDI has leaner mixture tuning and no secondary air (SAS). In the operation at full load (FL), or near to FL there are exhaust gas temperatures at tailpipe (after catalyst) in the range of 300 °C. With Carb. there is a reacher mixture tuning and there is an active SAS. As result there is a much stronger oxidation in the ox. cat. at FL-operation. The exhaust gas temperatures of this model are increasing up to the range of 750–800 °C. Due to this stronger oxidation there is less particle mass (PM) emission of the Carb. vehicle and the nanoparticles contain more solid part in the range of 10–17 %, while for TSDI the share of solids is in the range of 3–5 %, [5].

Measuring Apparatus and Test Procedures

The vehicles were tested on a chassis dynamometer with CVS dilution system. The CVS is equipped with dilution air filtration required since Euro 5 passenger cars legislation in view of the NP-count limits. The installation is equipped with

Fig. 2 Peugeot scooters: TSDI *(left)*, Carburetor *(right)*

emission measuring systems for legislated components and for nanoparticles. The nanoparticulates measurements in this research program were performed at stationary engine operation with

SMPS and with DC. DC (diffusion charging sensor) measures the total active particle surface independent of the chemical properties. It indicates the solids and the condensates. The investigations with each variant of exhaust conditions were performed according to the same procedure at constant speed and warm operation: 20 and 40 km/h; closed/open; with/without ox. cat.

In each test variant the nanoparticles measurements were performed at 5 sampling positions (Sp) according to the Fig. 3. With the closed variant of exhaust gas extraction there is only one dilution step of the tailpipe gas (TP) in the CVS-tunnel.

The dilution air is filtered with the legally required filtration quality.

With the open variant of exhaust gas extraction there is a first step of dilution directly after TP with a unfiltered ambient air. The second step of dilution follows in the CVS. For the open variant a higher CVS-flow is used to prevent the possibility of undesired reflow of the tailpipe gas in the aspirating cone (before Sp1).

The tests "without catalyst" were performed with a dummy catalyst without catalytic coating, but with identical geometry of the exhaust system. In this way it was assured, that there are no influences on the gas dynamic effects of the engine.

Results

Peugeot TSDI

This vehicle has: leaner tuning, no SAS, TP exhaust temperatures at 40 km/h approximately 300 °C. Figure 4 shows the PSD spectra of tested variants at 20 km/h with catalyst. Generally at Sp0 (engine out) there is the highest count concentration (in the range of 2×10^9 1/cm^3) of the smallest particles (maximum of PSD by 10–20 nm). This engine-out PSD (Sp0) varies from test to test.

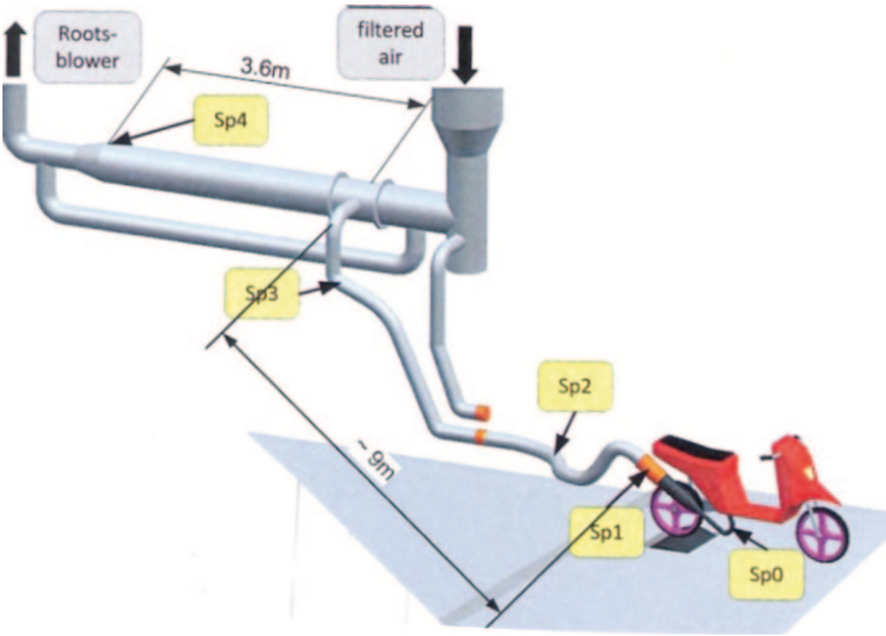


Fig. 3 Sampling positions (Sp) used in the tests

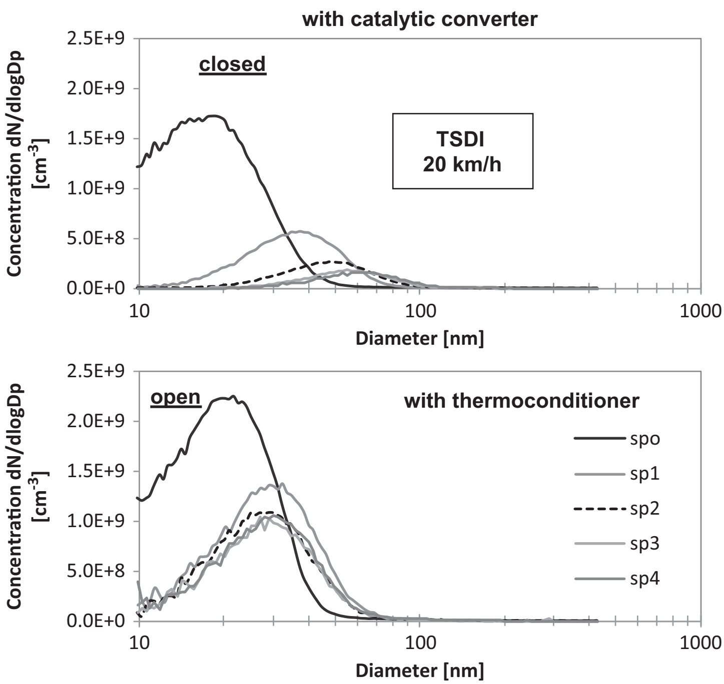


Fig. 4 SMPS—size spectra at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

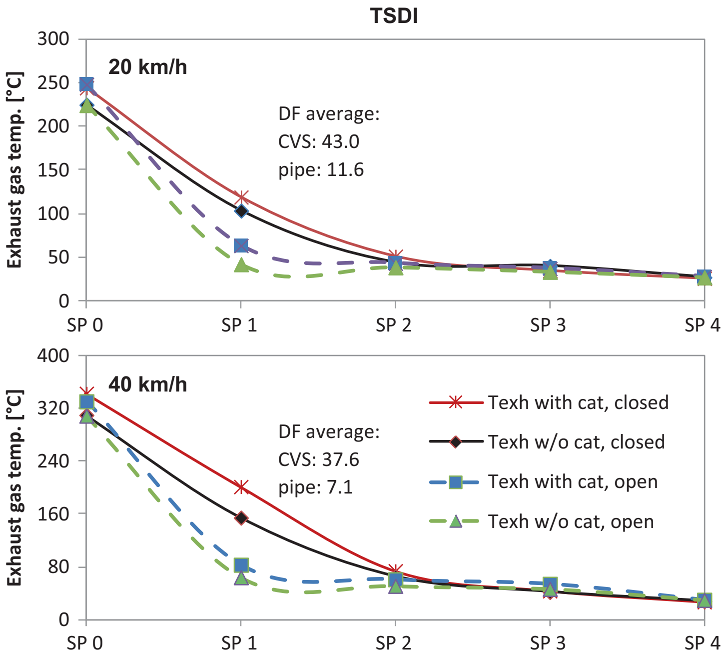


Fig. 5 Gas temperatures and dilution factors in the exhaust system at constant speeds 20 and 40 km/h, with TSDI

Regarding the single results it has to be kept in mind, that there is a certain dispersion of NP-emissions even for the same vehicle at the same operating conditions. Regarding different sampling positions with closed exhaust gas extraction the peak count concentration decreases and the CMD increases i.e. the spectra are moved to higher average NP-sizes. This is a combined effect of agglomeration and losses.

With the open gas extraction there is a substantial change of PSD between Sp0 and Sp1. Due to this 1st dilution step the PC-concentration decreases and the CMD increases—this is a similar tendency, like with closed system. Nevertheless in the further sampling positions of the open system (Sp1 to Sp3) only PC-losses and no more agglomeration are to be remarked. In the CVS-tunnel after the 2nd dilution step there are no differences between Sp. 2, 3 and 4. The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe, see temperatures and dilution factors in Fig. 5. At this operating point (20 km/h) the exhaust gas temperature in the catalyst was in the range of 200 °C and there is no influence of the catalyst on the PSD's. Figure 6 shows the integral NP-results (SMPS and DC) of tested variants at 20 km with catalyst. With the closed variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enables more intense thermophoresis—and diffusion losses. The reduction of integrated SMPS PC's between

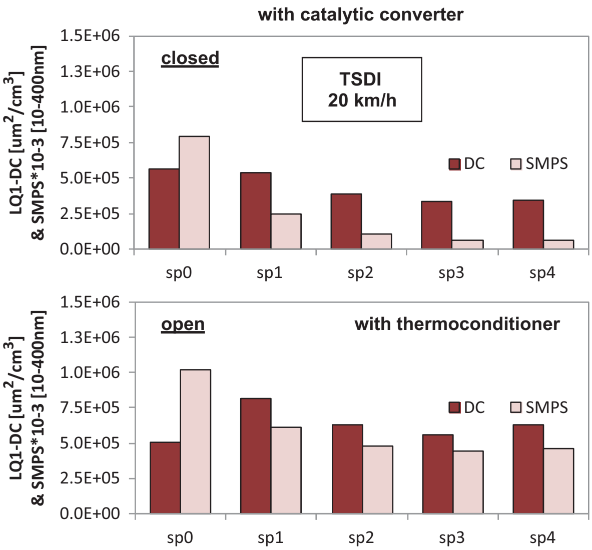


Fig. 6 DC signal and SMPS integral concentration from 10 to 400 nm at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

Sp0 and Sp1 is for the open variant much lower, than for the closed variant. In the 1st dilution step of the open variant effects of spontaneous condensation are most probable provoked by the temperature drop. With this, with the higher background PC-concentration of the dilution air and with the lower losses of the open variant is to explain the higher final NP-concentration (SMPS) at Sp4 (with "open"). The NP back-ground concentrations of ambient air are in the range of 3×10^3 #/cm^3 and the filtered dilution air has the near-to-zero NP-concentrations in the range of 4 #/cm^3. Between Sp0 and Sp1 DC-value (summary active surface of the aerosol) varies less, than the integral SMPS. This is caused by the bigger average particle sizes at Sp1 and by the fact that the aerosol surface increases with the 3rd power of the equivalent particle size.

This vehicle has: leaner tuning, no SAS, TP exhaust temperatures at 40 km/h approximately 300 °C. Figure 4 shows the PSD spectra of tested variants at 20 km/h with catalyst. Generally at Sp0 (engine out) there is the highest count concentration (in the range of 2×10^9 1/cm^3) of the smallest particles (maximum of PSD by 10–20 nm). This engine-out PSD (Sp0) varies from test to test.

Regarding the single results it has to be kept in mind, that there is a certain dispersion of NP-emissions even for the same vehicle at the same operating conditions.

Regarding different sampling positions with closed exhaust gas extraction the peak count concentration decreases and the CMD increases i.e. the spectra are moved to higher average NP-sizes. This is a combined effect of agglomeration and loses.

With the open gas extraction there is a substantial change of PSD between Sp0 and Sp1. Due to this 1st dilution step the PC-concentration decreases and the CMD increases—this is a similar tendency, like with closed system. Nevertheless in the further sampling positions of the open system (Sp1 to Sp3) only PC-losses and no more agglomeration are to be remarked. In the CVS-tunnel after the 2nd dilution step there are no differences between Sp. 2, 3 and 4.

The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe, see temperatures and dilution factors in Fig. 5.

At this operating point (20 km/h) the exhaust gas temperature in the catalyst was in the range of 200 °C and there is no influence of the catalyst on the PSD's.

Figure 6 shows the integral NP-results (SMPS and DC) of tested variants at 20 km with catalyst. With the closed variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enables more intense thermophoresis—and diffusion losses.

The reduction of integrated SMPS PC's between Sp0 and Sp1 is for the open variant much lower, than for the closed variant. In the 1st dilution step of the open variant effects of spontaneous condensation are most probable provoked by the temperature drop. With this, with the higher background PC-concentration of the dilution air and with the lower losses of the open variant is to explain the higher final NP-concentration (SMPS) at Sp4 (with "open").

The NP back-ground concentrations of ambient air are in the range of 3×10^3 #/cm^3 and the filtered dilution air has the near-to-zero NP-concentrations in the range of 4 #/cm^3.

Between Sp0 and Sp1 DC-value (summary active surface of the aerosol) varies less, than the integral SMPS. This is caused by the bigger average particle sizes at Sp1 and by the fact that the aerosol surface increases with the 3rd power of the equivalent particle size.

With the variant "open" the DC-level at Sp1 is even higher than at Sp0, because the lower counts at Sp1 have less influence on the summary aerosol surface, than the bigger particle sizes.

Figure 7 shows the PSD spectra of tested variants at 40 km/h with catalyst.

Due to the higher exhaust temperature in the catalyst in the range of 300 °C there are visible effects of the oxidation: with closed system an intense reduction of PC-concentration between Sp0 and Sp1 and slight agglomeration effects at Sp1 to Sp4, with open system also an intense oxidation, but superposition of the effects of nanoparticles from the dilution air and of the spontaneous condensates due to the temperature drop before Sp1; as a result there is a high number concentration in the nuclei mode (size range ≤ 20 nm) in the sampling positions Sp1–Sp4.

Figure 8 shows a direct comparison of NP-values (SMPS and DC) with both sampling variants: closed and open at 40 km/h. With the variant "open" there are always higher PC-concentrations. This is principally due to the lower NP-losses with the variant "open". The unfiltered dilution after TP has only a minor contribution (according to calculation less than 0.1 %) to the higher final NP-counts.

The oxidative activity of catalyst is demonstrated by much lower values of DC-signals and by the fact, that with catalysts there are almost no differences of DC between "closed" and "open". This means, that with catalyst there are no precursor

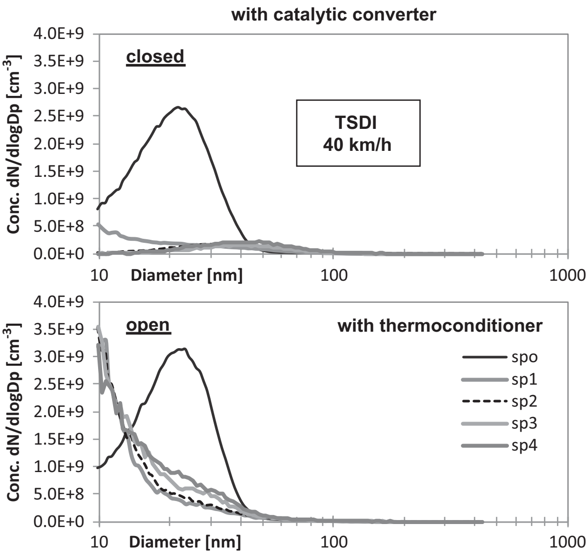


Fig. 7 SMPS—size spectra at constant speed 40 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

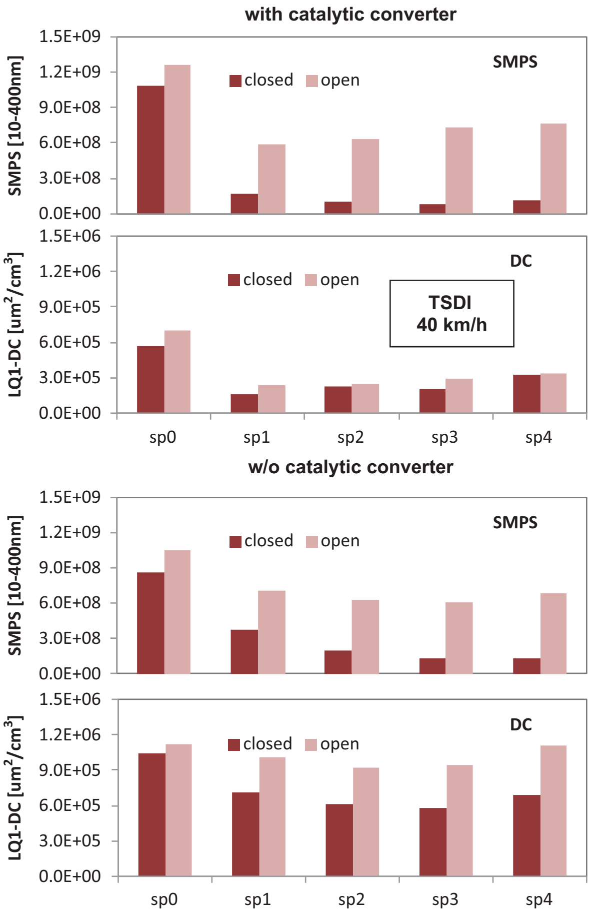


Fig. 8 Comparison of the DC signal and SMPS integral concentration at constant speed 40 km/h with open and closed exhaust sampling

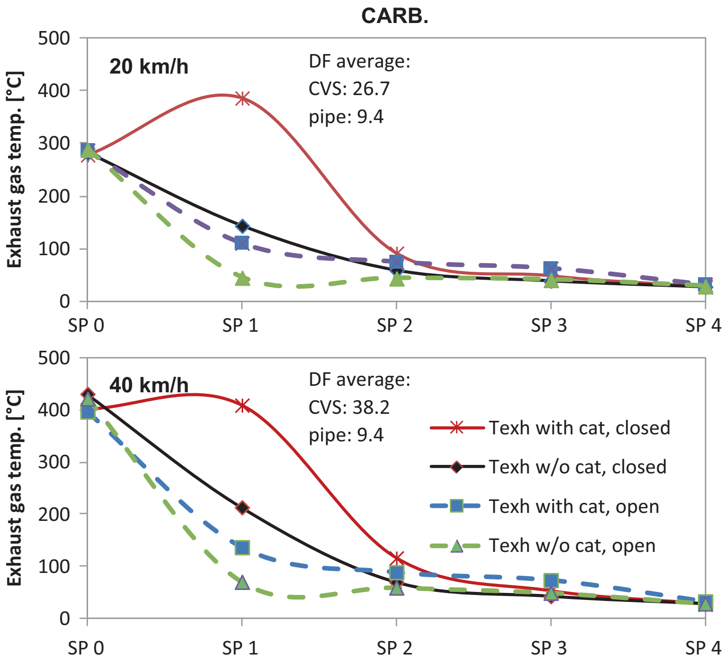


Fig. 9 Gas temperatures and dilution factors in the exhaust system at constant speeds 20 and 40 km/h, with Carburetor

substances for condensation (they are oxidized) and the resulting size distributions of both variants are almost the same.

Peugeot Carburetor

This vehicle has: richer tuning, active SAS, TP exhaust temperatures at Sp1 are approximately 400 °C.

Figure 9 shows the exhaust gas temperatures at all sampling positions and at both speeds 20 and 40 km/h. The intense exothermic heating between Sp0 and Sp1 is visible for "closed" gas extraction (for version "open" the thermocouple is placed downstream of the cone, after the 1st dilution step).

The results with catalyst at 20 km/h are represented in Fig. 10—SMPS PSD's and in Fig. 11—integral NP-values SMPS and DC.

With catalyst there are intense effects of oxidation between Sp0 and Sp1– nearly disappearing of the NP. The temperature in the catalyst is in the range of 400 °C.

The results of SMPS PSD's at 40 km/h (not represented graphically) show, that due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350 °C). With catalyst the temperature is in the range of 400 °C and the oxidation is so intense, that the particles are nearly eliminated.

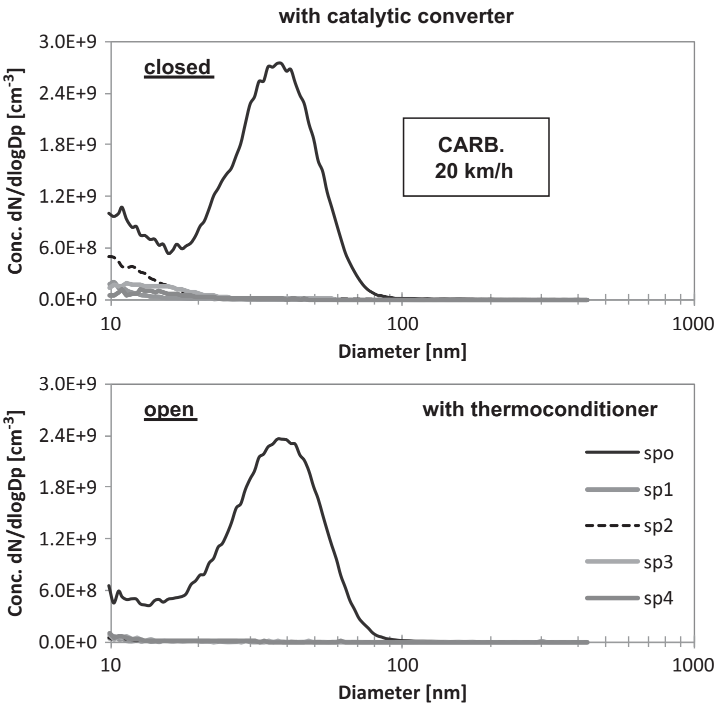


Fig. 10 SMPS—size spectra at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

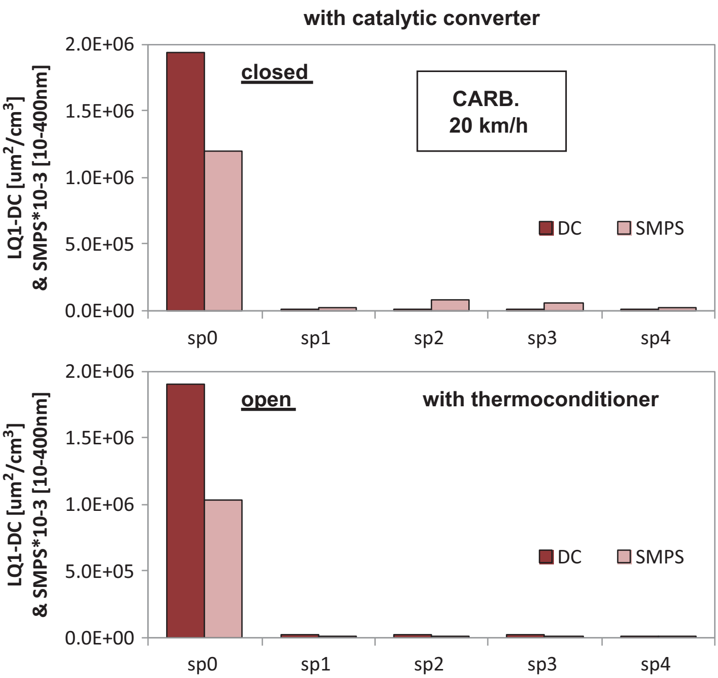
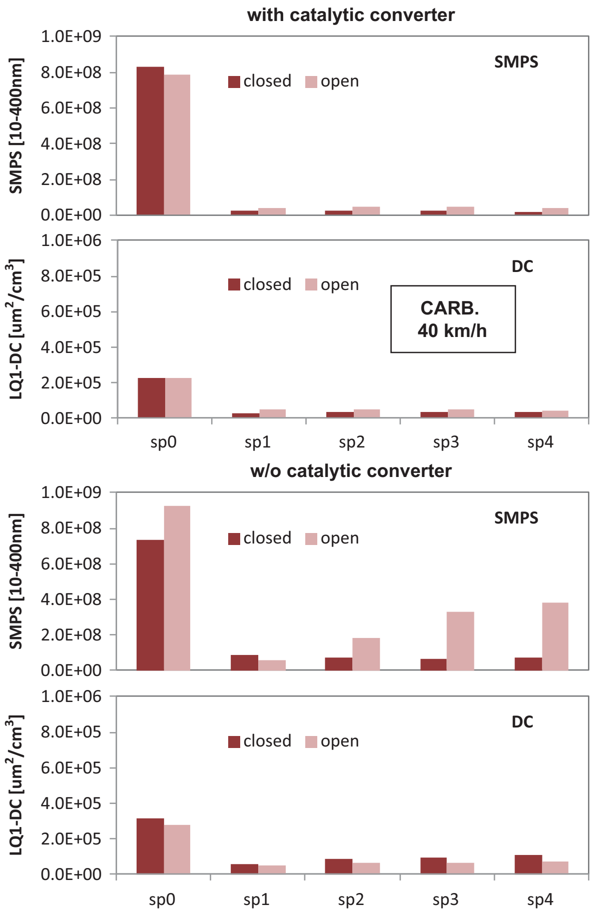


Fig. 11 DC signal and SMPS integral concentration from 10 to 400 nm at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

Fig. 12 Comparison of the DC signal & SMPS integral concentration at constant speed 40 km/h with open and closed exhaust sampling



There is a good repeatability of the results at Sp1 to Sp4.

Figure 12 shows the comparisons of SMPS integral concentrations and DC-values at all sampling positions and at 40 km/h.

The strong oxidation between Sp0 and Sp1 is visible already without catalyst.

The NP count concentrations with the variant "open" are higher. As main reason the lower losses, due to a higher dilution and lower temperature are regarded. The higher background concentration of the unfiltered dilution air has been found to be a negligible factor. The higher NP-concentrations with variant "open" are particularly visible with no catalytic oxidation (without catalytic converter). In this case the particle numbers along the gas way are growing, due to the spontaneous condensation in nuclei mode, while the summary active surface (DC) stays unchanged, or slightly diminishes.

Conclusions

It can be concluded that:

1. The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe.
2. The effects influencing the aerosol at different sampling positions are: agglomeration, condensation, diffusion loses and thermophoresis.
3. In the "open" variant of exhaust gas extraction there is a dilution step with unfiltered ambient air directly after tailpipe. This causes a stop of agglomeration, reduction of diffusion loses and increased back-ground NP-concentration. There is also lower postoxidation of CO and HC. In some cases spontaneous condensates due to the temperature drop are supposed.
4. With the "closed" variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enable more intense thermophoresis—and diffusion losses.
5. The NP-concentrations measured with "open" variant are always higher.
6. The oxidation catalyst principally lowers the NP count concentrations and moves the PSD-maximum to the lowest sizes. The intensity of oxidation depends on the exhaust gas temperature.
7. Most intense oxidation is observed with Peugeot Carb: due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350 °C). With catalyst the temperature is in the range of 400 °C and the oxidation is so intense, that the particles are nearly eliminated.

References

1. Czerwinski J, Comte P, Napoli S, Wili Ph Summer cold start and nanoparticulates of small scooters. Report B086 for BUWAL (SAEFL) Bern, Lab. For exhaust gas control, University of Appl. Sciences, Biel-Bienne, Switzerland, Nov. 2000. SAE Techn. Paper 2002-01-1096
2. Czerwinski J, Comte P Limited emissions and nanoparticles of a scooter with 2-stroke direct injection (TSDI). SAE Technical Paper 2003-01-2314
3. Czerwinski J, Comte P, Reutimann F Nanoparticle emissions of a DI 2-stroke scooter with varying oil- and fuel quality. SAE Technical Paper 2005-01-1101
4. Czerwinski J, Comte P, Larsen B, Martini G, Mayer A Research on particle emissions of modern 2-S scooters. SAE Technical Paper 2006-01-1078

5. Czerwinski J, Comte P, Astorga C, Rey M, Mayer A, Reutimann F (Nano) Particle from 2-S scooters: SOF/INSOF; improvements of afterreatment; toxicity. AFHB, JRC, TTM, BAFU, SAE Technical Paper 2007-01-1089
6. Czerwinski J, Comte P, Violetti N, Landri P, Mayer A, Reutimann F Catalyst aging and effects on particle emissions of 2-stroke scooters. SAE Technical Paper 2008-01-0455
7. Czerwinski J, Comte P, Mayer A, Reutimann F, Zürcher D Reduction potentials of particle emissions of 2-S scooters with combinations of technical measures. FISITA, Munich, Germany, Sept. 14-19.2008, Paper F2008-09-014, Congress Proceedings Vol. IV, p. 100, ATZ/ATZauto technology, Springer Automotive Media, Wiesbaden, Germany

The Fidas®—A New Continuous Ambient Air Quality Monitoring System that Additionally Reports Particle Size and Number Concentration

Juergen Spielvogel and Maximilian Weiss

Abstract Today's regulation demands that fine dust is continuously monitored and that the mass fractions PM_{10} and $PM_{2.5}$ comply with limit values [1]. These PM-fractions are defined by particle size since the original goal was to mirror the deposition in the human respiratory tract. PM_{10}would thereby correspond to the inhalable fraction whereas $PM_{2.5}$ would correspond to the respiratory fraction.

While the mass concentration can be routinely monitored it however carries little extra information when it comes to possible health effects [4, 8]. Studies suggest that especially small particles that penetrate deeper into the body [7] can lead to high plaque deposits in arteries causing vascular inflammation and atherosclerosis. Also where fine dust comes from—e.g. traffic, industry and heating plants [3]—is as important as its spread—e.g. from congested areas into the surroundings or as last year, when the eruption of the Icelandic volcano Eyjafjallajökull led to a closure of the European airspace [5].

Strictly speaking, the fine dust value measured at one location actually consists of the most various environmental conditions. Therefore, exact and time-resolved measurements of fine dust and meteorological parameters are of high importance, especially in terms of modeling.

In this paper, the Fidas® fine dust monitoring system is presented.

The Fidas® is a continuous ambient air quality monitoring system that reports all PM-fractions but in addition also particle size and number concentration. Due to its high time resolution of two minutes this system also allows monitoring dynamic events or provides useful real-time information for source apportionment.

Measurements will be presented, in which the additional size and number information helped evaluate health risk.

Definition of Fine Dust

Fine dust forms part of suspended particulate matter and is composed of natural particles (e.g. salt particles from the sea, dessert dust, flower dust, pollen, bacteria) and anthropogenic particles (e.g. car emissions, tire debris, mechanical and chemical

J. Spielvogel (✉) · M. Weiss
Palas® GmbH, Karlsruhe, Germany
e-mail: spielvogel@palas.de

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_20,

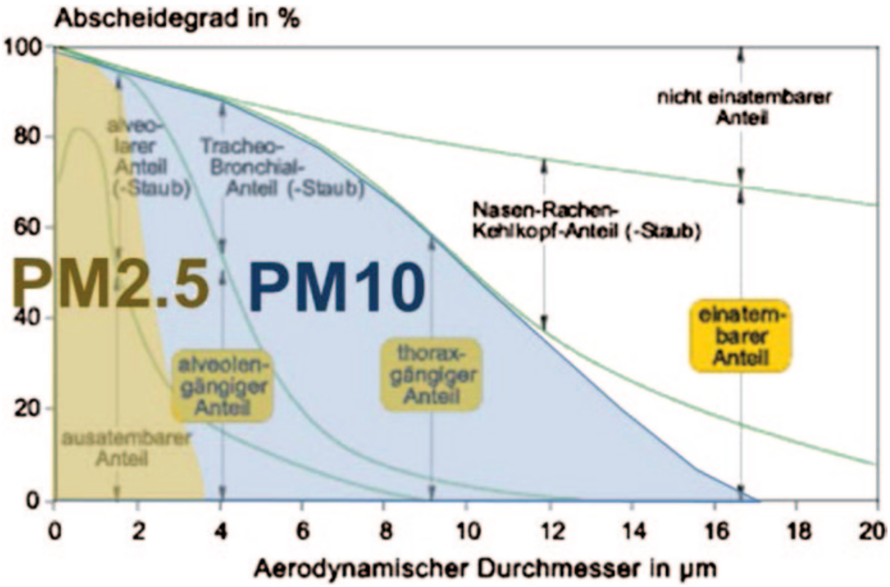


Fig. 1 Various definitions of the separation curve in relation to the particle size

processes in the industry). In 1987, the United States Environmental Protection Agency (EPA) introduced a *National Air Quality-Standard for Particulate Matter*, in which particulate matter was classified according to the inhalable emission fraction. One of the criteria used was the particle size. In the meanwhile, other categories such as $PM_{2.5}$, which describes the inhalable (alveolar) emission fraction, have been added to the original PM_{10} category.

The PM-value describes the aerodynamic diameter of particles, by which the separation function reaches a weighting of 50 %. This means that the categorization is not a clear-cut distinction but an attempt to reproduce the separation behavior of the human respiratory tract (see Fig. 1).

Fine Dust Measurement Devices for Emission Measurements

Even when the PM-standards [2] categorize fine dust according to the particle size, the quantification is carried out according to the particle mass. That is why reference procedures are based on a weighing of particles that—by means of a regulated volume flow and a selective sampling head—are gathered onto a filter.

Although this is a robust measurement procedure, the temporal resolution is very low (normally 24 hour day-averages) and it may come to varying measurement values because of the treatment and storage of the filter.

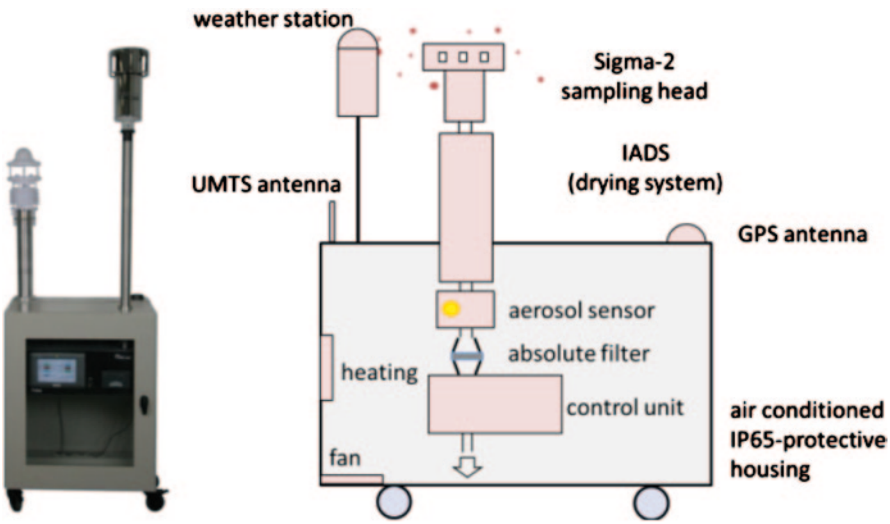


Fig. 2 Set up of the Fidas® fine dust monitoring system

Additionally, there are continuous measurement procedures with a high temporal resolution:

- mass determination with oscillating microbalance (e.g. TEOM FDMS)
- mass determination with selective sampling head and beta-absorption (e.g. BAM 1020)
- mass determination with optical aerosol spectrometer (e.g. Fidas®)

Set up of the Fidas® Fine Dust Monitoring System

The Fidas® fine dust monitoring and emission system allows the continuous and simultaneous monitoring of PM_1, $PM_{2.5}$, PM_4, PM_{10}, TSP (PM_{tot}) and the particle number concentration, optionally also the particle size distribution (see Fig. 2).

The system consists of a Sigma-2 sampling head [6], which allows also representative measurements in case of strong winds and an Intelligent Aerosol Drying System (IADS), which evaporates volatile elements and prevents erroneous classification of particles due to moisture.

The aerosol sensor is an optical aerosol spectrometer, which determines the particle size by means of a scattered light analysis according to Lorenz-Mie. The particles move separately through an optically differentiated measurement volume, which is homogeneously illuminated with white light. Each particle generates a scattered light impulse, detected at an angle of 85–95 degrees.

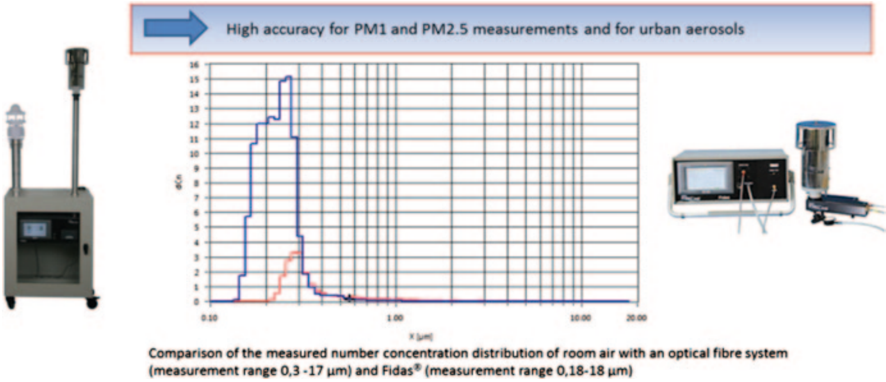


Fig. 3 Higher sensitivity with the Fidas® fine dust monitor for particle size 0.18–18 µm

The particle mass—the frequency of occurrence—that is the number concentration, is deducted from the number of scattered light impulses. The intensity of the scattered light is a measure for the particle diameter.

The lower detection limit was reduced to 180 nm by using optimized optics, higher light density and improved signal analysis (logarithmic analog digital converter). In this way, smaller particles, which are generated in high amounts during combustion processes, can be reproduced much better (see Fig. 3).

The better the classification precision and the resolution capacity of a particle measurement device, the more accurate the particle size distribution can be defined.

In order to be able to convert the measured particle number concentration and particle sizes into a mass concentration, classification accuracy and high resolution are indispensable. The mass is calculated with the data obtained from the particle size distribution and is initially based on spherical particles. Then, the number concentration is weighted separately according to the size of the particle (see Fig. 4).

Downstream to the optical sensor, there is a filter holder for an optional gravimetric validation of the measured data. The control unit offers intuitive handling by means of a big color touch screen. The integrated data logger allows the measured data to be saved and managed. An UMTS antenna enables remote maintenance and data transmission via the internet.

An optional meteorological station records wind direction and speed as well as the amount and kind of rainfall. For the exact location determination by mobile use, a GPS antenna can be integrated.

Example of a Technical Challenge

During a measurement campaign in Vienna, the comparison of Fidas® measurement values with TEOM FDMS values showed a significant decrease in the PM_{10} and $PM_{2.5}$ values of the Fidas®. For several days, the measurement values remained below those of the TEOM FDMS (see Fig. 5).

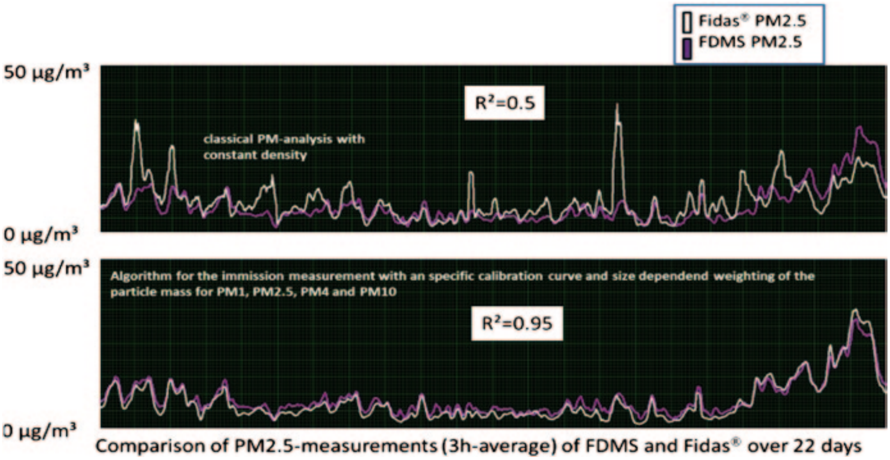


Fig. 4 Comparison of algorithms for the conversion of particle size distribution according to mass

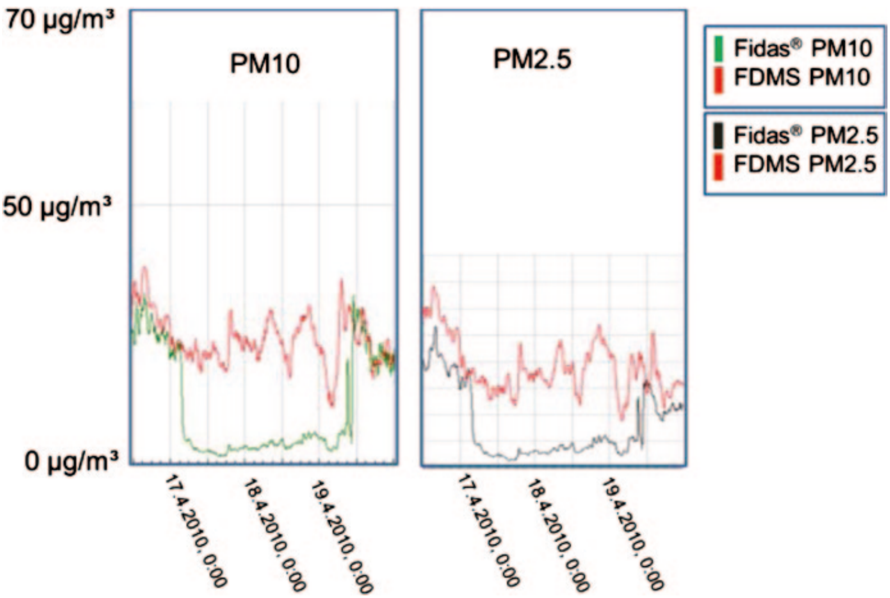


Fig. 5 Example of a technical challenge

Investigation revealed a contamination of the drying system by cobwebs. To avoid this in the future, an insect screen has been attached onto the sampling head and all edges at the transitions of different components have been eliminated. Additionally, an automatic cleaning procedure has been implemented, during which the drying system is temporarily heated up to 70° C daily at midnight.

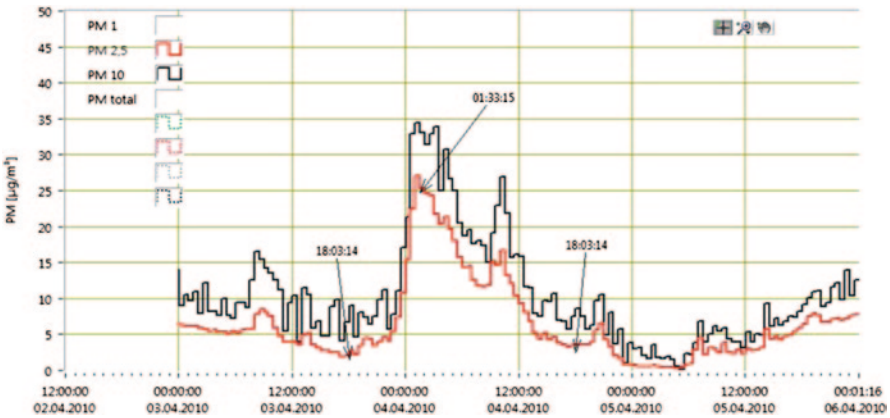


Fig. 6 Higher PM-concentration measured in Vienna during the night to Easter Sunday

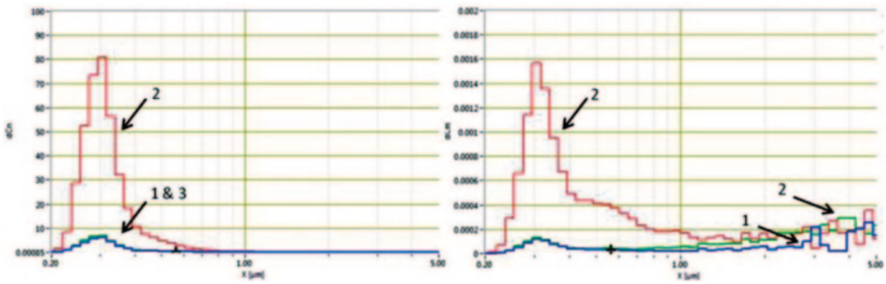


Fig. 7 *Left*, number concentration; *right*, mass concentration of the combustion aerosols generated by the Easter Fires. (*1*) 3.4.2010, 18.30 h; (*2*) 4.4.2010—1.33 h; (*3*)—4.4.2010, 18.03 h

Results of the Reliable Determination of PM-values

Eastern in Vienna

Every year during the night to Easter Sunday, in many cities in Germany and Austria, a clearly higher particulate load can be measured (see Fig. 6). This is caused by the Easter Fires, an old custom to chase away, to burn winter.

The generated combustion aerosols contain a high number of small particles (see Fig. 7 on the left, max. at ca. 300 nm). In order to be able to simulate the spreading behavior of fine dust, a high time resolution (a resolution of one second is technically feasible with the Fidas® system) as well as the particle size distribution is extremely important, because the physical characteristics of the particle are significant to be able to predict the spreading behavior. From the diameter, we can deduce e.g. the sink rate and from the number concentration, we can deduce the coagulation behavior.

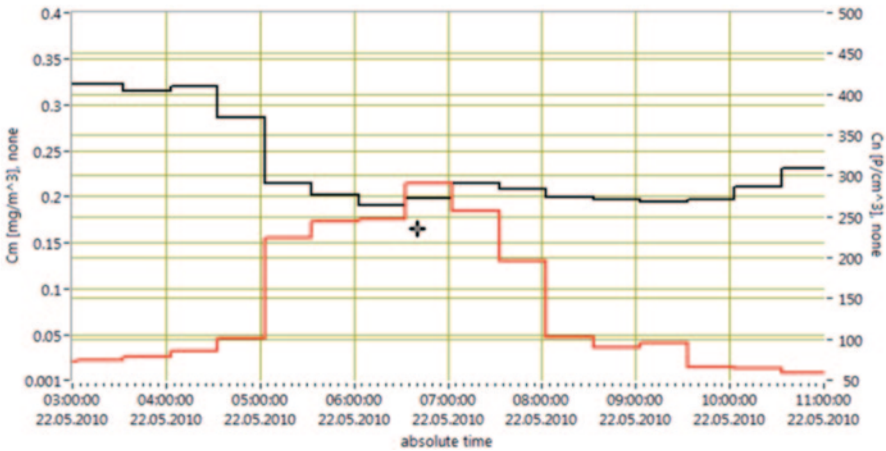


Fig. 8 The development of particle mass concentration and particle number concentration during fog measured in Lübeck

Fog in Lübeck

To enable a detailed record of fog formation, the moisture compensation of the monitoring system located in Lübeck was put off. In the morning of 22.05.2010, for three hours an increase in the mass concentration could be observed (see Fig. 8). Interestingly enough, there was no increase in number concentration, even a decrease could be observed. A possible explanation for this phenomenon was that the higher number of big droplets of fog offered the particles enough surface for them to coagulate and be eliminated effectively.

Having a more precise look at the particle size distribution, it could be seen that in the size range of ca. 3 to 15 µm, there had been detected one order of magnitude more particles than usually. At the same time, the meteorological sensors showed a high relative humidity and a low air temperature. A look at the weather in the internet confirmed the presence of fog during the measurement.

Figure 9 shows that during the fog formation, within one hour the size distribution changes dramatically and then, however, stays constant. The fading of the fog, on the contrary, takes much more time, as can be seen in Fig. 10. Here as well, a high time resolution as well as the particle size information is of extreme importance for the exact simulation of the fog formation process.

Conclusions

In this paper, the Fidas® fine dust monitoring system for reliable and time-resolved emission measurements has been presented. In contrast to other methods, the optical light scattering measurement technology allows the continuous measurement of

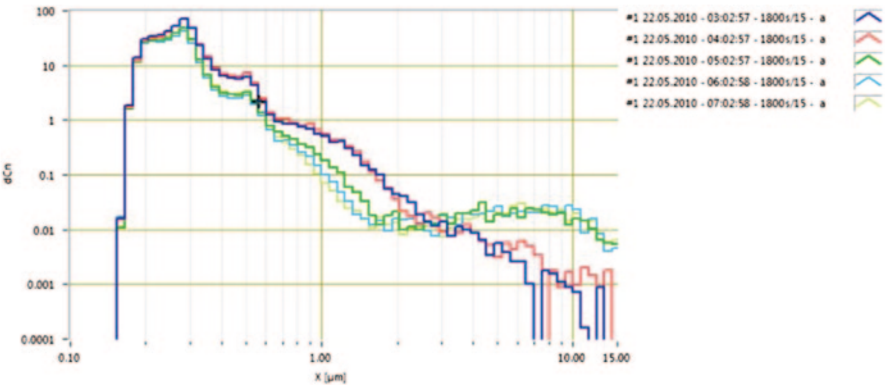


Fig. 9 The particle size distribution measured every hour during the fog formation process

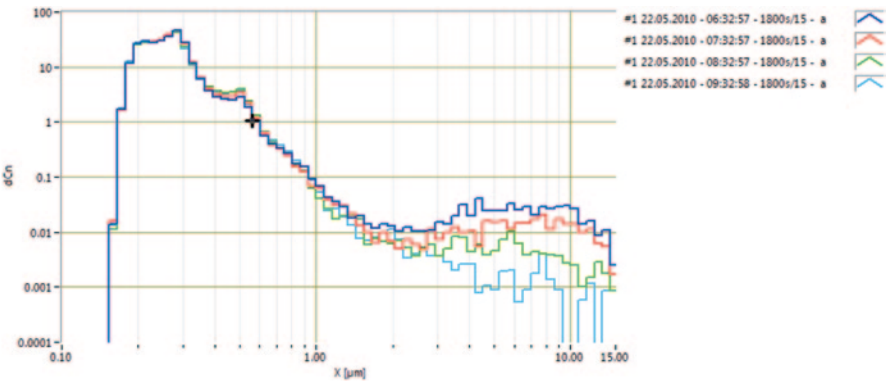


Fig. 10 The particle size distribution measured every hour during the fading of the fog

particle number and particle size as well as the simultaneous output of various PM values, such as PM_{10} and $PM_{2.5}$.

The examples of the small particles generated by a combustion processes (Easter Fires in Vienna) and the big droplets (fog in Lübeck) have shown how—by means of the additional information on the particle size distribution—the respective underlying formation and dispersion processes can be understood and definitely also be simulated better.

The Fidas® is presently undergoing aptitude and equivalency testing at the TÜV Rheinland for PM_{10} and $PM_{2.5}$ according to DIN EN 12341, DIN EN 14907, as well as the equivalency guideline. Concurrently, it will be certified to DIN EN 15267-1 & -2.

References

1. Council Directive (1999) 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air
2. Deutsches Institut für Normung (DIN) (1993) Workplace atmospheres; size fraction definitions for measurement of airborne particles; German version EN 481:1993, EPA: National Ambient Air Quality Standard, Particulate Matter (NAAQS-PM)
3. German Governemental Agency for Environment (2006) Side effects of coziness: particulates from fireplaces and wood stoves, background paper of the German Governemental Agency for Environment, March 2006
4. Heinrich J, Grote V, Peters A and Wichmann HE (2002) Health effects of fine dust: epiddemiology of long-term effects. In: Umweltmedizin in Forschung und Praxis. 7, Nr. 2, 2002, ISSN 1430-8681, p. 91–99
5. Stern.de (2010) Aschewolke bremst Europa aus. http://www.stern.de/reise/service/vulkanausbruch-aschewolke-bremst-europa-aus-1559360.html. Publised 2010-04-17
6. Verein Deutsche Ingenieure (VDI) (1997) Sigma-2 Sampling head according to VDI standard 2119-4
7. Witschger O and Fabries JF (2005a) Particules ultrafines et santé au travail: 1- caractéristiques et effets potentiels sur la santé. Hygiène et sécurité du travail. Cahiers de notes documentaires, INRS, 199:21–35
8. Working group the effect of fine dust on human health of the Commission on Air Pollution Prevention of VDI and DIN (2003) Assessment of current scientific and technical knowledge on health effects of particulate matter in ambient air. In: Umweltmedizin in Forschung und Praxis. 8, Nr. 5, 2003, ISSN 1430-8681, p. 257–278

Vehicular Emission Factor of Gases and Particulate Matter Measured in Two Road Tunnels in São Paulo, Brazil

P. J. Pérez-Martínez, A. Fornaro, T. Nogueira, M. F. Andrade, R. M. Miranda, R. Inoue and M. L. Guardani

Abstract In this paper we show measurements of air pollutants for a mixed vehicle fleet, heavy and light duty vehicles (HDV, LDV), in the Rodoanel and Janio Quadros tunnels in the Metropolitan Region of Sao Paulo (MRSP) in May-July 2011. Measurements of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and Particle Matter (PM_{10}) were performed by the air quality monitoring net from CETESB (Environmental Agency of Sao Paulo State). High concentrations correlated with high density traffic (approximately 3,000 ± 1,000 vehicles per hour), especially during weekdays, and have a characteristic diurnal pattern with two peaks: at morning (06:00–9:00 h) and at afternoon (16:00–19:00 h).

The emission factors (EFs) of pollutant species were heavily influenced by the pollutant species loads, so the total vehicle traffic and the fraction of HDV. The EF values for HDV were 3.5 ± 1.5 g/km, 1,427 ± 1,178 g/km, 9.2 ± 2.7 g/km, 0.290 ± 0.248 g/km, for CO, CO_2, NO_x and PM_{10} respectively, and for a temperature inside the tunnel of 20–25 °C. These values could be directly applicable to outside tunnel conditions because they are derived from pollutant species mass concentrations that are roughly a factor of only 2.5–3.5 higher than São Paulo typical urban concentrations. EF values of 5.8 ± 3.8 g/km, 219 ± 165 g/km, 0.3 ± 0.2 g/km, 0.178 ± 0.143 g/km, for CO, CO_2, NO_x and PM_{10} respectively, were obtained for LDV, assuming constant ratios between concentration increments of pollutant species x and trace CO and considering than the $EF(CO)_{LDV}$ were 1.5 times higher than the $EF(CO)_{HDV}$. In the methodology used to determine inside tunnel EF estimates,

P. J. Pérez-Martínez (✉) · A. Fornaro · T. Nogueira · M. F. Andrade · R. Inoue
Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG),
Universidad de São Paulo, Rua do Matão, 1226, São Paulo 05508-090, Brazil
e-mail: pjperez@caminos.upm.es

P. J. Pérez-Martínez
Sustainable Economy of Natural Environment Group (ECSEN), Universidad Politécnica de Madrid, C/Ramiro de Maeztu s/n, 28040 Madrid, Spain

R. M. Miranda
School of Arts, Science and Humanities, Universidad de São Paulo, Av. Arlindo Bettio, 1000, São Paulo 03828-000, Brazil

M. L. Guardani
São Paulo State Environmental Regulation Agency, São Paulo, Brazil

S. Rauch et al. (eds.), *Urban Environment,* DOI 10.1007/978-94-007-7756-9_21,

parameters such as velocity of the air, cross section area and length of the tunnel and vehicles passing at one hour time interval were considered, and sensitivity analyses was done.

Introduction

The vehicle traffic is the major source of air pollution in megacities. It is the source of regulated pollutants majority of carbon monoxide (CO), nitrogen oxides (NO_x) and hydrocarbons (HC), and contributes to the formation of particulate matter (PM) as well as being most source of CO_2. 97 % of all HC emissions and 40 % of all inhalable particulate matter (PM_{10}) emissions come from mobile sources [2]. Measurements of air pollutants in road tunnels can be used to quantify on-road traffic emissions. Tunnel studies can provide information on in-use vehicles to describe actual traffic emissions [15]. Although it is possible to estimate Emission Factors (EFs) under real urban conditions inside tunnels, the accuracy of the calculations depends on the dispersion of the pollutants [1]. Tunnel studies assume that the contribution of sources other than the vehicle is negligible [10, 11]. Another important consideration is that the rate of occurrence of photochemical processes is small since there is no action of radiation. Road traffic emission factors are one of the main sources of uncertainties in emission inventories; it is necessary to reduce these uncertainties to manage air quality more efficiently [14].

Emissions from road vehicles are important to evaluate the contribution of road traffic to environmental pollution [4]. EF describes the emitted mass (g) of a compound per distance (km) or volume of fuel consumed and expresses the individual contribution of each pollutant [3]. The present study shows the results of PM_{10}, CO, CO_2 and NO_x emission factors estimated in two road tunnels in the metropolitan area of São Paulo (MASP), Brazil.

Tunnel Experiments

Location, Traffic Volume and Sampling Analysis

Field measurements were performed in two experimental campaigns in the Janio Quadros Tunnel (TJQ), from 2 to 13 May 2011, and in the Rodoanel tunnel (TRA), from 4 to 19 July 2011. TJQ is located in the southwest area of São Paulo. It is a two-lane tunnel 850 m length with and the speed limit is 70 km h^{-1}. Inside tunnel, emissions are coming from gasohol and ethanol powered vehicles. TRA tunnel is located in the northeast area of São Paulo. It is a two-lane tunnel 1,150 m length. LDV and HDV vehicles burning gasohol, ethanol and diesel use TRA. Pollutant air concentrations were measured at the midpoint inside the tunnels (Fig. 1) and back-

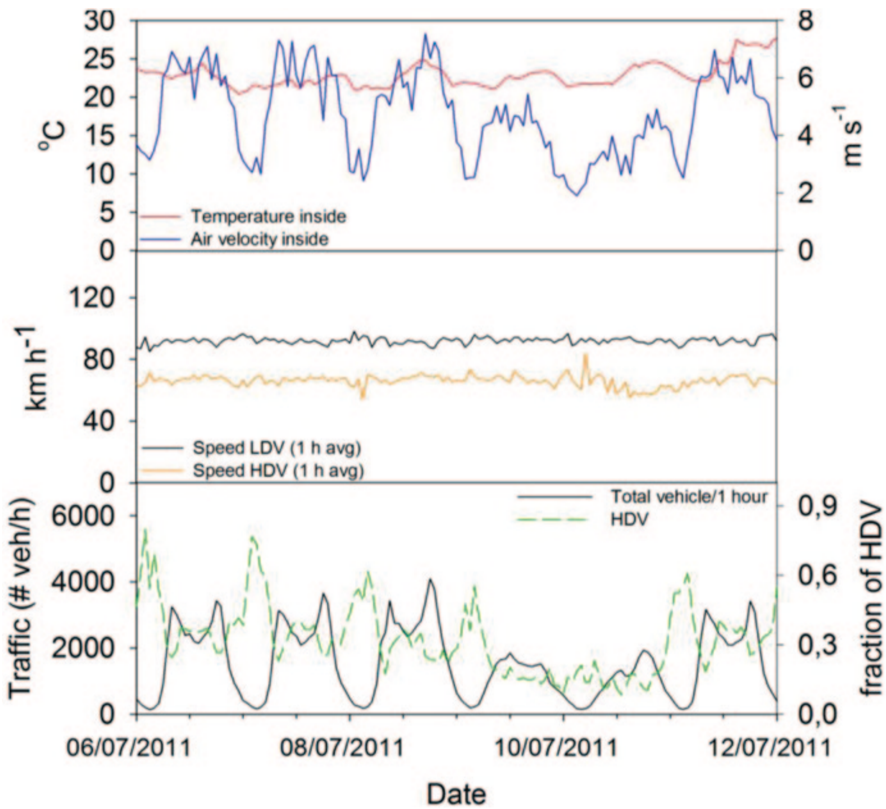


Fig. 1 Temperature, air speed, vehicle speed, traffic density and vehicle fleet composition (discrimination between LDV and HDV) during the measurements in the Rodoanel tunnel (TRA)

ground air concentrations were measured outside the tunnels. The sites outside the tunnels were located far from the tunnels in order to avoid their influence. Table 1 shows the assets of the two tunnels.

Cameras were installed in TJQ to obtain the traffic volume. In TRA an automatic system provided information of vehicle counts, type and average speed every 15 min. In TJQ vehicles were classified as motorcycles, light passenger vehicles, light-duty trucks/vans, and taxis whereas those using the TRA tunnel were classified as LDVs and HDVs.

Inside the tunnels and outside, air measurements were taken simultaneously to determine the concentrations of the species: Particulate Matter (PM_{10}), nitrogen oxide species (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2). The monitoring was performed continuously by the CETESB [2]. The pollutants measured and methods are summarized in Table 2.

Table 1 Estimation conditions for tunnels (one way, 2 lanes per direction)

	TRA (Normal/cong.)	TJQ (Normal/cong.)
Length, l (m)	1.150	850
Cross-sectional area, s (m^2)	100.5	80.6
Perimeter, P (m)	50.3	45.1
Natural flow velocity, u_0 ($m\ s^{-1}$)	4.9/1.0	6.1/1.0
Inlet ventilation rate, a_i (min^{-1})	0.3/0.2	0.3/0.2
Outlet ventilation rate, a_o (min^{-1})	0.3/0.2	0.3/0.2
Concentration in inlet air, C_i (µg CO m^{-3})	2.5/5.0	2.6/5.2
Concentration in outlet air, C_o (µg CO m^{-3})	3.9/7.6	3.7/7.4
Traffic volume, V (#vehicles h^{-1})	3.000/1.600	2.000/1.500
Vehicle speed, v (km h^{-1})	83/12	72/10
Percentage HDV, f_D (no units)	0.3/0.0	0.0/0.0
Vehicle emission factor (g NO_x kg^{-1})	12/48	8/32

Table 2 CO_2 and pollutants measured in the TJQ and TRA and methods

Pollutant	PM_{10}	NO_x	CO	CO_2
Method	Beta radiation	Chemi-luminescence	Non dispersive infrared analysis	Infrared analysis
Analyzer	5014i -Beta	Thermo electron (42i-HL)	Thermo electron (48B)	LI COR-6262 Picarro-G1301
Accuracy	±5%	±1.5%	±1–2.5%	±1%
Resolution	1 min	5 min	5 min	1 min
Units	µg m^{-3}	ppb	ppm/mg m^3	ppm

Emission Factors

To calculate the emission factors we used the following expression [11]:

$$E_p = 10^3 \left(\frac{\Delta[p]}{\Delta[CO_2] + \Delta[CO]} \right) \omega_c \tag{1}$$

where E_p is the emission factor of pollutant P (in g per kg of fuel burned), Δ[P] is the concentration of the pollutant (subtracted from the background value measured outside the tunnel, in µg m^{-3}), Δ[CO_2] and Δ[CO] are CO_2 and CO concentrations. The conversions of CO_2 and CO to mass units were done using a molecular weight of 12 g mol^{-1}, rather than 44 and 28 g mol^{-1}, and the concentrations were expressed in µg C m^{-3}. The weight fractions of fuel carbon ω_c were 0.85–0.87 g of carbon per gram of fuel, for gasohol and diesel respectively. The expression 1 can be used directly in TJQ since the tunnel has mainly LDVs. In the TRA, emissions from HDVs were obtained discounting the contribution of LDVs to the total emissions. Tunnel studies have shown that emissions from LDVs and HDVs have similar CO emission rates per kilometre [8, 9, 13]. CO_2 emissions were calculated from traffic data and fuel consumption parameters using the following equation:

$$\frac{\Delta[\mathrm{CO_2}]_\mathrm{D}}{\Delta[\mathrm{CO_2}]} = \frac{\mathrm{f_D U_D} \rho_\mathrm{D} \mathrm{w_D}}{(\mathrm{f_D U_D} \rho_\mathrm{D} \mathrm{w_D}) + ((1-\mathrm{f_D}) \cdot \mathrm{U_G} \rho_\mathrm{G} \mathrm{w_G})} \tag{2}$$

where $\Delta[CO_2]_D$ is the component of $\Delta[CO_2]$ emissions resulting from the diesel burned, f_D is the percentage of HDV, U is the average fuel consumption rate, ρ is the fuel density (740 and 840 g l^{-1} for gasohol and diesel fuel respectively), w is the fuel carbon fraction (0.85 g of C per g of fuel and 0.87 for gasohol and diesel respectively). The subscripts D and G denote diesel and gasohol. For the other pollutants, PM_{10} and NO_x, the share of HDV was expressed by:

$$\Delta[\mathrm{P}]_\mathrm{HDV} = \Delta[\mathrm{P}] - \Delta[\mathrm{CO}](1-\mathrm{f_D})\left(\frac{\Delta[\mathrm{P}]_\mathrm{LDV}}{\Delta[\mathrm{CO}]_\mathrm{LDV}}\right) \tag{3}$$

where $\Delta[P]_D$ is the component of $\Delta[P]$ in TRA related to HDV emissions and $\Delta[CO] \cdot (1-f_D)$ is the fraction of $\Delta[CO]$ emissions from LDV. The emission rates for LDV, $\Delta[P]_{LDV}/\Delta[CO]_{LDV}$, were measured in TJQ. These ratios were 0.025 and 0.054 for PM_{10} and NO_x respectively. Finally, the emission factor of pollutant P and vehicle type i (LDV and HDV), $E'_{P,i}$ (expressed in grams of pollutant per driven kilometre, g/km), was obtained using the following expression:

$$E'_{p,i} = E_{p,i} \cdot U_i \tag{4}$$

where U_i is the fuel consumption of vehicle i and $E_{P,i}$ comes from equation 1. U_i depends on the CO_2 emission factor (E_{CO2} in grams of CO_2 equivalent per driven kilometre, gCO_2/km), the density of fuel j (ρ_j, gasohol for LDV, 785 g l^{-1} of fuel, and diesel for HDV, 850 g l^{-1} of fuel) and the carbon intensity of fuel j (c_j, 2,331 g of CO_2 l^{-1} of gasohol and 2,772 g of CO_2 l^{-1} of diesel).

$$U_i = E_{CO2,i} \frac{\rho_j}{c_j} \tag{5}$$

The E_{CO2} for LDV and HDV was obtained using the following expression:

$$E_{CO2,LDV} = 10^{-6} \frac{\Delta[CO_2]_{LDV} \cdot s \cdot u_0 \cdot t}{V \cdot (1-f_D) \cdot l} \tag{6}$$

$$E_{CO2,HDV} = 10^{-6} \frac{\Delta[CO_2]_{HDV} \cdot s \cdot u_0 \cdot t}{V \cdot f_D \cdot l} \tag{7}$$

Table 3 Summary table including parameters used in equations 1–5

	$\Delta[PM10]_{LDV}$/ $\Delta[CO]_{LDV}$ (no units)	$\Delta[NOx]_{LDV}$/ $\Delta[CO]_{LDV}$ (no units)	$U_{G,D}$ (g km^{-1})	$\rho_{G,D}$ (g l^{-1})	$\omega_{G,D}$ (gC/g)	$c_{G,D}$ (gCO_2 l^{-1})
LDV (g)	0.025	0.054	75	785	0.85	2,331
HDV (d)	n.d.	n.d.	450	850	0.87	2,772

where $\Delta[CO_2]$ are the concentrations of CO_2 (μg m^{-3}), difference between the concentrations inside and outside of the tunnel, s is the cross section area of the tunnel (m^2), u_0 is the velocity of the air wind (m s^{-1}), t is the time interval corresponding to 1 h (3,600 s), V is the number of vehicles passing the tunnel at the time t, f_D is the percentage of HDV, and l is the tunnel length (km). The parameters used in the estimation of the emission factors are summarized in Table 3.

Results and Discussion

Hourly average concentrations are measured together with the number of vehicles inside and outside of the two tunnels. Figure 2 shows the variations of NO, NO_x, NO_2, CO, CO_2, VOCs, CH_4, PM_{10} and traffic for the second week of sampling in TRA. PM_{10} is correlated with vehicle traffic, especially at peak hours. NO_x emission shows higher concentrations in TRA compared to TJQ (TRA has large traffic of heavy vehicles).

NO_x concentrations were evaluated in both tunnels. The marked difference between the two tunnels indicates the significant emissions of NO_x by HDVs. On average, concentration values in TRA were about ten times greater than in TJQ. Important relationship between CO emissions and number of vehicles was found in the two tunnels. At the investigated period, morning peak was observed in TJQ due to traffic congestion. A significant reduction of CO emissions from LDVs was observed in TJQ [12]. Reductions of CO emissions can be explained by the improved combustion of gasoline and ethanol use. Ethanol has higher oxygen content resulting in lower particle and CO emissions [5].

All pollutants showed higher concentration values inside the tunnel than outside, expressed as ratios. In TJQ these ratios were: 3.3, 1.6 and 7.1 for CO, NO_x, and PM_{10} respectively. In TRA the differences between concentrations were: 3.1, 9.0, and 2.2.

Emission Factors

Emission factors were calculated for LDVs and HDVs according to the methodology proposed. The vehicles using TJQ had cleaner technology than in other parts of the city and, on the other hand, HDVs using TRA were old trucks. Thus the emission factors presented in this paper may underestimate the emission of LDVs and

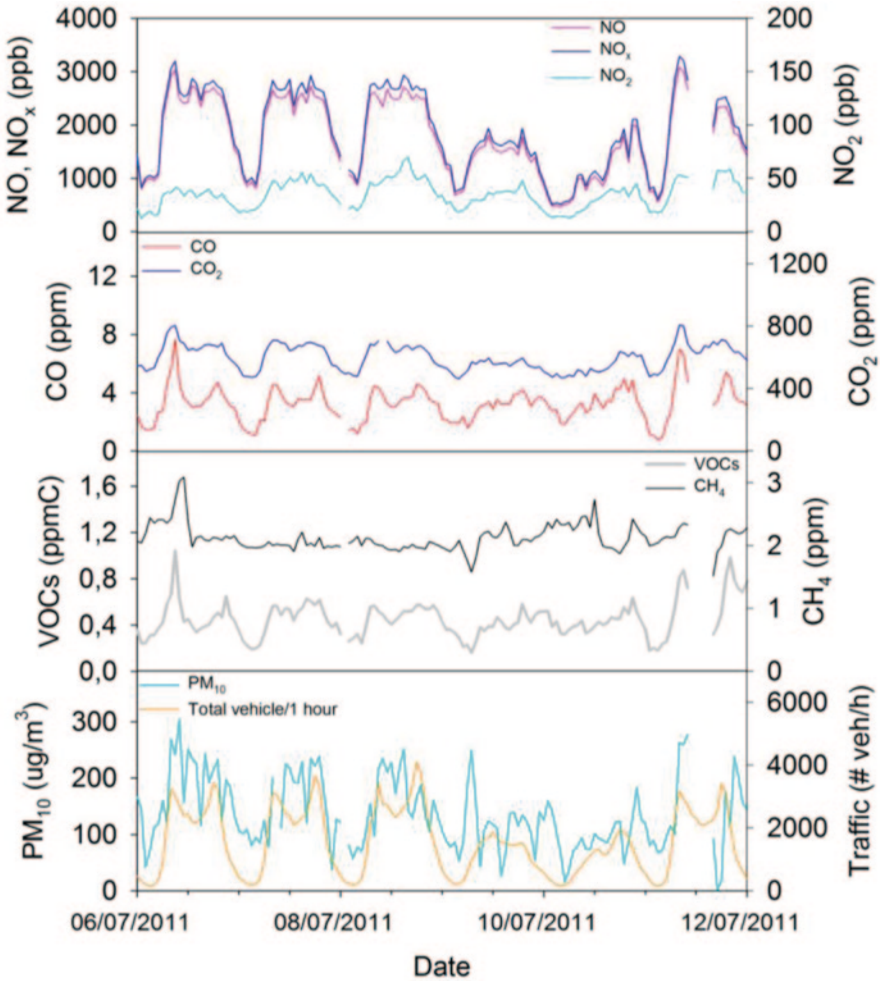


Fig. 2 Time variation of the researched gas and particulate associated compounds inside the Rodoanel tunnel (TRA)

overestimate the emission of HDV. The emission factors are presented in g km^{-1} in Table 4.

The values of EFs estimated for CO and NO_x for LDVs in the present work show significant reduction when compared the values of EFs calculated in the experiment conducted in 2004 [12]. The reduction ratio was 2.2 times for CO and 3.2 for NO_x. In recent decades, control of NO_x emissions from gasoline burning cars has been experienced by use of catalytic converters in the exhaust system of vehicles. Modern three way catalysts use platinum and rhodium surfaces, changing the nitrogen oxides back to nitrogen and oxygen elemental [6]. Similarly, for HDVs the values of EFs showed significantly reduction for CO and NO_x.

Table 4 Emission factors (g km^{-1}, g/kg of fuel burned) from 2011 in comparison with values calculated in 2004 study (mean ± standard deviation)

Veh.	Local measured	Fuel	CO	NO_x	PM_{10}	CO_2
		(km kg^{-1})	(g km^{-1})	(g km^{-1})	(g km^{-1})	(g km^{-1})
			(g kg^{-1})	(g kg^{-1})	(µg kg^{-1})	(g kg^{-1})
LDV	TJQ (2011)	13.7 ± 18.4	5.8 ± 3.8	0.3 ± 0.2	0.178 ± 0.143	219 ± 165
			78.9 ± 25.3	4.2 ± 2.6	2,441 ± 44	3,001 ± 85
HDV	TRA (2011)	2.24 ± 2.71	3.5 ± 1.5	9.2 ± 2.7	0.290 ± 0.248	1,427 ± 1,178
			7.8 ± 4.3	25.5 ± 8.1	692 ± 663	3,177 ± 90
LDV	TJQ (2004) [12]	n.d.	14.6 ± 2.3	1.6 ± 0.3	n.d.	n.d.
			n.d.	n.d.	n.d.	n.d.
HDV	TMM[1] (2004) [12]	n.d.	20.6 ± 4.7	22.3 ± 9.8	n.d.	n.d.
			n.d.	n.d.	n.d.	n.d.

Comparing the EFs of LDVs and HDVs we observed the highest contribution of light vehicles to CO emissions; this was expected since CO emissions originate from gasoline vehicles are higher than for diesel vehicles [7]. The marked difference between the two tunnels in terms of the concentration of NO_x and PM_{10}, indicates the significant emissions of such pollutants by HDVs. The emission factors for these two pollutants were shown to be higher for HDVs.

Conclusions

PM_{10} and inorganic gas species (CO, NO_x, CO_2) were measured in the TJQ and TRA tunnels during two weeks in May and July 2011. Concentrations had a typical diurnal profile with two concentration peaks related to vehicle traffic in the morning peak hour (6:00–9:00) and in the afternoon peak hour (16:00–19:00) on working days. The PM_{10} concentrations were higher on working days, when the percentage of HDVs (p) was 38.7 ± 4.3 %, while on weekends with p 20.1 %, the concentrations dropped by a factor of 2 (while the traffic did substantially decrease on weekends). The PM_{10} and NO_x concentrations were normalized to the CO_2 concentration, to account for the fuel consumption in the tunnels and were higher when the NO_x/PM_{10} and NO_x/CO had maximum values. High NO_x/PM_{10} and NO_x/CO ratios are usually associated to diesel vehicle emissions.

The EFs estimated for CO_2, CO, NO_x and PM_{10} and the NO_x/CO and PM_{10}/CO ratios were strongly affected by the traffic and proportion of HDVs. EFs for HDVs and LDVs were calculated in the TRA and TJQ tunnels. The $EF(PM_{10})_{LDV}$ was 0.178 ± 0.143 g km^{-1} and the $EF(PM_{10})_{HDV}$ was 0.290 ± 0.248 mg km^{-1} for a temperature of 20–25 °C inside the tunnels. Driving conditions and traffic composition were quite different in the two measurement tunnels.

References

1. Belalcazar LC, Clappier A, Blond N, Flassak T, Eichhorn J (2010) An evaluation of the estimation of road traffic emission factors from tracer studies. Atmos Environ 44(31):3814–3822
2. CETESB (2009) Relatório Anual de Qualidade do Ar no Estado de São Paulo 2009. CETESB-Companhia de Tecnologia de Saneamento Ambiental. São Paulo, Brazil
3. Colberg CA, Tona B, Catone G, Sangiorgio C, Stahel WA, Sturm P, Staehelin J (2005) Statistical analysis of the vehicle pollutant emissions derived from several European road tunnel studies. Atmos Environ 39(13):2499–2511
4. Colberg CA, Tona B, Stahel WA, Meier M, Staehelin J (2005) Comparison of a road traffic emission model (HBEFA) with emissions derived from measurements in the Gubrist road tunnel, Switzerland. Atmos Environ 39(26):4703–4714
5. Correa SM, Arbilla G (2008) Carbonyl emissions in diesel and biodiesel exhaust. Atmos Environ 42(4):769–775
6. Heck RM, Farrauto RJ (2001) Automobile exhaust catalysts. Appl Catal A-Gen 221(1–2):443–457
7. Heywood JR (1988) Pollutant formation and control in internal combustion engine fundamentals. McGraw-Hill Inc
8. Kirchstetter TW, Harley RA, Kreisberg NM, Stolzenburg MR, Hering SV (1999) On-road measurement of fine particle and nitrogen oxide emissions from light- and heavy-duty motor vehicles. Atmos Environ 33(18):2955–2968
9. Kirchstetter TW, Harley RA, Kreisberg NM, Stolzenburg MR, Hering SV (2002) On-road measurement of fine particle and nitrogen oxide emissions from light- and heavy-duty motor vehicles. Atmos Environ 36(39–40):6059–6059
10. Kristensson A, Johansson C, Westerholm R, Swietlicki E, Gidhagen L, Wideqvist U, Vesely V (2004) Real-world traffic emission factors of gases and particles measured in a road tunnel in Stockholm, Sweden. Atmos Environ 38(5):657–673
11. Marr LC, Kirchstetter TW, Harley RA, Miguel AH, Hering SV, Hammond SK (1999) Characterization of polycyclic aromatic hydrocarbons in motor vehicle fuels and exhaust emissions. Environ Sci Technol 33(18):3091–3099
12. Martins LD, Andrade MF, Freitas ED, Pretto A, Gatti LV, Albuquerque EL, Tomaz E, Guardani ML, Martins MHRB, Junior OMA (2006) Emission factors for gas-powered vehicles traveling through road tunnels in Sao Paulo, Brazil. Environ Sci Technol 40(21):6722–6729
13. McGaughey GR, Desai NR, Allen DT, Seila RL, Lonneman WA, Fraser MP, Harley RA, Pollack AK, Ivy JM, Price JH (2004) Analysis of motor vehicle emissions in a Houston tunnel during the texas air quality study 2000. Atmos Environ 38(20):3363–3372
14. Molina MJ, Molina LT (2004) Megacities and atmospheric pollution. J Air Waste Manage 54(6):644–680
15. Sanchez-Ccoyllo OR, Ynoue RY, Martins LD, Astolfo R, Miranda RM, Freitas ED, Borges AS, Fornaro A, Freitas H, Moreira A, Andrade MF (2009) Vehicular particulate matter emissions in road tunnels in Sao Paulo, Brazil. Environ Monit Assess 149(1–4):241–249

Source Identification and Seasonal Variations of Carbonaceous Aerosols in Beijing—A Stable Isotope Approach

Nina J. Schleicher, Yang Yu, Kuang Cen, Fahe Chai, Yizhen Chen, Shulan Wang and Stefan Norra

Abstract Carbonaceous aerosols constitute an important part of atmospheric particles in urban areas. Within this study, total carbon (TC) was investigated in total suspended particulates (TSP) and fine particles ($PM_{2.5}$) collected in the megacity Beijing, China. Beside mass and TC concentrations, also stable C isotopes were analyzed by isotope ratio mass spectrometry (IR-MS) coupled to an element analyzer (EA). Carbon isotope ratios ($\delta^{13}C$) can serve as a fingerprint for source identification, because different source materials have characteristic $\delta^{13}C$ values.

The $\delta^{13}C$ values in 2008 varied from −28.2 to −25.0‰ for $PM_{2.5}$ and from −25.5 to −22.3‰ for TSP samples. In order to gain more information about potential source material, the $\delta^{13}C$ values of different source samples from Beijing were analyzed, such as sand from desert regions, construction material, topsoil, or coal. The isotopic C ratio was lowest in summer and highest in spring and winter. The lower $\delta^{13}C$ values during summer are caused by a higher share of natural organic C collected, whereas higher $\delta^{13}C$ values during the other seasons correlate with higher TC concentrations from anthropogenic and geogenic sources.

Introduction

Air quality remains a major challenge for urban areas and megacities in particular. It is generally accepted that atmospheric particulate matter (APM) is harmful for human health with regard to morbidity, mortality, respiratory and cardiovascular diseases [7, 14]. Smaller particles are considered to be even more health relevant [19], because they can enter deep into the human respiratory system. Therefore,

N. J. Schleicher (✉) · S. Norra
Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology,
Karlsruhe, Germany
e-mail: nina.schleicher@kit.edu

Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Karlsruhe, Germany

Y. Yu · K. Cen
Chinese Research Academy of Environmental Sciences, Beijing, China

F. Chai · Y. Chen · S. Wang
Chinese University of Geosciences, Beijing, China

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_22,

this study considers both total suspended particles (TSP) and additionally fine particles ≤ 2.5 μm ($PM_{2.5}$).

Carbonaceous aerosols constitute an important part of APM in urban areas. Carbon occurs as carbonate (CC), organic carbon (OC), and elemental carbon (EC) or black carbon (BC), respectively, both representing soot and char. Beside negative health effect of carbonaceous particles [e.g. 4], they are of high importance due to their role in radiative forcing and climate change [6, 9].

Anthropogenic as well as geogenic sources for APM and C cause intensive particle loads in the Beijing atmosphere. Many studies focus on source apportionment in the megacity Beijing based on chemical composition of aerosols [e.g. 5, 11, 15, 16, 20, 21]. More and above that, this study shows that stable C isotopes can provide further knowledge about the different carbon sources. Therefore, four different seasons (one month representing each season 2008) were selected for analysis of stable isotopes of Beijing APM.

Experimental

Sampling

Weekly samples were collected on quartz fibre filters (Whatman, Maidstone, UK). For TSP, a low-volume TSP-sampler (flow rate of 1 m^3/h) and for $PM_{2.5}$, a Mini-Volume-Sampler (flow rate of 200 L/h), both manufactured by Leckel, Berlin, were used. The location of the sampling sites is shown in Fig. 1.

Analysis

Gravimetric analysis was carried out with a microbalance (Sartorius SE 2-F, Göttingen, Germany) for five times after at least 48 h equilibration at room conditions of 40–45 % relative humidity. For each season 2008, one month (Jan-08, Mar-08, Jun-08, Nov-08) was selected for further C isotope analyses (four weekly TSP and $PM_{2.5}$ filter samples each month, respectively).

TC and stable C isotope analysis was performed with an elemental analyzer (EA; EuroEA3000, EuroVector, Italy) coupled to an isotope ratio mass spectrometer (IR-MS; IsoPrime, GV Instruments, UK). Filter punches were packed into tin capsules for analysis and samples were measured in triplicates. Additionally, certified reference standards NBS-18, NBS-21, and USGS-24 were analyzed. Results are given in the common delta notation ($\delta^{13}C$) according to the equation:

$$\delta^{13}C[‰] = (Rsample\text{-}Rstandard/Rstandard)*1{,}000 \quad \text{with } R = 13C/12C \tag{1}$$

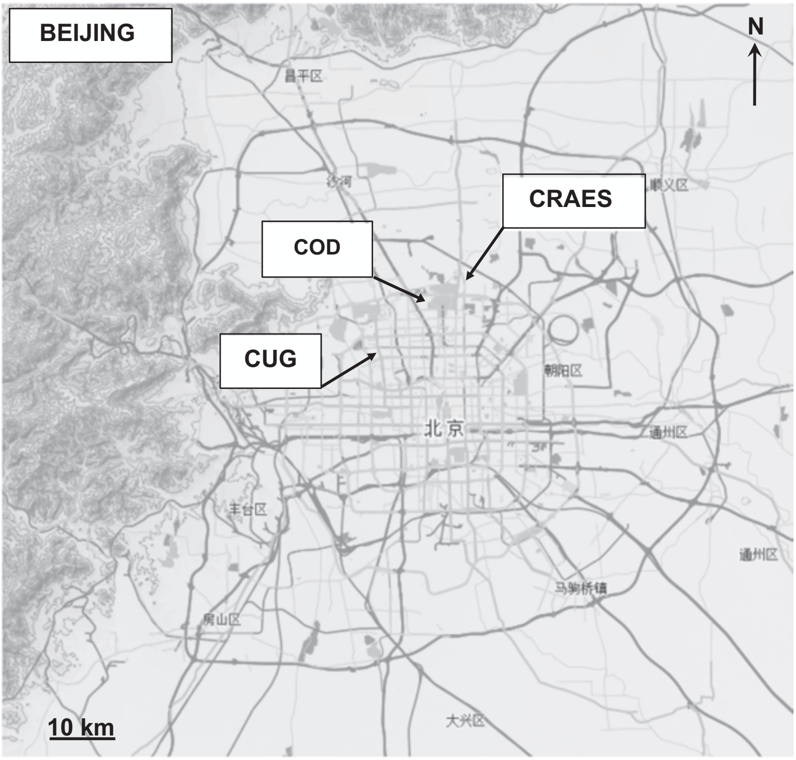


Fig. 1 Map of Beijing (source of the map: beijing2008.go2map.com) showing the location of the sampling sites CUG and CRAES. COD (Central Olympic District) marks the location of the Olympic Green

Reference standard is V-PDB (*Belemnitella americana* from the Cretaceous Peedee formation, South Carolina).

Results and Discussion

Weekly TSP mass concentrations in 2008 at site CRAES varied from 57.2 to 649 µg/m^3 (median concentration: 214 µg/m^3). Weekly $PM_{2.5}$ mass concentrations at site CUG varied from 5.0 to 346 µg/m^3 (median: 63.5 µg/m^3). The annual variations for the whole year 2008 are shown in Fig. 2. The filled bars in Fig. 2 represent the sampling weeks selected for further $\delta^{13}C$ analysis. In July and August 2008, samples were collected in a higher time resolution due to an intensive campaign during the Olympic Summer Games in Beijing. Therefore, the weekly concentrations for these weeks are calculated from daily samples. Detailed results for the

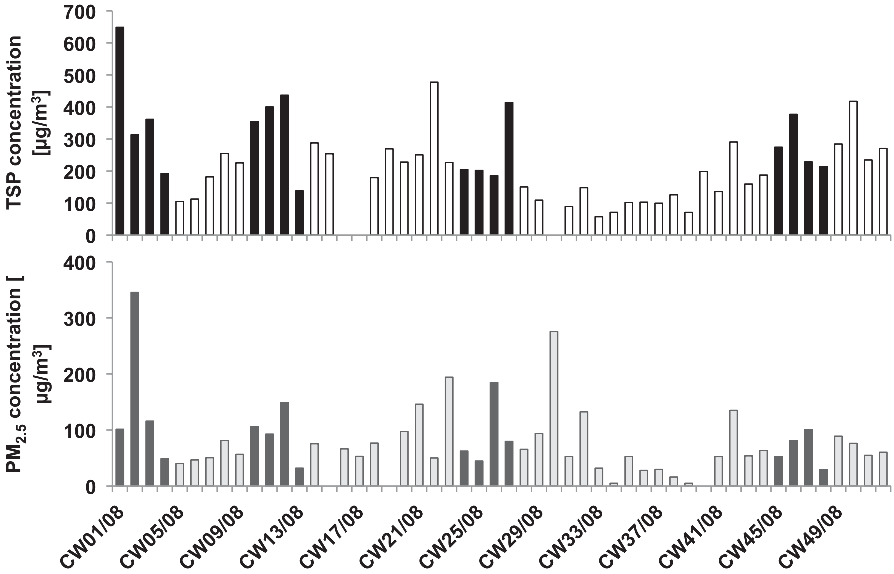


Fig. 2 Weekly TSP and $PM_{2.5}$ mass concentrations in Beijing 2008 at site CRAES and site CUG, respectively. The darker columns mark the sampling weeks selected for further $\delta^{13}C$ analysis

Olympics, a period with strictly enforced mitigation measures, can be found in [17] and [18].

Potential Source Material

Different source materials from Beijing and other potential source areas, such as the Gobi desert, were analyzed. These results and further $\delta^{13}C$ values from literature are shown in Fig. 3. Most negative $\delta^{13}C$ values in Fig. 3 originate from C3 biomass (−25 to −32 ‰ [2]). Coal from Beijing analyzed within this study had $\delta^{13}C$ values of −23.0 ± 0.0 5 ‰. Furthermore, different construction materials, such as street rubble, asphalt, red brick, or mortar, were analyzed and had $\delta^{13}C$ values between −8.0 and −17.5 ‰. On the contrary, sand from the Gobi desert and from desert areas in Inner Mongolia near Baotou were isotopically heavier with $\delta^{13}C$ values of −3.25 ± 0.49 and −1.75 ± 0.90 ‰, respectively.

Seasonal Variations of Carbon Concentrations

Carbon concentrations showed pronounced seasonal variations. The TC concentrations for TSP samples are shown for the distinct seasons 2008 in Fig. 4. The annual course is characteristic for Beijing with highest concentrations in winter and fall

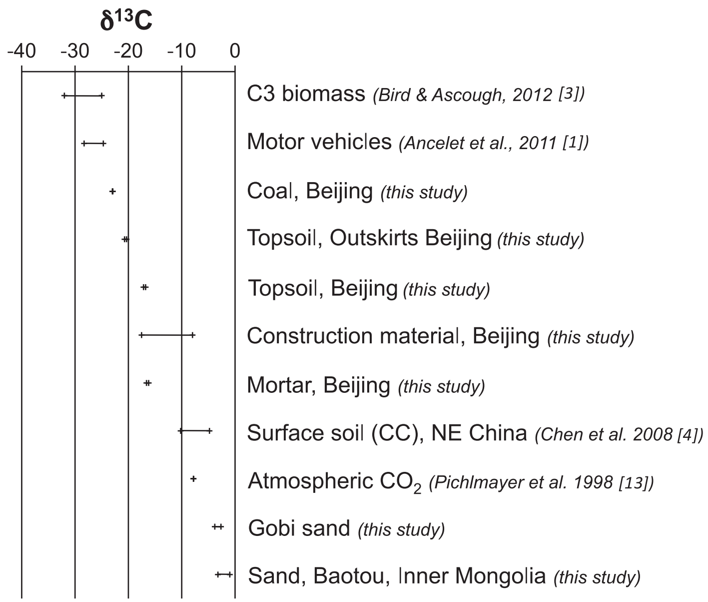
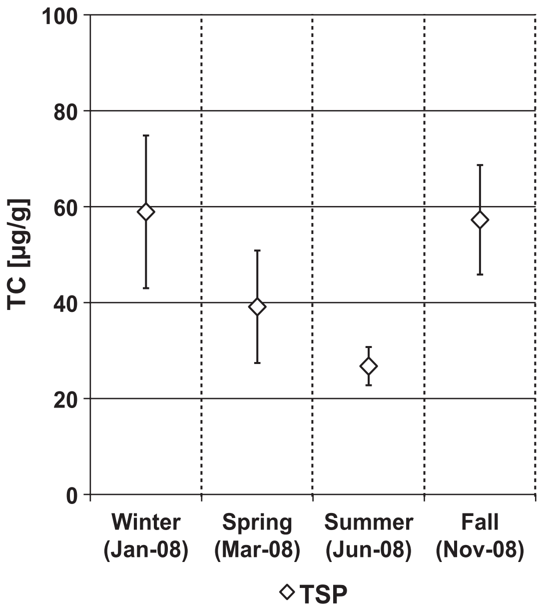


Fig. 3. δ^{13}C values of different source material analyzed within this study (N=20) as well as data from literature

Fig. 4 TC concentrations of TSP samples from Beijing, China. Each point results from an average of N=4 samples



and lowest in summer and is similar to other years in Beijing as reported for BC in [13] and [21].

High winter concentrations are due to stagnant meteorological conditions and additional C sources such as coal burning for heating purposes. In summer, most precipitation occurs in Beijing and, therefore, particle and C concentrations are lowest during this time of the year. In order to gain additional knowledge about the various C sources, the seasonal variations of $\delta^{13}C$ values are discussed in the following section.

Seasonal Variations of $\delta^{13}C$ Values in TSP and $PM_{2.5}$ Samples

Not only the C concentrations, but also the $\delta^{13}C$ values of the analyzed samples varied considerably. Results for each season are shown in Fig. 4. In January as well as in November 2008, a large contribution from coal combustion for domestic heating contributes to the C content of aerosols in Beijing. This finding is in accordance with other studies, which report heavier $\delta^{13}C$ values for OC and EC in winter samples in northern China [e.g. 3] or in Mongolia [10].

In March 2008, the $\delta^{13}C$ values varied strongly during the four sampling weeks. In the second March week (calendar week 11/2008), the $\delta^{13}C$ value of TSP was the isotopically heaviest (-22.3 ± 0.4 ‰) of all samples included in this study. For $PM_{2.5}$ samples, this trend with higher $\delta^{13}C$ values in spring is not pronounced. This indicates a high influence from geogenic minerals (e.g. carbonate) from arid areas and desserts NW of Beijing. This assumption is further supported by air masses originating from western areas during this time period. The geogenic C sources from arid and semi-arid areas contribute more to TSP than $PM_{2.5}$ samples highlighting a dominance of coarser geogenic particles.

In summer, the isotopically lighter C reflects a strong influence from C3-plants. Here, the trend during the four June weeks is similar for TSP and $PM_{2.5}$ samples. This indicates an influence by this source for both particle fractions.

Other C sources, such as traffic, are constant during the whole year and contribute to the C content of aerosols in Beijing in all seasons. Traffic-related C was also found in other studies. For example, [12] reported that automotive exhaust significantly affected atmospheric PAHs (polycyclic aromatic hydrocarbons) in Beijing (Fig. 5).

Conclusions

Seasonal variations of TC concentrations and $\delta^{13}C$ values in Beijing were pronounced. Mainly, different sources, such as coal combustion for domestic heating in winter or geogenic minerals in spring, are responsible for this variability.

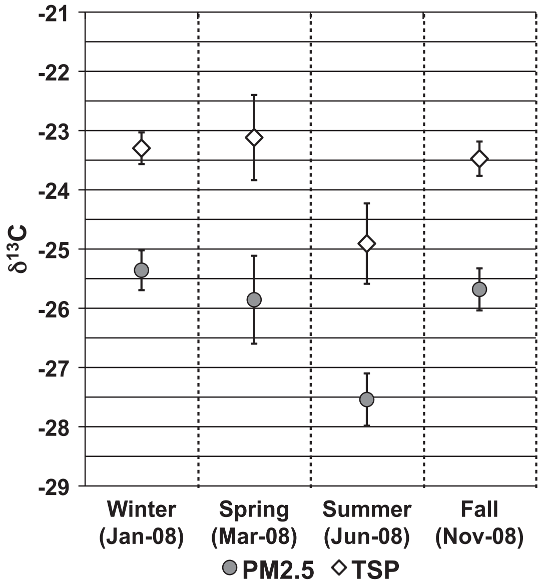


Fig. 5 $\delta^{13}C$ values for TSP and $PM_{2.5}$ samples from Beijing, China. Each point results from an average of $N=4$ samples

The study showed that the analysis of stable C isotopes is a good additional tool for source apportionment in urban areas. However, more detailed knowledge about all possible C sources is still necessary. Furthermore, other stable isotopes, such as $\delta^{34}S$, could additionally support source apportionment studies of atmospheric particles.

Generally, C sources are abundant in Beijing and furthermore, many of those sources are not constant over the annual course. During the period of the Olympic Summer Games in Beijing in August 2008 also carbonaceous aerosols were reduced significantly. Future urban planning and mitigation measures might contribute to a decrease of C sources in Beijing and also in other urban areas worldwide.

Acknowledgments This study was funded by the German Research Foundation (DFG) under grant STU 169/32-1,2. Laboratory analyses were carried out at the Institute of Mineralogy and Geochemistry (IMG), Karlsruhe Institute of Technology (KIT), Germany. The authors express their special gratitude to the technical staff at IMG for their support. The authors also thank all colleagues in China at CRAES and CUG for collecting the filter samples.

References

1. Ancelet T, Davy PK, Trompetter WJ, Markwitz A, Weatherburn DC (2011) Carbonaceous aerosols in an urban tunnel. Atmos Environ 45:4463–4469
2. Bird MI, Ascough PL (2012) Isotopes in pyrogenic carbon: a review. Org Geochem 42:1529–1539

3. Cao J-J, Chow JC, Tao J, Lee S-C, Watson JG, Ho K-F, Wang G-H, Zhu C-S, Han Y-M (2011) Stable carbon isotopes in aerosols from Chinese cities: influence of fossil fuels. Atmos Environ 45:1359–1363
4. Chen B, Kitagawa H, Jie D, Hu K, Lim J (2008) Dust transport from northeastern China inferred from carbon isotopes of atmospheric dust carbonate. Atmos Environ 42:4790–4796
5. He K, Yang F, Ma Y, Zhang Q, Yao X, Chan CK, Cadle S, Chan T, Mulawa P (2001) The characteristics of PM2.5 in Beijing, China. Atmos Environ 35:4959–4970
6. Jacobson M (2001) Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. Nature 409:695–697
7. Kappos A, Bruckmann P, Eikmann T, Englert N, Heinrich U, Höppe P, Koch E, Krause G, Kreyling W, Rauchfuss K, Rombout P, Schulz-Klemp V, Thiel W, Wichmann H-E (2004) Health effects of particles in ambient air. Int J Hyg Envir Health 207:399–407
8. Li X, Brown D, Smith S, MacNee W, Donaldson K (1999) Short-term inflammatory responses following intratracheal instillation of fine and ultrafine carbon black in rats. Inhal Toxicol 11:709–731
9. Menon S, Hansen J, Nazarenko L, Luo Y (2002) Climate effects of black carbon aerosols in China and India. Science 297:2250–2253
10. Nishikawa M, Matsui I, Batdorj D, Jugder D, Mori I, Shimizu A, Sugimoto N, Takahashi K (2011) Chemical composition of urban airborne particulate matter in Ulaanbaatar. Atmos Environ 45:5710–5715
11. Norra S, Schleicher N, Stüben D, Chai F, Chen Y, Wang S (2010) Assessment of aerosol concentration sampled at five sites in Beijing from 2005 till 2007. In: Rauch S et al (eds) Highway and urban environment, alliance for global sustainability bookseries 17. Springer, pp 133–140
12. Okuda T, Kumata H, Naraoka H, Takada H (2002) Origin of atmospheric polycyclic aromatic hydrocarbons (PAHs) in Chinese cities solved by compound-specific stable carbon isotopic analyses. Org Geochem 33:1737–1745
13. Pichlmayer F, Schöner W, Seibert P, Stichler W, Wagenbach D (1998) Stable isotope analysis for characterization of pollutants at high elevation Alpine sites. Atmos Environ 23:4075–4085
14. Pope CA, Dockery DW (2006) Health effects of fine particulate air pollution: lines that connect. J Air Waste Manage 56:709–742
15. Schleicher N, Norra S, Chai F, Chen Y, Wang S, Stüben D (2010) Anthropogenic versus geogenic contribution to total suspended atmospheric particulate matter and its variations during a two-year sampling period in Beijing, China. J Environ Monitor 12:434–441
16. Schleicher N, Norra S, Chai F, Chen Y, Wang S, Cen K, Yu Y, Stüben D (2011) Temporal variability of trace metal mobility of urban particulate matter from Beijing—A contribution to health impact asseessment of aerosols. Atmos Environ 45:7248–7265
17. Schleicher N, Norra S, Dietze V, Yu Y, Fricker M, Kaminski U, Chen Y, Cen K (2011) The effect of mitigation measures on size distributed mass concentrations of atmospheric particles and black carbon concentrations during the Olympic Summer Games 2008 in Beijing. Sci Total Environ 412–413, 185–193
18. Schleicher N, Norra S, Chen Y, Chai F, Wang S (2012) Efficiency of mitigation measures to reduce particulate air pollution—a case study during the Olympic Summer Games 2008 in Beijing, China. Sci. Total Environ 427–428, 146–158
19. Schwartz J, Dockery D, Neas L (1996) Is daily mortality associated specifically with fine particles? J Air Waste Manage 46:927–939
20. Sun Y, Zhuang G, Wang Y, Han L, Guo J, Dan M, Zhang W, Wang Z, Hao Z (2004) The airborne particulate pollution in Beijing—concentration, composition, distribution and sources. Atmos Environ 38:5991–6004
21. Yu Y, Schleicher N, Norra S, Fricker M, Dietze V, Kaminski U, Cen K, Stüben D (2011) Dynamics and origin of PM2.5 during a three-year sampling period in Beijing, China. J Environ Monitor 13:334–346

Monitoring of Ultrafine Particles in Rural and Urban Environments

F. Lenartz, C. Mentink, M. Severijnen and B. Bergmans

Abstract Ultrafine particles (UFPs) can penetrate deeper into the respiratory system and cause more adverse health effects than particulate matter of a larger size. Therefore, their measurement should be promoted and not only episodically. Within the framework of the PM-Lab project, Belgian, Dutch and German partners from the Meuse-Rhine Euregion joined their efforts to investigate this topic. The present study describes, on one hand, the technological choices together with the set up requirements to include such a system within an air quality network, and on the other hand, the first results of our different mobile campaigns. As the monitoring of UFPs is neither regulated by a European directive nor normalized yet, major differences exist between the systems available on the market; our choices are discussed. The sampling strategy consisted in a long-term monitoring at a rural background station in Vielsalm (Belgium), along with several short-term campaigns led in different locations, a mixed urban background and traffic site in Herstal (Belgium), a traffic site in Maastricht (The Netherlands) and an urban background site in Mülheim (Germany). Corresponding analyses and results are described with a focus on the differences appearing between rural and urban sites, mainly in terms of time and size distributions.

Introduction

An ultrafine particle (UFP), or nanoparticle (NP), is a small object that behaves as a whole unit in terms of properties and transport, and of which the size is comprised between 100 and 1 nm [3]. They can originate either from natural or anthropogenic sources. Among the latter, discrimination must be made between the intentionally manufactured particles and the byproducts of specific processes. The first ones have

F. Lenartz (✉) · B. Bergmans
Institut Scientifique de Service Public, Rue du Chéra 200, 4000, Liège, Belgium
e-mail: f.lenartz@issep.be

C. Mentink
Center of Sustainable Environment, Postbus 550, 6400, Heerlen, The Netherlands

M. Severijnen
Province of Limburg, Postbus 5700, 6202, Maastricht, The Netherlands

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_23,

application in the cosmetic, medical, pharmaceutical and technological fields, e.g. TiO_2 NPs allow sunscreen to be transparent, easier to apply and more UV-absorbing [4], Fe_2O_3 NPs improve alimentary canal, liver as well as cell imagery [6], Ag_2O NPs promote wound healing [1] and carbon nanotubes (CNT) increase the elasticity of polyethylene, are tested both for use as transistors in electrical circuits and for storage of hydrogen in fuel cells [7]; the second ones result from combustion reaction, peeling of citrus fruits, xerographic printing, etc. [5].

Several characteristics of particulate matter (PM) have been suggested to be responsible for the adverse health effects associated with exposure to PM_{10} and $PM_{2.5}$ [8]. Population based studies have related particles with mortality, cardiorespiratory morbidity and hospital admissions. More specifically, the ultrafine fraction has been linked to a number of conditions including systemic inflammation. Toxicological studies have shown that the small size of ultrafine particles facilitates their deposition deeper in the lungs and makes passing the lung-blood barrier into systemic circulation possible. In addition, their high number concentration also results in a larger deposition surface area increasing their toxicity [10].

The 2008/50/EC directive on ambient air quality and cleaner air for Europe presently regulates mass concentration of particulate matter of which the aerodynamic diameter is less than 10 µm and 2.5 µm (respectively PM_{10} and $PM_{2.5}$). On average, UFPs represent 3 % of $PM_{2.5}$ mass concentration and 88 % of $PM_{2.5}$ number concentration. As the latter are thought to be more harmful for both environment and human health, it is likely that, sooner or later, the monitoring of UFPs will also be mandatory. In order to anticipate a future regulation and as the opportunity arose to buy some instruments in the framework of the Interreg IV-A PM-Lab project, the *Institut Scientifique de Service Public* (ISSeP) and the *Provincie Limburg* have bought two systems that allow to determine particle number size distributions.

Issues related to the chosen devices and experimental setup of the measurement campaigns, along with the data treatment performed on the number concentration by size bin, are described in Section "Material and method". Results of our analyses are presented and discussed in Section "Results", while conclusions are finally drawn in Section "Conclusion".

Material and Method

The selected system is a scanning mobility particle sizer (SMPS), similar to one of those used by the *Leibniz-Instut für Troposphärenforschung* of Leipzig (IfT) in the framework of the German ultrafine aerosol network (GUAN) [2]. In the framework of this study it was set up with the following characteristics:

- Pre-separator: A PM_{10} head is used to prevent coarse particles to enter the sampling line. A $PM_{2.5}$ head could also be used but it would require a more frequent cleaning, which is not desired in our network configuration.

- Sampling: The main line is made out of stainless steel to minimize particle losses. For the same reason, sampling is performed at a high flow rate (~40 l min^{-1}) and lines are kept as short as possible after the isokinetic splitting.
- Drying: Over 40 % of relative humidity, a Nafion membrane is used to minimize a possible diameter shift due to hygroscopic growth. On the field, a zero-air station is used to generate dry air.
- Neutralizer/Bipolar charger: A nuclear source (241Am—3.7 MBq) is used to ionize the sampled aerosol.
- Differential Mobility Analyzer (DMA): a cylindrical capacitor that separates particles according to their electrical mobility, and de facto, according to their size (10–850 nm). The ratio between the flow rates of the sheath air entering the DMA and the sampled air is 5:1
- Condensation Particle Counter (CPC): The selected CPC (TSI 3772) has a flow rate of 1 l min^{-1} driven by a critical orifice. A smaller flow rate would yield larger diffusion losses and should be avoided. Since the CPC has no internal splitting, it allows flow rate verification by the user. Water-based CPC has been excluded to avoid maintenance problem, especially for the saturator wick, and overestimation due to the possible presence of hydrophilic material. Thus n-butanol is used as working fluid.
- Scanning: Time interval of each up and down scans is set to 2.5 min. Information for the 64 size bins, which cover the 8.7–846.5 nm range, are thus made available every 5 min.
- Additional data: Differential and absolute pressures, temperature and humidity are recorded to allow for a posteriori corrections in the data treatment.

A more comprehensive source of information for technical details can be found in [9]. The sampling strategy consisted in setting up one SMPS (WGUAN2) in a rural background site, namely that of Vielsalm (Belgium), while the other one (WGUAN1) was placed for periods of one to two months in other sites of or close to the Meuse-Rhine Euregion. Table 1 presents the schedule of the different campaigns and Fig. 1 displays the location of the stations.

In order to be run continuously, such systems require several maintenance operations. Here are the tests to be performed at each service occasion, i.e. every two weeks:

- Check zero count by using High-Efficiency Particulate Air (HEPA) filters;
- Check aerosol and sheath air flow rates manually by using an electrical bubble flow meter;
- Check accuracy of the voltage applied to the DMA;
- Check sizing accuracy by using an aerosol of calibrated polystyrene latex particles.

The dN/dlogDp values provided by the SMPSs already include

- The so-called inversion procedure, which transforms the measured electrical particle mobility distribution into a particle number size distribution;

Table 1 Summary of the measurement campaigns set up

Period	Site	Longitude (°E)	Latitude (°N)
13/01/2011–27/02/2011	Vielsalm	6.0017	50.3032
28/02/2011–25/04/2011	Herstal	5.6278	50.6584
26/04/2011–30/05/2011	Maastricht	5.7100	50.8450
06/02/2012–02/03/2012	Mülheim (an der Ruhr)	6.8655	51.4547

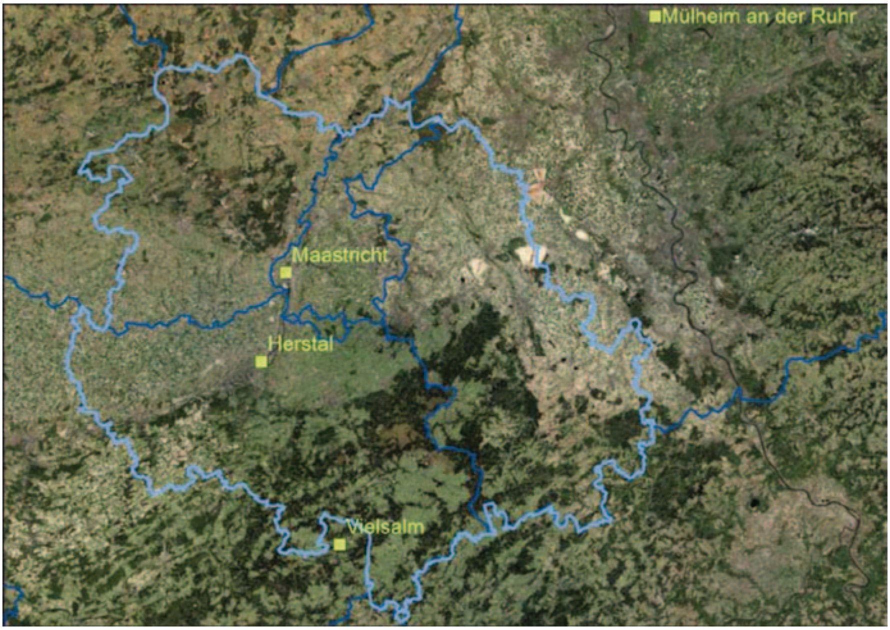


Fig. 1 Location of the measurement sites

- The multiple charge correction;
- The ISO15900 recommendations for bipolar charge equilibrium

But does not yet include

- The diffusion losses, which are taken into account via the equivalent pipe length method (see Fig. 2);
- The correction of the CPC detection efficiency for the smallest size classes, i.e. below 20 nm (see Fig. 3). In order to ensure a long-term quality of this correction, the CPC response curve has to be revised every year.

As mentioned above, depending on the sampling line length and the aerosol flow rate, diffusion loss can be significant, particularly for the smallest particles. Thus, it is necessary to take these losses into account in order to compare the values of

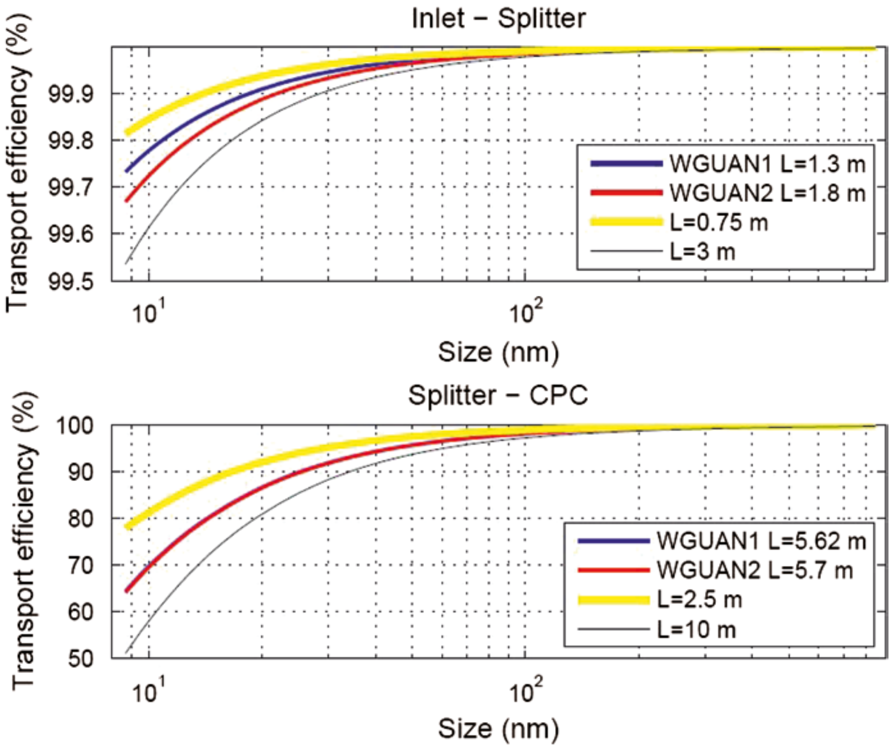


Fig. 2 Theoretical percentage of measured UFPs by both SMPSs and two hypothetical systems

systems presenting slightly different characteristics. Transport efficiency computation has been performed according to the following equations:

$$\eta_1 = 1 - 5.5\mu^{2/3} + 3.77\mu$$

$$\eta_2 = 0.819\exp(-11.5\mu) + 0.0975\exp(-70.1\mu) + 0.0325\exp(-179\mu)$$

$$\text{with } \mu = D\frac{L_{eq}}{Q}$$

where D is the diffusion coefficient, L_{eq} is the equivalent pipe length of the SMPS elements and Q the flow rate. These equations are respectively valid for $\mu < 0.007$and $\mu \geq 0.007$.

Fig. 2 shows the theoretical percentage of UFP going through the inlet-to-splitter part at a flow rate of 2.3 $m^3\ h^{-1}$ and through the splitter-to-CPC part at a flow rate of 1 l min^{-1}. Both our systems and two hypothetical ones, with respectively shorter

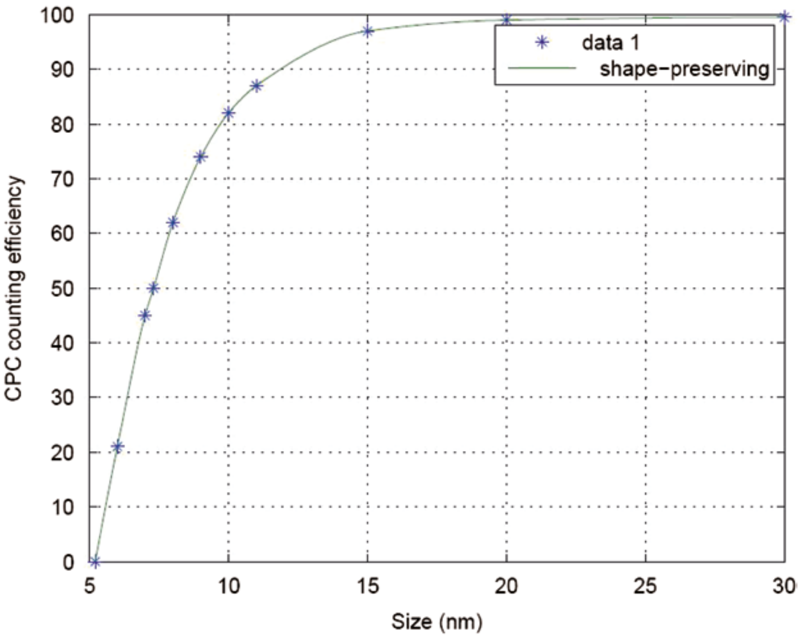


Fig. 3 CPC counting efficiency

and longer sampling lines, are depicted. It is worth noticing that, if no correction is applied, more than 12 % of particles smaller than 20 nm are not accounted for and more than 30 % of particles smaller than 10 nm.

As mentioned above, a CPC does not count as efficiently all particles, since diffusion losses also affect it. Figure 3 shows the percentage of measured particles as a function of their size. Here again, it is worth noticing that, if no correction is applied, about 1 % of particles smaller than 20 nm are skipped and about 20 % of particles smaller than 10 nm. For both our systems, more than 50 % of particles whose diameters are greater than 7.4 nm are accounted for.

Once these corrections are made, some further data treatment is required to make the recorded dN/dlogDp values more meaningful. First, to facilitate the comparison between sites and to prevent possible spurious values to play a too important role, a time averaging was performed on a 1-h basis (lower common frequency of all considered monitors). Then, to obtain the number concentration (NC) and an approximation of the mass concentration of the finest particles (PM_1), the three following arithmetical formula were applied:

$$dN = \frac{dN}{d\log Dp} d\log Dp$$

$$NC_{x-y} = \int_x^y dN$$

$$PM_1 = \int \rho \frac{\pi Dp^3}{6} dN$$

with dlogDp = log(Dp^u) − log(Dp^l) where Dp^u and Dp^l are respectively the upper and lower bounds of a size bin, x and y the smaller and larger diameters considered for a specific number concentration computation and ρ the density. Although somewhat unrealistic, by lack of appropriate knowledge on the particles composition, we used a size-independent value for the latter parameter.

Finally, one should mention that great care was taken in selecting data sets containing exclusively simultaneously-made-on-both-sites measurements, since the relevance of a comparative study strongly depends on that factor. The median and median absolute deviation were computed for the following parameters:

- SMPS: $NC_{10–50}$, $NC_{50–100}$, $NC_{100–500}$, $NC_{500–850}$ and PM_1;
- GRIMM: PM_1, $PM_{2.5}$ and PM_{10}.

GRIMM analyzers are based on the light scattering principle and used in the telemetric network of Wallonia to monitor in real-time the particulate matter levels.

Results

Results of the different campaigns are presented in chronological order. For each case, comparison was performed between the visited site and the rural background one.

The first campaign, led in Vielsalm during Winter 2011, aimed at determining the typical inter-instrument differences that could be observed on the field. Two tests were made: one with both devices sampling from a same line and one with devices sampling through different lines. Figure 4 displays the number concentrations measured by both SMPSs for the whole period. One can see that from February 4, 2011 on, the curves do not superimpose as nicely as before the change in sampling conditions. The relative error on median values computed over the size range 10–850 nm is 7.2 % during the first period and 15.1 % during the second one.

Smaller errors are observed in the 50–500 nm range, respectively 4 % and 12.5 %. Not surprisingly, the Spearman's rank correlation coefficient is high in both cases, with values greater than 0.99 for each size class and each period.

The second campaign was led in Herstal during Winter and Spring 2011. Numerous exceedance days in terms of PM_{10} levels were counted at this station in the years 2009 to 2011, hence making of this site an interesting site for UFPs measurements. Figure 5 displays the number concentrations measured simultaneously at Herstal

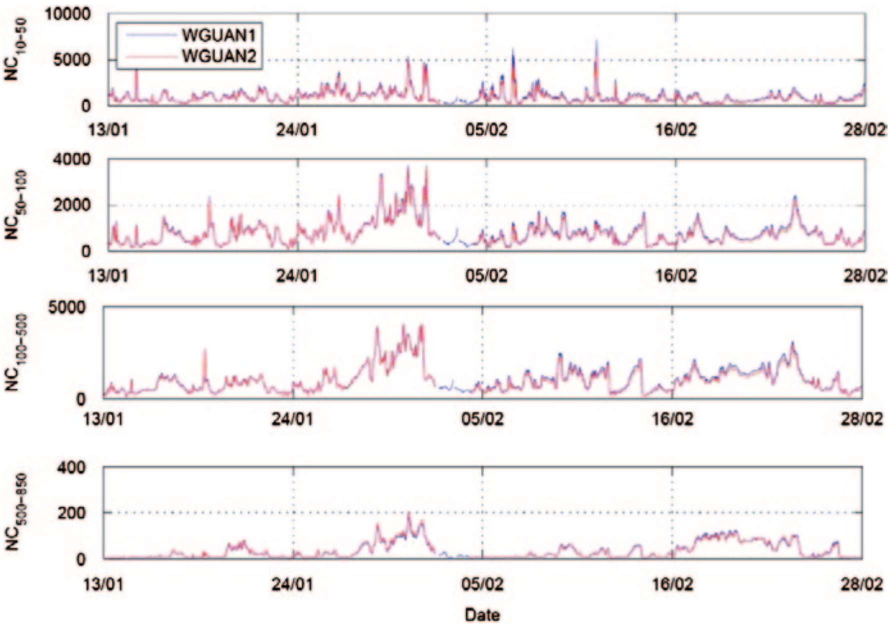


Fig. 4 Number concentrations measured at Vielsalm for four size classes

and Vielsalm. If number concentrations are of the same order of magnitude for the largest particles, one easily sees that there is a factor of about 2–8 for the other size-classes. One can also observe that some patterns are found at both sites, e.g. April 10 and 11, while other peaks are only visible in the Herstal timeseries, e.g. April 18; the first ones are probably due to a large-scale background signal, while the second ones to local processes.

The third campaign was led in Maastricht during Spring 2011. This site, located in the direct vicinity of the A2 highway, is particularly good to estimate the impact of traffic. In Fig. 6, typical day values of dN/dlogDp are displayed. For readability's sake, they are expressed as logarithm values. Therefore, one *colorbar* unit indicates a factor 10. In the present illustration, besides the order of magnitude which is significantly different between the sites, one can also see an important difference in the distributions of particles over time. At Maastricht, a very strong pollution event in terms of UFPs is detected around 6 a.m. GMT, which corresponds to the rush hour at that period of the year. High number concentrations are observed in the whole 20–100 nm range at that moment, depicting quick coagulation and condensation processes. This is in contrast with the slower growth, at the same time in terms of particle size and number concentration, observed at both sites in the afternoon and evening. Such phenomenon remains unobserved if analyses are solely based on PM_x measurements. This is depicted in Fig. 6.

Finally a fourth campaign was led in Mülheim an der Ruhr. Unfortunately, only one system was running at that time and no comparison with the rural background

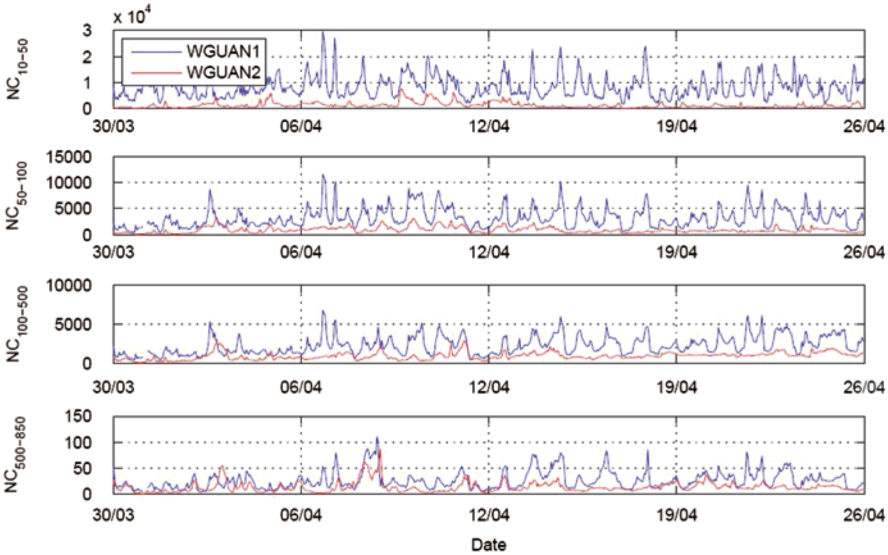


Fig. 5 Number concentrations measured at Herstal and Vielsalm for four size classes

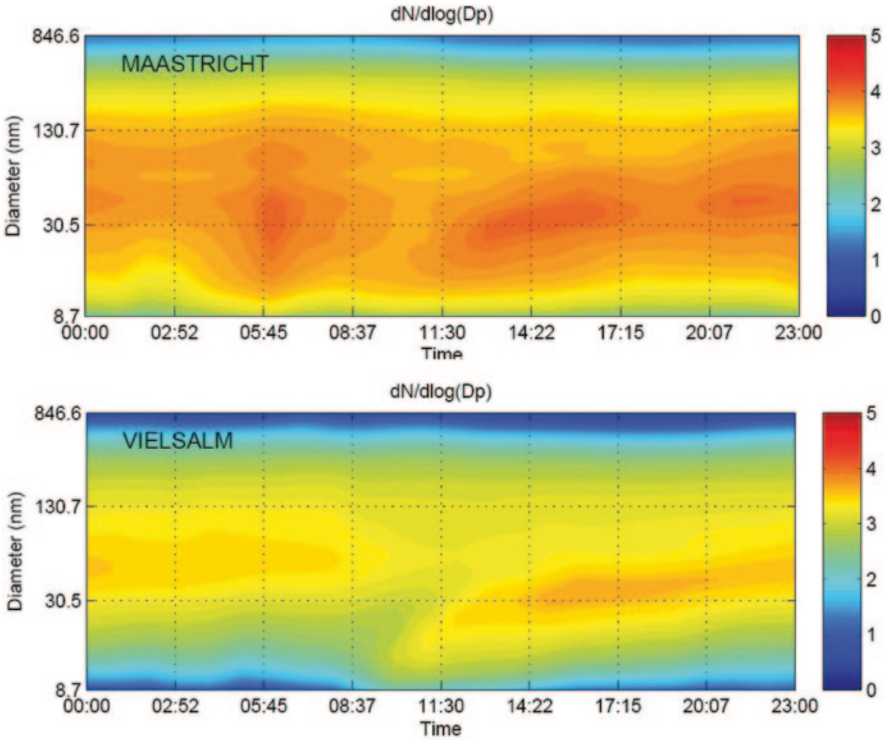


Fig. 6 Time-size distribution of UFPs during a typical day in Maastricht and Vielsalm

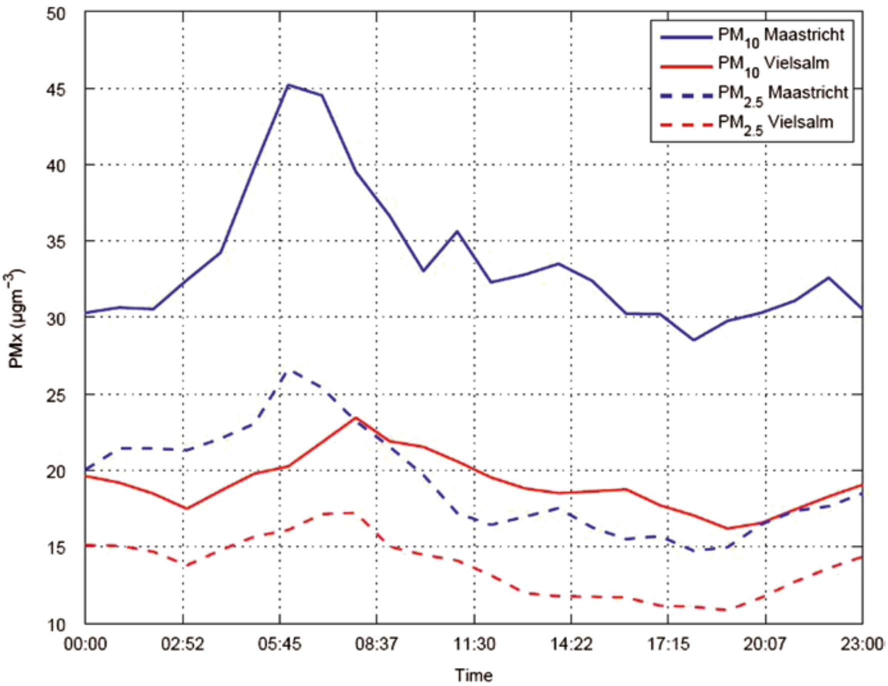


Fig 7 Time distribution of PM_x during a typical day in Maastricht and Vielsalm

site is possible. One can mention that, in contrast with what was observed at the other sites, PM_1 values calculated by using a density of 1.6×10^3 kg m^{-3} overestimate the ones measured with the Tapered Element Oscillating Microbalance (TEOM) analyzer from IUTA, which is somewhat counter-intuitive. However, the Spearman's rank correlation coefficient between the two signals is still rather high 0.81, as can be guessed by inspection of Fig. 7.

Eventually, Table 2 and 3 provide a summary of the typical level of UFPs number concentrations and PM_x mass concentrations (median values), as well as their typical variability (median absolute deviation) in round brackets, observed during the different campaigns (Fig. 8).

Conclusion

Number concentrations of ultrafine particles (UFPs) have been measured by means of two scanning mobility particle sizers (SMPSs) in several sites within or close to the Meuse-Rhine Euregion. In a brief description of the systems and the required maintenance, we have attempted to explain the use of such devices in a monitoring network perspective. Afterward, we have presented the correction applied to

Table 2 Median values and median absolute deviations of UFPs number concentrations

	NC 10–50	NC 50–100	NC 100–500	NC 500–850
Vielsalm	792 (332)	709 (296)	919 (431)	18 (13)
Vielsalm	674 (286)	642 (272)	856 (401)	18 (14)
Herstal	7507 (2423)	2764 (1153)	2001 (788)	22 (6)
Vielsalm	984 (415)	737 (307)	895 (266)	11 (4)
Maastricht	3333 (1499)	1805 (693)	1635 (587)	19 (9)
Vielsalm	893 (409)	747 (308)	694 (206)	6 (3)
Mülheim	6163 (2288)	3664 (1180)	2850 (951)	33 (16)
Vielsalm	NA	NA	NA	NA

Table 3 Median values and median absolute deviations of PM_x mass concentrations

	PM_1	$PM_{2.5}$	PM_{10}
Vielsalm	15 (8)	16 (8)	17 (8)
Herstal	17 (7)	21 (7)	31 (11)
Vielsalm	12 (5)	14 (5)	18 (7)
Maastricht	NA	17 (6)	31 (8)
Vielsalm	NA	12 (5)	17 (6)
Mülheim	15 (6)	NA	34 (11)
Vielsalm	15 (8)	NA	17 (8)

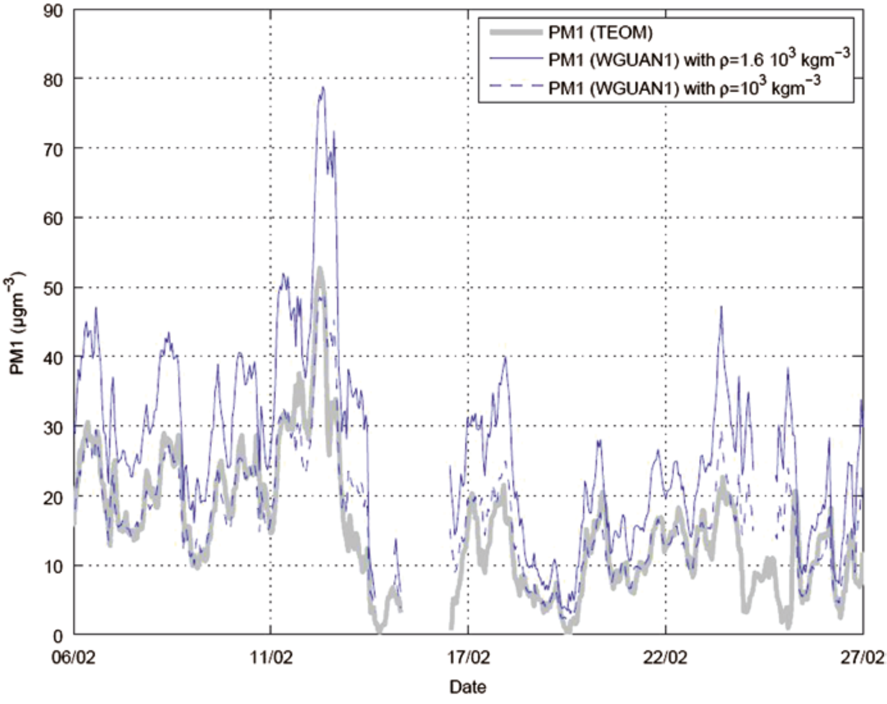


Fig. 8 Time series of the measured and computed PM_1 mass concentrations

take into account diffusion losses and the data treatment performed on the records collected during the measurement campaigns. In a first step, a comparison study of both our systems has allowed to determine the relative error to be expected i.e. about 15 % for the whole size range. The campaigns led in the mixed urban background and traffic site of Herstal and the traffic site of Maastricht both showed significantly larger number concentrations than those recorded at Vielsalm, which is not so clear for PM measurements (especially PM_1). Typically the median values observed differ from a factor going from 2 to 8, depending on the size class considered. Correlation between UFP results and other parameters is not evident. Analysis of timeseries has also allowed us to show that the measurement of UFPs is complementary to that of PM_x, as it brings new information. Long-term measurement if UPFs, both in rural and urban environments, should thus be promoted.

Acknowledgments We are thankful to Tim Nawrot for his contribution, to the Agence wallonne de l'Air et du Climat, the Provincie Limburg, the Landesamt für Natur, Umwelt und Verbraucherschutz NRW and the Institut für Energie- und Umwelttechnik e.V. for allowing the use of their data. The PM-Lab project is financed by the European Regional Development Fund through the Interreg IV-A initiative.

References

1. Atiyeh BS, Costagliola M, Hayek SN, Dibo SA (2007) Effect of silver on burn wound infection control and healing: review of the literature. Burns 33:139–148. doi:10.1016/j.burns.2006.06.010
2. GUAN (2012) German ultrafine aerosol network. From IfT Wiki. Available at: http://wiki.tropos.de/index.php/GUAN, accessed 26/11/2013
3. Iijima S (1985) Electron microscopy of small particles. J Electron Microsc (Tokyo) 34(4):249
4. Jaroenworaluck A, Sunsaneeyametha W, Kosachan N, Stevens R (2006) Characteristics of silica-coated TiO_2 and its UV absorption for sunscreen cosmetic applications. Surf Interface Anal 38(4):473–477
5. Spengler JD (2000) Indoor air quality handbook. ISBN 978-0-07-150175-0
6. Wang D, He J, Rosenzweig N, Rosenzweig Z (2004) Superparamagnetic Fe_2O_3 beads−CdSe/ZnS quantum dots core−shell nanocomposite particles for cell separation. Nano Lett 4(3):409–413. doi:10.1021/nl035010n
7. Wanga X, Lia W, Chena Z, Wajea M, Yana Y (2006) Durability investigation of carbon nanotube as catalyst support for proton exchange membrane fuelcell. J Power Sources 158(1):154–159
8. WHO Working Group (2003) Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide, WHO report
9. Wiedensohler A et al (2012) Mobility particle size spectrometers: harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions. Atmos Meas Tech 5:57–685. doi:10.5194/amt-5-657-2012
10. Wittmaack K (2007) In search of the most relevant parameter for quantifying lung inflammatory response to nanoparticle exposure: particle number, surface area, or what? Environ Health Perspect 115(2):187–194

BaP Air Quality Modelling Simulation Using CMAQ Air Quality Modelling System

R San José, JL Pérez, M Callen, JM López and A Mastral

Abstract Air Quality Modelling has become an essential tool to investigate the transport, transformation and deposition of toxic pollutants. BaP is one of the most toxic pollutants which are present in the atmosphere. Because of this reason, the Directive 2004/107/CE of the European Union establishes a target value of 1 ng/m3 of BaP in the atmosphere. In this paper, the main aim is to estimate the BaP concentrations in the atmosphere by using last generation of air quality dispersion models with the inclusion of the transport, scavenging and deposition processes for the BaP. To reach this aim, a detailed emission inventory has been developed. BaP is injected into the atmosphere as particle and the degradation of the particulate BaP by the ozone has been considered. The aerosol-gas partitioning phenomenon in the atmosphere is modeled taking into a count that the concentrations in the gas and the aerosol phases are in equilibrium. The model has been validated in the area of Zaragoza (Spain) during 10 weeks in 2010. A validation process of the BaP results obtained with the model at local scale in the atmosphere of the Zaragoza city has been conducted. The agreement is generally satisfactory with important influence of the meteorological conditions.

Introduction

Benzo(a)pyrene (BaP) is one of the most dangerous Polycyclic Aromatic Hydrocarbons (PAH) due to its high carcinogenic and mutagenic character. Because of this reason, the Directive 2004/107/CE of the European Union establishes a target value of 1 ng/m3 of BaP in the atmosphere. They are mainly of anthropogenic origin, including incomplete combustion of fossil fuels and biomass [2].

BaP is a semivolatile compound that can be transported in the atmosphere [5] over large distances either as gaseous species or bound to fine particles. Accurate

R. S. José (✉) · J. Pérez
Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid, Campus de Montegancedo, Boadilla del Monte, 28660 Madrid, Spain
e-mail: roberto@fi.upm.es

M. Callen · J. López · A. Mastral
Instituto de Carboquímica (ICB-CSIC), c/Miguel Luesma Castán, 4, 50018, Zaragoza, Spain

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_24,

calculation of gas/particle partitioning on a regional/local scale requires information about the spatially and temporally resolved physical characteristics and chemical compositions of atmospheric aerosols. Since urban environments constitute a main focus of atmospheric PAHs concentrations [12], there is a great concern of determining their ambient air concentrations, transport and pollution sources.

To investigate the pathways of PAHs, it is indispensable to apply proper emission data and meteorological fields in addition to pollutant properties. To simulate adequately the processes that determine the transport, degradation and deposition of BaP and other PAHs, it is essential to have a chemical transport model that represents the state of the art in atmospheric modelling as well as in aerosol chemistry and dynamics.

BaP Modelling

We used the Community Multiscale Air Quality (CMAQ) model of the US-EPA [3, 4]. This Eulerian modelling system can be used to model the atmospheric distribution of aerosols. The CMAQ already includes a detailed representation of atmospheric aerosols and it can be expanded to other substances. It can be conveniently linked to the mesoscale meteorological model Weather & Research Forecasting system (WRF) developed by NCAR and others [8, 11], which is used here to calculate the meteorological input fields so CMAQ model is driven by WRF meteorological model with 1 hour temporal resolution. WRF model can be directly linked to CMAQ via a Meteorological Chemistry Interface Preprocessors (MCIP).

The purpose of this study is to add modules to simulate BaP with the CMAQ model version 4.7.1 (June 2010). CMAQ can be used to study the behavior of air pollutants from local to regional scales. The model includes gas phase, aerosol and aqueous chemistry. In this study, the CB05 mechanism [13] is used with the Euler Backward (EBI) solver [6]. WRF meteorological model is a 3D non-hydrostatic prognostic model that simulates mesoscale atmospheric circulations. In this work the version 3.3.1 (September 2011) is used. The link between WRF and CMAQ is developed with the MCIP version 3.6 (June 2010). Meteorological model is driven by data from the global meteorological model Global Forecast System (GFS) each 6 hours. For nesting, a two-way scheme is used with the meteorological domains.

BaP Extension

In this contribution, an extension to CMAQ (CMAQ-BaP) is presented. We use the new extended version of CMAQ (CMAQ-BaP) developed by us to investigate BaP spatial and temporal distribution over Iberian Peninsula and Zaragoza area. The basic version of CMAQ is modified to read emissions and to simulate the transport, scavenging, and deposition of BaP. CMAQ wet deposition includes rainout and washout from convective precipitation and scavenging. Two new BaP species have been added, aerosol (BAP) and gas (SV_BAP). BaP in the gas-phase primarily react with OH although, the representative lifetime with respect to reaction with OH is higher than BaP in the particulate-phase, so the BaP in gas phase is treated as inert gas (no chemical reactions). BaP is emitted in particle phase, 99% accumulation mode (0.1–2.5 μm) and 1% Aitken mode (0.1 μm). Deposition and scavenging of the aerosol BaP is the same parameterizations as for CMAQ organic aerosols. Deposition velocity of BaP gas is the same as the semi-volatile alkanes that is calculated by CMAQ.

The gas-particle partitioning has a substantial effect on transport in case of BaP. We added new developments to simulate gas phase and organic carbon (OC)-bound particulate transport and chemistry. The BaP extension to CMAQ calculates the partition of the compound between the gas and the particle phase. Absorptive mechanism plays the dominant role in the air affected by urban sources, although adsorption mechanism would be important when atmospheric particulate material is comprised solely of mineral materials, urban particulate material generally contains a significant amount of amorphous organic carbon. An OC absorption model is implemented to model gas-particle partitioning of BaP based on the absorptive partitioning model of Pankow [10] and Odum [9]. The BaP concentration in aerosol phase is calculated according to equation (1):

$$C_{aer} = C_{tot} - C^{*}_{sat} \frac{C_{aer}/m}{Tot_{org}} \tag{1}$$

where:

C_{aer}: Concentration in the particle phase
C_{tot}: Total concentration (gas + particle)
C_{sat}: Saturation concentration
m: Molecular weight
Tot_{org}: Total abosorbing organic mass

The inverse of the saturation concentration of the compound is equivalent to the definition of the partitioning coefficient used in [10]. Saturation concentration is modified as a function of temperature.

The total absorbing organic mass (Tot_{org}) used in equation (1) is defined as equation (2):

$$Tot_{org} = \sum_{j=1}^{n} \frac{C_{aer}}{m} + \frac{C_{init}}{m_{init}} \tag{2}$$

where n is the number of compounds in the absorbing organic particle phase, m is the molecular weight and C_{init} is any additional absorbing material in the particle phase. So the total absorbing organic mass is not known a priory and the set of nonlinear equations (j = 1…n) is solved by an iteration method using a globally convergent variation of Newton method.

The gas phase concentrations of the BaP have to exceed a threshold concentration before can be transferred to the particle phase. Until the threshold value is reached, BaP gas does not partition to the particle phase. If the pre-existing organic aerosol concentrations are zero gas/particle equilibrium is established.

We incorporate also BaP loss due to oxidation by Ozone (O3) with a first order reaction. Reaction with ozone can be an important degradation pathway for the particulate BaP in the atmosphere. Degradation of the aerosol BaP by the Ozone has been implemented into CMAQ based on Kwamena et al. [7] following the equation 3:

$$K = \frac{K_{\max} K_{o_3} [O_3]}{1 + K_{o_3} [O_3]} \tag{3}$$

where:

K: Degradation rate cinstant
K_{max}: Maximum rate coefficient (0.06 s^{-1})
K_{O_3}: Ozone gas to surface equilibrium constant (0.028 $10^{-13} cm^3$)
$[O_3]$: Ozone concentration

BaP Simulation

The mother modelling domain is a Lambert Conformal Conic projection centred at 41.69 N, 0.89 W, with 67 × 55 grid squares of 27 km resolution for Iberian Peninsula. Three nesting domains have been setup centered over Zaragoza city. First nesting level is 49 × 49 grid squares of 9 km resolution, second 31 × 37 of 3 km and finally 28 × 28 of 1 km resolution. We use 15 vertical terrain following levels up to 100 hPa.

The accuracy of simulations depends strongly on emission data and unfortunately there are uncertainties in BaP emissions. The main source of BaP is incomplete combustion processes of organic material, in particular wood and coal in private households. Industrial heating and cookeries as well as road traffic are also large sources of BaP. Emissions of BaP are emitted as particle phase. Gridded hourly emission data are created from annual total emission estimates. Emissions of main pollutants, ammonia, nitrogen oxides, sulphur dioxide, and non-methane volatile organic compounds as well as emissions of particulate matter with diameter of less than 10 or 2.5, including anthropogenic point and diffuse sources, were provided by the Netherlands Organization for Applied Scientific Research (TNO) with 7 km of resolution. In case of BaP emission we decide to use global emission from the European Monitoring and Evaluation Program (EMEP) inventory with 0.5 degrees of spatial resolution. The EMEP dataset is compiled from BaP emissions which are officially reported by the parties under the convention on Long-Range Transport. The uncertainties of emission inventories for PAHs in general were estimated to be within a factor of 2–5 [1].

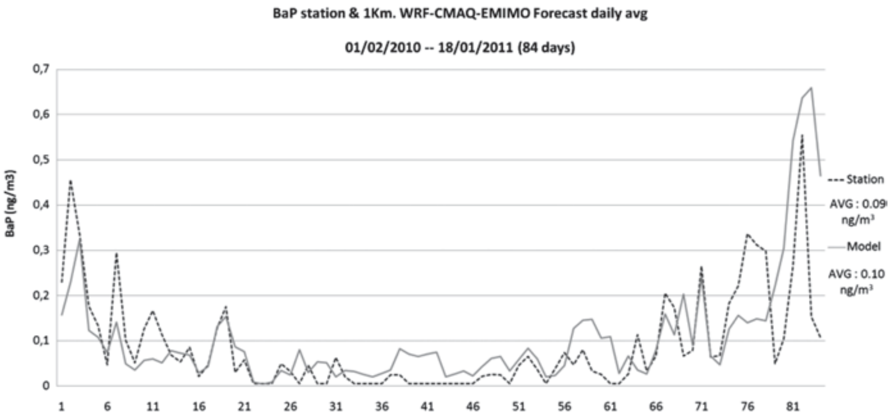


Fig. 1 Comparison BaP model 1 km resolution (*solid line*) and BaP monitoring station (*dot line*). Daily average during 12 weeks (1 week per month)

The spatial distribution of BaP emissions was interpolated to our model grid. A projection process from source grids to Lambert conformal conic domains was developed through an interpolation process with mass conservation.

The BaP emissions are broken down into the SNAP 12 categories. In case of high resolution domains (1 km, 3 km and 9 km), a top- down process scheme has been used to going to the desired resolution. The downscaling process is based on surrogates to allocate the emission into the model grid.

Model runs for 12 weeks (11 weeks from 2010 and 1 from 2011) corresponding to the field campaign. The measurement data are used to examine the model results under very different meteorological conditions. The model run was started one day before the time period of interest began to avoid the influence of the initial conditions. These 12 weeks are representative for a year simulation.

Results

To evaluate the atmospheric concentrations calculated with the new CMAQ-BaP extension, modelled values are compared to observations. The monitoring site was a sub-urban area mainly influenced by vehicle traffic due to the proximity of the highway. It is used for providing daily BaP concentrations. For rest of pollutants we have available data from 32 air quality networks (26 from Aragon air quality network and 6 from Zaragoza air quality network). These stations provided hourly concentrations of over mainly pollutants (NO2, O3, SO2, PM10). BaP modelled concentrations for the monitoring location was then compared to the actual daily mean measurements, Fig. 1.

The CMAQ-BaP model shows mean concentration of 0.10 (ng/m3) and measurement is 0.09 (ng/m3), so good results are obtained because model and measurement

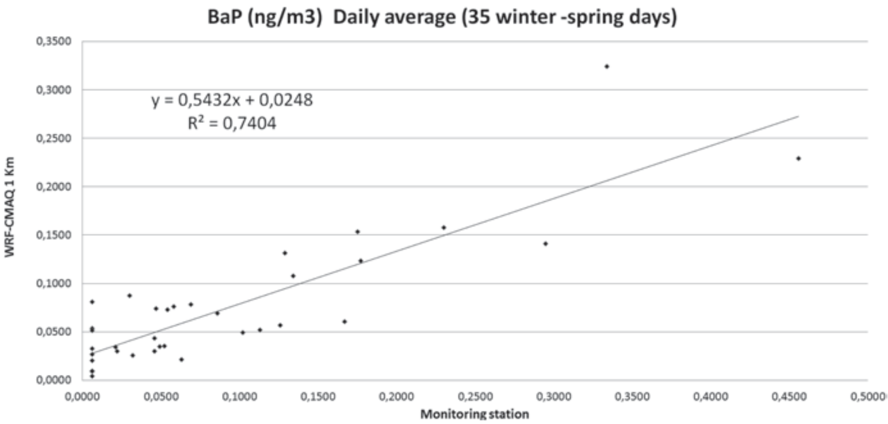


Fig. 2 Linear regression of BaP model 1 km resolution (*y axes*) and BaP monitoring station (*x axes*). Daily average during 35 winter and spring days. R = 0.86

values are quite close. Fig. 2 compares the measured mean values with calculated from simulations in a scatterplot.

It suggests that the correlation between measured and simulated values is good, as also indicated by Pearson's correlation coefficient r of 0.86.

The agreement is generally satisfactory, the best results are observed in winter period, which is the most important for the BaP concentrations. The model validation shows the BaP extension performance is correct over the modeled area. The BaP concentrations agree well with the observations, particularly very high BaP peaks are resolved by the extended model.

The modelling system reproduces the degree of seasonality of the BaP, with higher concentrations in the winter months. This is particularly prevalent at urban locations, where domestic combustion is the major source. In the rest of areas, for example industrial zones, concentrations are affected by other meteorological parameters, temperature, boundary layer, wind speed and direction.

Now we can see in Fig. 3 the BaP spatial surface results over Iberian Peninsula (27 km resolution) and in Fig. 4 Zaragoza (1 km resolution).

The data are average of the 12 weeks simulated. The simulation shows the BaP hot spots over Iberian Peninsula and Zaragoza. Some regions with higher BaP concentrations than the EU target value of 1 ng/m3 has been identified close to the metropolitan regions around Porto and Lisbon (Portugal), North west and South of Spain.

In case of the 1 km resolution domain, higher concentrations are located close to roads (with lines) and one important emission point is located in the north-west area of the city but it is not close to target value of 1 ng/m3. Due to the relatively short lifetime of BaP, the spatial distribution of BaP concentrations in the atmosphere is dominated by local emissions and meteorological conditions.

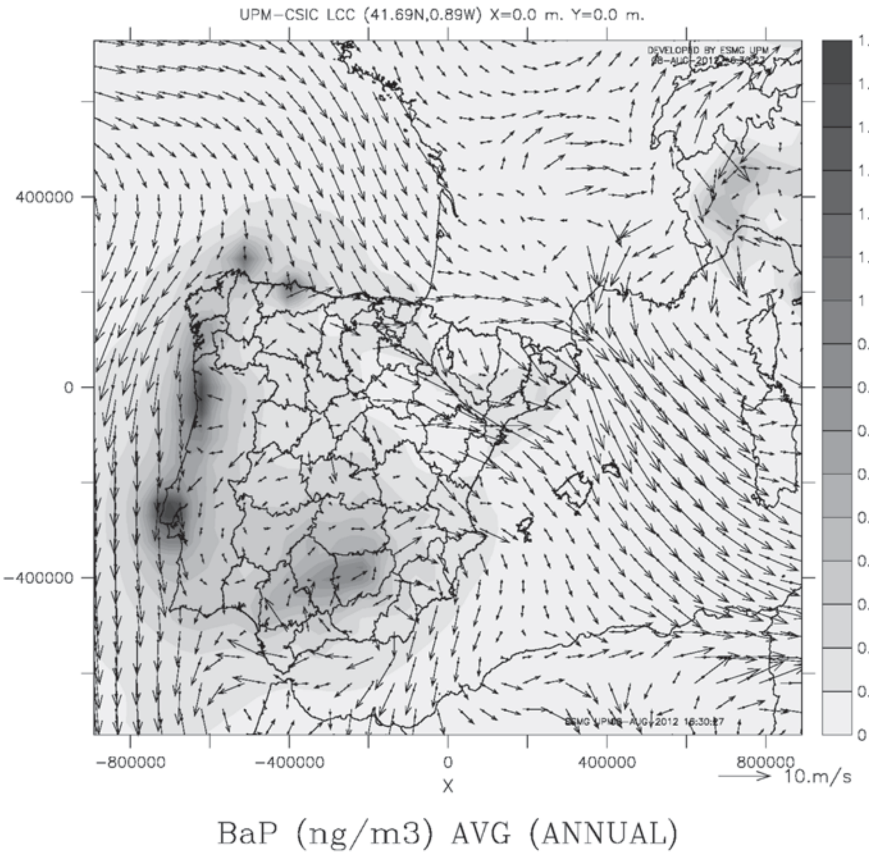


Fig. 3 BaP surface results, temporal average. over Iberian Peninsula with wind vectors

Conclusions

We have added the ability to simulate the atmospheric behavior of BaP to CMAQ model. This includes the addition of two processes: gas/particle partitioning and degradation by ozone. Other aspects such as transport and diffusion are developed using de CMAQ framework. Also the CMAQ aerosol module provides the necessary aerosol parameters to the gas/particle partitioning model.

WRF-CMAQ modelling system, which has been extended to simulate BaP concentrations, can be used to get the spatial and temporal distribution of BaP concentrations across large areas domain and to also assess the impact of different emissions reduction strategies. Generally, the model calculates annual average BaP concentrations over Zaragoza below the European lower assessment threshold of 0.4 ng/m3. But several regions over Iberian Peninsula where the European target

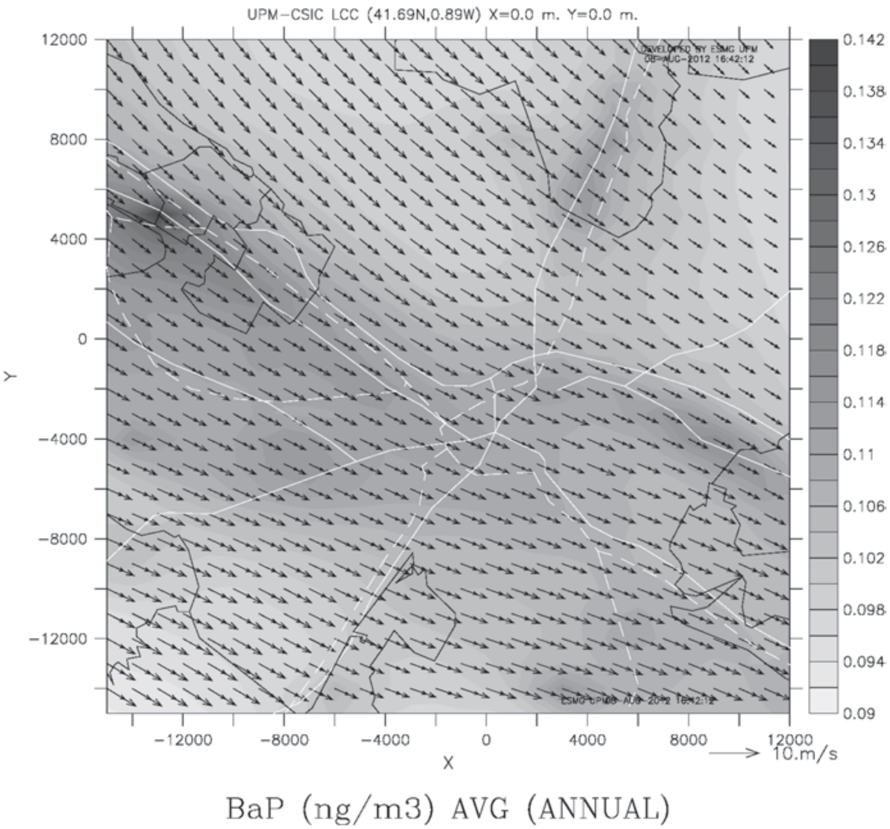


Fig. 4 BaP surface results, temporal average. over Zaragoza with wind vectors

value of 1 ng/m3 is exceeded have been identified. Finally the results from the modelling can be used to assess the possible health impacts of BaP concentrations above the EU target value.

The evaluation results in this paper suggest that the new CMAQ-BaP is able to simulate fairly well the ambient air concentrations of BaP. For further verification of the model performance, long-term runs will be carried out and more measurement points will be used.

Acknowledgments Authors would like to thank Aula Dei-CSIC (R. Gracia), the Ministry of Science and Innovation (MICIIN) and the E plan for supporting the project CGL2009–14113-C02–01. J.M. López would also like to thank the MICIIN for his Ramón y Cajal contract. Also to thank Departamento de Medio Ambiente del Gobierno de Aragón, Dirección General del Catastro del Gobierno de Aragón, Sistema de Información Territorial del Gobierno de Aragón and Ayuntamiento de Zaragoza. Authors thankfully acknowledge the computer resources, technical expertise and assistance provided by the Centro de Supercomputación y Visualización de Madrid (CeSVIMa) and the Spanish Supercomputing Network (BSC).

References

1. Berdowski J et al (1997) The European emission inventory of heavy metals and persistent organic pollutants for 1990. TNO-MEP and Umweltbundesamt
2. Boström CE, Gerde P, Hanberg A, Jernström B, Johansson C, Kyrklund T, Rannug A, Törnqvist M, Victorin K, Westerholm R (2002) Cancer risk assessment, indicators and guidelines for polycyclic aromatic hydrocarbons in the ambient air. Environ Health Persp 110:451–488
3. Byun D, Ching J (1999) Science algorithms of the EPA Models-3 Community multiscale air quality (CMAQ) ModelingSystem EPA/600/R-99/030. /http://www.epa.gov/asmdnerl/models3/doc/science/science.htmlS
4. Byun D, Schere K (2006) Review of the governing equations, computational algorithms, and other components of the models-3 community multiscale air quality (CMAQ) modeling system. Appl Mech Rev 59:51–77
5. Fernández P, Grimalt JO, Vilanova RM (2002) Atmospheric gas/particle partitioning of polycyclic aromatic hydrocarbons in high mountain regions of Europe. Environ Sci Technol 36:1162–1168
6. Hertel O, Berkowicz R, Christensen J, Hov (1993) Test of two numerical schemes for use in atmospheric transport-chemistry models. Atmos Environ 27:2591–2611
7. Kwamena N, Thornton J, Abbatt J (2004) Kinetics of surface-bound benzo[a]pyrene and ozone on solid organic and salt aerosols. J Phys Chem A 108 (52):11626–11634
8. Michalakes J, Chen S, Dudhia J, Hart L, Klemp J, Middlecoff J, Skamarock W (2001) Development of a next generation regional weather research and forecast model. In: Zwieflhofer W, Kreitz N (eds) Developments in teracomputing, proceedings of the ninth ECMWF workshop on the use of high performance computing in meteorology. World Scientific, Singapore, pp. 269–276
9. Odum JR, Hoffmann T, Bowman F, Collins D, Flagan RC, Seinfeld JH (1996). Gas/particle partitioning and secondary organic aerosol yields. Environ Sci Technol 30:2580–2585
10. Pankow JF (1994) An absorption model of gas-particle partitioning of organic compounds in the atmosphere. Atmos Environ 28:185–188
11. Skamarock WC, Klemp JB, Dudhia J, Gill D, Barker D, Wang D, Powers JG (2005). A description of the advanced research WRF Version 2, NCAR Technical Note NCAR/TN-468+STR
12. Tsapakis M, Stephanou EG (2005) Occurrence of gaseous and particulate polycyclic aromatic hydrocarbons in the urban atmosphere: study of sources and ambient temperature effect on the gas/particle concentration and distribution. Environ Poll 133:147–156
13. Yarwood G, Rao S, Yocke M, Whitten G (2005) Updates to the carbon bond chemical mechanism: CB05 final report to the US EPA, RT–0400675
14. Zhang Y, Tao S (2009) Global atmospheric emission inventory of polycyclic aromatic hydrocarbons (PAHs) for 2004. Atmos Environ 43:812–819.

Very High Resolution Urban Simulations with WRF/UCM and CMAQ over European Cities

R. San José, J.L. Pérez and R.M. González

Abstract The results showed in this paper, are part of the activities into the FP7 EU project "Sustainable urban planning decision support accounting for urban metabolism (BRIDGE)". It provides the means to close the gap between bio-physical sciences and urban planners and to illustrate the advantages of accounting for urban metabolism issues on a routine basis in design decisions. BRIDGE is focused on the following components of urban metabolism: Energy, water, carbon and pollutants. WRF and CMAQ models are used in very high spatial resolution (200 m) to analyze and study the impact of urban metabolism with different alternatives in urban planning scenarios over five European cities: Helsinki, Finland; Athens, Greece; London, United Kingdom; Firenze, Italy and Gliwice, Poland. An off-line linkage between WRF and CMAQ has been implemented through the MCIP interface processor. The high resolution datasets have been integrated in a Decision Support System (DSS). In general the model—when running with very high spatial resolution—produces good results although the quality in slightly reduced. Some numerical stability could be involved in the very high spatial resolution run.

Introduction

Numerical techniques for simulation of the atmospheric dynamics have been improved substantially and the advanced of the computer power allows performing very high resolution simulations.

One of the more advanced mesoscale meteorological model is the Weather Research and Forecasting (WRF) [9] model developed by NCAR (US). Over urban areas the resolution has to become higher and mesoscale meteorological models have been "urbanized" in order to introduce the urban effects in the mesoscale flow

R. S. José (✉) · J. L. Pérez
Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid, Campus de Montegancedo, Boadilla del Monte, 28660 Madrid, Spain
e-mail: roberto@fi.upm.es

R. M. González
Department of Meteorology and Geophysics, Faculty of Physics, Ciudad Universitaria, 28040 Madrid, Spain

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_25,

In order to better represent the physical processes involved in the exchange of heat, momentum, and water vapor in urban environment in mesoscale model, the Urban Canopy Model (UCM) [6] is used with the WRF model. The main purpose of the coupled model is to improve the description of lower boundary conditions and to provide more accurate forecasts for urban regions.

WRF/UCM outputs have been used to drive air quality simulations with the Community Multi-scale Air Quality (CMAQ) [1] modelling system (EPA, US). An off-line linkage between WRF and CMAQ has been implemented through the MCIP interface processor, EMIMO emission model developed by UPM is used to estimate emissions, including traffic emissions. Some spatial surrogates, such as population, building density, roads, land use, are used to allocate macro-scale emissions to grid cells as required by the air quality model.

The results showed in this paper, are part of the activities into the FP7 EU project "Sustainable urban planning decision support accounting for urban metabolism (BRIDGE)". It provides the means to close the gap between bio-physical sciences and urban planners and to illustrate the advantages of accounting for urban metabolism issues on a routine basis in design decisions. BRIDGE is focused on the following components of urban metabolism: Energy, water, carbon and pollutants. There are many challenges of the sustainable urban planning with regards to the above components (for example to optimize energy efficiency of urban structure, to minimize primary water consumption, to minimize the emissions to atmosphere, reduce air pollution, etc.) This information can be extracted from meteorological and air pollution models.

The WRF/UCM-CMAQ high resolution (200 m.) simulated datasets have been integrated in a Decision Support System (DSS). The environmental impacts of the respective physical flows can be assessed with the DSS which will be used to support the decision making needed to achieve the above challenges by proposing quantitative measures and guidelines for sustainable use of energy and materials in urban planning. Five European cities have been selected as BRIDGE case studies: Helsinki, Finland; Athens, Greece; London, United Kingdom; Firenze, Italy and Gliwice, Poland.

Simulations Setup

The implemented models have been run over five European cities: Helsinki (Finland), Athens (Greece), London (United Kingdom), Firenze (Italy) and Gliwice (Poland) for full year 2008 and 2010 summer period. WRF/UCM has been implemented for all cities and CMAQ to Athens and Florence.

Two domains have been set. First level: 37*37 grid cells, 5.4 km. grid resolution and the second level: 28*28 grid cells, 0.2 km. grid resolution. Chemical simulations have to be run with one grid cell less by each side, to make the coupling of the WRF and CMAQ domains. We run the WRF model using the initial and boundary conditions from the global model GFS (Global Forecast System).

We have set the following configuration in WRF. Cumulus parameterization: Grell 3D ensamble scheme [4]. PBL scheme and diffusion: Yonsei Universtiy (YSU) PBL [5]. Explicit moisture scheme: Lin et al. Scheme microphysics [7]. Radiation schemes: Rapid radiative transfer model (RRTM) longwave radiation [8]. Simple cloud-interactive shortwave radiation scheme Dudhia radiation [3] Land surface model: Noah/UCM [2].

It is necessary to prepare different sets of input data. Emissivity and albedo data have been provided by FORTH, data are images which are in geotiff format and they are got from the MODIS satellite, 1 km of spatial resolution. For land uses, Corine Land Cover (CLC 2000) raster data with 100 m of resolution are used by default, these data are improved with the supplied information by the city authorities. The CLC classification is different that the USGS/UCM used in WRF/UCM-CMAQ models, so we have needed translate CLC categories to USG-UCM classification. For topography, Aster GDEM raster data with 30 m of resolution are used by default, these data are improved with the supplied information by the city authorities.

The grid based emission inventory for urban areas have been established using traffic flow to transport snap activities and land uses plus building density to the rest of snap activities. Cities authorities have sent information about traffic flow at some measurement points of the city. Krigging interpolation procedure is applied to estimate the traffic flow in each grid for Florence and Athens, according to the streets distributions.

Results

Figure 1, shows the spatial distribution of sensible heat flux over the five cities during 2008 year average, maximum values are observed at Florence and Athens (72 and 102 W/m^2) located on the south of Europe with more radiation reaching the surface. Helsinki and Gliwice have the same average value of 52 (W/m^2). The most negative values are located over the London River.

Fig. 2 displays latent heat flux partitioning into canopy evaporation, soil evaporation, and transpiration over Florence domain. The maximum values of latent heat flux are observer over non-urban areas and the main contribution to the latent heat flux is made by the transpiration effect.

Ozone and Nitrogen dioxide concentrations ($\mu g/m^3$) can be observed in the Fig. 3. The WRF-CMAQ simulation with 200 m resolution is over Athens during 2008. The higher values of Nitrogen dioxide are located over the city center with high traffic density and for the Ozone the maximum values are moved to the surroundings areas. Figure 4, 5 show the comparison between the model results at 5.4 km (left) and 0.2 km (right) of spatial resolution and measurements on Florence and Gliwice of air temperature (upper) and sensible heat flux (bottom).

In case of the air temperature the regression coefficient is more than 0.9 and for the sensible heat flux is about 0.8 in Florence and 0.7 and Gliwice. The results at

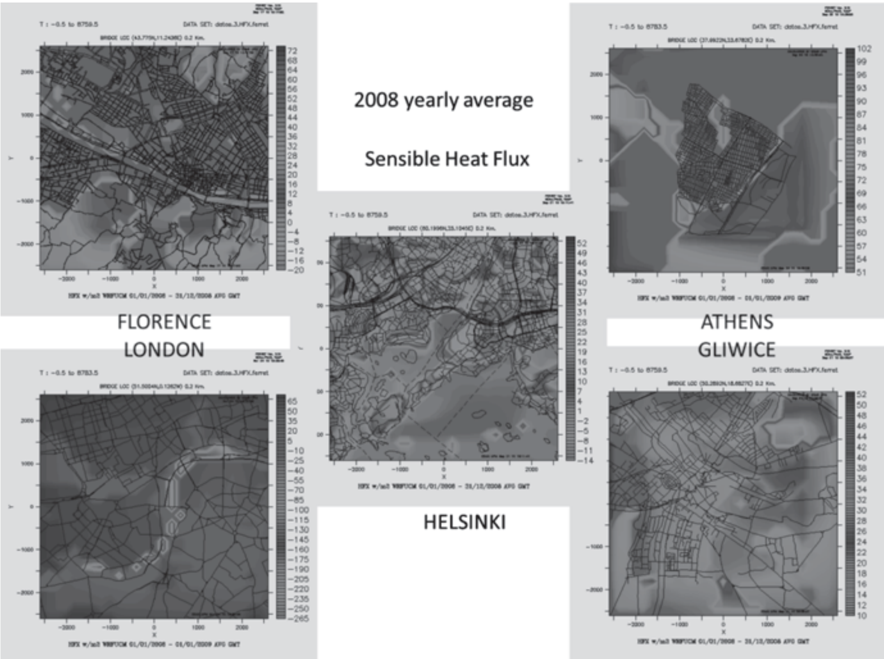


Fig. 1 Sensible heat flux (W/m[2]) over Florence, London, Helsinki, Athens and Gliwice. 2008 Annual average

the coarse resolution are much better than the high resolution, but high resolution simulations provide more detailed information to the urban metabolism.

We can see Fig. 6 the comparison between observed and modeled pollution data, NO_2 (left) and O_3 (right) for the simulated domain over Athens with 200 m resolution, full year 2008 (daily average values). The performance of the modeling system is very good, with average values very close between measurements and modeled and correlation coefficients over 0.7. Finally in the Fig. 7 we can see the comparison of air temperature (upper) and wind speed (bottom) at a London measurement with the model results with 0.2 km. resolution (left) and 5.4 km. resolution (right). In case of the 0.2 km resolution when the wind speed in growing a numerical instability is produced and the wind speeds are not realistic (hurricane winds) but air temperature results are agreed. The simulations with 5.4 km resolution are more stable but they do not supply enough information to the urban metabolism.

Conclusions

We have been able to implement a system of air quality modelling (Meteorology and Pollution) with high resolution, 200 m, successfully. The new tool is an integrated system where was included the mesoscale models WRF/UCM-EMIMO-

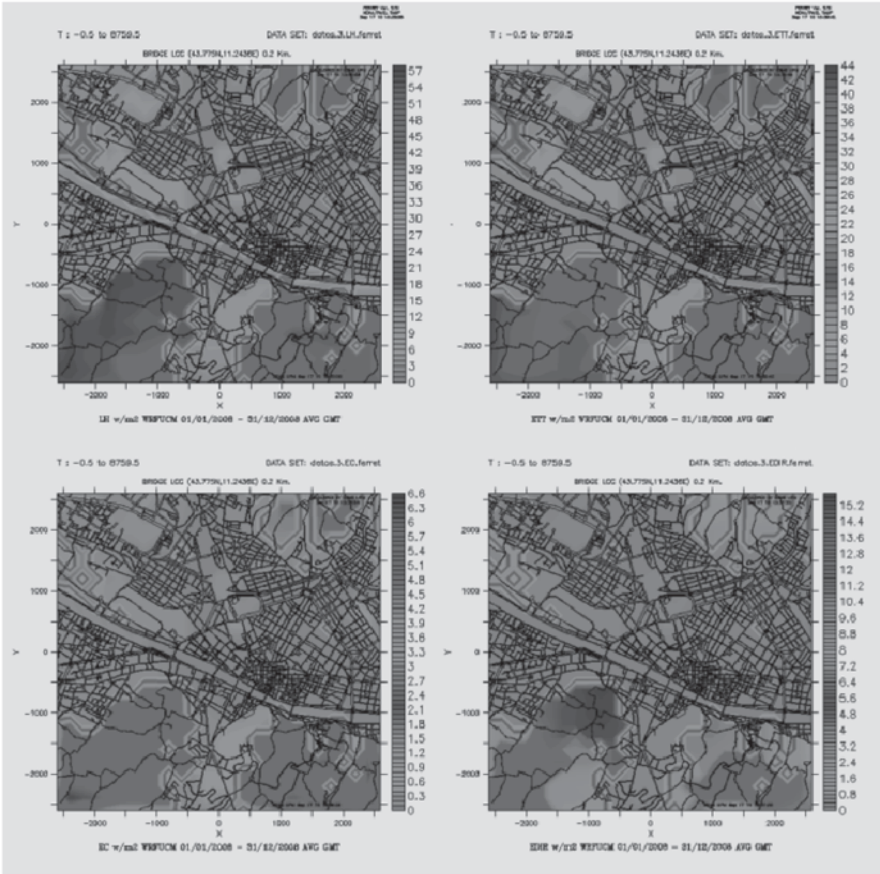


Fig. 2 Latent heat flux (*upper-left*), total plant transpiration (*upper right*), canopy water evaporation (*lower-left*) and direct soil evaporation (*lower-right*) during 2008 year average (W/m^2)

CMAQ. So, the new tool allows urban-simulations for analysis and study of the urban metabolism which is an essential tool for urban planning and policy makers. The results for analysing the urban metabolism at very high spatial resolution are very promising; the system has been applied to fire European cities with very good results compared with measured data.

The comparisons between observed and modeled results are excellent for several parameters such as temperature and heat fluxes. Wind speed comparisons are found to be poorer than for temperature and fluxes results. The runs show that increase in the high spatial resolution produces a decrease on the quality of the comparison between observational monitoring data and modeling data.

In general the comparisons between observed data and modeled data is very good, and simulated values reasonably follow the trend of measurements In London during a few weeks, the wind speed is separately substantially to the observed

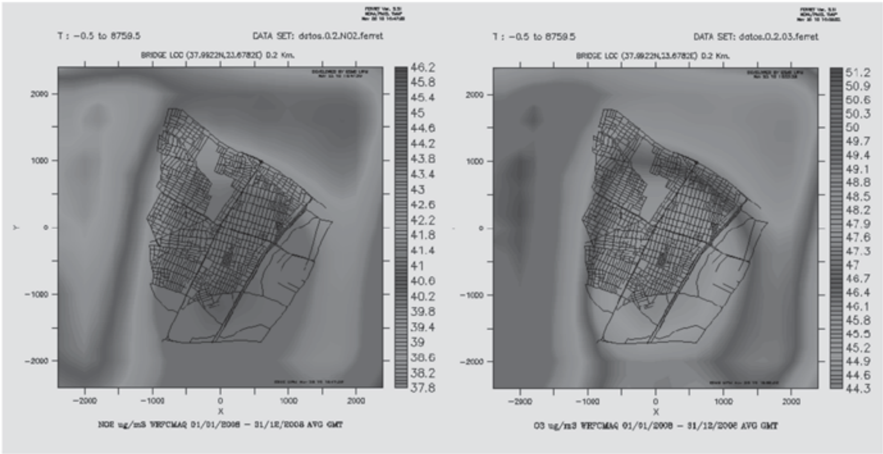


Fig. 3 Air pollution concentrations (μg/m^3) over Athens. 2008 annual average for O_3 (*right*) and NO_2 (*left*). Simulation with WRF-CMAQ

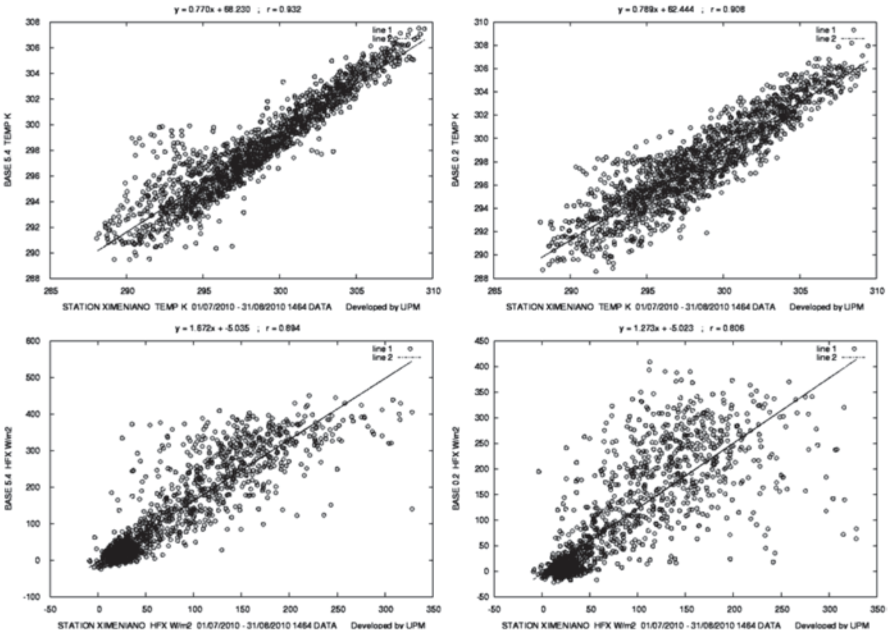


Fig. 4 Florence comparison 01/07/2010 – 31/08/2010. *Left*: 5.4 km. resolution. *Right*: 0.2 km. resolution. *Top*: Air temperature (K). *Bottom*: Sensible heat flux (W/m2). *X axis* measurement and *Y axis* model results

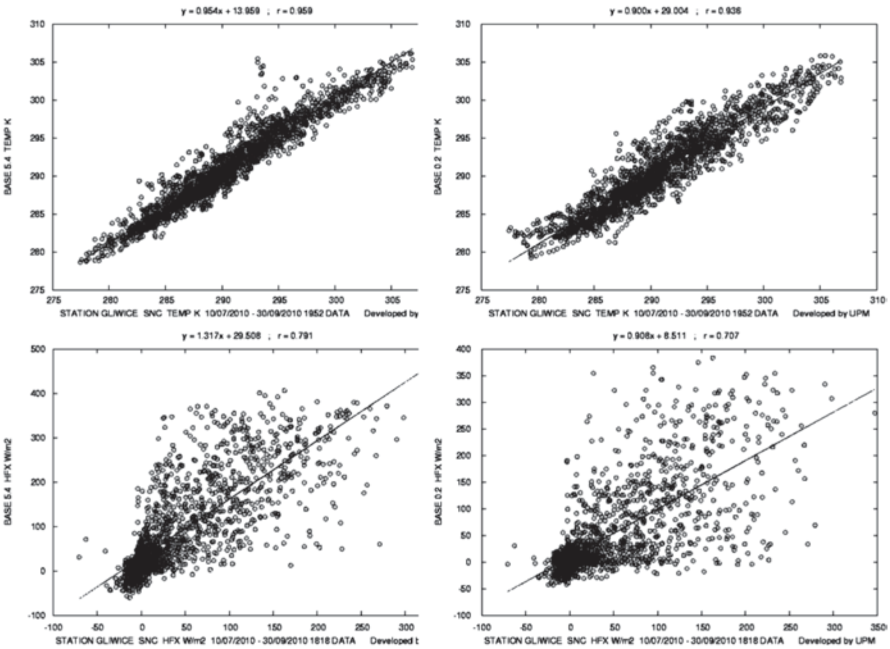


Fig. 5 Gliwice comparison 10/07/2010 – 30/09/2010. *Left*: 5.4 km. resolution. *Right*: 0.2 km. resolution. *Top*: Air temperature (K). *Bottom*: Sensible heat flux (W/m2). *X axis* measurement and *Y axis* model results

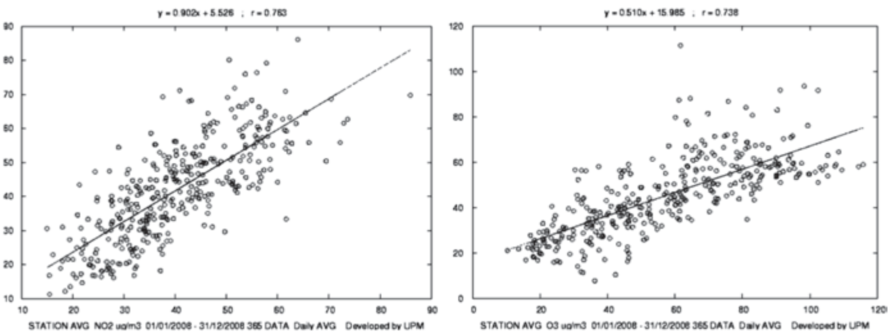


Fig. 6 Athens comparison 2008 (daily average values) 200 m resolution. *Left*: O_3 (μg/m3). *Right*: NO_2 (μg/m3). *X-axis* measurement and *Y-axis* model results.

wind speed. Some numerical instability could be present in the London runs which are probably due to the height of the buildings and abrupt changes in topography heights.

The limitations in computer time are the main cause for not having run the high spatial resolution runs (200 m) following the nesting rate approach of three times as required for numerical and stability reasons. An important controversy is actually

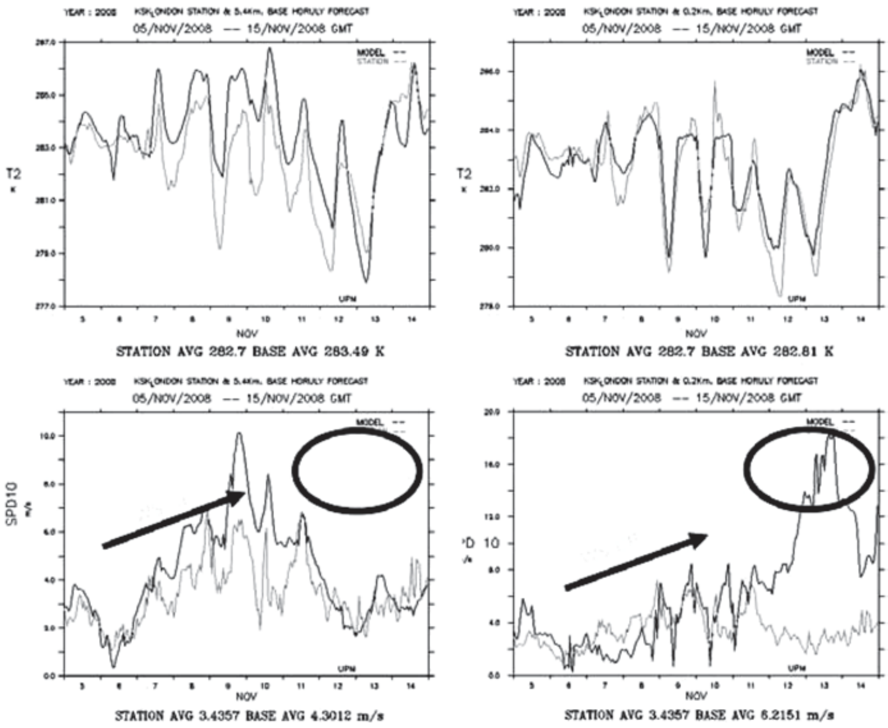


Fig. 7 London comparison 05/10/2008– 14/10/2008. *Left*: 5.4 km. resolution. *Right*: 0.2 km. resolution. *Top*: Air temperature (K). *Bottom*: Wind speed (m/s). *Dark lines* are model results and *light lines* are measurements

in place for very high spatial resolution WRF runs (200 m, 600 m) and numerical issues are raised together with a substantial increase of vertical layers (higher than 100 vertical layers is suggested by several authors). More investigation is needed on the issue related to running WRF under super-high spatial resolution.

Acknowledgments We have used the computer resources, technical expertise and assistance produced by the Centro de Supercomputación y Visualización de Madrid (CESVIMA) and the Spanish Supercomputer Network. The research leading of these results has received funding form the European Community's Seventh Framework Programme (FP7/2007-2013) under gran agreement nº 211345.

References

1. Byun DW, Young J, Gipson G, Godowitch J, Binkowsky F, Roselle S, Benjey B, Pleim J, Ching JKS, Novak J, Coats C, Odman T, Hanna T, Alapaty K, Mathur R, McHenry J, Shankar U, Fine S, Xiu A, Lang C (1998) Description of the models-3 community multiscale air quality (CMAQ) model. Proceedings of the American Meteorological Society, 78th Annual Meeting Phoenix, AZ, Jan. 11-16, 264–268.

2. Chen F, Kusaka H, Tewari M, Bao J-W, Kirakuchi H (2004) Utilizing the coupled WRF/LSM/Urban modeling system with detailed urban classification to simulate the urban heat island phenomena over the greater Houston area. In: Proceedings of the 5th conference on urban environment, 22–26 August 2004, Vancouver, Canada
3. Dudhia J (1989) Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional Model. J Atmos Sci 46:3077–3107
4. Grell GA, D Devenyi (2002) A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys Res Lett 29(14):381–384
5. Hong S-Y, Dudhia J (2003) Testing of a new non-local boundary layer vertical diffusion scheme in numerical weather prediction applications. In: Proceedings of the 16th conference on numerical weather prediction. Seattle, WA.
6. Kusaka H, Kondo H, Kikegawa Y, Kimura F (2001) A simple-layer urban canopy model for atmospheric models: comparison with multi-layer and slab models. Boundary-Layer Meteorology 101:329–358
7. Lin Y, Farley RD, Orville HD (1983) Bulk parameterization of the snow field in a cloud model. J Appl Meteor 22:1065–1092
8. Mlawer, Taubman SJ, Brown PD, Iacono MJ, Clough SA (1997) Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. J Geophys Res 102(D14):16663–16682
9. Skamarock WC, Klemp JB, Dudhia J, Gill D, Barker W, Wang JG, Powers (2005) A description of the advanced research WRF Version 2. NCAR Technical Note NCAR/TN-468 + STR

Modeling Urban Air Quality in Beijing during the Olympic Summer Games 2008

Stefanie Schrader, Heike Vogel, Bernhard Vogel, Klaus Schäfer, Renate Forkel, Peter Suppan, Guiqian Tang, Yuesi Wang, Nina Schleicher and Stefan Norra

Abstract Air pollution is one of the most significant environmental concerns in China today, particularly in the highly industrialized Eastern Chinese mega cities. During the Olympic Summer Games in 2008, the air pollution in China's capital city of Beijing became an issue of international interest. Air pollution in Beijing has a number of key constituent components, including anthropogenic gaseous pollutants, and small airborne particles from natural and anthropogenic sources. These often exceed WHO recommended levels. To investigate the influence of anthropogenic nitrogen oxides (NO_x) and ozone (O_3) on the air quality in Beijing and its vicinity, the fully online coupled model system COSMO-ART is applied for the first time to Northern China. For this purpose a five-day simulation period from August 4th to 8th in 2008 was conducted. The simulated NO_x and O_3 concentrations are compared to observations from a measurement station located in Beijing. Backward trajectories are calculated to get more information about the source areas of the air pollutants. Comparisons of measured and modeled NO_x and O_3 showed that the daily course of the concentrations can be reproduced by the model very well.

S. Schrader (✉) · N. Schleicher · S. Norra
Institute of Geography and Geoecology (IfGG), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
e-mail: stefanie.schrader@kit.edu

S. Schrader · K. Schäfer · R. Forkel · P. Suppan
Institute of Meteorology and Climate Research—Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

H. Vogel · B. Vogel
Institute of Meteorology and Climate Research—Tropospheric Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

G. Tang · Y. Wang
Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), Beijing, P.R.China

N. Schleicher · S. Norra
Institute of Mineralogy and Geochemistry (IMG), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_26,

Introduction

Most cities in Beijing are suffering from increasing air pollution due to the ongoing industrialization and urbanization processes in the country. Beijing is among these highly polluted Chinese mega cities, which are mainly located in the rapidly developing economic area of Eastern China. Due to the ability of airborne pollutants to migrate significant distances, the air quality of Beijing and its surrounds is highly influenced not only by local anthropogenic emissions but also by regional sources [8]. The main air pollutants affecting Beijing are NO_x, CO, O_3 and particulate matter from both anthropogenic and natural sources. The combined loading of the anthropogenic pollutants and aerosols from natural sources, such as mineral dust, can lead to a severe decrease of air quality which has strong negative effects on the residents' health [1]. Moreover, the gaseous pollutants can be precursors for secondary particle formation processes. These secondary particles can act as cloud condensation nuclei, altering cloud formation processes and have influence on the atmospheric long- and shortwave radiation budget [3, 6].

During the Olympic Summer Games from August 8th to 24th 2008, the air pollution in Greater Beijing came under international scrutiny. During this period, several measures were undertaken to reduce the amount of gaseous pollutants and PM_{10} and $PM_{2.5}$ concentrations in the urban atmosphere [5, 8]. To date, many studies have investigated the effectiveness of these measures on the air quality in Beijing [5, 8]. From these studies, it is evident that the measures taken in Beijing during the Olympic Games were effective in drastically reducing concentrations of gaseous pollutants including NO_x, SO_2, CO and O_3 in particular, as well as $PM_{2.5}$ [5, 11]. However less modeling studies have been conducted to investigate the reduction of air pollutants during the Olympics. Streets et al. [8] used the US EPA's Models-3/CMAQ to estimate the influence of local and regional sources to the $PM_{2.5}$ and ozone concentrations in Beijing. The studies of Wang et al. [7] focus on the quantification of new build emission inventories for 2008. Wang et al. [11] tried to analyze the influence of measures in Beijing on a rural site situated downwind of the city using the GEOS-Chem model system.

Simulations with COSMO-ART were conducted to identify the influence of NO_x and O_3 on the air quality situation of Greater Beijing during August 2008 This is the first attempt to model NO_x and O_3 with the comprehensive model system COSMO-ART for Eastern Asia. The focus of this study lies on the Greater Beijing region, as well as Hebei, Shandong and Shanxi province to investigate the influence of regional sources on the air quality in Greater Beijing.

Methodology

COSMO-ART

The fully online coupled model system COSMO-ART (Consortium for Small Scale Modeling—Aerosols and Reactive Trace Gases) has been designed to simulate the

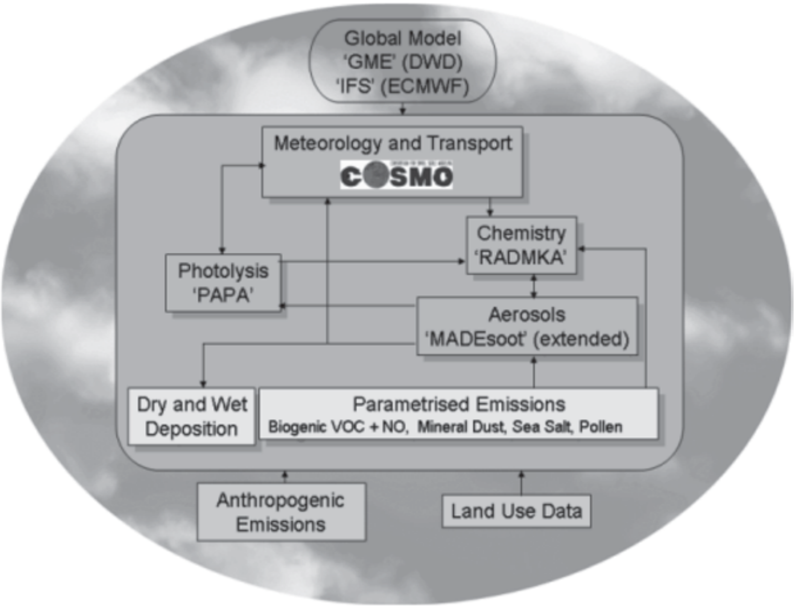


Fig. 1 Modular structure of COSMO-ART. [7]

temporal and spatial distribution and dispersion of trace gases and aerosols on continental to local scales [9]. The model also allows the investigation of feedback processes between trace gases, aerosols and the state of the atmosphere.

The meteorological driver of the model system is the operational weather forecast model COSMO developed by the German Weather Service (DWD) (Fig. 1). Trace gases and aerosols are calculated in ART, which is a model that is online coupled with the COSMO model. COSMO-ART is based on the model system KAMM/DRAIS/MADEsoot/dust.

The model can be used to calculate 80 gaseous species and five aerosol modes in Aitken and accumulation mode. The first two aerosol modes are internally mixtures of sulphate, nitrate, amonium formed by secondary particle formation processes from gas phase reactions. The second two modes additionally contain pure soot. Pure soot represents the 5th aerosol mode. The aging of aerosols due to condensation and coagulation is taken into account. In addition, directly emitted species such as mineral dust, pollen and sea salt can be calculated. These directly emitted particles are represented by log normal distributions with fixed mean diameters and standard deviations [9].

The online coupling of gas phase chemistry and aerosol dynamics with the meteorological parameters allow the investigation of the dispersion of non reactive and reactive trace gases and aerosols. For this purpose, physical processes such as dry and wet deposition, transport and turbulent diffusion are considered. Feedback processes between aerosols, meteorological parameters including temperature, humidity and cloud formation processes are also included in the model. Interactions

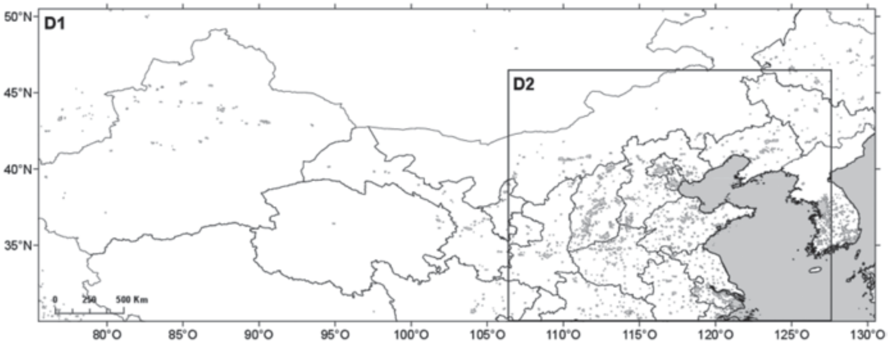


Fig. 2 Model domains D1 and D2 with the main urban areas in China and Korea. Beijing is marked with an asterix

between the different parameters can be simulated. For the calculation of photolysis frequencies the radiation scheme, GRAALS (General Radiative Algorithm Adapted to Linear-type Solutions) is used.

Model Domain and Anthropogenic Emission Inventory

The first model domain (D1) covers the whole of northern China, whereas, the second domain (D2) covers northeast China and the Korean peninsula. The second domain includes all main urban areas of northeast Asia to reconsider the regional influence of these areas on Greater Beijing. Both domains have a horizontal resolution of 28×28 km. The model domains used for this case study are shown in Fig. 2. The model includes 40 vertical layers, which are terrain following and of varying thickness with denser layers near the surface.

The anthropogenic emissions are calculated based on the INTEX-B emission inventory and were updated for the year 2008 by information from the statistical yearbook of China. The emissions are separated into four sectors, namely transportation, industry, residential and power plants, and consider all main gaseous pollutants. For the simulation of the Olympic period the emissions have been reduced to account for the effects of the reduction measures. During the Olympic Games the daily emissions of NO_x, SO_2, NMVOC and PM_{10} in Beijing were reduced by 47 %, 41 %, 57 % and 55 % compared to June 2008 [7]. The closing and relocation of industrial plants was the primary measure that reduced SO_2 emissions, whereas the strict traffic control measures had its strongest effect on the NO_x and NMVOC emission decrease [7]. The local PM_{10} emissions were most influenced by the decommissioning of construction areas [7].

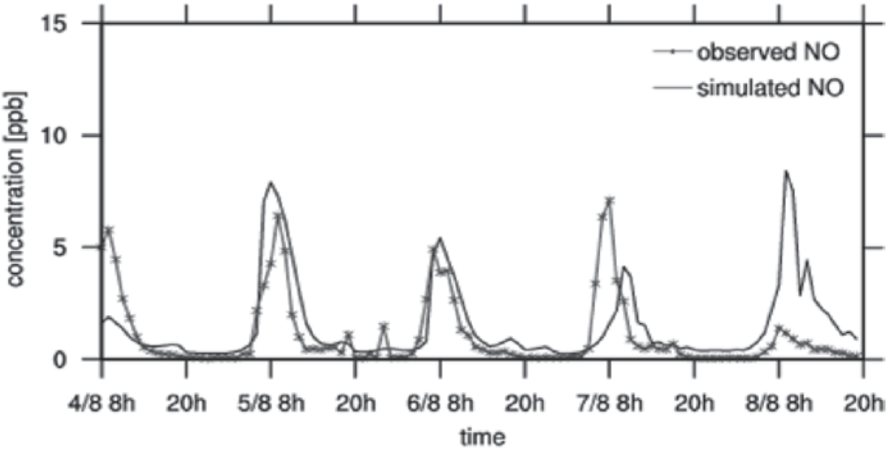


Fig. 3 Comparison of measured and modeled NO concentrations in Beijing from August 4th to 8th

Hysplit Model

In this study five-day backward trajectories were calculated using the Hysplit model. Hysplit model (Hybrid Single-Particle Langrangian Integrated Trajectory) is a model system for the calculation of backward trajectories of air parcels. The model allows the detection of source areas of air masses and can be run interactively on the Air Resources Laboratory (ARL) site [4]. For each day two backward trajectories were calculated, one every 12 hours at 08:00 h a.m. and 08:00 p.m. The trajectories were calculated at 250 m height, ending over the Beijing city center.

Results and Discussion

The model results were compared to measurement data of O_3 and NO_x taken from the CAS-IAP measurement network for the Beijing-Tianjin-Hebei area [10]. For August 2008, hourly O_3 and NO_x data from the Beijing measurement station were available for comparison.

NO Concentrations

Figure 3 shows the time series of NO during the simulation period from August 4th to 8th. The Olympic Games started on August 8th at 8 h in the evening with a big opening ceremony. The maximum values of measured NO concentrations reach values of 12 ppb during the morning peak and decrease during the afternoon until there

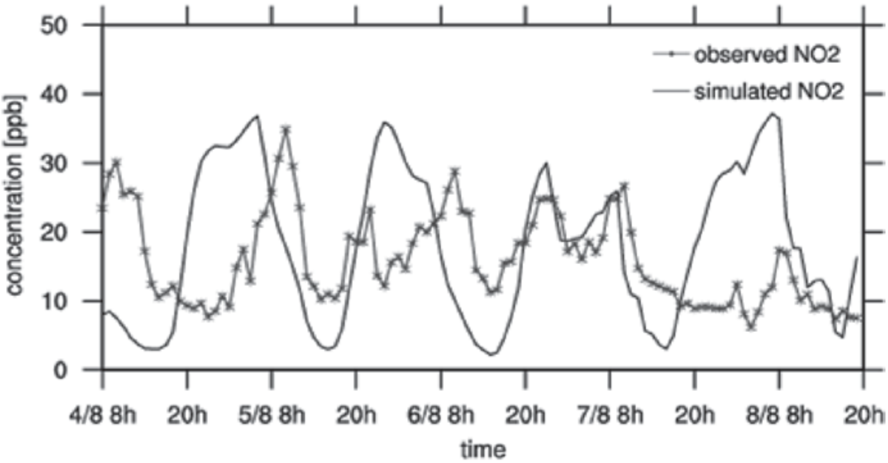


Fig. 4 Comparison of measured and modeled NO_2 concentrations in Beijing from August 4th to 8th

is a very small second peak in the early evening. Both peaks are mainly determined by emissions from traffic during the morning and evening rush hour.

The model output generally matches the measured NO concentrations well over the course of each day, particularly for the 4th, 5th and 6th of August. However, there are discrepancies seen at certain points of time. The morning peak on August 7th found by the model had a delay of two hours, and a lower concentration, than what was actually measured at that time. By contrast, the simulated concentrations on August 8th were higher than those which were measured. These discrepancies may be explained by the local control measures, including the shutting down of local NO point-sources [7]. In addition, strict traffic restrictions and the closing of additional industrial facilities and construction areas were implemented from the morning of August 8th [5, 7] potentially further explaining the difference between the modeled and measured NO concentrations.

NO_2 Concentrations

The measured NO_2 concentrations during the simulation period reach maximum values of up to 35 ppb on August 5th and decrease during the following days. On August 8th, the concentrations reach the lowest values during the simulation period. There are significant day-to-day variations of NO_2 concentrations observed. This variability can be reproduced by the model to a certain extent. On August 5th and 6th a temporal shifting of the daily peaks can be seen. This temporal discrepancy becomes less obvious from the 6th 08:00 h p.m. to the end of the simulation time on the 8th 08:00 p.m. (Fig. 4)

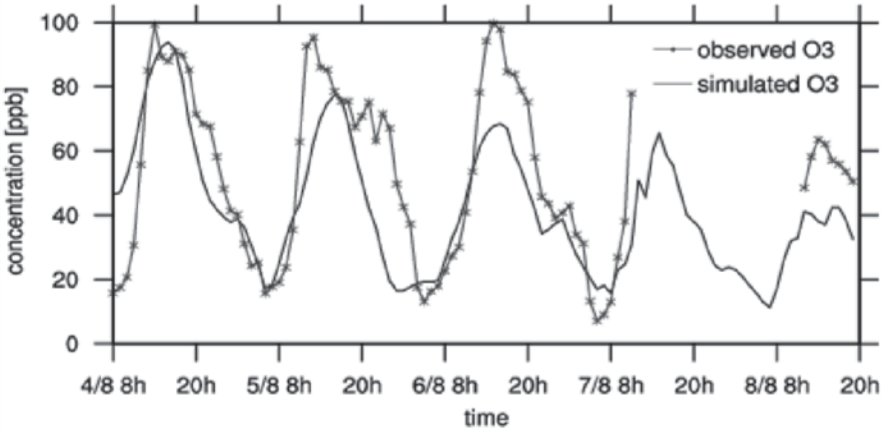


Fig. 5 Comparison of measured and modeled O_3 concentrations in Beijing from August 4th to 8th

However from August 7th 08:00 p.m. to the 8th 08:00 a.m. there is a significant overestimation of NO_2 concentrations by the model. This overestimation, which can also be seen for the comparison of measured and modeled NO, may be explained by the local emission reduction measures.

O_3 Concentrations

The measured O_3 concentrations reach values up to 100 ppb during the early afternoon of the 4th, 5th and 6th of August (Fig. 5). From 9:00 a.m. August 7th to 12:00 p.m. 8th, there is a lack of measured data, as seen in Fig. 4. During the periods for which there is measured O_3 concentrations, the diurnal pattern of the observed and simulated O_3 concentrations are in good accordance. However the simulated maximum O_3 concentrations are underestimated by up to 30 ppb on August 6th. This underestimation can also be seen in modeling studies using CMAQ model [7], whereas simulations with the GEOS-Chem model showed a continuous overestimation of O_3 during the Olympics [2].

Backward Trajectories

The backward trajectories calculated with the HYSPLIT model highlight the source regions of the air masses arriving Greater Beijing during August 4th to 8th. Figure 6 shows the air masses arriving Beijing from August 4th to 8th every 12 hours in 250 m height above the ground. The main direction of the air masses reaching Beijing is South-West to North-East. Usually air quality is lower on days with air mass-

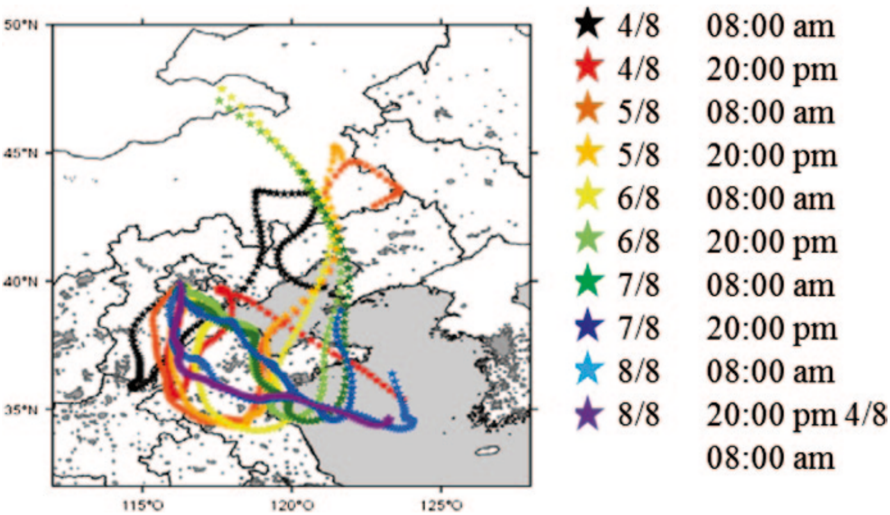


Fig. 6 Comparison of measured and modeled O_3 concentrations in Beijing from August 4th to 8th

es arriving Beijing from the south, because of the dense population and the large numbers of industrial plants located in this area. This fact can be seen in the measurement and modeling data. However it can also be seen that NO_2 concentrations decrease during August 7th although the air masses originated from these areas. This fact may be explained by the measures conducted in Beijing. Almost all local sources were cut off, which lead to a reduction of the air pollutants concentrations. But there is still a background level, caused by regional sources influencing the air quality of the Beijing city area [8].

Conclusions

The first results of the NO_x and O_3 simulations with COSMO-ART for Northeastern China show that the diurnal and daily variations of NO_x and O_3 concentrations can be captured by the model. However, there are still some deviations between modeled and measured diurnal NO_2 concentrations. The daily trend of NO and O_3 over the simulation period is reproduced very well by the model. Within the daily trend of the modeled NO_2 concentrations a temporal shift can be found during the first three days of simulation.

The good reproduction of the temporal variability of NO, NO_2 and O_3 by the model indicates that meteorology and chemical reactions are the dominant factors for their diurnal and daily variation. This result is also in accordance with the studies of Wang et al. [2].

All of the three gaseous pollutants are overestimated by a factor of 2. This overestimation is due to the fact that the emissions data in the emissions inventory for 2008 didn't take into consideration the influence of air pollution mitigation measures that were implemented during the summer of 2008 in the Beijing city area and the surrounding areas. These mitigation measures reduced NO_x and O3 emissions by 50 %, as was also reported by Wang et al. [7]. When the emission reduction measures are taken into account, the modeled and measured concentrations are in better accordance. This is particularly the case for O_3, for which the model showed that the emission reductions of O_3 precursors during the Olympic Games had a strong effect on O_3 concentrations during this period. The model results show that a further decrease of precursors like NO_x, CO and NMVOC over Eastern China will certainly have a positive effect on the air quality in this region.

Acknowledgments The authors thank the Helmholtz Graduate School for Climate and Environment (GRACE) at the Karlsruhe Institute of Technology for financial support of this project.

References

1. Bangert M et al (2012) Saharan dust event impacts on cloud formation and radiation over Western Europe. Atmospheric Chemistry & Physics 12:4045–4063
2. Draxler, R.R.a.R., G. D., HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://ready.arl.noaa.gov/HYSPLIT.php). NOAA Air Resources Laboratory, Silver Spring, MD., 2012
3. Kaufman YJ, Tanré D and Boucher O (2002) A satellite view of aerosols in the climate system. Nature 419(6903):215–223
4. Pope CA (2000) Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk? Environ Health Perspect 108(Suppl 4):713
5. Schleicher N et al (2012) Efficiency of mitigation measures to reduce particulate air pollution—a case study during the Olympic Summer Games 2008 in Beijing, China. Science of The Total Environment 427–428(0):146–158
6. Streets DG et al (2007) Air quality during the 2008 Beijing Olympic Games. Atmos Environ 41(3):480–492
7. Vogel B et al (2009) The comprehensive model system COSMO-ART—radiative impact of aerosol on the state of the atmosphere on the regional scale. Atmos Chem Phys 9(22):8661–8680
8. Wang Y et al (2009) Ozone air quality during the 2008 Beijing Olympics: effectiveness of emission restrictions. Atmos Chem Phys 9:5237–5251
9. Wang S et al (2010) Quantifying the air pollutants emission reduction during the 2008 Olympic games in Beijing. Environ Sci Technol 44(7):2490–2496
10. Wang T et al (2010) Air quality during the 2008 Beijing Olympics: secondary pollutants and regional impact. Atmos Chem Phys 10:7603–7615
11. Xin J et al (2012) Reductions of PM2.5 in Beijing-Tianjin-Hebei urban agglomerations during the 2008 Olympic Games. Adv Atmos Sci 29(6):1330–1342

The Effect of Government Policies on the Temporal Development of Contamination Characteristics Within the Aerosol Distribution in Beijing, China

Yuan Chen, Nina Schleicher, Yizhen Chen, Fahe Chai, Shulan Wang and Stefan Norra

Abstract To host Green Olympic Games, the Beijing municipal government took comprehensive measures to improve air quality in 2008, which partly are still in force in 2012. The aim of this study is to investigate the temporal distribution of aerosol contamination characteristics and their variations under different government intervention policies. $PM_{2.5}$ samples were collected continuously from 2007 to 2010 in the north of Beijing City. Element concentrations were analyzed by HR-ICP-MS. Results showed that concentrations of traffic-related elements such as Sn, Sb and Pb varied with the strength of traffic restrictions. Elements like Cr, Co and Ni, which are correlated with industries, were reduced under special policies like the relocation of Capital Steel Company. In general, the improving air quality demonstrates the success of government intervention policies although still the concentrations are too high if compared to international threshold values.

Introduction

Atmospheric aerosol pollution has increased dramatically since the preindustrial period [5, 12] and has become one crucial part of air environment study. Atmospheric particulate aerosols play a significant role in the climate change [3, 4, 11] and could have deleterious influence on human health [1, 7, 9, 19].

Y. Chen (✉) · N. Schleicher · S. Norra
Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology,
76131 Karlsruhe, Germany
e-mail: yuan.chen@kit.edu

N. Schleicher · S. Norra
Institute of Geography and Geoecology, Karlsruhe Institute of Technology,
76131 Karlsruhe, Germany
e-mail: yuan.chen@kit.edu

Y. Chen · F. Chai · S. Wang
Institute of Urban and Regional Atmospheric Sciences, Chinese Research Academy of
Environmental Sciences, 100012 Beijing, China

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_27,

Particles with an aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$), which can be inhaled into the lung with toxic materials and hence affect human health, have been one of the most concerns of the scientist and the public.

In Beijing, the capital of China, approximately 20 million people [2] are living and suffering from aerosol pollution. In late October 2011, for example, hazy days lasted for more than one week in Beijing and, as a consequence, the chief culprit $PM_{2.5}$ was identified and became one of the topics of people's daily life. Based on the public's voice, the Chinese government drafted a standard for $PM_{2.5}$ concentration with an annual mean limit value 35 and 75 μg/m^3 for 24 h mean (level II) [14]. This threshold values is scheduled to be implemented in 2016.

In preparation for 2008 Beijing Olympic Games, the Beijing Municipal Government took a series of emission control measures to improve the air quality and protect the air environment. The main ones consisted of relocating heavy polluters (e.g., the Capital Steel Company), improving emission standards for power plants and heating factories, afforestation outside and inside Beijing City and controlling traffic. Up to now, numerous of studies show that these measures have been operated successfully and had a positive effect on aerosol reduction [13, 17, 18, 22].

However, most of these investigations focused on the period of the 2008 Olympic Games and compared it with the situation before or a short period after the Olympics. To the authors' knowledge, only few articles about longtime comprehensive study around this event were published.

In this study, systematic sampling and measurement for more than 3 years was implemented so the influence of the government policies on fine particle reduction and the variation of chemical composition can be observed over a long time sequence in Beijing urban area. This study discusses mass concentration, temporal distribution of elements and correlations between element pollution levels and government mitigation policies. Results shown in this study are an example of the profound insights on the characteristics of the fine particles and the effects of government intervention policies on them.

Experimental

Sampling

The sampling site is located in the north of Beijing City, between the 5th ring road and 6th ring road, and is set up on the roof of the Chinese Research Academy of Environmental Sciences (CRAES) at a height of about 20 m (Fig. 1). From Sep. 30th 2007 to Jan. 4th 2011, $PM_{2.5}$ weekly samples were collected continuously on quartz fiber filters (Whatman Inc., Maidstone, UK) with an active Mini-Volume Sampler (Leckel, Berlin) at a flow rate of 200 L/h. During 2008 Olympic Games, in August and September, intensive sampling was implemented with a higher time-resolution

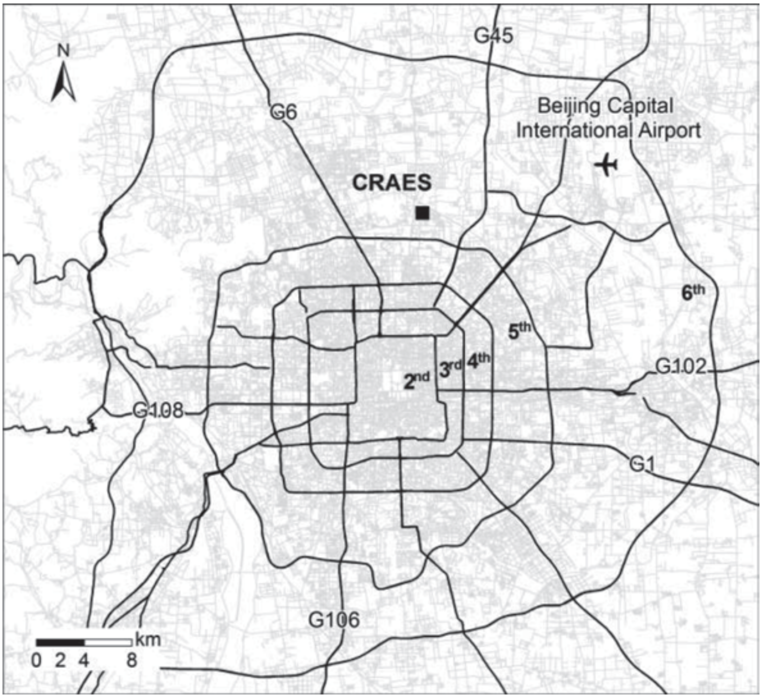


Fig. 1 Sampling site (CRAES) and the main traffic network of Beijing urban area, including 2nd–6th ring roads (Data source: OpenStreetMap)

of 12 h intervals to show more details about the fine particles reduction [18]. Here we calculated the weekly concentrations from these 12-hourly samples for a whole week in order to get the corresponding weekly average. For the 171 weeks during the sampling time, we obtained 158 valid weekly samples (14 of the 12-hourly samples in one week during 2008 Olympic Games were considered as one weekly sample), accounting for 92.4 % of all samples.

Mass Concentration Analysis

Mass concentrations were calculated by gravimetric analysis of filters carried out with a microbalance (Sartorius SE 2-F, Göttingen, Germany) for three times after at least 48 h equilibration in constant temperature (22 ± 3 %) and humidity (40 ± 2 %) at the Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology (IMG-KIT), Germany. Accuracy control was implemented by blank filters which were also sent to Beijing but not used and sent back to Germany for analysis.

Chemical Analysis

Element concentrations were determined by a high-resolution inductively coupled plasma mass spectrometer (HR-ICP-MS, Axiom, VG Elemental). One quarter of each filter was cut down to digest for ICP- MS analyses. Details of digestion of samples can be found in previous studies of the same project [16, 24]. Standard reference material SRM 1648 (urban particulate matter) and GXR 2 (soil sample) from NIST (National Institute of Standards & Technology, USA) were additionally analyzed to control analytical quality. Element concentrations of standard material were usually within ±10% of the certified values. Methodological blank values of the blank samples were determined and subtracted from analytical results of $PM_{2.5}$ samples. All analysis was performed at the IMG-KIT.

Results and Discussion

Mass Concentration and Meteorological Condition

The weekly mass concentration of $PM_{2.5}$ during the whole sampling period (Fig. 2) ranged from 22.5 to 226 μg/m^3, and the average concentration in the whole period was 86.1 μg/m^3, which was 5.7 times to the USA standard (15 μg/m^3) and about 2.5 times to the drafted annual limit value (35 μg/m^3) in China. This was a slightly higher than the average particle concentration (65.6 μg/m^3) reported by Yu et al. [24] for a different site in the North-West of Beijing City. Particle concentrations that exceeded standards revealed the pollution severity of fine particles in Beijing and the necessity of macro-control by government.

In general, $PM_{2.5}$ pollution level began to decrease since 2008 when government strengthened the enforcement of measures, such as the traffic restriction measures, afforestation and greening and improving emissions standards.

During the heating season from November 15th to March 15th in the second year, average mass concentration of $PM_{2.5}$ (104.4 μg/m^3) was higher than that during non-heating period (74.3 μg/m^3) (Fig. 2). Seasonal pattern showed that spring and winter usually had higher concentrations than summer and autumn mainly due to sand dust storms and the heating activities respectively (Fig. 3), which was also reported by previous studies [6, 16, 24].

The statistic correlation between particle concentration and meteorology has already revealed the precipitation had a direct and rapid influence on reducing particle concentration [6]. In this study the particle concentration obviously showed a negative correlation with precipitation. Thus, wet deposition was the principal way of washing out particles in aerosol (Fig. 2).

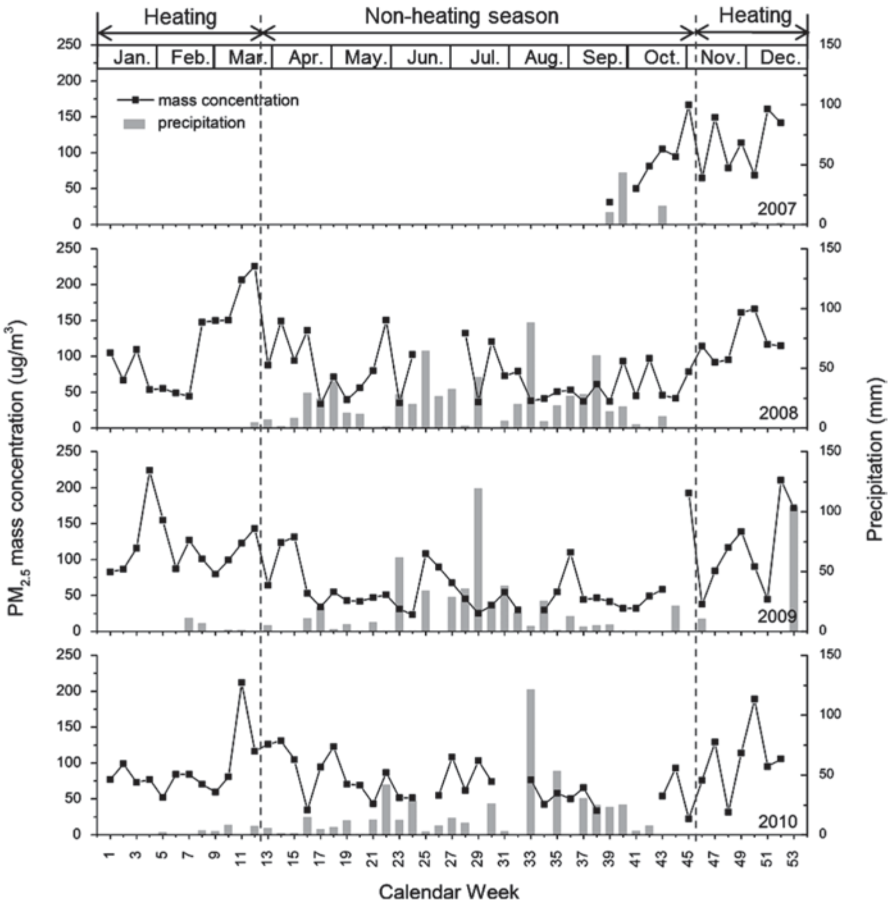
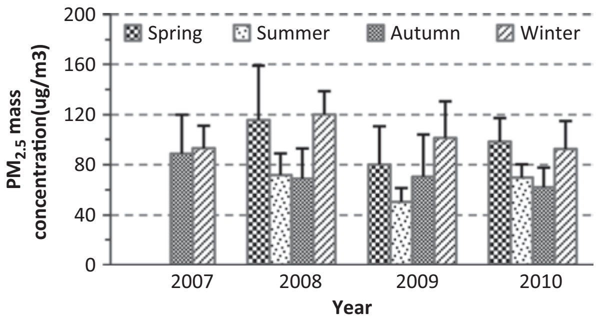


Fig. 2 PM$_{2.5}$ weekly mass concentration from 2007 to 2010 with precipitation

Fig. 3 Seasonal variation of PM$_{2.5}$ mass concentration (average and standard deviation)



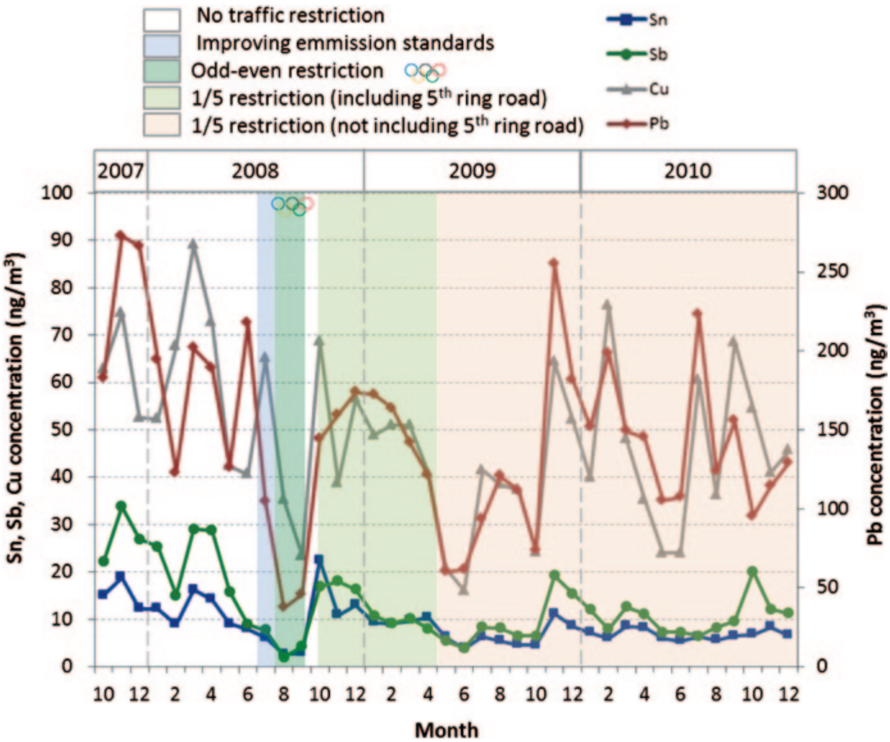


Fig. 4 Concentration of traffic-related elements under different traffic restriction measures

Effects of Government Intervention Polices on Contamination Characteristics of Chemical Element Composition

Influence evaluation of Traffic Restriction Measures on $PM_{2.5}$

In previous studies [8, 10, 20, 21, 23], Sb, Pb, Sn and Cu were recommended for markers of motor vehicle emissions. Their concentrations varied with the strength of traffic restriction policies according to the last number of license plates (Fig. 4). During the Olympic Games, the government implemented “odd-even restriction” policy which reduced around half of the vehicles on roads and brought the lowest element concentrations for the whole sampling period. After a short pause (October 2008) of intervention policies with obvious increasing concentrations (Fig. 4), 1/5 restriction police (including 5th ring road) was put into force on weekdays. This cut down around 1/5 of total number of vehicles running on roads.

From April 2009 and still in effect at the end of 2012, 1/5 restriction police (not including 5th ring road) is under way on weekdays. Since the sampling site (CRAES) is near to the 5th ring road, this policy could be one reason of increasing

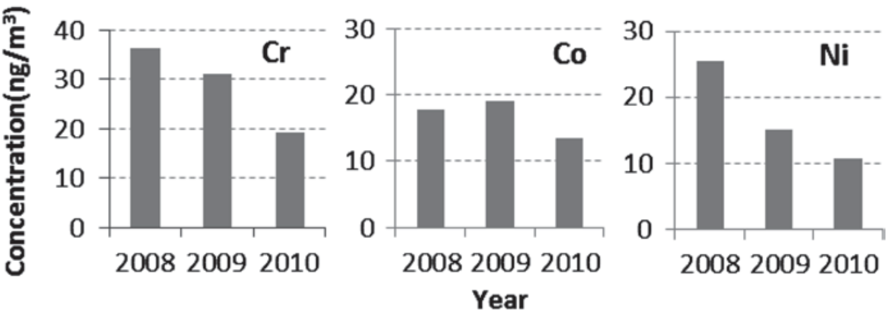


Fig. 5 Annual concentration variation of steelwork-related elements in $PM_{2.5}$

element concentrations in 2010 compared with concentrations in 2009. In January 2011 a lottery drawing for car license plates in Beijing started and lots of people purchased cars in 2010, which led to a sharp increase in the amount of vehicles exceeding 4.8 million at the end of 2010 in Beijing [2]. This government intervention policy also contributes to the elevation of traffic-related element concentrations in 2010 before its execution. But the contamination level in 2010 was still lower compared to the period before Olympic Games (Fig. 4).

Influence Evaluation of Policies on Capital Steel Company on $PM_{2.5}$

Among the government policies to control industry emissions, the relocating project of Capital Steel Company (moving it out of Beijing and relocating in Hebei Province which is near to Beijing) was the biggest one and of most influence. At the beginning of 2008, Capital Steel Company shut down its capacity step by step and its relocation program was finally finished in 2010. According to Reimann and Caritat [15], Co, Ni and Cr had common anthropogenic sources released to the atmosphere, primarily from fossil fuel (oil and coal) combustion and steel works, and, therefore, they were taken for evaluation of these policies within this study. Figure 5 shows that the element contamination level declined since 2008 and had in 2010 the minimum concentrations within the three years, which stated the effectiveness of the relocation project on reducing relevant toxic elements in $PM_{2.5}$.

Conclusions

$PM_{2.5}$ pollution level began to decrease since 2008 when government strengthened the enforcement of measures. After the Olympic Games the concentrations increased again but remained lower than prior to the control measures. Decreasing concentrations of elements, such as Sn, Sb, Cu and Pb, demonstrated the effectiveness of traffic restriction measures of government on controlling relevant compositions in $PM_{2.5}$. Reducing concentrations of Cr, Co and Ni proved the success of policies on controlling emissions, especially the relocation project of Capital Steel Company. Since some of the government intervention polices are not in effect anymore but some are still in force, it is necessary to continue this study on the effects of government policies on the temporal development of contamination characteristics of chemical compositions of $PM_{2.5}$ in Beijing City.

References

1. Ackermann-Liebrich U, Leuenberger P, Schwartz J, Schindler C, Monn C, Bolognini G, et al (1997) Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team (1997) Lung function and long term exposure to air pollutants in Switzerland. Am J Respir Crit Care Med 155:122–129
2. Beijing Bureau of Statistics (2012) Beijing statistical yearbook. China Statistics Press, Beijing
3. Bergstrom RW, Pilewskie P, Russell PB, Redemann J, Bond TC, Quinn PK, Sierau B (2007) Spectral absorption properties of atmospheric aerosols. Atmos Chem Phy 7:5937–5943
4. Buseck PR, Adachi K (2008) Nanoparticles in the atmosphere. Elements 4:389–394
5. Calvo AI, Pont V, Liousse C, Dupree B, Mariscal A, Zouiten C, Gardrat E, Castera P, Lacaux CG, Castro A, Fraile R (2008) Chemical composition of urban aerosols in Toulouse, France during CAPITOUL experiment. Meteorol Atmos Phys 102:307–323
6. Chen Y, Cen K, Norra S, Schleicher N, Yu Y (2010) Study on pollution characteristics of $PM_{2.5}$ in the aerosol, tracing and tracking atmospheric particulates in Beijing City. Geoscience 24:345–354. (In Chinese, English abstract)
7. Clancy L, Goodman P, Sinclair H, Dockery DW (2002) Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. Lancet 360:1210–1214
8. Cyrys J, Sölzel M, Heinrich J, Kreyling WG, Menzel N, Wittmaack K, Tuch T, Wichmann H-Erich (2003) Elemental composition and sources of fine and ultrafine ambient particles in Erfurt, Germany. Sci Total Environ 305:143–156
9. Goldberg MS, Burnett RT, Yale JF, Valois MF, Brook JR (2006) Associations between ambient air pollution and daily mortality among persons with diabetes and cardiovascular disease. Environ Res 100:255–267
10. Huang X, Olmez I, Aras NK, Gordon GE (1994) Emissions of trace elements from motor vehicles: potential marker elements and source composition profile. Atmos Environ 28:1385–1391
11. IPCC (2001) In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Climate change: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, New York, NY, USA, 881
12. Legrand M, Mayewski P (1997) Glaciochemistry of polar ice cores: a review. Rev Geophys 35:219–243
13. Ma WL, Sun DZ, Shen WG, Yang M, Qi H, Liu LY, Shen JM, Li YF (2011) Atmospheric concentrations, sources and gas-particle partitioning of PAHs in Beijing after the 29th Olympic Games. Environ Pollut 159:1794–1801
14. Ministry of Environmental Protection (MEP) of the People's Republic of China (2012) Ambient air quality standard GB3095-2012. China Environmental Science Press, Beijing
15. Reimann C, Caritat P (1998) Chemical elements in the environment-factsheets for the geochemist and environmental scientist. Springer, Berlin, pp 92–229

16. Schleicher N, Norra S, Chai F, Chen Y, Wang S, Stüben D (2010) Anthropogenic versus geogeni contribution to total suspended atmospheric particulate matter and its variations during a two-year sampling period in Beijing. China J Environ Monit 12:434–441
17. Schleicher N, Schleicher N, Norra S, Dietze V, Yu Y, Fricker M, Kaminski U, Chen Y, Cen K (2011) The effect of mitigation measures on size distributed mass concentrations of atmospheric particles and black carbon concentrations during the Olympic Summer Games 2008 in Beijing. Sci Total Environ 412–413, 185–193
18. Schleicher N, Norra S, Chen Y, Chai F, Wang S (2012) Efficiency of mitigation measures to reduce particulate air pollution—a case study during the Olympic Summer Games 2008 in Beijing, China. Sci Total Environ 146–158
19. Schwartz J, Dockery DW (1992) Increased mortality in Philadelphia associated with daily air pollution concentrations. Am Rev Respir Dis 145:600–604
20. Sternbeck J, Sjödin A, Andréasson K (2002) Metal emissions from road traffic and the influence of resuspension-results from two tunnel studies. Atmos Environ 36:4735–4744
21. Wåhlin P, Berkowicz R, Palmgren F (2006) Characterisation of traffic generated particulate matter in Copenhagen. Atmos Environ 40:2151–2159
22. Wang X, Westerdahl D, Chen LC, Wu Y, Hao J, Pan X, Guo X, Zhang KM (2009) Evaluating the air quality impacts of the 2008 Beijing Olympic Games: on-road emission factors and black carbon profiles. Atmos Environ 43:4535–4543
23. Wongphatarakul V, Friedlander SK, Pinto JP (1998) A comparative study of $PM_{2.5}$ ambientaerosol chemical databases. Environ Sci Technol 32:3926–3934
24. Yu Y, Schleicher N, Norra S, Fricker M, Dietze V, Kaminski U, Cen K, Stüben D (2011) Dynamics and origin of $PM_{2.5}$ during a three-year sampling period in Beijing, China. J Environ Monit 13:334–346

Using GIS to Derive Spatial Indicators of Pedestrian Exposure to Urban Traffic Noise

Paulo Rui Anciães and Giles Atkinson

Abstract Pedestrians are particularly susceptible to urban environmental nuisances such as transport noise. While we have methods for measuring pedestrian noise exposures in specific locations, policy-makers also require larger-scale evidence on how their policies affect exposures. This paper assesses the role of pedestrian mobility on exposures of people living and working in different areas and using different travel modes at different times. Two GIS-based indicators measure exposure. Non-employed individuals are exposed along the routes to nearby locations and employed individuals are exposed on the walking sections of the optimal routes to work.

The indicators are applied in the assessment of the expansion of the road network and traffic in the Lisbon Metropolitan Area. The exposures of the non-employed have increased in central areas, affecting elderly residents. Areas above exposure standards tend to have employed populations with above-average qualifications while areas below standards have below-average qualifications. Areas above standards for both employed and non-employed individuals also have below-average qualifications.

Introduction

Policy-makers are increasingly interested in promoting walking as an environmentally-friendly type of mobility. However, the quality of this mobility also depends on environmental factors. Transport noise has a particularly marked effect on pedestrians, due to its effects on psychological wellbeing, safety and social interaction [1, 3]. While researchers have developed methods for measuring exposures in specific locations and inside different types of vehicles, there is less evidence on how transport and urban policies affect pedestrian exposures and create conflicts between motorised and pedestrian mobility throughout the city. These conflicts may be politically relevant, if they are to the disadvantage of groups vulnerable to losses in pedestrian mobility or with higher reliance on walking, such as the elderly or

P. R. Anciães (✉) · G. Atkinson
London School of Economics and Political Science, London, UK
e-mail: p.r.anciaes@gmail.com

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_28,

the low-income populations [4]. This disadvantage may also have a geographical dimension, if the areas where these groups walk have higher noise levels.

The objective of this paper is to map indicators of pedestrian noise exposure that integrate the patterns of daily mobility of the population in each neighbourhood, including the destinations accessed at different times of day and the travel modes used to access them. The hypothesis is that individuals are most vulnerable to noise when walking around their neighbourhood or on their way to work, including the walking sections of trips by private or public transport. The paper adds to studies that quantify and map pedestrian mobility, which have been mostly confined to aspects related with urban planning, such as pedestrian accessibility and street "walkability" [5, 6], and seldom analysed the extent to which walking is restricted by motorised traffic. The work also adds to studies on the distribution of noise according to age and socio-economic status [2]. This literature usually assumes that exposure occurs at home and is the same for all individuals in the unit of analysis. The distributions are then based only on residence location, not taking into account that individuals move across different parts of the city throughout the day. The contribution of our work is to consider choices over destinations and travel modes as additional factors explaining the distribution of exposures.

The method is applied to the case of the Metropolitan Area of Lisbon, analysing the effects of the expansion of the motorway network and private transport usage and urban fragmentation in the period between the last two population censuses. The assessment of the quality of pedestrian mobility is relevant in face of trends common with other European cities such as population ageing, macroeconomic instability and cultural shifts towards healthier lifestyles, which have increased the relevance of walking and the need to take into account the needs of vulnerable groups.

Methods

The analysis is conducted at the level of the census enumeration district. However, to take into account internal variations in land use, the indicators of noise exposure are assessed for a series of points representing all different contiguous areas of residential land inside each district, and then averaged for the district according to the estimated spatial distribution of the population. The calculations use GIS network models for the private, public and pedestrian transport systems in 1991 and 2001. Exposures depend on the distribution of noise levels throughout the day. The analysis is restricted to the period 6:00–00:30. All the variables used to estimate exposures are then split into two periods: peak (6:30–9:30 and 16:30–19:30) and off-peak (9:30–16:30 and 19:30–0:30).

Peak and off-peak noise surfaces are modelled for 1991 and 2001. In a first stage, noise levels are calculated for each segment of the road and rail networks, based on the segment characteristics and on estimated traffic levels, composition and speeds. These variables are obtained by assigning commuting and non-commuting pri-

Table 1 Exposure to transport noise of a neighbourhood's population

Employment status	Destinations	Transport mode	Exposure
Not employed	Nearby places	Walk	Walking to destination
		Walk	Walking to/from/between stations/bus stops
Employed	Workplace	Public transport	Waiting at stations/bus stops
		Private transport	Walking to/from car parks

vate transport flows to the road network and by modelling bus and train routes and schedules. Network speeds are based on the link characteristics and congestion. In a second stage, the noise levels on the network are used to obtain levels in a 40 m grid covering the study area, considering the noise propagation over space and the geometric relationships between each point and the noise source. This estimation uses several GIS datasets representing the local natural and built environment. Finally, the noise level at each point of the grid combines the modelled noise from the road and rail networks and noise from other sources such as major industries, airports and flight paths. Noise from these sources is obtained by extrapolating data available for recent years. Noise levels at railway and underground stations are modelled separately, using formulas from the literature. The grid is finally converted to a surface, giving the peak and off-peak equivalent continuous sound level in every location of the metropolitan area.

We consider that the mobility of the residents in each district depends on their employment condition. Different assumptions apply for the destinations, travel modes and pedestrian noise exposures of the non-employed and employed population (Table 1).

Non-Employed Population

For the non-employed population, pedestrian mobility is a means for intra or inter-neighbourhood accessibility. A set of possible destinations is built for every district in 1991 and 2001. This set is obtained by a sampling of all inhabited 40 m cells in a grid covering the study area and is the largest possible set such that all points are at least 400 m apart and the probability that each point is included in the set is proportional to its population density. It is assumed that pedestrians only consider destinations within 800 m straight-line distance.

These restrictions ensure that each district has a maximum of 12 possible destinations. Each destination is assigned an attractiveness score specific to each origin and depending on the number of opportunities for social interaction. This number is measured by the population living nearby, which is estimated by assigning the population of the metropolitan area to its nearest point in the set of all pedestrian destinations. For destinations at 500–800 m straight-line distance, this number is multiplied by 50 % to correct for the effect of distance on propensity to walk. Individuals are then exposed along the optimal walking routes from the representative points of the district to the destinations of that district. Optimality is based on walking time, with speeds depending on slopes.

The indicator of pedestrian noise exposure of the non-employed population in district *i* (En_i) is the sum for all destinations *k* of the length-averaged noise levels on the optimal routes to each destination multiplied by the probability that individuals choose that destination. This probability is the proportion of that destination's attractiveness for the population in that district ($P_{i,k}$) and the attractiveness of all the destinations ($\Sigma_k P_{ik}$). We assume the number of pedestrian trips is constant throughout the day and as such the noise levels $N_{i,k}$ are a weighted average of peak and off-peak levels, where the weights are the number of hours in each period.

$$En_i = \sum_k \frac{P_{i,k}}{\sum_k P_{i,k}} * N_{i,k}$$

Employed Population

For the employed population, walking is either a means to complement the trip to work by motorized transport or to access directly the workplace. Motorized transport users access a set of destinations representing major centres of employment, including 207 and 240 points in 1991 and 2001. This set was constructed considering sectoral employment and business data at the municipality and sub-municipality level. Land use maps and other ancillary information were then used to identify precise locations for the employment in each sector. Workers walking to work access the same set of destinations defined above for the non-employed population. However, the attractiveness score of each destination is an average of the attractiveness for workers of different sectors, with local population measuring attractiveness for the service sector and agricultural and industrial space measuring attractiveness for the corresponding sectors.

Individuals are exposed on the walking sections of the optimal routes to work. Private transport users walk between car parking areas and the workplace. Parking is only modelled for origins and destinations in major cities, assuming that individuals have access to free parking close to their residence and workplace in the other cases. Public transport users walk between home/work and bus stops/train stations and during interchange to different modes or services. We assume that individuals are also exposed to transport noise during waiting time at all stops, to account for the fact that the usual noise loudness at bus stops tends to exceed standards in our study area, due to the location of many of them along major transport arteries. For both motorized modes, optimal routes depend only on time, including the effect of congestion. Public transport times also include waiting and interchange time and penalties for delays and variations in service headway due to congestion.

The daily exposure to noise of users of motorized mode *m* (private or public transport) starting work during period *p* and ending at the corresponding period *p'* is given by the equivalent exposure level of the exposures in all walking sections of the return trip to work. In the formula below, $T_{i,j,m,p}$ and $T_{j,i,m,p'}$ are the total walking times in the trip from district *i* to destination *j* using mode *m* during periods *p* and *p'* respectively. $N_{i,j,m,p}$ and $N_{j,i,m,p'}$ are the length-averaged noise levels in the walking routes used, or the noise level at the stop or station, in the case of waiting time. In the cases where car parking is not modelled, we assume that exposure is the background noise level.

$$E_{i,j,m,p} = 10 * \log_{10}\left[T_{i,j,m,p} * 10^{\frac{N_{i,j,m,p}}{10}} + T_{j,i,m,p'} * 10^{\frac{N_{j,i,m,p'}}{10}}\right]$$

The indicator of pedestrian exposure of the employed population in district *i* is the weighted average of the exposures of workers travelling to each destination at each period of the day by each transport mode. In the formula below, $F_{i,j,m,p}$ is the proportion of all workers in district *i* that start work during period *p* at location *j* and travel by motorized mode *m* and $W_{i,k,p}$ is the proportions of workers starting work during the same period *p* at location *k* accessed by walking. $E_{i,j,m,p}$ is the exposure in the pedestrian sections of the journey to work by motorised mode, as defined above, while $E_{i,k,p}$ is the length-weighted average of noise levels in the routes taken by workers walking to work. The disaggregation of destinations, times of day and travel modes at each district uses several datasets from the population census and mobility surveys.

$$Ee_i = \sum_{j,m,p} F_{i,j,m,p} * E_{i,j,m,p} + \sum_{k,p} W_{i,k,p} * E_{i,k,p}$$

Application

The approach is used to map the distribution of pedestrian noise exposures in the Lisbon Metropolitan Area in 1991 and 2001. Figs. 1 and 2 show the exposures for the non-employed and employed population. In both cases, the values are generally higher and less variable than those usually found in literature mapping exposures at home. This is because pedestrians visit with the highest probability the noisiest areas surrounding their residence, that is, the most populated areas (in the case of the non-employed) and the areas where bus stops and train stations are location (in the case of the employed population). The exposures of the non-employed population are high (55–65 db(A)) in main centre of the metropolitan area (Lisbon) and very high (>65 db(A)) in the surrounding suburban areas. Values are also high alongside parts, but not all, of the main transport corridors to Lisbon. The affected areas in these corridors tend to be those that are surrounded by several motorways, where most pedestrian destinations have high noise levels. The situation is especially acute in the Northeast corridor, which is formed by a long and narrow strip of residential land sided by national-level road and rail infrastructure, along flight paths and beside the major industrial corridor in the metropolitan area. There is also a high

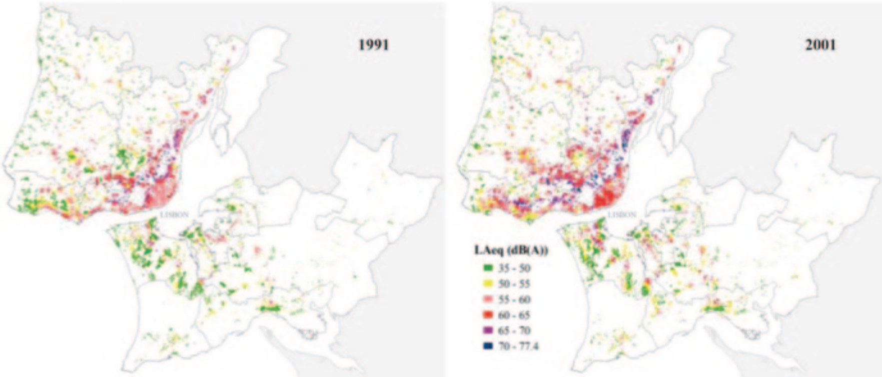


Fig. 1 Pedestrian noise exposures of the non-employed population

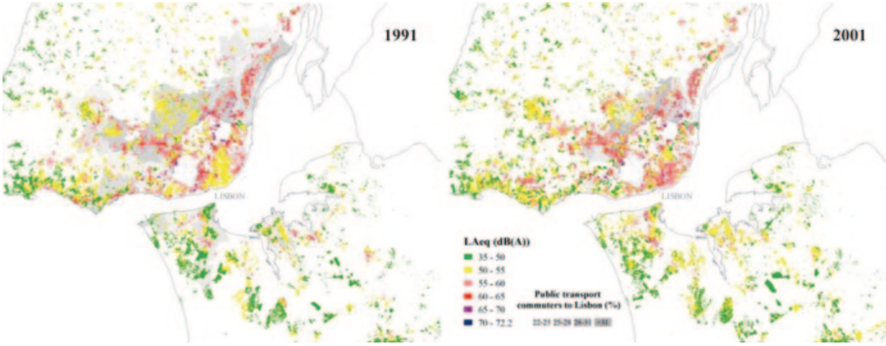


Fig. 2 Pedestrian noise exposures of the employed population

degree of variability of exposures within each municipality, which is partly independent of the location of the major transport infrastructure. From 1991 to 2001, exposures have increased in most districts, with values above standards spreading to the semi-rural areas of the outer municipalities. The densification of the motorway network around Lisbon also led to the increase of exposures in areas where they were already high. Exposures are also above average in some of the new urban developments in less dense areas. As growth has been largely discontinuous, these areas often have few pedestrian destinations, accessible only by using busy roads.

The exposures of the employed population are generally lower than those of the non-employed population and follows pattern mainly based on levels of public transport commuting to Lisbon. This is explained by the fact that destinations in Lisbon tend to have the highest noise levels and as such, waiting at stations and bus stops on the return trip will contribute to higher daily exposures. Exposures above standards tend to be higher in the Northwest and Northeast corridors. Despite having comparable proportion of the workers commuting to Lisbon by all transport

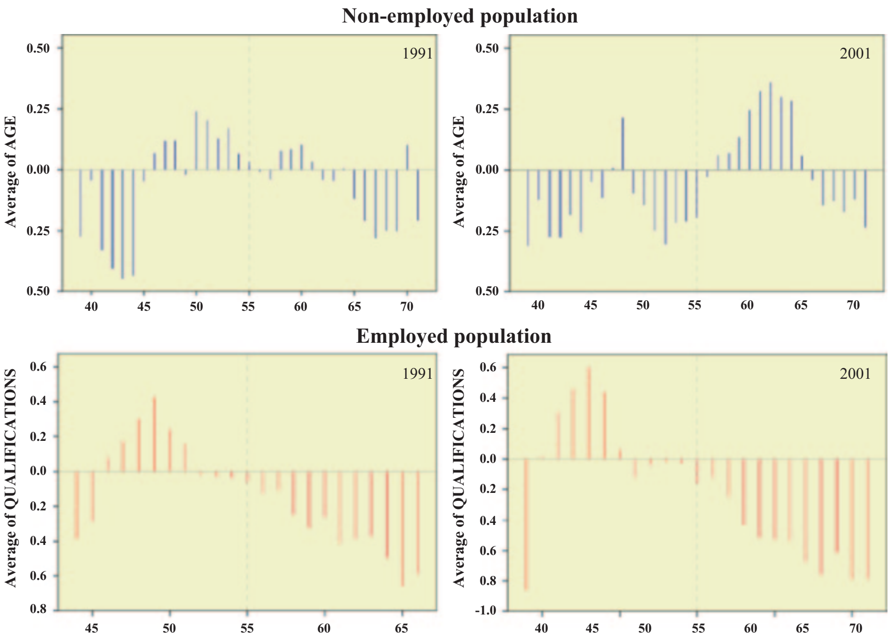


Fig. 3 Pedestrian noise exposures and socio-economic factor scores

modes, the West corridor shows lower exposures than those two corridors, due to the smaller proportions of public transport users, as these users are generally more exposed to noise. However, despite the overall decrease in the proportion of public transport commuters to Lisbon, exposures did not decrease in any of the corridors from 1991 to 2001. This may be explained by the increase of noise levels in Lisbon, which is reflected in the noise exposures of the population working in this city.

These distributions are then analysed in terms of the underlying socio-economic profile of each district. The analysis focuses on two main vectors of variables, obtained by a previous factor analysis to census data. For each indicator, we focus on one vector, chosen to take into account the vulnerable groups identified in the introduction. In the case of the non-employed population we focus on a vector labelled *Age*, associated with the age of both population and buildings. In the case of the employed population we focus on a vector of *Qualifications*, associated with variables measuring educational and professional qualifications and with other variables linked to socio-economic status, such as large and large and owner-occupied dwellings, values of rents and mortgage payments. Both vectors are standard variables, with zero mean and unit variance.

Figure 3 shows the population-weighted averages of these factors for each class of noise exposure. The top part of the figure shows that in the period concerned there was a structural change in the distribution among age groups of exposures for the non-employed population. In fact, apart from the most extreme exposure levels,

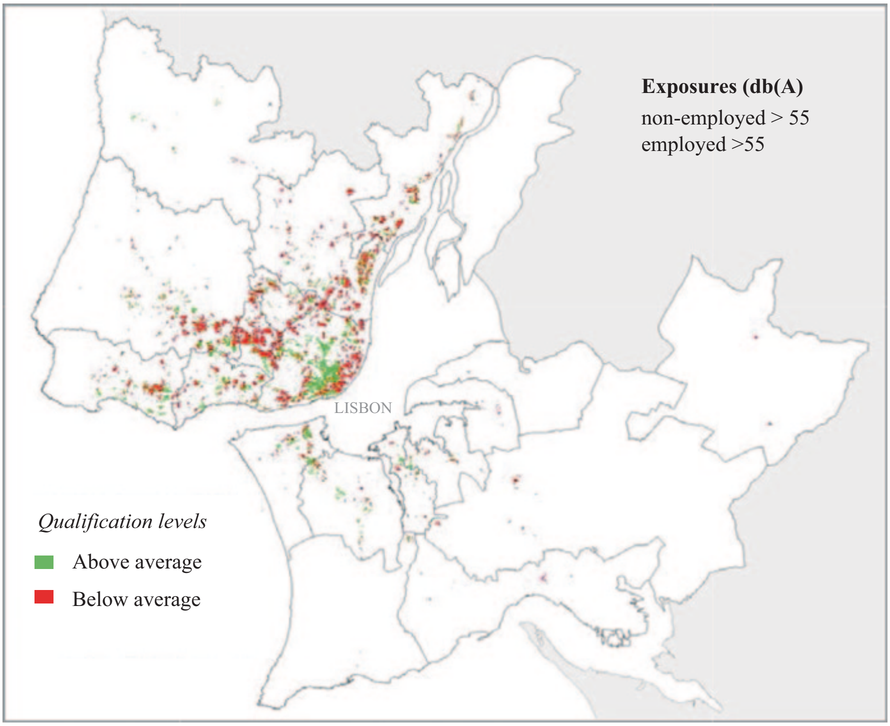


Fig. 4 Noise above standards and qualification levels

which remain associated with negative values of the *Age* variable, the average value of the variable for noise exposures above 55 dB(A) has increased substantially, while the averages for less noisy values (45–55 db(A)) shifted from positive to negative. Figure 1 suggests that these changes may be linked to the increase of noise levels in the city of Lisbon and other central areas, as the population in these areas is considerably older than in the rest of the metropolitan area.

The distribution of exposures for the employed population according to qualification levels (bottom part of Fig. 3) has remained unchanged from 1991 to 2001, showing an almost perfect separation between above-average qualifications in areas above standards and below-average qualifications in areas below standards. The exception to this pattern occurs in the areas with the smallest noise exposures, which correspond to isolated areas in rural municipalities (Fig. 2). These regions tend to have populations with relatively low qualification levels. It is also relevant in terms of transport policy implications to analyse whether the disadvantage for the low-qualified employed population is cumulative to a disadvantage for the low-qualified non-employed population. The map of the areas that exceed the standards of exposures for both non-employed and employed population in 2001 (Fig. 4**)** shows that areas with exposures above standards for both indicators and with above-average qualifications are limited to the central part of Lisbon, while the large majority of the other areas above standards have below-average qualifications.

Conclusions and Further Work

This paper proposed a GIS-based method to measure the spatial distribution of pedestrian noise exposures in a metropolitan area. This method provides information to policy-makers that is not captured by the usual noise maps, as it integrates hypothesis about the daily mobility of the individuals affected. This information can be used in the social and environmental assessments of strategic plans in the transport sector. The application of our method to the case of the Lisbon Metropolitan Area showed that there is a variety of different spatial patterns in the distribution of exposures, which can apply in other urban areas.

These patterns are based on the location of large transport infrastructure, commuting corridors and different areas within each municipality. The analysis also provides insights on equity aspects related to transport planning. The expansion of the road infrastructure and traffic in the study area contributed to increased exposures for the non-employed individuals in areas with predominantly elderly populations, while not reducing the differences in exposures for the employed individuals of different qualification groups.

The research also raises questions for further analysis regarding the role of noise as a factor restricting pedestrian mobility. Subjective assessments of noise annoyance do not depend only on noise levels but also on other sound attributes (such as the duration and frequency of noise events), the characteristics of the individual exposed, and the physical and social environment. The analysis in this paper can then be extended to include further measures of noise (such as quantile-based measures) and information on people's perceptions about the sound attributes of different noise sources in different parts of the city at different times.

Acknowledgements This research was supported by the Portuguese Foundation for Science and Technology. Thanks go to Steve Gibbons, Helena Titheridge and Andrew Lovett for their comments and suggestions.

References

1. Appleyard D (1981) Livable streets. University of California Press, Berkeley
2. Brainard J, Jones A, Bateman I, Lovett A (2003) Exposure to environmental urban noise pollution in Birmingham, UK. Urban Stud 41:2581–2600
3. Korte C, Grant R (1980) Traffic noise, environmental awareness, and pedestrian behavior. Environ Behav 12:408–420
4. Manaugh K, El-Geneidy A (2011) Validating walkability indices: how do different households respond to the walkability of their neighborhood? Transport Res D 16:309–315

5. Marshall JD, Brauer M, Frank LD (2009) Healthy neighborhoods: walkability and air pollution. Environ Health Perspect 117:1752–1759
6. Witten K, Pearce J, Day P (2011) Neighbourhood destination accessibility index: a GIS tool for measuring infrastructure support for neighbourhood physical activity. Environ Plann A 43:205–223

The Influence of Washout Processes on Dust Concentrations in the Air

Jaroslav Fišák and Kristýna Bartůňková

Abstract Ecosystems are greatly affected by dry deposition. Dry deposition is the deposition of air-borne dust from the atmosphere. Many authors have studied the chemical composition of air-borne dust, its particle size distribution and its influence on human health.

The present study examines the content of dust in atmospheric precipitation. Attention is paid to the influence of liquid precipitation on the amount of dust in the atmosphere. This study is complemented by results from the project whose aim was to review the contribution of one dust source to the dustiness of an entire area.

Introduction

Ecosystems are greatly affected by dry deposition. Dry deposition is the deposition of air-borne dust from the atmosphere. Many authors have studied the influence of air-borne dust on human health [1, 7]. There are also studies that have considered the particle size distribution of dust and its concentration as a function of time [4, 6]. Other studies have investigated the chemical and mineralogical composition of particles contained in the atmosphere [8]. The chemical composition of particles contained in precipitation was studied, for example, by Fišák et al. [3] and Li and Shao [5].

The present study does not examine the chemical composition of dust but rather its content in atmospheric precipitation. Attention is paid to the influence of liquid precipitation on the amount of dust in the atmosphere. There are also used results from the project whose aim was to review the contribution of one dust source to the dustiness of an entire area.

In the following, it is supposed that the dust concentration in the air depends on precipitation, especially rain, as well as on soil dampness. Two parameters were used for quantification:

- Precipitation amount

J. Fišák (✉) · K. Bartůňková
Institute of Atmospheric Physics, AS CR, v.v.i., 1404 Boční II,
141 31 Prague 4, Czech Republic
e-mail: fisak@ufa.cas.cz

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_29,

- Volumetric soil dampness (Braňany station only)

For the assessment of the dust concentration in the air, a dry filtering method was used in which the air was drawn in by a suction pump through the pump's head with a filter. To obtain samples that were capable of being measured in the laboratory, the selected time of exposure of the filter was approximately one week. The samples were sampled in two stations: Ledvice (since July 2009) and Braňany (since May 2011). On 27.4.2010, a rain gauge was installed in the Ledvice station. The Braňany station featured a meteorological station with a rain gauge and sensor for the detection of soil dampness at depths of 10 and 20 cm.

The time of sampling of dust samples/filters was not absolutely constant (the exposure time was 6–8 days and differed in the number of hours). In both stations, the precipitation amounts were recorded during the sampling time. In the Braňany station, the volumetric soil dampness at depths of 10 and 20 cm was also recorded. The measured values were saved in 10 min intervals. Because of the different sampling times, it was necessary to use relative characteristics. Accordingly, precipitation amounts recorded for one day were used.

The means of values recorded at depths of 10 and 20 cm during the sampling time were chosen as the characteristics of soil dampness.

Description of the Stations

Both stations are located in a North Bohemian brown coal field, where coal is mined mainly in strip mines. Both stations, Ledvice and Braňany, are located in the neighbourhood of one of these strip mines. In addition to the mines, the area also hosts many mining facilities such as hoppers, works and dumps of mined coal. Also, there is high motor and railway traffic associated with the mining. Moreover, there are many thermal power stations in the surrounding area, where mined-out coal is burned. Indeed, there is no lack of dust sources in the region.

The Ledvice station is located between a strip mine and a thermal power station. The Braňany station lies in open countryside at the edge of a strip mine next to the village.

Methods

Dust Collection

Dust was collected using a filtering method. The device that was used is shown in Fig. 1. The dust was drawn in by a suction pump through the pump head with a filter. In this case, membrane filters composed of glass fibres were used (Fisher F263

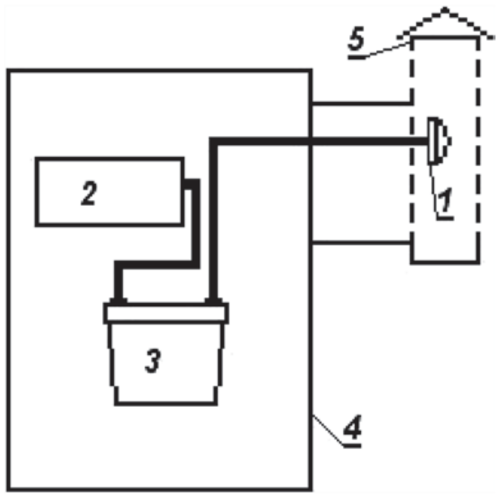


Fig. 1 Scheme of the device for dust sampling by filtering 1—sampling head with the filter; 2—suction-pump; 3—gas meter; 4—case of device; 5—protection against precipitation

47 mm). Each filter was weighed before use. A gas meter was attached to the filter on the pump head. This gas meter measures the volume of air that is drawn. After exposure, the filters were dried and weighed. Based on the amount of dust and the volume of air that were measured, the mean concentration of dust in the air during the time of exposure was determined.

Measurements conducted at the Ledvice station have begun on 24.6.2009 and proceeded over 3 periods. Collection was continuous, with the filter being changed approximately every 7th day. In each of the 3 periods, a different suction pump was used:

1. From 24.6.2009 to 17.11.2009, only calculated values of precipitation were available. The suction pump used was a LAVAT VM 30S12.
2. From 23.2.2010 and to 19.4.2010, only calculated values of precipitation were available. The suction pump used was a GAST 1532-701-RM012.
3. From 27.4.2010 to 17.7.2010, measured values of precipitation were already available. The suction pump used was a GAST 1532-701-RM012.
4. From 14.7.2010 to the present, measured values of precipitation have been available. The suction pump used is a LAVAT VM 40D.

The first period ended because of an irreparable defect in the suction pump that compromised continuous measurement. On 23.2.2010, another suction pump was substituted for the original, allowing measurement to continue. A definitive change in the type of suction pump used was made on 14.7.2010 (4th period). Outfitting the device with a more efficient suction pump allowed for measurement of two samples at a time. After collection, the samples were weighed and submitted to chemical analysis. For analytical purposes, the concentration of dust [$mg_* m^{-3}$] was used.

Precipitation Measurement

During the first and second periods, only precipitation information from a meteorological observatory in Kopisty (IAP, AS CR) was available. During the third period, a rain gauge was installed near the dust collector in Ledvice. Since then, precipitation data from dust-collecting areas have been available.

In the Braňany station, precipitation amounts have been measured since the beginning of the study.

Elaboration and Results

Measurements made at the Ledvice station have been used since the beginning of the 4th period (14.7.2010) and those at the Braňany station since 25.5.2011. Since then, the same device for dust sampling has been used at each station, and the precipitation amounts have been measured at the sampling station. At the Braňany station, the correlation between soil dampness at two depths and dust concentration were also studied. The results of periods 1–3 at the Ledvice station have already been published by Fišák and Bartůňková [2].

Dependence of Dust Concentration on Mean Daily Precipitation

As stated above, in this study, data obtained from the Ledvice station have been used since the beginning of the 4th period. This term was chosen for the following reasons: (i) Precipitation measurements and dust sampling have been performed at the same place and (ii) The dust sampling period is comparable to the sampling period at the Braňany station. To determine the dependence of the mean dust concentration on mean daily precipitation and the precipitation amounts during the sampling time, exponential regression was used.

The dust sampling period was not always constant. The differences range from an abnormal instant to 24 h. Therefore, mean daily precipitation has been chosen as one of the precipitation characteristics. As shown in Fig. 2, it is clear that the mean daily precipitation is high when the dust concentration is low (most of the samples showed mean daily precipitation amounts of 1 mm and above). The calculated confidence coefficient $R^2 = 0.5885$ and equivalent regressive coefficient $r = \sqrt{R^2} = 0.77$ are quite high (Fig. 8).

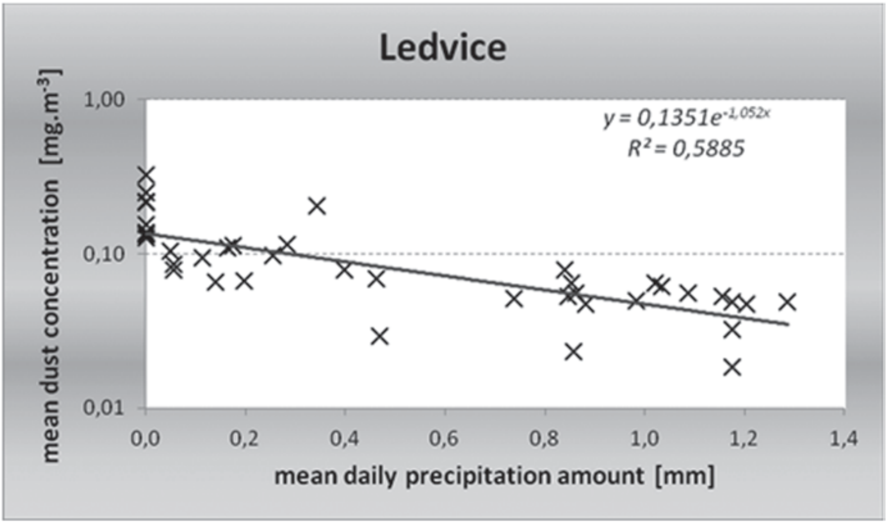


Fig. 2 Dependence of mean dust concentration on mean daily amount of precipitation at the station Ledvice

Dependence of Dust Concentration on Precipitation Amount During Sampling Time

The fact that the dust sampling time varied by ±24 h was expected to influence the results. However, as shown in Figs. 4 and Figs. 5, no effect was observed. Some decreases in the confidence coefficient and regression coefficient were observed, but the values were not significant. It is clear that using the precipitation amount measured during the sampling time is sufficient, and it is not necessary to measure the mean daily precipitation.

Dependence of Dust Concentration on Soil Dampness

Soil dampness was measured at depths of 10 and 20 cm at the Braňany station. Measurements were made using a VIRRIB sensor.

As shown in Figs. 6 and Figs. 7, the volumetric soil dampness at depths of 10 and 20 cm and the dust concentration show an exponential dependence. In fact, the dependence is very strong, as indicated by the regression coefficients, which are r = 0.75 for a depth of 10 cm and r = 0.81 for a depth of 20 cm. As shown, the soil dampness at 20 cm influences dust concentrations in the air more than that at 10 cm. Because the values are means, it is possible to say that soil dampness at lower depths (10 cm in this case) is more variable and high dampness can be very quickly replaced by the desiccation of the layer at these depths. High dampness at higher depths may likely indicate higher dampness in the surface layer.

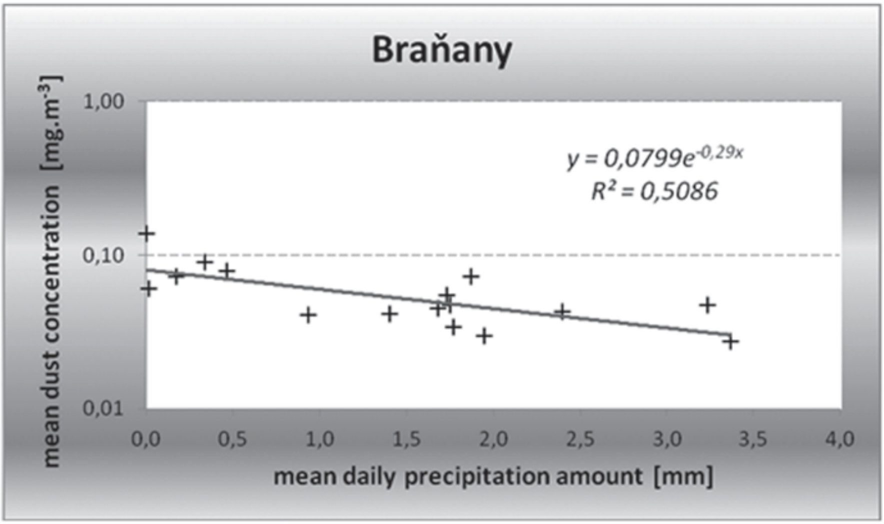


Fig. 3 Dependence of mean dust concentration on mean daily amount of precipitation at the station Braňany

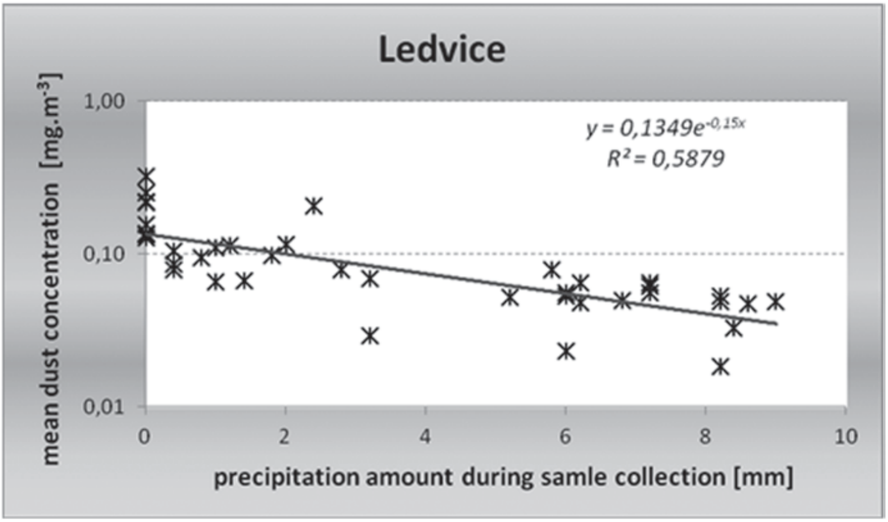


Fig. 4 Dependence of mean dust concentration on mean daily amount of precipitation amount in the time of sampling duration at the station Ledvice

Conclusions

The concentration of dust in the air is strongly affected by solid precipitations when they occur. It is believed that part of the dust is captured by water drops and thus becomes a part of wet deposition. The part of dust that is mainly of terrestrial origin

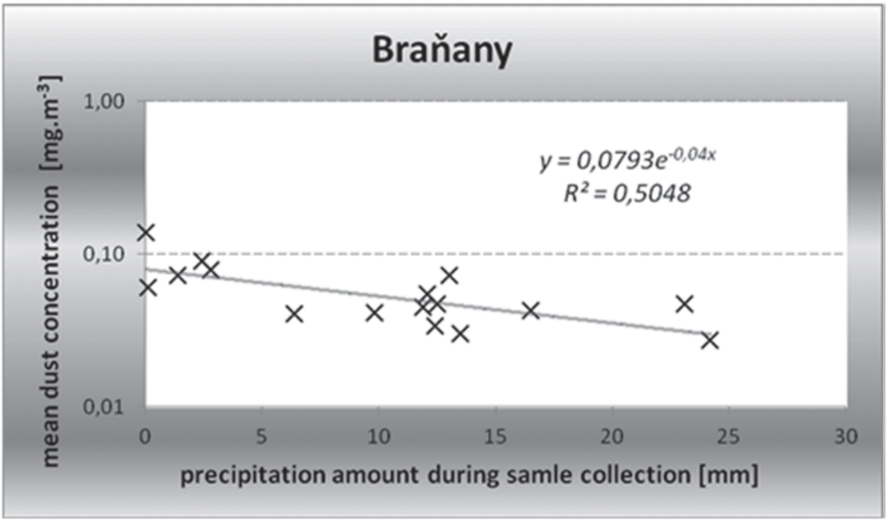


Fig. 5 Dependence of mean dust concentration on mean daily amount of precipitation amount in the time of sampling duration at the station Braňany

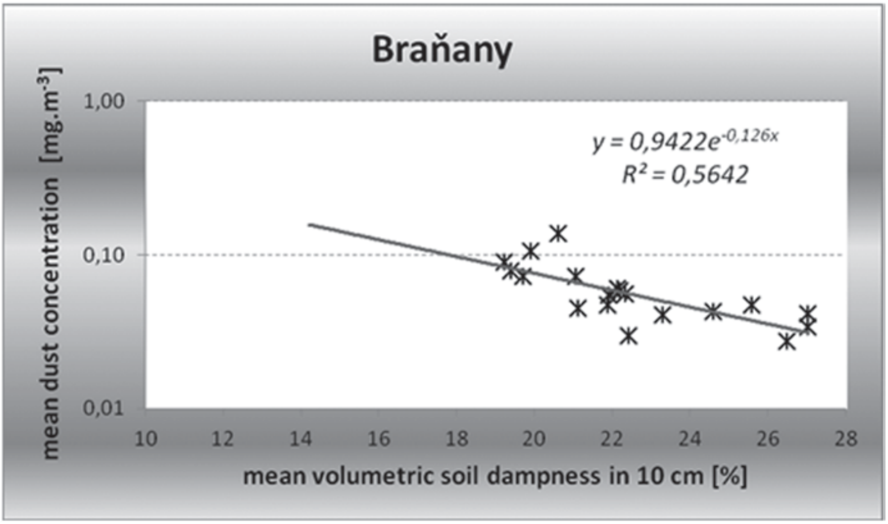


Fig. 6 Dependence of mean dust concentration on soil dampness in 10 cm (Braňany)

is never released into the air. With the increase in the amount of precipitation, the dust concentration in the air decreases. The results are not strongly affected when considering mean daily precipitation amounts instead of precipitation amounts measured throughout the entire dust sampling period.

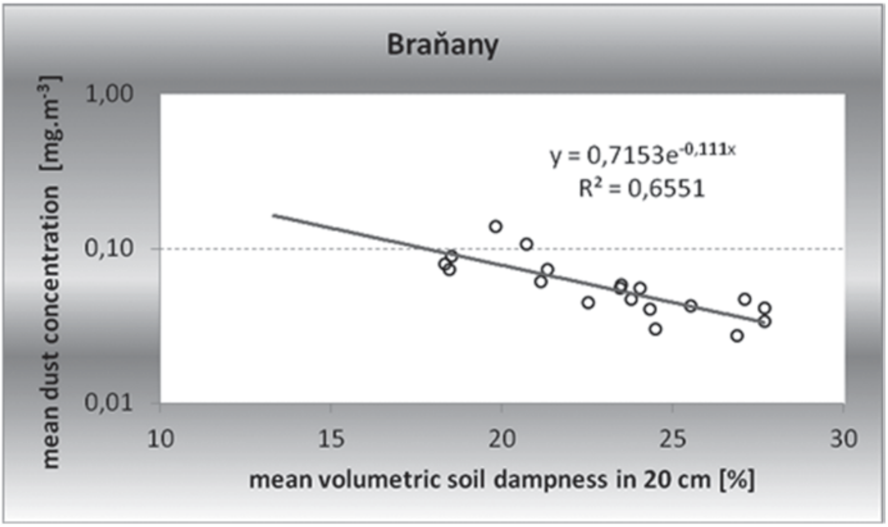


Fig. 7 Dependence of mean dust concentration on soil dampness in 20 cm (Braňany)

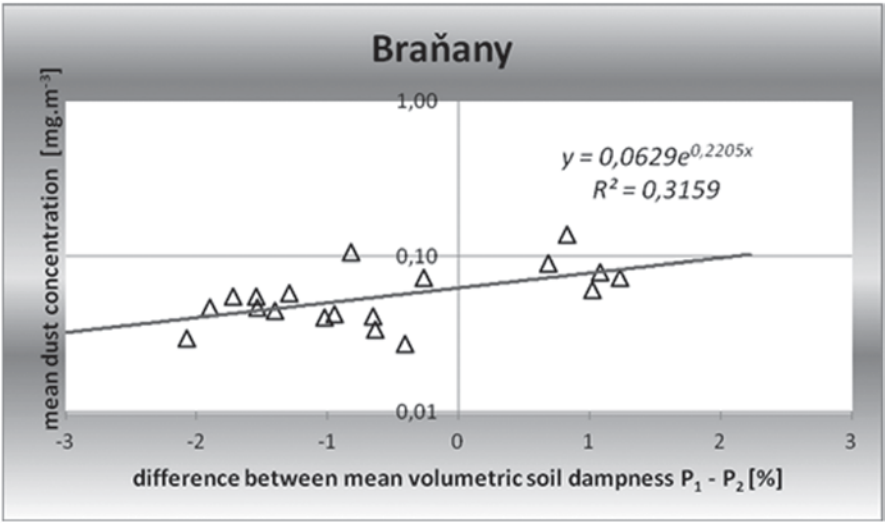


Fig. 8 Dependence on differences between mean soil dampness P_1 and P_2 [%] (P1 [P_2]—volumetric soil dampness in 10 cm [20 cm])

The results are strongly influenced by the locations of the sampling stations. The Ledvice station, where the dependence of dust concentrations on the precipitation amounts is higher, is located very close to a build-up area. In contrast, the Braňany station lies in an open area. Buildings in the surrounding region are low and farther apart. However, this conclusion is not necessarily final because the elaborated dataset from Braňany was obtained over a much shorter period than that from Ledvice, and these results are only preliminary. The results confirm the conclusions of the study by Fišák and Bartůňková [2], in which periods 1–3 at the Ledvice station were researched. Thus, these results may be generalised. It is believed that another measurement will show similar results, even in other sampling stations.

Dust concentration depends more strongly on soil dampness, and this factor indicates the effects of dust generated by mining, traffic, agriculture and building. It can be supposed that the dust concentration is reduced by the particles that, due to soil dampness, are never released into the air to a greater degree than by the particles that are washed out from the atmosphere by rain.

Acknowledgements The results described in this paper were obtained within the framework for AS CR with the support of the GACR Project Nr. 205/09/1918, research intention AV0Z30420517, and the support of the Project Severočeské doly, a.s.—Doly Bílina.

References

1. Brook RD, Franklin B, Cascio W, Hong Y, Howard G, Lipsett M, Luepker R, Mittleman M, Samet J, Smith SC, Tager J, Tager I (2004) Air pollution and cardiovascular disease: a statement for healthcare professional: from the American Heart Association. Circulation 109:2655–2671
2. Fišák J, Bartůňková K (2011) Dependence of rain on dust concentrations in air. In: Šír M, Tesař M (eds) Hydrology of small catchment areas 2011. UH ASCR Prague, Czech, pp 93–100
3. Fišák J, Stoyanova V, Chaloupecký P, Řezáčová D, Tsacheva T, Kupenova T, Marinov M (2009) Soluble and insoluble pollutants in fog and rime water samples. Soil Water Res 4:S123–S130
4. Hays MD, Seung-Hyun Cho SH, Richard Baldauf R, James J, Schauer JJ, Shafer M (2011) Particle size distributions of metal and non-metal elements in an urban near-highway environment. Atmos Environ 45:925–934
5. Li W, Shao L (2009) Characterization of mineral particles in winter fog of Beijing analyzed by TEM and SEM. Environ Monit Assess 161:565–573
6. Lonati G, Cernuschi S, Giugliano M (2011) The duration of PM10 concentration in a large metropolitan area. Atmos Environ 45:137–146
7. Poppe III AC, Dockery DW (2006) Health effects of fine particulate air pollution: lines that connect. Air Waste Manag Assoc 56:709–742
8. Stoyanova V, Schoumkova A, Fišák J, Tsacheva T (2010) SEM-EDX identification of particles from fog in an industrially polluted region of Czech Republic, Proceedings of 10th International Multidisciplinary Scientific Geoconference, “Modern Management of Mine Producing, Geology and Environmental Protection”. SGEM 2010 2:269–276

Part V
Urban Climate Change and Adaptation

Urban Climate—Impact and Interaction of Air Quality and Global Change

Stefan Emeis, Joachim Fallmann and Peter Suppan

Abstract Urban climate impacts on more than half of mankind. Two dominating features are urban heat islands and changed precipitation patterns. Urban climate features are linked to and interact with local and regional air quality and Global Change. Especially urban heat islands have negative impacts so that mitigation and adaptation strategies are desirable. This review will present some mitigation and adaptation strategies. The use of complex numerical models such as meso-scale chemistry transport models is strongly recommended in order to assess the effect of planned measures against urban heat islands and to estimate their impact on urban air quality.

Introduction

Urban areas exhibit a special climate due to their special land use and surface properties which is different from its surroundings. For example, the presence of buildings lead to higher aerodynamic roughness that slows down mean wind speeds in cities but increases turbulence intensity. Radiation is partly trapped in street canyons and part of this surplus heat energy is stored in buildings. The water budget is changed as well. Impervious surfaces and scarce vegetation cause higher (and warmer) runoffs directly after precipitation events and supply less water for evaporation later. The formation of an urban heat island is a well-known consequence of these special urban features.

The excess temperatures in urban heat islands have several consequences that make it advisable to reduce the intensity of the urban heat is land. On the one hand excess heat exerts heat stress on all beings living in Xa city and increases the need of them for fresh water. This is accompanied by additional energy consumption for cooling, particularly in summer.

On the other hand higher temperatures and reduced humidity alter the conditions for chemical reactions of atmospheric traces gases and for the formation of secondary aerosols. Additionally, higher temperatures in a city give rise to a secondary

S. Emeis (✉) · J. Fallmann · P. Suppan
Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Garmisch-Partenkirchen, Germany
e-mail: stefan.emeis@kit.edu

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_30,

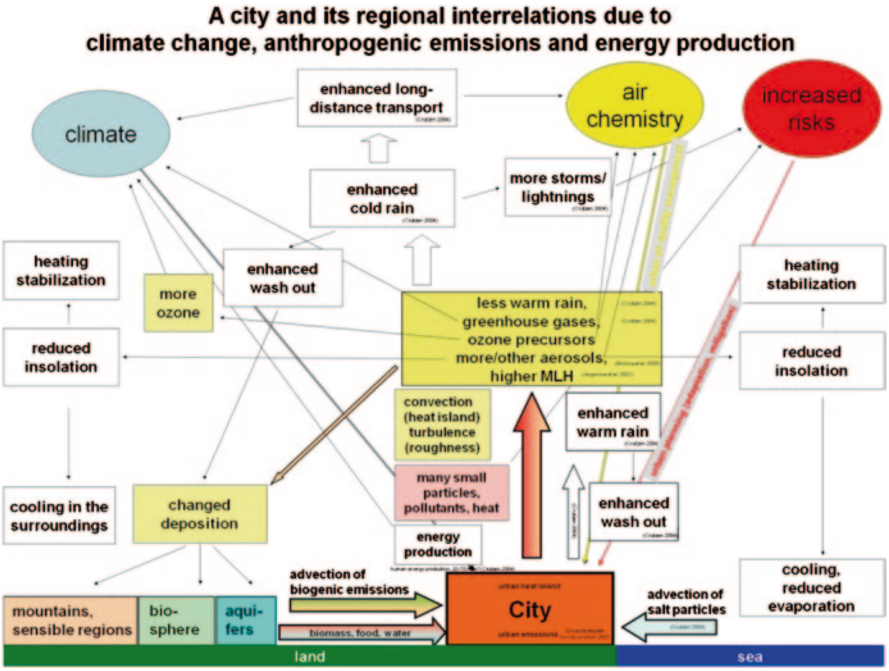


Fig. 1 Schematic of interrelations between a city, its surroundings, air quality and climate change

wind circulation which imports near-surface air from the surroundings and export warmer and chemically transformed air in an urban plume into higher layers of the atmospheric boundary layer or even into the lower free troposphere (upward pointing arrow in Fig. 1). This makes cities to be remarkable reaction vessels within which rural biogenic emissions and urban anthropogenic emissions are processed under special conditions such as increased temperature and turbulence and reduced humidity. Numerical modelling can be used to make this secondary circulation visible. Figure 2 shows the difference in vertical velocity between a simulation with and without a city.

Global Change is very likely threatening to aggravate the negative consequences of urban climate and urban heat islands. A growing global human population increases the size of large cities even further. The energy consumption of this growing population increases anthropogenic emissions and heat production in cities and thus enhances the heat island effect again. The growing needs of this urban population for water, food and energy foster unfavourable land use changes and emissions in the surroundings. The globally rising temperature enhances the heat stress to the urban population.

Most of the abovementioned processes are highly nonlinear. The complex interaction of population growth, land use change and Climate Change (see Fig. 1) cannot be judged from simple models but requires the execution of complex numerical

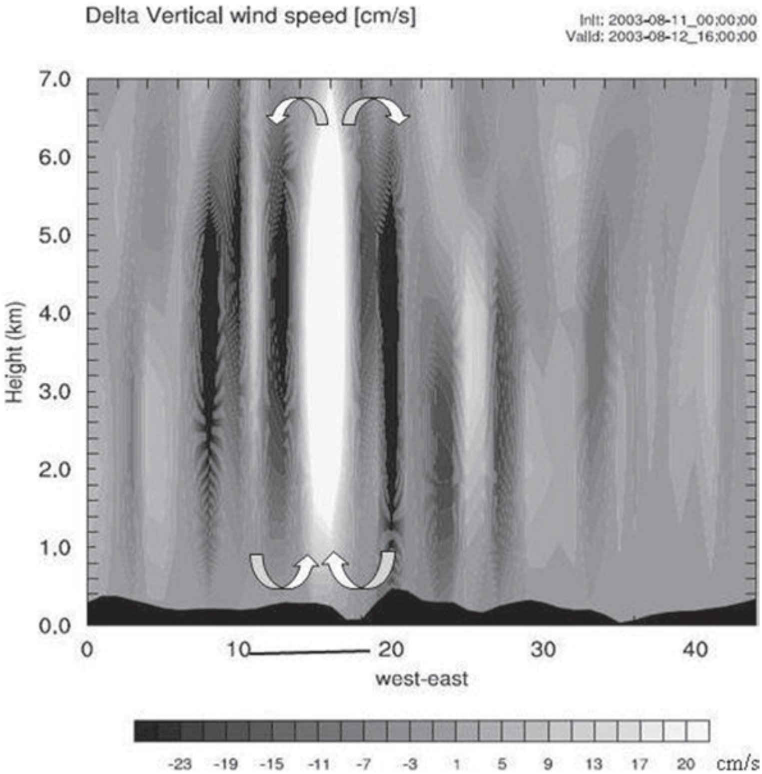


Fig. 2 Difference of the vertical velocity in cm/s over a given transect covering urban area (marked by the line between 10 and 20 on the x-axis) and rural surroundings. Bright colours indicate uplift, dark colours downdrafts. Difference calculated from two model runs, one with full urban canopy and one 'zero case' where the urban surface is replaced by grassland

models. Only such model simulations will be able to give meaningful hints for suitable mitigation and adaptation strategies which will allow for acceptable living conditions in the cities of tomorrow's world.

This review summarizes some of the most important aspects of urban climate. This is followed by an overview of possible mitigation and adaptation strategies to reduce the impact of urban heat islands. This review concludes with a discussion of present approaches to observe and to model the highly complex and nonlinear interaction of the different ongoing processes.

Urban Climate

Currently, about 1.2% of the Earth's land surface is considered to be urban [18]. Since 2007, more than half of the world's population is living in cities and three out of five humans will probably do so by 2030 [20]. It is expected that more than 16%

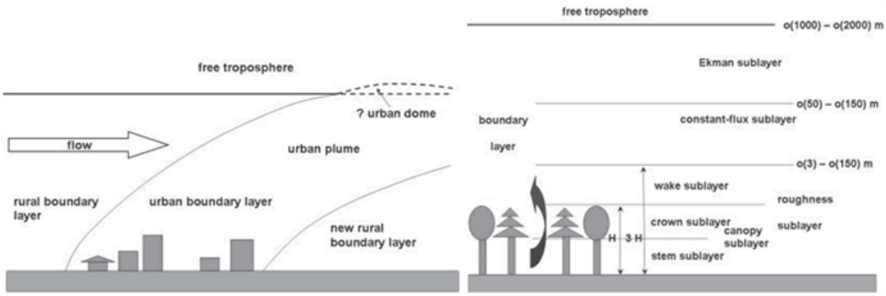


Fig. 3 The urban boundary layer and urban plume as an internal boundary layer (*left*) and the detailed layering of the urban boundary layer (*right*). [6]

of all cities will be megacities by 2015 [7]. The evolution of large cities and megacities has been the largest change in surface characteristics which ever happened on land surfaces (see the definition of the astysphere [14]). Land use change from rural terrain to urban terrain has consequences for the local and regional climate. We will especially address changes in air temperature and in precipitation here. Changes in relative humidity are less systematic. Probably, relative humidity is enhanced in urban areas shortly after precipitation events when excess humidity is available for evaporation from impervious surfaces, while relative humidity is reduced after longer dry episodes.

Urban Heat Island

The urban heat island is the most prominent feature of urban climate. Calm weather and clear skies favour its evolution while cloudy skies and stronger winds work against its formation. We concentrate here on the atmospheric heat island forming in the urban boundary layer (Fig. 3) and showing an enhancement in air temperature near the surface and in the urban roughness sublayer. The heat island is most pronounced at night-time. An inverse feature (urban cold island) can evolve for a few hours after sunrise when rural surfaces warm up more rapidly than urban surfaces. Main scaling parameter for the urban heat island intensity (i.e. the air temperature difference between the city and the rural surroundings) is the size of the population of a city. Empirically the heat island intensity increases linearly with the logarithm of the number of inhabitants. The slope of this increase is not uniform. There are indications that the increase is stronger in dry climates and temperate latitudes than in the humid tropics [2].

Main reasons [2] for the formation of the heat island over cities are an enhanced absorption of short wave radiation (i.e., a reduced albedo), an enhanced storage of heat due to the larger heat capacity of buildings and other structures (this is the main reason for the shift of the diurnal temperature variation to later hours and the maximum heat island intensity at night-time), anthropogenic heat production [4], reduced emission of long wave radiation (only part of the sky is visible due to surrounding buildings), and less sensible heat is converted into latent heat (reduced evaporation).

Precipitation

The urban influence on precipitation is less clear and straightforward. Shepherd [18] and Souch and Grimmond [19] list several aspects why precipitation could be enhanced over larger urban areas. This includes first of all a roughness effect. The rougher city surface slows down the wind speed at the upwind edge of the town leading to flow convergence and compensating mean upward motion. Another contribution comes from the urban heat island which leads to a destabilization of the layering of the boundary layer and additional upward convective motion. Urban aerosols may be an additional source for cloud condensation nuclei.

The first effect could produce additional clouds and precipitation at the windward side of larger cities. The latter two processes probably foster the cloud and precipitation production in the lee of larger cities. The properties of the oncoming air masses play the most important role in urban precipitation modification. Probably, the conditions in the air masses approaching the city have already to be close to the onset of the release of precipitation. Only then, the urban influence is able to add the decisive small additional input to produce precipitation.

Urban Air Quality

The special urban climate features, the secondary circulation system and the high amount of anthropogenic emissions lead to a typical chemical weather in cities. Crutzen [4] calls it the 'urban pollution island' discussing its interrelation with atmospheric chemistry and climate. Concentrations of primary trace gases such as carbon oxides and nitrogen oxides are enhanced in urban boundary layer air due to proximity to the large emission sources, while concentrations of secondary trace gases such as ozone are enhanced in the lee of cities in the urban plume. Formation of secondary trace gases is often positively correlated with temperature. Thus, the urban heat island increases the production rates for many of these trace gases.

Urban air quality is also influenced by the secondary circulation caused by the heat island (upward motion over the city and compensating near-surface inflow from the rural surroundings) bringing biogenic trace gases from rural areas closely together with anthropogenic trace gases from urban sources. There is no other place in the world where trace gases from both origins are brought together so thoroughly. Thus, one can consider the urban boundary layer as a special chemical reaction vessel within which a very special chemistry happens. One example could be the formation of photo-oxidants from biogenic VOCs and anthropogenic nitrogen oxides. This urban chemistry definitely needs further attention.

Mitigation Strategies

Several proposals have been made to mitigate the urban heat island and its consequences. Apart from reductions in human energy consumption and the anthropogenic heat production, most mitigation measures are solar radiation management (SRM) techniques. SRM techniques either base on an enhancement of the urban albedo or in a reduction of radiation capture in street canyons and between houses. Additionally, a better insulation of buildings could reduce the heat storage effect—at least as long as the energy consumption during the production of the insulation material is less than the saved amount of heating or cooling energy.

Enhancement of urban albedo is most easily be done by increasing the shortwave reflectivity of pavement and roof materials (‘white roofs’ or ‘cool roofs’). White roofs have a twofold positive effect. They directly reflect a larger part of solar radiation back into space and thus reduce the available energy for the formation of the heat island. In warmer countries, they reduce the necessary amount of cooling or air conditioning as well. This reduces the anthropogenic heat production and the emissions of carbon dioxide. The latter effect also contributes to mitigate Global Warming [1]. Negative consequences of white roofs might be an additional heating demand in cold seasons. This could probably be partly compensated by darker side walls of these buildings, because the sun usually shines from lower angles in cold seasons.

Radiation and heat capture in street canyons and between buildings and other urban structures can be reduced by optimizing the distance between buildings and road widths. Either very large or very small distances and road widths are helpful. Large distances and wide roads do not obstruct outgoing long wave radiation and provide space for urban vegetation. Very small distances and narrow roads prevent the heating up of the pavement and the lower stories of buildings by incoming short wave radiation. This later option can be combined with white or cool roofs (see, e.g., white Greek cities or desert towns in Northern Africa). Both strategies have negative implications as well. Wide roads and large building distances favour urban sprawl while narrow roads obstruct goods and commuters traffic.

Adaptation Strategies

Possibly, a complete mitigation of the urban heat island is not possible. Measures to reduce radiation capture are nearly impossible to be implemented in existing cities. Therefore, adaptation strategies are necessary as well. Unfortunately, many of the adaptation measures have considerable negative consequences as well.

Air conditioning and cooling requires more energy and presumably enhances greenhouse gas emissions. Added urban vegetation and green roofs rise the fresh water demand which might be difficult to be secured in a warmer and drier climate. Furthermore, the water demand of the vegetation competes with the rising demand of a growing population. The type of urban vegetation also needs attention. VOC-emitting species in a high nitrogen oxide-emission environment may lead to a dangerous increase in the formation of harmful photo-oxidants. Larger water bodies in cities could be an ideal breeding place for insects contributing to the spreading of infectious diseases.

Further options might be fresh air aisles which allow for cool air drainage flows and diurnal winds (e.g., for a daytime sea breeze in a coastal megacity) to enter the town. Such aisles may though in some cases be negative for pedestrian comfort. A better health care system may help to cure people suffering from increased heat stress but needs lots of financial resources.

There are heat island impacts for which probably no adaption strategy exists. For example, photovoltaic cells operate worse with higher temperatures and warm urban run-off heats river water which reduces its ability to serve as cooling medium in power plants (disregarding whether they are driven by fossil fuels or not).

Tools for Decision Makers

The highly complex nature of interactions between the different compartments of an urban environment (meteorology, urban structures, air chemistry, water cycle) and between an urban area and its surroundings requires the use of complex tools in order to observe the existing situation and to assess the suitability of suggested mitigation and/or adaptation measures.

Ground-based [6] and space-borne [5] remote sensing techniques are good tools to observe and monitor urban climate features. Optical sensing techniques (lidars, ceilometers, DOAS, FTIR) can give trace gas and aerosol concentrations while acoustic (sodar) and electro-magnetic (RASS, wind profiler) techniques provide information on wind, turbulence and temperature distributions.

A meso-scale chemistry and transport model (e.g., WRF-chem, [8]) is a good assessment tool. It is able to simulate the regional flow regime including the heat driven secondary circulations and the chemical transformations in the moving air masses. It must be supported by a proper emission module which supplies the biogenic and anthropogenic emissions. Land use and elevation data must be made available as well. Such a model resolves surface properties and air motions down to a spatial scale of about one kilometre and time scales of 10–30 min. Processes happening at smaller scales must be parameterized. Rotach [17] has shown from field experiments that the assumption of height-constant fluxes is not valid in the urban roughness layer up to heights of two to three times the building height. Therefore, the usually employed Monin-Obukhov theory cannot be used to parameterize vertical turbulent fluxes in this layer.

Further, the surface energy balance cannot be derived from standard approaches, because shading and multiple reflection is not included in these approaches [10]. Therefore, several schemes have been developed to cope with these deficiencies. They can roughly be classified into three types [13]:

1. Roughness schemes (slab models)
2. Single-layer urban canopy models (UCMs)
3. Multi-layer urban canopy models (drag force approach)

An example for a roughness scheme is presented in Dandou et al. [5]. They modify the boundary layer parameterization in WRF [9] for unstable stratification and larger roughnesses and include the anthropogenic heat production. One example of a single-layer UCM is the Town Energy Budget (TEB) model of Masson [12], which contains a generalised description of street canyons. Building effect parameterisations (BEP) formthe third class of urbanisation schemes for meso-scale models. Following Martilli et al. [10] these multi-layer models describe cities as a series of parallel epipeds (made from concrete) with uniform length, width, and distance, but with different heights. The soil surface forms the lowest model layer. Several of the next layers lie within the building layer.

The advantages of multi-layer models are that

1. The influence of buildings on momentum and heat fluxes is distributed to all layer within the canopy layer (and not solely attributed to the lowest layer). Thus, the Reynolds stresses increase with height in the canopy layer in accordance to measurement data from [15].
2. A modification of the length scales limits the increase of turbulent kinetic energy in the canopy layer, again in accordance with measurement data from [16].
3. Retention of radiation and shading in street canyons is considered. This permits the simulation of nocturnal UHI.

Such a multi-layer approach has been used here to assess the influence of "white roofs" on near-surface temperature. Figure 4 shows 2 m temperatures along a cross section through a larger and several smaller cities. The albedo of impervious surfaces is set to 0.2 in the control case and to 0.7 in the assessment case.

Conclusions

Many of the special features of urban climate have proven to have negative impacts on larger parts of mankind. These impacts include public health and urban air quality. Therefore, especially the urban heat island effect deserves control and limitation. Mitigation strategies are obviously more sustainable than adaptation strategies. It is always better to avoid a negative effect before it comes into existence rather than to take rescue measures to reduce the negative consequences of an existing unfavourable situation.

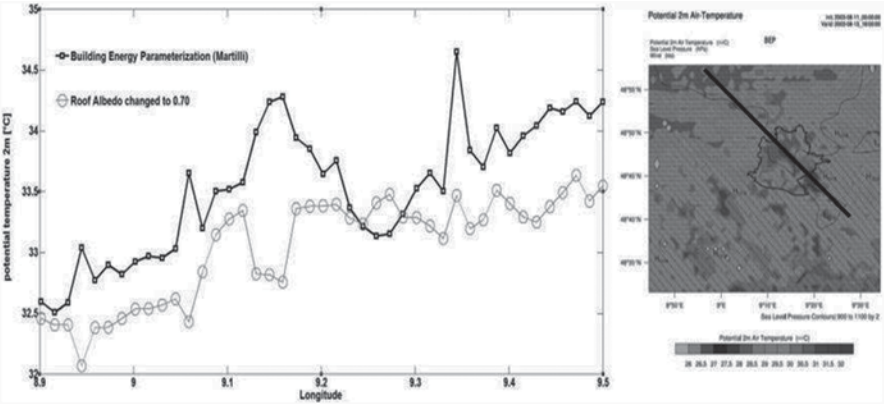


Fig. 4 Impact of 'white roofs'. 2 m potential temperature (*left*) along a cross section through urban and rural terrain (*right*). *Bold curve*: albedo of impervious surfaces is set to 0.2, *thin curve*: albedo of these surfaces is set to 0.7. Upward peaks in the bold curve mark urban areas

Urban climate is nonlinear phenomenon depending on a larger number of influencing factors including climate change and air quality. Thus, any assessment of mitigation or adaptation measures—e.g., those to fight urban heat islands—requires the use of complex nonlinear models in order to estimate the impacts of taken measures. Such nonlinear models are available and have been adapted to urban applications in the last decade. We expect that stakeholders, policy makers and city planners can now get important assistance from the output of simulations with these assessment models.

References

1. Akbari H, Menon S, Rosenfeld A (2009) Global cooling: increasing world-wide urban albedos to offset CO_2. Climatic Change 94:275–286
2. Chow WTL, Roth M (2006) Temporal dynamics of the urban heat island of Singapore. Int J Climatol 26:2243–2260
3. Crutzen PJ (2004) New directions: the growing urban heat and pollution "island" effect—impact on chemistry and climate. Atmos Environ 38:3539–3540
4. Dandou A, Tombrou M, Akylas E, Soulakellis N, Bossioli E (2005) Development and evaluation of an urban parameterization scheme in the Penn State/NCAR Mesoscale Model (MM5). J Geophys Res 110:D10102, doi:10.1029/2004JD005192
5. Emeis S (2010) Measurement methods in atmospheric sciences. In situ and remote. Series: quantifying the environment, vol 1. Borntraeger, Stuttgart. XIV + p 257
6. Emeis S (2011) Surface-based remote sensing of the atmospheric boundary layer. Series: atmospheric and oceanographic sciences library, vol 40. Springer, Heidelberg, X + p 174
7. Fernando HJS, Lee SM, Anderson J, Princevac M, Pardyjak E, Grossman-Clarke S (2001) Urban fluid mechanics: air circulation and contaminant dispersion in cities. Environ Fluid Mech 1:107–164

8. Grell GA, Peckham SE, Schmitz R, McKeen SA, Frost G, Skamarock WC, Eder B (2005) Fully coupled ‘online’ chemistry in the WRF model. Atmos Environ 39:6957–6976
9. Hong S-Y, Pan H-L (1996) Nonlocal boundary layer vertical diffusion in a medium-range forecast model. Mon Weather Rev 124:2322–2339
10. Martilli A, Clappier A, Rotach MW (2002) An urban surface exchange parameterisation for mesoscale models. Bound-Lay Meteorol 104:261–304
11. Martilli A, Roulet Y-A, Junier M, Kirchner F, Rotach MW, Clappier A (2003) On the impact of urban surface exchange parameterisations on air quality simulations: the Athens case. Atmos Environ 37:4217–4231
12. Masson V (2000) A physically-based scheme for the urban energy budget in atmospheric models. Bound-Lay Meteorol 94:357–397
13. Miao S, Shen F, LeMone MA, Tewari M, Li Q, Wang Y (2009) An observational and modeling study of characteristics of urban heat island and boundary layer strutures in Beijing. J Appl Meteor Climatol 48:484–501
14. Norra S (2009) The astysphere and urban geochemistry—a new approach to integrate urban systems into the geoscientific concept of spheres and a challenging concept of modern geochemistry supporting the sustainable development of planet earth. Environ Sci Pollut Res 16:539–545
15. Rotach MW (1993a) Turbulence close to a rough urban surface. Part 1: Reynolds stress. Bound-Lay Meteorol 65:1–28
16. Rotach MW (1993b) Turbulence close to a rough urban surface Part 2: Variances and gradients. Bound-Lay Meteorol 66:75–92
17. Rotach MW (2001) Simulation of urban-scale dispersion using a lagrangian stochastic dispersion model. Bound-Lay Meteorol 99:379–410
18. Shepherd JM (2005) A review of current investigations of Urban-induced rainfall and recommendations for the future. Earth Interactions 9(12):27
19. Souch C, Grimmond S (2006) Applied climatology: Urban climate. Prog Phys Geog 30:270–279
20. United Nations (2008) State of the world’s Cities 2008/2009—Harmonious cities. United Nations Human Settlements Programme (UN-HABITAT). Earthscan, London. p 259. http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2562, read Sept. 10, 2012

Simulations of the Impact of Lake Area on Local Microclimate by Using COSMO NWP Model

Kristýna Bartůňková, Zbyněk Sokol and Jaroslav Fišák

Abstract A hydric coal mine restoration creates new water areas, which change surface characteristics of the locality. These changes consist primarily in different thermal properties, different surface roughness and different albedo compared to the original surface. It is evident that the hydric restoration influences the atmosphere and thus affects the temperature and humidity, as well as other meteorological quantities around the lake. The impact of the restoration can influence much larger areas by changing precipitation climatology.

This study deals with the quantitative evaluation of the impact of a new lake, which was created by hydric restoration of a coal mine, on local climate. First results of a numerical weather prediction model are presented.

Introduction

A hydric coal mine restoration creates new water areas, lakes, which change surface characteristics of the locality. These changes consist primarily in different thermal properties (heat capacity, thermal conductivity), different surface roughness and different albedo compared to the original surface. It is evident that the hydric restoration influences the atmosphere and thus affects the temperature and humidity, as well as other meteorological quantities around the lake. The impact of the restoration can influence much larger areas by changing precipitation climatology.

Evaluation of the impact of new lakes on local climatology is important because it is a necessary part of the approval process of restoration projects. This evaluation is a difficult task because it is done before a lake exists and we cannot directly utilize measured data. From this viewpoint the two approaches can be applied. The first one is based on the application of analogy when findings based on observations before and after flooding an area, where the restoration was already performed, are subjectively transferred to the location of our interest. This approach requires having available sufficiently long series and density of observations. For example the

K. Bartůňková (✉) · Z. Sokol · J. Fišák
Institute of Atmospheric Physics, AS CR, 1404 Boční II,
141 31 Prague 4, Czech Republic
e-mail: kbar@ufa.cas.cz

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_31,

Fig. 1 The map of the lake and its surroundings with marked meteorological stations AK Most (**a**), lake station (**b**), CELIO (**c**) and Kopisty (**d**). The Milesovka station is about 20 km from the lake in the south-west direction

impact of flooding on precipitation climatology was studied by this technique by Conradt et al. [2] and Klimánek [3].

The second approach uses a numerical model to simulate the impact of a new lake on local climate. The advantage of this approach consists in the fact that the impact can be evaluated in advance before a lake is created and only original local climatology is needed. On the other hand modelling of local climate using a numerical model with a high resolution of the orders of hundreds meters is a complicated physical problem and it is very difficult to verify quality of the model outputs. Such approach was used for mapping of huge lakes on precipitation climatology [5]. So far we have not found information on the solution of a similar problem as we are interested in here.

This study deals with the quantitative evaluation of the impact of a new lake, which was created by hydric restoration of a coal mine, on local climate. The study was triggered by the ongoing restoration near the town Most in the north Bohemia. In this region a former mine is being flooded and a new lake (lake Most) is created (Fig. 1). The Most lake lies in the altitude of 199 m above sea level, its size will be 311 ha and its maximum depth will be 75 m. The whole study will include both statistical processing of observed data in the target region and simulations by a high resolution numerical weather prediction model. After completion the study should result in the creation of a methodology that would be used in the future for similar studies because hydric reclamation is planned for other mines in northern Bohemia after their extraction.

This paper is concentrated on the application of a numerical weather prediction (NWP) model to the evaluation of the lake impact on local climate. The first results will be shown.

Lake

The bottom and banks of the lake were adapted in 2002 and since 2006 the lake is being artificially flooded. It is expected that flooding will be finished in 2013. The current state of the lake is shown in Fig. 1. It can be argued that since 2008 the water area was sufficiently large to influence its vicinity and the previous period can be considered as unaffected by the lake. This splitting of data is used in the statistical evaluations of the lake impact on the local climatology, which is not the topic of this paper.

Data

Two professional meteorological stations are located in the vicinity of the lake, which measure common meteorological elements like air temperature, humidity, pressure, wind speed and wind direction, solar radiation, visibility, soil temperature and others. The station Kopisty (250 m a. s. l.) is about 500 m from future lake's bank. The station provides standard measurements and it is also equipped by 80 m meteorological tower, which measures temperature, relative humidity and wind direction and speed at levels 20, 40, 60 and 80 m. Data are available from 1970.

The second station is located at the top of the Milesovka hill at 836 m a. s. l. This station, which is about 20 km from the lake, serves as a reference station, which is supposed to be negligibly influenced by the lake and by other local changes in this region. It has provided meteorological measurements since 1905.

Within the running project there were built three new stations. Two of them are very close to the lake (CELIO—264 m a.s.l. on the left bank of the lake, AK Most—330 m a.s.l. on the right bank of the lake) and the third one is placed directly on the water-level in the lake. The lake station measures temperature, relative humidity and wind speed and direction 2 m above the water-level of the lake. In addition it measures water temperature at 16 levels to a depth of 20 m. These stations started their operation in June 2011. Positions of all stations are shown in Fig. 1. The results presented in this paper were obtained using observed data only from the warm part of the year 2011.

NWP Model

We applied the non-hydrostatic COSMO NWP model (version 4.18 [1]), which has been developed by the Consortium for Small-scale Modeling (http://www.cosmo-model.org/). The model was used with switched on the Flake model, which describes interactions between atmosphere and water reservoirs. The application of the Flake model was not intended to simulate the temperature development in the lake but it is used to consider fluxes near a water surface. The soil model used within the COSMO model considered seven underground levels.

COSMO contains one-moment cloud microphysical scheme with five classes of hydrometeors: rain water, cloud water, snow, ice and graupel. The model is able to resolve and explicitly simulate at least the larger-scale elements of organised convection [4], therefore, the parameterisation of deep convection was not used.

Preliminary tests confirmed that the selection of the turbulent scheme may significantly influence model results. The COSMO model offers several types of such schemes. Based on tests we decided to apply the turbulence scheme which includes prognostic calculation of 3D turbulence (itype_turb = 8, l3dturb = .TRUE.). Our experiments shown that the standard turbulence model (itype_turb = 3), which is frequently used in operational runs of COSMO, gave unrealistic results not only in values, but also in the structure of the near ground fields that were too smooth.

More details about model configurations are given in the following Section.

Calculation of the Impacts of the Lake on Local Climate

The impact of a water area on local climate depends on specific local conditions namely on orography. To obtain general features of the impacts, which could be applied to other localities, where the hydric restoration will be carried out, we calculated the lake impact on the local climate under idealized conditions.

We supposed that the orography is flat, soil is homogeneous and its type was set to the prevailing type in the northern Bohemia. We also set surface roughness to a constant value, which was equaled to 0.1 m in the calculations presented in this paper. We simplified the shape of the lake on the rectangle whose size was 2.7 km by 1.6 km. Our artificial lake had approximately the same area like the Most lake. The size of the COSMO model domain and the lake position is shown in Fig. 2.

The impact of the lake we studied in the following way. We selected days with typical meteorological conditions for which we had measurements from all stations described in Section "Data" and prepared initial conditions for the model. The boundary conditions were periodic. Then we integrated the model in time. The homogeneous initial conditions gradually changed in dependence on how the lake, mainly the lake temperature, modified near surface layers of atmosphere. Tests showed that the model would never find an equilibrium state. However, after 3 h of the integration the surface values stabilized and only slowly changed. Therefore the difference between the initial fields and fields after 3 h of integration we consider to be the impact of the lake. It is important to mention that the model integration is done with radiation switched off because we have to remove diurnal variation, which would prevent finding a quasi-equilibrium state.

The initial conditions for the model were prepared using observations from the Kopisty station. We prepared soil temperatures in corresponding levels, ground temperature, surface pressure and vertical profiles of pressure, temperature, rela-

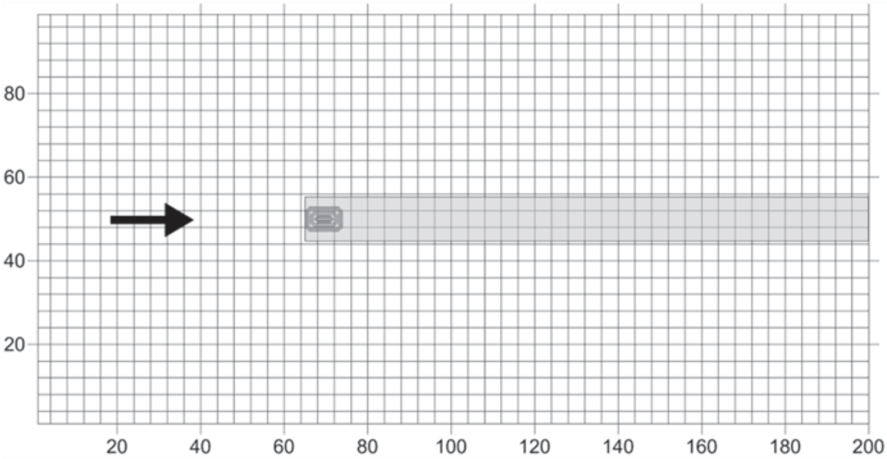


Fig. 2 The COSMO model domain consists of 200 by 99 grid points. The *rectangle* shows the lake position and the *arrow* indicates the wind direction. In the *grey* bend minimum, maximum and mean values were studied

tive humidity and wind speed. Standard pressure and temperature vertical gradients were used and the wind speed profile was obtained using a power law formula to have all fields required by the model. In order to further simplify the calculations and the interpretation of the results the wind blew always in the direction from left to right as indicated in Fig. 2. Moreover we switched off Coriolis force in the model to avoid rotation of the wind, which significantly complicates interpretation of the results.

COSMO was integrated with a horizontal resolution of 333 m and with 60 vertical levels unequally distributed from the ground to the top at 15 km with a high density of model levels near the surface. The lowest nine levels were at: 0.10, 0.38, 0.87, 1.64, 2.76, 4.33, 6.42, 9.16 and 12.64 m. The model time step was 3 s.

Results

Using the procedure described in Section "Calculation of the impacts of the lake on local climate" we processed altogether 76 cases from June, July and August 2011, which were selected to represent typical summer meteorological situations. The cases were selected from 19 days and the model we applied to data from 00, 06, 12 and 18 UTC.

Figure 3 shows examples of model simulations. It shows changes in air temperature at 2 m above ground on 25 July 2011 for 00, 06, 12 and 18 UTC. These examples illustrate how differences in input data (Table 1) influence temperature changes. The inhomogeneous character of the horizontal fields is caused by gravity

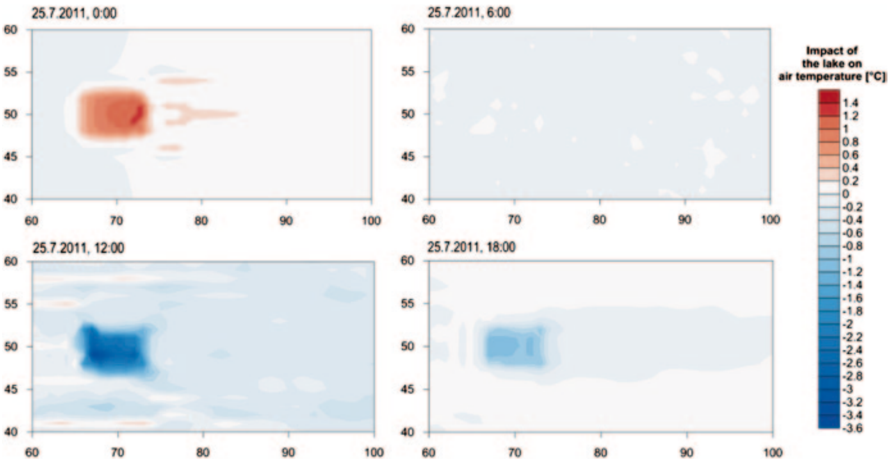


Fig. 3 Impact of the lake on air temperature at 2 m above the ground on 25 July 2011 at 00, 06, 12 and 18 UTC. Only the cut-out of the model domain is presented. Values on x and y axes indicate grid points of the whole domain

waves evoked by the existence of the lake. From this figure it is clear that the lake effect cannot be evaluated in single points but a larger area must be considered.

We concentrated on the evaluation of changes in temperature and humidity caused by the lake existence. The changes were calculated in dependence on the height above the ground and on the distance from the lake. To at least partly suppress inhomogeneity in horizontal fields illustrated in Fig. 3 we processed grid values in a band whose width was 11 grid points (3.3 km) and which went through the lake from the left to the right. We studied mean, maximum and minimum values in y direction in the band as a function of x.

The changes in temperature and humidity were evaluated in dependence on the differences between ground temperature, T_g, and water-level temperature, T_w, or air temperature at 2 m, T_{2m}, and T_w. The idea of this division is clear—the impact of the lake definitely depends on differences between T_g and/or T_{2m} on one side and T_w on the other side. Some of the results are shown in Fig. 4 (air temperature) and Fig. 5 (relative humidity). These figures depict minimum, maximum and mean values calculated within the band as described above. The results are shown in vertical levels 0.10 m (a) and 12.64 m (b) in dependence on $T_g - T_w$. Figures 4 and 5 show that on average the impact of the lake is limited to the nearest vicinity of the lake. However, for some meteorological situations the impact may be apparent in both directions; both warming/relative humidity increase and cooling/relative humidity decrease can be registered.

The changes of temperature and relative humidity are smaller for the higher level of 12.64 m but still apparently visible and they have the same character as for the lowest level.

The temperature changes in dependence on $T_{2m} - T_w$ are logical and understandable. The dependence of the changes on the distance from the lake is not clear. The

Table 1 Selected input data for the COSMO NWP model for 25 July 2011 at 00, 06, 12 and 18 UTC

	25 July 2011			
	0:00	6:00	12:00	18:00
Mean temperature of water column [°C]	10.3	10.2	10.1	10.2
Water surface temperature [°C]	18.7	18.6	19.9	19.5
Air temperature at the ground [°C]	9.0	10.1	34.0	20.0
Air temperature at 2 m [°C]	10.1	8.5	21.1	19.0
Wind speed at 10 m [m*s^{-1}]	0.8	0.0	3.7	4.0
Relative humidity at 2 m [%]	90	100	50	46
Air pressure [hPa]	976	976	975	975

lake influences temperature of atmosphere near the ground up to approximately 1 km from the lake's bank if the water temperature differs from the T_{2m}. For longer distances the impact of the lake is much smaller but visible and it is independent on the distance. This might be caused by too narrow model domain. This should be further investigated.

To explain the changes in relative humidity is less straightforward. For example when water is significantly cooler than surrounding air then the air relative humidity decreases by cooling but simultaneously increases by evaporation. It might be that instead of the relative humidity another more proper humidity characteristic should be studied.

Conclusions and Outlooks

The first results confirm that the COSMO model and the applied procedure is a reasonable tool for estimating the impact of a new lake on the local climatology of temperature and humidity. We cannot directly validate our results but they do not contradict observations and agree with expectations.

On average the impact of the lake on the local temperature in the warm part of the year is very small for areas distant more than 1 km from the lake banks. On the other hand in single cases the change of temperature may exceed 0.5 °C. Similar results were obtained for relative humidity. On average the impact is close to zero, however; extreme values are of order per cents. Future work will include:

- Actual vertical profiles of meteorological variables will be used. They will be prepared either from sounding data from Prague station of ECMWF analysis will be used.
- More cases (days) will be selected and processed. The data will be processed separately for the warm and cold part of the year.
- The lake effect will be studied for various length of the lake. Beside the currently used length h = 2.3 km also 2*h, h/2 and h/4 will be considered.

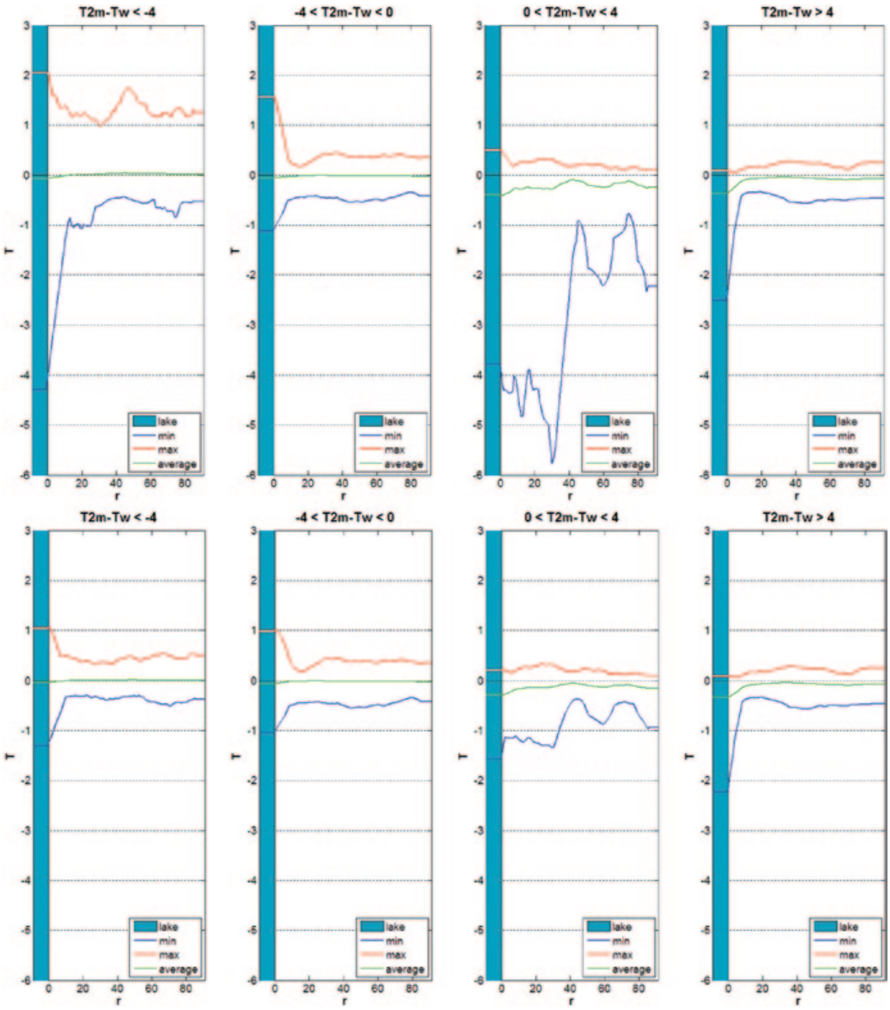


Fig. 4 Minimum, maximum and average values of changes in air temperature [°C] in vertical levels 0.10 m (*above*) and 12.64 m (*below*).The figure is divided according to the differences between air temperatures in 2 m (T_{2m}) and water surface temperatures (T_w) into four parts: (1) $T_{2m}-T_w<-4$, (2) $-4<T_{2m}-T_w<0$, (3) $0<T_{2m}-T_w<4$ and (4) $T_{2m}-T_w>4$. r is the distance from the lake in grid points

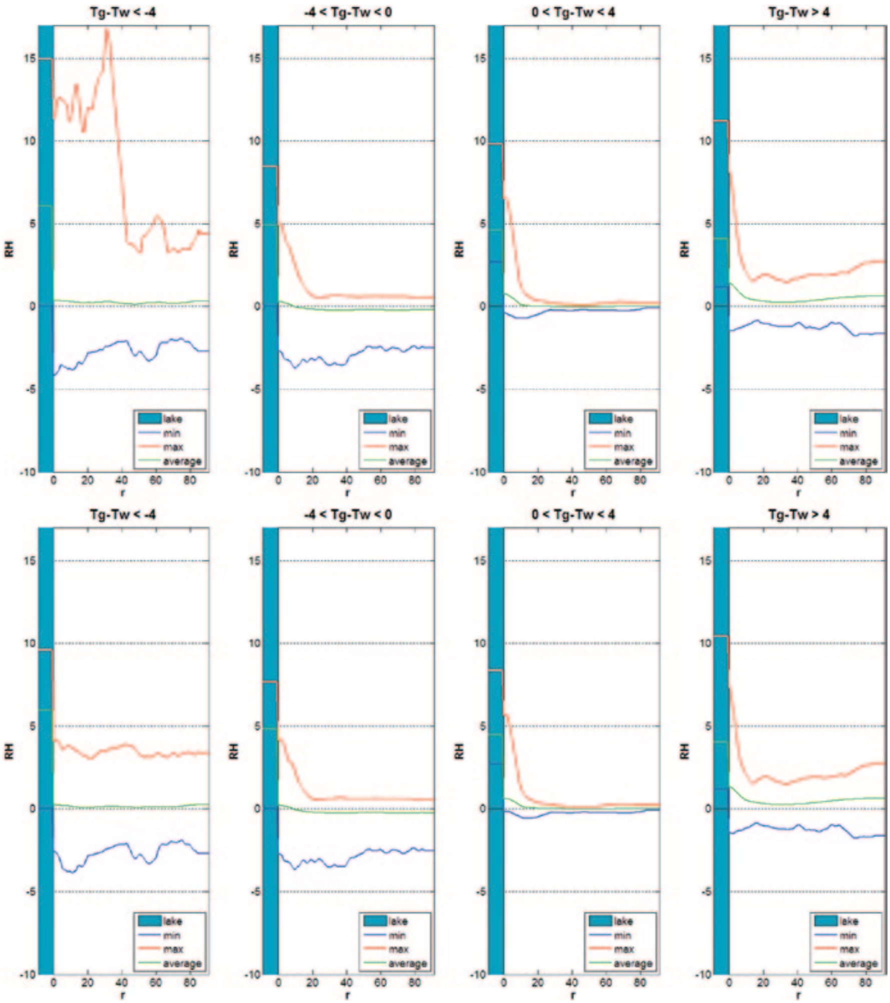


Fig. 5 Minimum, maximum and mean values of changes in relative air humidity [%] in vertical levels 0.10 m (*above*) and 12.64 m (*below*).The figure is divided according to the differences between ground temperatures (T_g) and water surface temperatures (T_w) into four parts: (1) $T_g - T_w < -4$, (2) $-4 < T_g - T_w < 0$, (3) $0 < T_g - T_w < 4$ and (4) $T_g - T_w > 4$. r is the distance from the lake in grid points

Acknowledgement This work was supported by grants TA01020592. The COSMO code was kindly provided by the German Weather Service, which was highly appreciated.

References

1. Baldauf M, Seifert A, Förstner J, Majewski D, Raschendorfer M, Reinhardt T (2011) Operational convective-scale numerical weather prediction with the COSMO model: description and sensitivies. Mon Weather Rev (in print). doi:10.1175/MWR-D-10-05013.1
2. Conradt T, Kundzewicz, ZW, Hattermann F, Wechsung F (2007) Measured effects of new lake surfaces on regional precipitation. Hydrolog Sci J 52:936–955
3. Klimánek M (2004) The climatological impact of water reservoirs Novomlýnské nádrže on floodplain forest. In: Rožnovský J, Litschmann T. XIV. Czech-Slovac bioclimatological conference, Lednice na Moravě, 2–4 Sept 2004. ISBN 80-85813-99-8. pp 161–179
4. Stephan K, Klink S, Schraff C (2008). Assimilation of radar derived rain rates into the convective scale model COSMO-DE at DWD. Q J R Meteorol Soc 134:1315–1326
5. Wilson JW (1977) Effect of Lake Ontario on precipitation. Mon Weather Rev 105(2):207–214

The Estimation of CO_2 Emission from Road Vehicles by Traffic Macro-Simulation

Gabriela Mitran, Sorin Ilie and Ion Tabacu

Abstract Remarkable growth of population and mobility needs in the last century, especially in urban areas, is associated with air pollution. Reducing emissions of greenhouse gases from road vehicles is the main concern about the sustainability of road transport. The main factor derived from anthropogenic activities that contribute to increased greenhouse effect is CO_2. This is the main product resulting from the combustion process that occurs during operation of thermal self-propelled vehicle. In this paperwork is estimated the volume of CO_2 from road vehicles depending on speed. The case study is conducted for a medium sized city in Romania, Bistrita. The average speed of the vehicles on urban road network, the structure and volume of traffic flow were determined by transport modeling macro-simulation of road traffic using PTV-VISUM specialized software. The variation curves of CO_2 volume according to the average speed used in this application has been validated for the structure of national fleet in the document *Romania—Technical assistance for the elaboration of the General Transport Master Plan*. These were determined according to CORINAIR methodology agreed by European Environment Agency, for the following categories: cars, light trucks, medium trucks and heavy trucks. Applying the methodology of calculation of CO_2 based on average travel speed integrated with traffic modeling (knowing the average travel speed and the number of vehicles of existing categories on each segment of road network) allows the estimation of the volume of CO_2 from mobile sources (vehicles) on any road network segments analyzed.

Introduction

One of the polluting substances which has increased substantially over time, the effects of which are manifested globally over a centuries period and which is the most important greenhouse gas emitted by human activities is dioxide carbon. This is the main product resulting from the combustion process. The emissions associated with the operation of road vehicles, in the most part, come from burning fuels,

G. Mitran (✉) · S. Ilie · I. Tabacu
University of Pitesti, Pitesti, Romania
e-mail: gabriela.mitran@upit.ro

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_32,

in this way the road transport being one anthropogenic sources discharging into the atmosphere a significant amount of CO_2.

In Romania, according to a study by the European Commission, Directorate-General for Energy and Transport (DG TREN) in 2010—*"CO_2 Emissions from Transport by Mode"*—the total amount of CO_2 emitted into the atmosphere experienced a reduction of 35 % between 1990–2007, but at the same time the contribution of road transport increased by about 85 %, from 6.5 one million tones in 1990 to 12 million tones in 2007 [2], which is worrying considering the policies to reduce the amount of CO_2 in the air launched worldwide.

In this paper the authors propose a method to estimate the concentration of CO_2, existing in the breathable air, that comes from road transport activities in urban areas based on a model for estimating traffic flow at macroscopic level.

Background

The study was developed for a medium sized city in Romania, Bistrita, located in the North of the country. At the beginning of 2012 in this city were registered 85,000 inhabitants [6]. The road network of the city has a major deficiency, don't has a bypass for long distance traffic or a high-speed and capacity infrastructure near by. The road network axis in the NW-SE direction, consisting of European roads E60-E576-E58, which connects between Hungary and Republic of Moldova (Fig. 1), crosses through the Bistrita downtown.

Methodology

The methodology for estimating air pollution with CO_2 consists in several sequences of modeling procedures of traffic flows, CO_2 emissions of vehicles and dispersion of these emissions in the atmosphere. The logic diagram of the method for estimating CO_2 pollution is shown in Fig. 2.

The output data from the transport model, the size and structure of traffic flows and the average travel speed on each arc of the network are input data into the model for estimation of emissions from road vehicles. The amount of CO_2 emitted into the atmosphere is as an input to the dispersion model, which gives the final result of CO_2 concentration in the air, associated of road traffic.

Fig. 1 The location of Bistrita city relative to the national road network

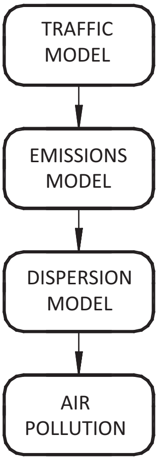
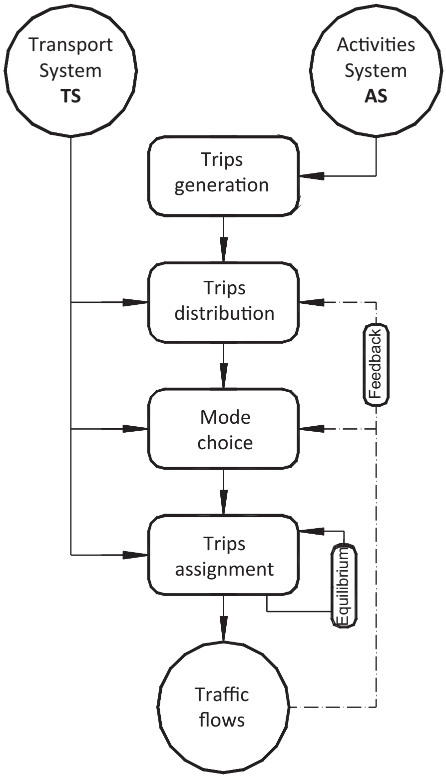


Fig. 2 The logic diagram of the method for estimating the air pollution

Traffic Model

In order to estimate the traffic flows, the classical "four-steps" model has been applied, whose structure is shown in Fig. 3 [7], that was implemented for the analyzed area with the VISUM software system (PTV VISION product). Thus, were obtained

Fig. 3 The structure of the "four steps" model



the traffic flows in the rush hour, traffic composed of the following types of vehicles: cars, light duty trucks, medium duty trucks and heavy duty trucks.

CO_2 Emission Model

Knowing the volumes of the traffic flows, their structure (number of vehicles in each category) and average travel speed on each arc of the road network, to estimate the amount of CO_2 emitted into the atmosphere were applied the variation functions for this emission factor with to average travel speed. These functions were established for each category of vehicles in the Romania fleet forecasted for year 2012 in the *General Transport Master Plan* [4].

The quantities of CO_2 emitted into the atmosphere by cars for variations of average travel speed between 10 and 130 km/h and by commercial vehicles (light duty trucks, medium duty trucks and heavy duty trucks) for average travel speeds between 10 and 100 km/h are shown in Figs. 4, 5, 6 and 7.

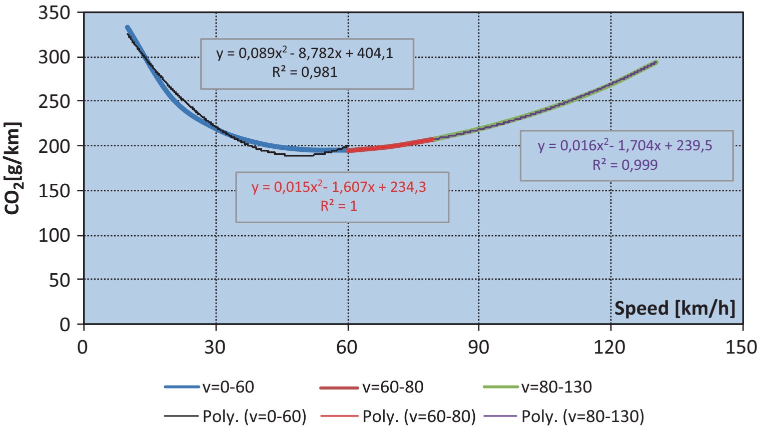


Fig. 4 The variation of CO_2 emission rate depending on average speed—cars, Romania fleet

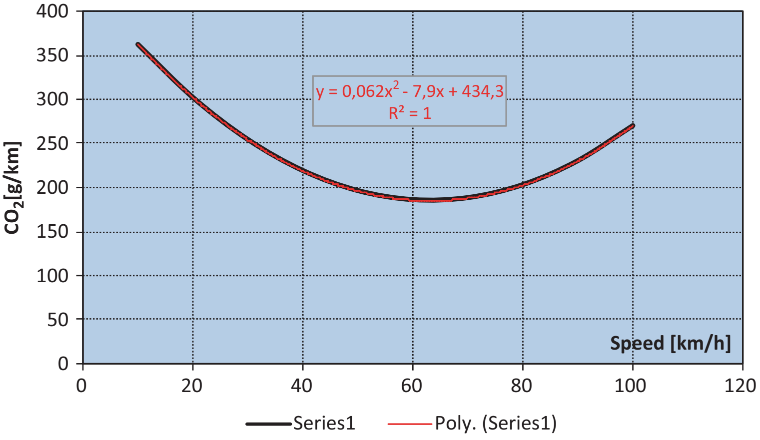


Fig. 5 The variation of CO_2 emission rate depending on average speed—light duty trucks, Romania fleet

Dispersion Model

The dispersion in the atmosphere of the total quantity of CO_2, obtained by summing the values associated with each category of vehicle, for each arc of the road network, was made by applying Gaussian dispersion model. This is the most used model of dispersion of emissions from transport activities, requiring input data easily obtained. Mathematical expression is:

$$C(x,y,z) = \frac{E}{\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \cdot \exp\left[-\frac{1}{2}\cdot\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \exp\left[-\frac{1}{2}\cdot\left(\frac{z}{\sigma_z}\right)^2\right] \quad \left[\frac{g}{m^3}\right]$$

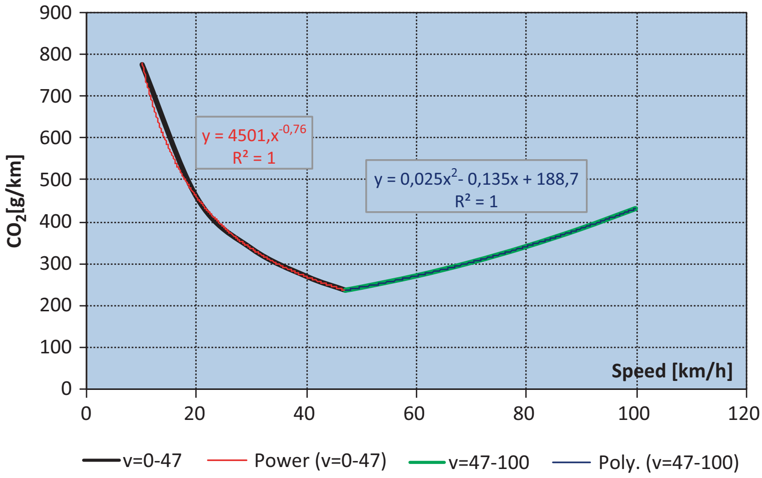


Fig. 6 The variation of CO_2 emission rate depending on average speed—medium duty trucks, Romania fleet

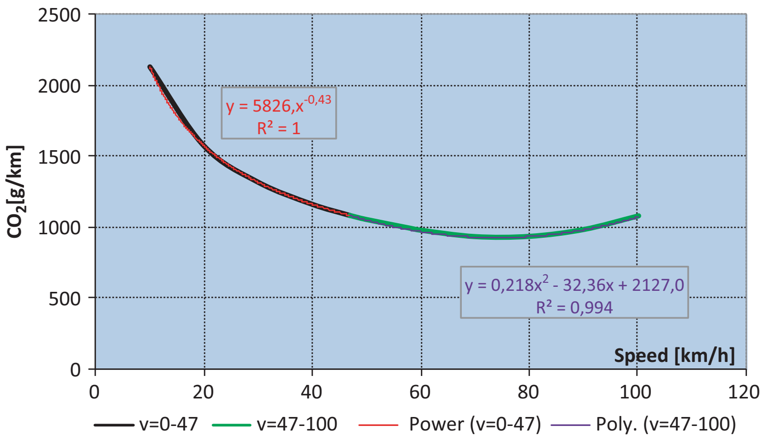


Fig. 7 The variation of CO_2 emission rate depending on average speed—heavy duty trucks, Romania fleet

where:

1. C is the pollutant concentration in the point of coordinates (x,y,z);
2. E [g/s] is the amount of emissions per time unit;
3. u [m/s] is the average wind speed in the direction parallel to the axis Ox;
4. σ_y [m] and σ_z [m] are standard deviations of plume concentration distribution at a distance x from the source, in the wind direction.

Fig. 8 The traffic flows, rush hour

The values of standard deviations for distributions of the emission factors concentration are influenced by atmospheric stability, wind speed and intensity of solar radiation specific in the monitored area. The values of these two parameters were determined with the relations introduced by Bringgs for urban area [1] corresponding to the Pasquill atmospheric stability regimes [3, 8]. The atmospheric stability regime for the case study was determined based on meteorological data on wind speed and solar radiation intensity obtained from the on-line monitoring of air quality at national level, in which is integrated the station for continuous monitoring of air quality in Bistrita [5]. The dispersion was modeled in the following assumptions: in the point placed at 7 m from the axis of the road, on the sidewalk, at height of 1.5 m for a range of representative area of 100 m.

Results and Discussion

By applying the traffic model were obtained traffic flows in rush hour, namely the traffic levels for following vehicles categories: cars, light duty trucks, medium duty trucks and heavy duty trucks (Fig. 8). The commercial vehicles are directed on a street which years ago had a bypass function, but now is inside of the inhabited area of the city, the population of the city is so affected by the externalities induced by long distance traffic, especially heavy duty trucks. Also, in the city center were

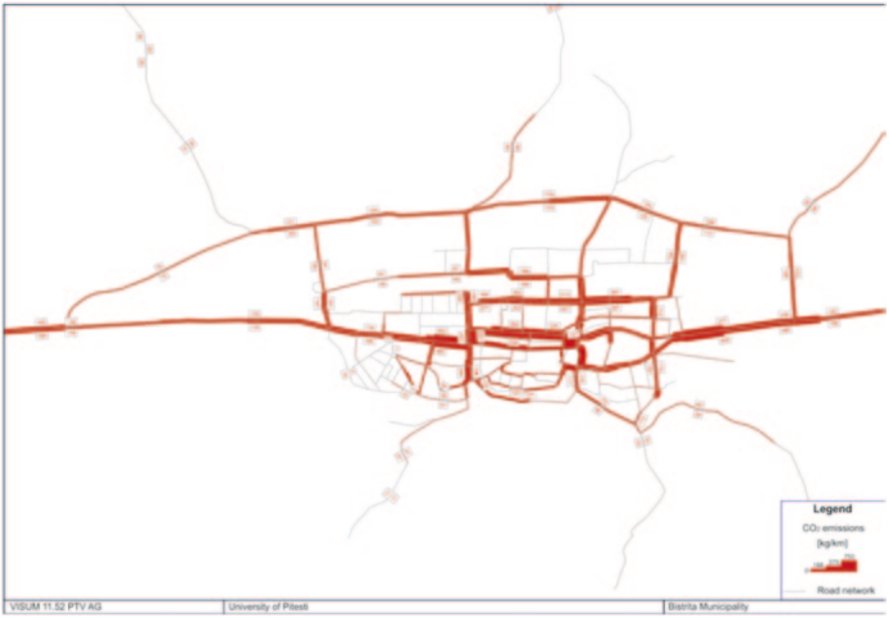


Fig. 9 The CO_2 emissions, rush hour

recorded traffic flow values up to 2,000 cars, in the rush hour. Knowing the traffic flows values and the average travel speeds on each network segment, by applying the model for estimating the CO_2 emissions were obtained the quantities of this substance, expressed in [kg/km] that are discharged from road traffic into the atmosphere in the hour in which were recorded the maximum values of the traffic flows. These are represented with functions of the VISUM software in the form of bands along the arcs of the network, band width being proportional to the emission values (Fig. 9).

The CO_2 concentrations present in the breathable atmosphere at 1.5 m height, coming from road vehicles, near the road network of Bistrita were represented using the functions of the VISUM software (Fig. 10). In the center area were obtained values of CO_2 concentration between 2 and 5.5 kg/m^3, wich are high values for a town with 85,000 inhabitants.

Conclusions

Reducing greenhouse gas concentrations in the atmosphere, especially CO_2, is a problem that has global relevance and interest. Proposing policies and strategies aimed at reducing this substance in the atmosphere requires, first, knowing the current situation and identifying the sources of CO_2 production. The difficulty of

Fig. 10 The concentration of CO_2 in the breathable air, rush hour traffic

quantifying the contribution of the road transport to the accumulation of various pollutants in the atmosphere is given in special by knowing the specific traffic parameters for transport networks associated with different areas of analysis. Thus, the volume and structure (vehicles types) of the traffic flows and the average travel speed are the key elements in the applications for estimating the atmospheric pollution caused by road transport mode. The modality to quantify these parameters for each segment of a transport network is traffic macro-simulation. Creating a macro-simulation traffic model allows both assessing the current situation in terms of traffic and therefore pollution generated from it, as evidenced by the methodology proposed in this paper and highlight the changes that occur at different forecast horizons. The methodology proposed, by the operation of traffic modeling phase of the various proposals for traffic management and transport network development, facilitates quantification of the effects of these changes on air pollution.

Acknowledgments This work was partially supported by the strategic grant POSDRU/88/1.5/S/52826, Project ID52826 (2009), co-financed by the European Social Fund—Investing in People, within the Sectoral Operational Programme Human Resources Development 2007–2013.

References

1. Briggs G (1973) Diffusion estimation for small emissions—U.S. National oceanic and atmospheric administration, ERL Report, Atmospheric turbulence and diffusion laboratory—106, Tennessee, USA
2. European Commission (2010) Directorate-General for Energy and Transport (DG TREN) CO_2 Emissions from Transport by Mode
3. Laskarzewska B, Mehrvar M (2009) Atmospheric chemistry in existing air atmospheric dispersion models and their applications: Trends, advances and future in urban areas in Ontario, Canada and in other areas of the world. Int J Eng (IJE) 3(1):21–57 (Malaysia) (ISSN 19852312)
4. Ministry of Transport and Infrastructure Romania (2009) European commission, Louis Berger SAS, technical assistance for the elaboration of the general transport master plan, Ministry of Transport and Infrastructure—Romania, Bucharest
5. National Environmental Protection Agency Romania (2012) http://www.calitateaer.ro/—site. Accessed 15 June 2012
6. National Institute of Statistics Romania (2012) http://www.insse.ro/cms/rw/pages/index.en.do. Accessed 18 May
7. Ortúzar J de D, Willumsen L (2001) Modelling transport, 3rd ed. Wiley, Publishing House, ISBN 13:978-0-471-866110-2 (H/B) Chichester, West Sussex, England, reprinted in February 2008
8. Wester Regional Climate Center, USA. http://www.wrcc.dri.edu/data-projects/. Accessed 20 May 2012

Energy Consumption and CO_2 Emissions of Road Transport Toll Highways in Spain

P.J. Pérez-Martínez and R.M. Miranda

Abstract This paper estimates the energy consumption of transport toll highways for 202 road segments and for seven vehicle types: gasoline cars, diesel cars, motorcycles, vans, articulated trucks, rigid trucks and buses. Energy consumption is related to traffic volume, Annual Average Daily Traffic (AADT) and Annual Average Hourly Traffic per lane (AAHT), and factors such as speed, road slope and percentage of heavy-duty vehicles (HDVs). Energy consumption estimates give an evaluation of the levels of energy efficiency of road segments. Energy consumption is estimated using fuel consumption-speed curves which regression parameters are balanced according with the coefficients from an empirical model based on site survey data. According with the paper, the mean energy consumption and subsequent CO_2 emissions from toll highway segments are estimated to be respectively 1,895 MJ/h/lane-km and 0.15 tCO_2eq./h/lane-km. These values increase to 2,644 and 0.22 if energy and carbon emissions of transport infrastructure are considered. Material Input per Service (MIP) is determined, as the life cycle wide energy consumption by the toll highway construction and vehicles, and set against passenger-kilometres and ton-kilometres transported. If the MIP of the infrastructure construction is allocated to the users according to traffic, the MIP is much higher for motorcycles than for car traffic. The aggregated MIP is significantly lower for articulated trucks than for vans. The aggregate of Spain's toll highway segments requires 2.6 MJ/tu-km (0.6 infrastructure and 2.0 traffic).

P. J. Pérez-Martínez (✉)
Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG),
Universidad de São Paulo, Rua do Matão, 1226, 05508-090 São Paulo, Brazil
e-mail: pjperez@caminos.upm.es

P. J. Pérez-Martínez · R. M. Miranda
Sustainable Economy of Natural Environment Group (ECSEN), Universidad Politécnica de Madrid, C/Ramiro de Maeztu s/n, 28040 Madrid, Spain

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_33,

Introduction

Energy saving through reduction of road transport demand on highways has traditionally focused on external cost amelioration, whereas decrease of the energy intensity has generally been ignored. However, there are some studies focused on the right monitoring of energy and environmental transport impacts per service unit offered [10, 12, 13]. The material input per service unit (MIP) measures the potential of reducing energy and environmental impacts of transport per unit of product or service offered, serving as a transport intensity indicator [11].

The energy consumption absolute figures depend on the increase in the units transported (passengers and freight) in each mode of transport [1, 7]. Energy intensity is determined by two factors: the energy required to move the vehicle and the use of the vehicle's capacity [8]. Environmental intensity is measured in emissions of CO_2 (and of each pollutant) for the same units of transport.

Road transport sector is also energy intensive and consumes a high amount of energy resource per unit of transport. In this work, the MIP approach has been applied to calculating the energy resource consumption and CO_2 emissions of road transport in Spanish toll highway segments. MIP estimates have been analysed and significant factors in the formation of the MIPs have been investigated. Energy consumption and CO_2 emission patterns are also identified.

Data Sources and Methodology

Activity Data, Monitoring Stations and Traffic Parameters

The Spanish Road Traffic Survey (SRTS) provides with measurements of traffic flows at locations across the Spanish high capacity road network [5]. The SRTS provides a measure of the distance travelled by the interurban road vehicles. In total 202 sites were sampled in 2007 with a length of 1,869 km, traffic of 19,837 million vehicle-km and AADT of 35,002 vehicles per day. These sites represent 63.8 % of the total length of Spanish toll highways and have 79.1 % of total traffic on Spanish toll highways. Vehicle traffic parameters are available at a micro level such as AADT, percentage of HDVs (p), average travel space speed (v) and Annual Average Hourly Traffic per lane (AAHT). The highway segments have on average 2.3 lanes per direction and passenger cars dominate the traffic with about 29,384 vehicles on the mean days. The mean HDVs' traffic is about 14.3 % and its share is significantly smaller during the weekends.

The traffic fundamental equation relates traffic volume and density through speed:

Table 1 Traffic flow parameters in Spanish toll highways (2007), n=202. Source: Ministry of Public Works. [2]

Traffic parameter	Mean	sd	Min	Max	Median	CV	Units
AADT	35,002	31,936	2,516	150,513	23,074	91	veh/day
AAHT	560	402	46	1,816	454	72	veh/h/lane
Density (D)	5.76	5.81	0.41	49.7	4.08	101	veh/km/lane
Speed (v)	106.2	10.2	36.5	111.9	111.0	10	km/h
Peak-hour (k)	0.07	0.00	0.06	0.08	0.07	6	%
Peak-direction (d)	0.56	0.04	0.51	0.67	0.55	8	%
Lanes direction (η)	2.3	0.5	2.0	4.0	2.0	21	lanes
AAHT car g	119	91	11	419	89	77	veh/h/lane
AAHT car d	287	220	26	1,015	215	77	veh/h/lane
AAHT van	57	47	3	235	45	82	veh/h/lane
AAHT motorcycle	6	12	0	87	2	212	veh/h/lane
AAHT art. truck	54	40	1	160	48	74	veh/h/lane
AAHT rig. truck	36	27	1	139	33	75	veh/h/lane
AAHT bus	2	2	0	9	1	81	veh/h/lane
% HDVs (p)	14.3	8.2	1.5	43.0	14.0	57.1	%

$$\mathrm{AAHT} = \mathrm{D} \cdot v \tag{1}$$

where AAHT is the annual average hourly traffic per lane (vehicles/h/lane), D is the traffic density (vehicles/km/lane) and v is the average travel speed (km/h). Therefore, v could be expressed as a function of AAHT:

$$\mathrm{v} = \mathrm{b}_0 - \mathrm{b}_1 \cdot e^{(b_2 \cdot s)} - \mathrm{b}_3 \cdot e^{(b_4 \cdot \partial(AAHT, p))} \tag{2}$$

where s is the slope of the highway segment (%) and ∂ is a function of the proportion of HDVs (p) and AAHT. In this work we relate AADT (vehicles/day) and AAHT (vehicles/h/lane) using the following expression [9, 14]:

$$\mathrm{AAHT} = \mathrm{AADT} \cdot \frac{(k \cdot d)}{\eta} \tag{3}$$

where k is the proportion of AADT occurring in the peak-hour, d is the proportion of peak-hour traffic in the peak direction and η is the number of lanes per direction. Table 1 shows the detailed statistics of the traffic flow parameters, composition and characteristics of the 202 sites and segments.

Table 2 shows a representation of speed flow relationships. The curves illustrate different traffic conditions and vehicle types.

Energy Consumption of Vehicles

To estimate the energy consumption and CO_2 emissions of the Spanish toll highway network a similar methodology is used as in the national emission inventory (NEI)

Table 2 Speed flow relationships. Source: Ministry of Public Works. [2]

Veh. type	s^a (%)	p^b(%)	Eq. 2 (v = speed (km/h))	b_0	b_1	b_2	b_3	b_4 (10^{-3})	Range[c] (veh/h/lane)
LDV	0	10	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.(1+p)))}$	120	8	0.23	0.2	2.97	≤1,700
	0	30	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT+p))}$	120	8	0.23	0.1	4.46	≤1,400
	5	10	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.(1+p)))}$	120	6	0.23	0.5	2.50	≤1,700
	5	30	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT+p))}$	120	6	0.23	0.1	4.50	≤1,400
HDV	0	10	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.p))}$	96	11	0.25	0.3	2.90	≤1,700
	0	30	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.p))}$	96	10	0.25	0.1	14.4	≤1,400
	5	10	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.p))}$	86	5	0.25	0.1	34.0	≤1,700
	5	30	$b_0 - b_1 . e^{(b2.s)} - b_3 . e^{((b4).(AAHT.p))}$	96	5	0.33	0.1	14.0	≤1,400

Note: [a] Slope of the toll highway segment (%)
[b] Percentage of HDVs
[c] Annual average hourly traffic (vehicles/h/lane)

from the Spanish Ministry of Environment [6] based on the IPCC inventory practice guidance [3], the EU Corinair report [2] and the National Inventory Submissions [15]. To make the inventory, category-wise vehicle and fuel consumption statistics are used from official publications and for 2007 [4]. A combination of the Spanish road traffic survey (SRTS), the permanent road freight sample survey (PRFSS), the road transport passenger transport observatory (RTPO) and the fuel-efficiency data from the Copert model, based on the Corinair methodology, are also used. The energy consumption and CO_2 emissions of toll highway segment k have been estimated using the following expressions:

$$E_k = \Sigma_i \Sigma_j f_{i,j} \cdot NCV_j \cdot AAHT_{i,j} \tag{4}$$

$$C_k = E_{k,i,j} \cdot CEF_j \tag{5}$$

where E_k is the energy consumption of segment k, expressed in mega-joules ($MJ = 10^6$ Joules) per hour and lane kilometre (MJ/h/lane-km), $f_{i,j}$ is the fuel consumption factor of vehicle type i using energy source j, in grams of oil equivalent per vehicle-kilometre (goe/vehicle-km), NCVj is the net calorific value of fuel j, in MJ per goe (MJ/goe), $AAHT_{i,j}$ is the traffic of vehicle type i using energy source j, in vehicles per hour and per lane (vehicle/h/lane), C_k are the CO_2 emissions of segment k, in tons of CO_2 equivalent (tCO_2 eq.) per hour and lane kilometre (tCO_2 eq./h/lane-km) and CEF_j is the carbon emission factor of fuel j, in tons of CO_2 equivalent per tera-joule ($TJ = 10^{12}$ Joules, tCO_2eq./TJ). The fuel consumption estimates, available in grams of gasoline and diesel (or litres of fuel) per hour lane-km (goe/h/lane-km) have been converted to energy units (mega-joules, MJ) through the fuel specific net caloric value (NCV). Analogously, the CO_2 emissions are estimated in tons of CO_2 from the energy consumption through the carbon emission factor (CEF). The NCV and CEF values used in this paper are: 0.036 MJ/goe (gasoline), 0.039 MJ/goe (diesel), 86 tCO_2eq./TJ (gasoline) and 81 tCO_2eq./TJ (diesel).

Based on the distribution of the Spanish fleet, technology of vehicles and engine capacity, mean fuel consumption curves from the Copert model were weighted. These curves characterize mean energy consumption of different vehicles and relate fuel consumption factors (f) to vehicle operation speed (v).

Effect of Speed, Slope and Roughness on Energy Consumption

Fuel consumption (f) varies with transport speed (v) following a U shaped function. Therefore, fuel consumption follows the expression:

$$f_{i,j} = a_{0,i,j} + \frac{a_{1,i,j}}{v} + a_{2,i,j} \cdot v^2 + a_{3,i,j} \cdot v^3 + a_{4,i,j,s} + a_{5,i,j,r} \tag{6}$$

where $a_{0,i,j}$, $a_{1,i,j}$, $a_{2,i,j}$ and $a_{3,i,j}$ are adjusted consumption coefficients that depend on vehicle type i using fuel j and v is the transport operational speed in km/h; $a_{4,i,j,s}$ is the slope coefficient that measures the effect of the slope of the highway segment s (%); $a_{5,i,j,r}$ is the roughness coefficient that measures the effect of the international roughness index r (mm/m). The first four coefficients of Eq. 6 are adjusted using the weighted consumption factors coming from the Copert model; $a_{4,i,j,s}$ and $a_{5,i,j,r}$ are adjusted using data from reviewed studies. Fuel consumption increases as s and r increase. Similarly to the effect of slope, there are empirical studies that measure the influence of highway surface on energy consumption through r and the rolling coefficient (r_c). Figure 1 represents the relationships between fuel consumption, operational speed, slope and roughness by vehicle type. 5 % increase in the slope results in 50–160 % and 60–220 % increase in consumption of LDVs and HDVs respectively. The effect of the roughness is much lower: 5–15 % increase for LDVs and 6–20 % for HDVs. The effect of the slope is about 8–12 times greater than the effect of roughness.

Material per Input Service (MIP)

The calculations of the MIPs are based on data on the construction of the transport infrastructures and data of the use of the vehicles. The MIPs estimation for toll highway transport segment k, vehicle i and fuel j, expressed in MJ per vehicle kilometre (MJ/vehicle-km), is done using the following expression:

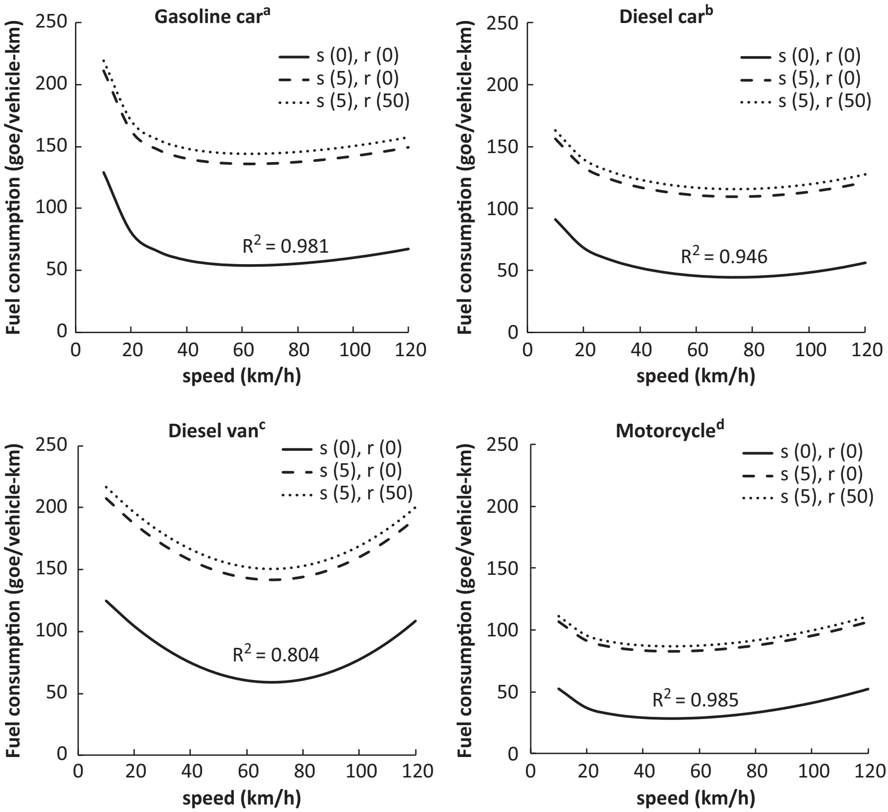


Fig. 1 Weighted fuel consumption curves (g/km) as function of operational speed (km/h), highway segment slope s (%) and roughness r (mm/m) in the Spanish high capacity network (2007)

$$MIP_{k,i,j} = \left[X_k \cdot \left(\frac{1}{AADT_k \cdot p_{i,j} \cdot 365 \cdot cv_k} \right) + Y_{i,j} \cdot \left(\frac{1}{cv_{i,j}} \right) \right] \quad (7)$$

where, X_k is the intensity of infrastructure k (MJ/km), $AADT_k$ is the annual average daily traffic of the toll highway segment k (vehicles/day), $p_{i,j}$ is the percentage of average daily traffic related to vehicle type i using fuel technology j, c_{vk} is the life cycle of infrastructure k (30 years), $Y_{i,j}$ is the intensity of vehicle i and fuel j (MJ/vehicle) and $cv_{i,j}$ is the life cycle of vehicle i using fuel j (270 10^3 gasoline and diesel car kilometres, 400 10^3 diesel van kilometres and 1,000 10^3 truck kilometres). 28.1 10^6 MJ per kilometre was considered as mean value of infrastructure intensity.

The number of people and quantity of freight tonnage transported divides the Eq. 7 and the end result is expressed in MJ per passenger kilometre or ton kilometre (MJ/p-km, MJ/t-km):

$$MIP'_{k,i,j} = \frac{MIP_{k,i,j}}{fo_{i,j}} \quad (8)$$

where $fo_{i,j}$ is the occupancy rates or load factor of vehicle i and fuel j (passengers/vehicle and tons/vehicle). The average capacity utilization assumed for motorcycles, cars and buses are, respectively, 1.2, 1.9 and 18 passengers. The average tonnage transported by vans, rigid trucks and articulated trucks are taken as 0.5, 4.5 and 7.2 t.

Finally, the aggregated MIP of toll highway segment k is estimated in mega-joules per transport unit (tu) kilometre (MJ/tu-km) using the following expression:

$$MIP'_{k} = \Sigma_i \Sigma_j \, p_{i,j} \cdot MIP'_{k,i,j} \quad (9)$$

where $p_{i,j}$ is the percentage of vehicle type i using fuel j when infrastructure is allocated according to traffic volume for each vehicle type (tu equals to 1 passenger-km and 1 ton-km).

Results

Energy Consumption of Toll Highway Segments

The mean energy consumption and subsequent CO_2 emissions from toll highway segments are estimated to be respectively 1,895 (±1,215) MJ/h/lane-km and 0.15 (±0.10) tCO_2eq./h/lane-km. These values increase to 2,644 and 0.22 if energy and carbon emissions of transport infrastructure are considered (approximately 28 % of total energy is attributed to infrastructure construction and maintenance). Mean energy consumptions from the 202 segments broken up by all categories of vehicles are: 345 MJ/h/lane-km (gasoline cars, 13 %), 672 (diesel cars, 25 %), 292 (vans, 11 %), 116 (motorcycles, 4 %), 707 (articulated trucks, 27 %), 387 (rigid trucks, 15 %) and 124 (buses, 5 %). Freight vehicles, with an average share of 53.0 % (1,386 MJ/h/lane-km), have dominance in the total estimated energy consumption and CO_2 emissions from studied toll highway segments.

The MIPs Estimates for Infrastructure, Passenger and Freight Transport

MIPs estimates for each toll highway vehicle type are calculated using Eqs. 8 and 9. There have been big differences in the average MIPs estimates of different vehicle types, expressed in terms of mega-joules consumed per transport unit kilometre. Consequently, the aggregate of Spain's toll highway segments requires 2.6 MJ/tu-km (0.6 infrastructure and 2.0 traffic uses). MIPs mean estimates vary between 1.4 (diesel car) to 29.1 (motorcycle). Similarly, the aggregate of Spain's gasoline car and diesel van transport required 1.6 (0.4 infrastructure and 1.2 traffic uses) and 11.8 MJ/tu-km (4.1 and 7.7) respectively.

In general and considering only traffic use, mass-passenger transport modes consume less energy per transport unit than individual-private modes (0.6 vs. 1.2 MJ/tu-km). In freight transport and considering only traffic use, articulated trucks consume much less energy per tu-km than vans (1.9 vs. 7.7). Toll highway modes present a high variation in energy consumption per transport unit depending on vehicle and fuel types: buses have MIPs values similar to trucks, and gasoline cars present values of over 1.6 MJ/tu-km. The most inefficient toll highway modes, in gasoline and diesel technologies are motorcycles (29.1 MJ/tu-km) and diesel vans (11.8 MJ/tu-km). The share of MIPs related to infrastructure use in motorcycles and buses are especially high, 94.6 and 81.7 %.

Conclusions

This paper attempts to make an accurate estimation—segment-based—of the energy consumption and CO_2 emissions of 202 sites on Spanish toll highways. Based on interurban road transport counts from the SRTS, I multiply the vehicle-km data, for different vehicle types and engine technologies, by the fuel consumption factors, derived from the Corinair and Copert models and optimized for the Spanish driving conditions and fleet, to estimate the energy consumption, and consequent CO_2 emissions, by the interurban toll highway transport (Eqs. 4–5). An effort is done to estimate correctly the fuel consumption factors across different categories of vehicles operating on the interurban toll Spanish highways. The interurban toll highway transport in Spain has been estimated to consume 1,895 MJ per hour and lane-kilometre in 2007 that significantly varies among highway segments from 140 to 6,456 (standard deviation of 1,215 MJ/h/lane-km). Thus, the interurban toll highway transport, with 0.12 t of CO_2 equivalent per hour and lane-kilometre, has contributed almost with 12 million t of CO_2 equivalent to the national transport emissions in 2007.

The MIPs of the 202 sites, that represent 79.1 % of total traffic on Spanish toll highways and carries relatively little traffic compare with free highways, are calculated and serve as a proxy of the life cycle of highway segments. In the MIPs, the energy consumption is set against the traffic figures and is expressed in passenger-kilometres and ton-kilometres. MIPs values for cars are many times lower than for motorcycles. The MIPs values of bus travel are significantly higher than for cars, this is because buses involve relatively significant infrastructure resources (81.7 %) in relation to the traffic using those (18.3 %). Looking at freight transport, the articulated truck has significantly lower MIPs values than the rigid truck. The MIPs values for the vans are, however, many times higher than for the other vehicles. The differences of the MIPs values can mainly be explained by the capacity of the different vehicles. An articulated truck moves 7.2 t and is thus more efficient than a van transporting only 0.5 t.

The estimated differences in MIPs between segments are due to differences in total energy consumption and highway slope. Therefore, the MIPs are correlated to the mean energy consumption of the individual segments (bigger mean consumption leads to higher MIPs); consequently it is the downward trend between segments, related to the increase of the total energy consumption and decrease in slope. MIPs decreased to 1.6 MJ/tu-km at 5,000 MJ/h/lane-km in flat segments (slope lower than 2.5 %) and decrease to 4.0 MJ/tu-km at 5,500 MJ/h/lane-km in mountainous segments (slope higher than 2.5 %).

References

1. Advenier P, Boisson P, Delarue C, Douaud A, Girard C, Legendre M (2002) Energy efficiency and CO_2 emissions of road transportation. Comparative analysis of technologies and fuels. Energy Environ 13:631–646
2. EMEP/CORINAIR (2009) Emission inventory guidebook—3rd edn September 2009 update. Technical report. European Environment Agency, EEA, Copenhagen
3. IPCC (1995) Greenhouse gas inventory reference manual: IPCC guidelines for national greenhouse gas inventories. Bracknell
4. MFO (2009) Transport and postal services. 2008 Annual report. Publications center, General Technical Secretariat, Ministry of Development, Madrid
5. MFO (2009) Traffic map. Ministry of development, Publications Centre, General Technical Secretariat, Madrid
6. MMA (2009) Inventory of greenhouse gases in Spain-Edit 2009 (series 1990–2008), summary of results. General Environmental Quality Branch, Ministry of Environment, Madrid
7. Orasch W, Wirl F (2007) Technological efficiency and the demand for energy (road transport). Energy Pol 25:1129–1136
8. Pérez-Martinez PJ, Sorba I (2010) Energy consumption of passenger land transport modes. Energy Environ 21(6):577–600
9. Pline JL (1999) Traffic engineering handbook. Institute of transportation engineers, 5th edn. Prentice-Hall, Englewood Cliffs
10. Ritthoff M, Rohn H, Liedtke C (2002) Calculating MIPS, resource productivity of products and services. Publications of Wuppertal Institute, Wuppertal
11. Saari A, Lettenmeier M, Pusenius K, Hakkarainen E (2007) Influence of vehicle type and road category on natural resource consumption in road transport. Transportation Res D 12(1):23–32
12. Schmidt-Bleek F (1993) Wie viel Umwelt braucht der Mensch. MIPS. Das Maß für ökologisches Wirtschaften. Birkhäuser Verlag, Berlin
13. Sinivuori P, Saari A (2006) MIPS analysis of natural resource consumption in two university buildings. Build Environ 41:657–668
14. TRB (2000) Traffic flow parameters introduction and traffic characteristics. In: Highway Capacity Manual (HCM). Transportation Research Board of the National Academies, Washington D.C.
15. UNFCCC (2010) National inventory submissions 2010. United Nations framework convention on climate change, Bonn

Energy and CO_2 Emissions in German and Colombian Manufacturing Industries: An Econometric Application

Alexander Cotte Poveda and Clara Inés Pardo Martínez

Abstract This chapter seeks to determine and analyse the tendencies in carbon dioxide (CO_2) emissions for the industries of: Germany that has applied several measures to promote the shift towards a low-carbon economy and Colombia that has shown substantial improvements in the decline of CO_2 emissions. This study applies panel data cointegration methods to evaluate the causality between CO_2 emissions, production aspects and energy sources. The results indicate that the trend in the countries analysed in this study is to produce more output with less pollution. The trends in CO_2 emissions also indicate that there are differences between the developed country and the developing country with respect to emissions levels. Moreover, the results of Germany demonstrate that to achieve economic growth and sustainable development are possible by the reduction of CO_2 emissions. For Colombia, the reduction of CO_2 emissions requires integral policies that include technical and economic programs and promote the use of new technologies and application of cleaner production.

Introduction

It is now widely accepted that the increase in carbon emission levels might be associated with meaningfully increased risks of adverse climate change and severe negative socio-economic effects in the long run where the relationship between climate change and energy is one of the main challenges for sustainable development, implying the need to make better use of energy and reduce CO_2 emissions [14, 15, 34]. In the formulation of new energy and climate change policies, it is necessary

A. C. Poveda (✉)
Department of Economics, University of Göttingen, Platz der Göttinger Sieben 3, 37073 Göttingen, Germany
e-mail: alexcotte@yahoo.com

Faculty of Accounting and Administration, University of La Salle, Cra. 2 No. 10–70 Bogotá, Bogotá, Colombia

C. I. P. Martínez
Faculty of Administration, Universidad del Rosario, Calle 14 No. 6–25 Bogotá, Bogotá, Colombia

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_34,

to determine the different mechanisms that can lead to changes and encourage increased energy efficiency and lower greenhouse gas emissions [9, 13].

In this context, we assess the trends of CO_2 emissions and several factors that influence these trends in one developed country, Germany, with important advances in the decline of greenhouse gas emissions and improvements in its energy systems [7, 31]. In contrast, as a developing country Colombia is selected by the results in energy use and CO_2 emissions being a leader in the region in environmental topics [5, 18].

The trends of greenhouse gas emissions in manufacturing industries have been investigated in different context. In 25 European countries, it evaluated fossil-fuel CO_2 emissions using emission accountability from energy-use data determining the importance of system boundary definition and the possibilities the reduction of CO_2 emission with transport models [4]. In OECD countries, it established the causes of emission growth with decomposition methods using variables of economic growth, energy intensity, energy consumption, the share of fossil fuels and carbon intensity indicating that growing in emissions depends of the improvements in energy efficiency and a declining share of fossil fuels decrease CO_2 emissions [8].

In specific industrial sectors CO_2 emissions have been evaluated mainly in the cement industry, several alternatives to reduce CO_2 emissions and determined that investment in new technologies and the application of alternative fuels and raw materials determining the importance the policies that includes funding for technology change, development and deployment in this industrial sector [8]. In the steel industries of Japan, Germany, Sweden and Russia, carbon emissions and several technological strategies to reduce CO_2 emissions were studied by [16, 19, 33].

CO_2 emissions, energy consumption and economic growth have been also studied with empirical techniques. In eight Asia-Pacific countries using the panel data, it determined that there are long-run equilibrium relationships between CO_2 emissions, energy consumption and economic growth where the increase economic growth should decrease energy consumption and emissions [22]. In Brazil, China, India and Russia, it evaluated the effects of both economic growth and financial development on environmental degradation applying a panel cointegration technique establishing a bi-directional causality between emissions and financial instruments and a unidirectional causality running from output to financial instruments where in these countries must strengthen investments in energy supply and energy efficiency to decrease CO_2 emissions without affecting competitiveness [24]. These studies have characterised to determine the relationship between carbon dioxide emissions, energy consumption and economic growth without taking into account other variables that should affect this relationship.

With this background, this chapter has as main contributions the study and evaluation of the CO_2 emissions in the German and Colombian manufacturing industries with several variables and empirical techniques determining the causality between carbon dioxide emissions, production factors and energy sources. This paper is organized as follows. In Section "Dataset and Methods", a description of the methodology and data used in this study is presented. Section "German and Colombian Manufacturing Industries" shows the trends in CO_2 emissions and activity indicators of manufacturing industries of the three countries. In Section "Analysis and Discussion of Results", we analyze and discuss the results of this study, and the main conclusions are presented in Section "Conclusions".

Dataset and Methods

Dataset

The sample period for this analysis was defined by the availability of consistent and disaggregated CO_2 emission and energy data in both countries and covered the period 1995–2008. Hence, for the two countries selected, the study applied for the 19 manufacturing industries at the 2-digit level of disaggregation of the International Standard Industrial Classification (ISIC—Rev. 3.1). The main data sources were statistical offices and energy agencies such as: Statistiches Bundesamt and DENA (Germany) and DANE and UPME (Colombia) and the database of the Organisation for Economic Co-operation and Development (OECD) in the module industry. All monetary variables were deflated to 2005 euro values for both countries.

Model Specification

According to the empirical research in energy economics, it is plausible to form a long-run association between CO_2 emissions and other variables (OV) as energy sources, output and production factors, energy prices and investments in a linear logarithm see the following equations [1, 3, 23].
Energy sources

$$LCO_{it} = \beta_0 - \beta_1 LFF_{it} + \beta_2 LELE_{it} + \beta_3 LOES_{it} + u_{it} \tag{1}$$

Output and production factors

$$LCO_{it} = \beta_0 - \beta_1 LVA_{it} + \beta_2 LE_{it} + \beta_3 LK_{it} + u_{it} \tag{2}$$

Energy price

$$LCO_{it} = \beta_0 - \beta_1 LEP_{it} + \beta_2 LE_{it} + u_{it} \tag{3}$$

Investment

$$LCO_{it} = \beta_0 + \beta_1 LINV_{it} + \beta_2 LOF_{it} + u_{it} \tag{4}$$

1. where i defines the manufacturing sector for every country and
2. i = 1,…, N t determines the time and t = 1,…, T
3. and uit is supposed to be a serially uncorrelated error term.

The variables *LCO, LFF, LELE, LOES, LVA, LE, LK, LEP* and *LINV* represent the logarithm of CO_2 emissions (measured as tons of carbon dioxide), fossil fuels (measured in terajoules), electricity (measured in terajoules), other energy sources (in the case of Colombia, represented by natural gas, and measured in terajoules), value added (measured in euros), total energy consumptions (measured in terajoules), capital (measured as the capital stock in euros), energy prices and investments (measured in euros), respectively. In the energy price model and investment model, ratio capital-labour (measured in euros) and energy intensity (measured as energy consumption per value added).

The Empirical Method

The model is estimated using a dynamic OLS (DOLS) panel cointegration technique suggested by [17] and [28] in which the relationship between CO_2 emissions, production factors and energy sources is determined using several test and panel data cointegration methods: *Panel unit root test:* this test determines that all of the variables are integrated to the same order by an autoregressive specification [20] with the test proposes by Im–Pesaran–Shin [12] (IPS); *Cointegration techniques*: that it is denominated as Pedroni [27] heterogeneous panel cointegration test establishes long-run relationship exists among the variables; *DOLS estimators:* was proposed by [17] as an addition of the Stock and Watson [32] estimator to determine the long-run cointegration vector for non-stationary panels and correct the serial correlation and endogeneity of regressors that are normally present in a long-run relationship.

German and Colombian Manufacturing Industries

In both countries, the manufacturing industry is one of the most significant economic activities due to its effects on the gross domestic product, employment, development and innovation. German manufacturing industries are global leaders in several sectors due to their advanced technological applications, human capital intensity and quality of goods [35]. Colombian manufacturing industries are experiencing growth and development and are viewed as regional leaders in different sectors such as agribusiness and chemicals [26]. The tendencies of carbon dioxide emissions, energy, production value and value added in the manufacturing industries during the sample period show that in Germany, these indicators are similar: an increase in economic indicators and a reduction in energy and CO_2 emissions. In contrast, Colombia indicates an increase in economic indicators and the reduction in CO_2 emissions and energy is less in Colombia compared with Germany. Therefore, in Colombia, it is important to strengthen a reduction in CO_2 emissions using different instruments.

Fossil fuels, electricity and natural gas are the main energy sources in the industrial sector of both countries. However, Germany have increased its electricity and bio-fuels use and reduced their consumption of fossil fuels. In Colombia, the use of electricity and natural gas has increased while fossil fuel use has reduced.

Analysis and Discussion of Results

Panel Unit Root Tests and Panel Cointegration Tests

Tables 1 and 2 displays the results of the panel unit root test for Germany and Colombia. Test statistic is calculated for each variable, that is, the IPS test. The results indicate that most of the level values for the variables are panel non-stationary, but in the test of the first difference show that each variable is non-stationary. Therefore, the joint null hypothesis at 1 % significance is rejected. Therefore, all series are I(1) and integrated of the same order; hence, the cointegration between the variables can be studied.

Table 3 shows the results of Pedroni's panel cointegration test for two countries specify that a rejection of the null hypothesis of no cointegration in all four models proposed, which allows the applying of the panel data cointegration relationships.

Estimating the Panel Model Using DOLS Estimator

After confirming that the variables are cointegrated, we estimate the cointegrating vector using the DOLS estimator. Tables 4, 5, 6, 7 and 8 show the estimates for every model and country. In general, the results are expected to indicate that higher clean fuel consumption, energy prices, energy taxes and investments decrease CO_2 emissions, while higher economic activity, energy consumption, fossil fuels and energy intensity increase CO_2 emissions.

Model of Energy Sources

Table 4 shows the estimate of energy sources by country. For the two countries analysed, a decrease in fossil fuel consumption and an increase in electricity lead to lower CO_2 emissions, indicating that the substitution of fuels increases the use of fuels characterised to generate less greenhouse gas emissions, especially CO_2 emissions. Moreover, energy switching to lower carbon energy in the industrial sector has been determined to expand the use of higher environmental quality fuels while maintaining production standards [11].

Table 1 Results of panel unit root tests for Germany—Individual intercept and trend

Test		CO_2	Fossil fuels	Electricity	Value added	Capital	Energy	Energy prices	Investments	Capital-labour	Energy intensity
Im, Pesaran and Shin	Level	−3.949[a]	−2.258	−3.922[a]	−3.487[a]	−3.294[a]	−9.060[a]	−2.867[a]	−3.248[a]	−3.787[a]	−3.484[a]
	1st difference	−5.246[a]	−6.148[a]	−6.076[a]	−3.138[a]	−2.584[b]	−19.60[a]	−3.708[a]	−2.914[a]	−5.827[a]	−3.110[a]
	Decision	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

[a] denotes significance at the 1 % level
[b] denotes significance at the 5 % level

Table 2 Results of panel unit root tests for Colombia—Individual intercept and trend

Test		CO2	Fossil fuels	Elecri-city	Natural Gas	Value Added	Capital	Energy	Energy prices	Investments
Im, Pesaran and Shin	Level	-2.867^{a}	-3.006^{a}	-3.084^{a}	-2.912^{a}	-2.997^{a}	-2.636^{b}	-2.981^{a}	-6.547^{a}	-3.519^{a}
	1st difference	-5.468^{a}	-5.339^{a}	-5.870^{a}	-5.963^{a}	-4.633^{a}	-3.970^{a}	-5.430^{a}	-9.756^{a}	-5.432^{a}
	Decision	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

[a] denotes significance at the 1 % level
[b] denotes significance at the 5 % level

Table 3 Results of panel cointegration tests for Germany and Colombia

Pedroni panel cointegration test		Germany	Colombia	Germany	Colombia	Germany	Colombia	Germany	Colombia
		(1)	(1)	(2)	(2)	(3)	(3)	(4)	(4)
		Energy sources		Output and production factors		Energy prices		Investments	
Panel cointegration test	Panel PP-statistic	0.314	−45.58[a]	−26.14[a]	−3.987[a]	−21.10[a]	−3.776[a]	−25.68[a]	−2.901[a]
	Panel ADF-statistic	−3.601[a]	−16.86[a]	−8.094[a]	−4.425[a]	−5.263[a]	−9.588[a]	−6.586[a]	−4.037[a]
Group mean cointegration test	Group PP-statistic	1.922	−49.75[a]	−28.00[a]	−3.212[a]	−22.56[a]	−2.977[a]	−27.72[a]	−1.997
	Group ADF-statistic	−2.967[a]	−17.61[a]	−7.807[a]	−3.703[a]	−4.729[a]	−9.479[a]	−6.219[a]	−3.268[a]

[a] denotes significance at the 1 % level

Table 4 DOLS estimates—Model of energy sources

Parameter	Germany	Colombia
	(1)	(1)
Fossil fuels	0.722^{a}	0.932^{a}
	(24.02)	(21.46)
Electricity	−0.108^{a}	−1.156^{a}
	(−4.78)	(−11.18)
Natural gas		−0.612^{a}
		(−4.91)

The value in parentheses denotes the t-statistic
$^{a, b c}$ denote the statistical significance at the 1, 5 and 10 % levels, respectively

Table 5 DOLS estimates—Model of output and production factors

Parameter	Germany	Colombia
	(2)	(2)
Value added	2.286^{a}	0.393^{a}
	(3.61)	(3.26)
	1.113^{b}	0.351^{a}
Capital	(2.28)	(3.29)
Energy	1.022^{a}	0.672^{a}
	(18.16)	(11.79)

The value in parentheses denotes the t-statistic
$^{a, b, c}$ denote the statistical significance at the 1, 5 and 10 % levels, respectively

Model of Output and Production Factors

The results of the model of output and production factors are reported in Table 5. Higher energy consumption should generate greater economic activity and a higher level of CO_2 emissions, which is consistent with the results of [23, 24] in the context of the BRIC countries.

Model of Energy Prices

Energy prices are considered a key instrument for energy policy especially in the manufacturing industries because higher energy prices should encourage a more rapid adoption of energy-saving, low-carbon technologies [25]. The results of the model for energy prices are displayed in Table 6. In both countries, energy prices have a negative and significant coefficient, indicating that higher energy prices generate lower CO_2 emissions, whereas higher energy consumption increases CO_2 emissions. These results are important in the design and application of an adequate energy price policy that encourages energy savings and lowers CO_2 emissions through new technologies and production standards while maintaining productivity and promoting sustainable development.

Table 6 DOLS estimates—Model of energy price

Parameter	Germany	Colombia
	(3)	(3)
Energy prices	−0.368[a]	−0.792[a]
	(−3.57)	(−11.21)
Energy	0.530[a]	0.0009
	(5.10)	(0.02)
Investments	−0.332[a]	
	(−4.38)	
Capital-labour	-0.063	
	(-0.58)	
Value added		0.734[a]
		(6.56)

The value in parentheses denotes the t-statistic
[a, b c] denote the statistical significance at the 1, 5 and 10 % levels, respectively

In Germany, the results indicate that the level of energy prices and investments leads to lower CO_2 emissions, thus indicating the interdependent relationship between energy prices and investments. Therefore, when energy prices increase from a cost minimisation perspective, manufacturing industries prefer to invest in improvements in technology and processes designed to decrease production costs and increase environmental performance [21]. In the Colombian case, energy prices have a negative and significant coefficient, indicating the importance to design adequate energy price instruments that encourage a low-carbon economy and sustainable development.

Model of Investments

The results of the DOLS estimators for the model of investments are reported in Table 7. In both countries, investments have a negative sign, indicating that higher investments decrease CO_2 emissions. However, in Germany, the coefficients have a statistical significance at the 1 % level, while in Colombia, the statistical significance is only 10 %. These facts suggest that in developed countries, many of the investments are intended to improve environmental performance through energy savings and low-carbon technologies, whereas in Colombia, the main objective of the investments is to reduce production costs and increase productivity through investments in machinery and equipment and in production plants that indirectly should improve environmental performance [10]. In Germany, the results show that increases in investments, energy prices and energy efficiency (measured as energy intensity) have led to reduced CO_2 emission intensity. These results are consistent with several public and voluntary instruments developed in this country [6, 29].

Table 7 DOLS estimates—Model of investments

Parameter	Germany	Colombia
	(4)	(4)
Investments	−0.668[a]	−0.051
	(−4.12)	(−1.62)
Energy		0.004
		(0.09)
Energy prices	−0.591[a]	
	(−30.64)	
Capital-labour	0.048	
	(0.26)	
Energy intensity	0.172[a]	
	(7.37)	
Value added		0.423[a]
		(3.80)

The value in parentheses denotes the t-statistic
[a, b, c] denote the statistical significance at the 1, 5 and 10 % levels, respectively

Conclusions

This chapter analysed and compared the tendencies in carbon dioxide emissions with their main factors for the German and Colombian manufacturing industries for the sample period 1995–2008. Panel data cointegration techniques were used to calculate the causality between CO_2 emissions, energy sources and production factors through the DOLS estimator for four models for every country: (1) energy sources, (2) output and production factors, (3) energy prices and (4) investments.

The empirical results of this chapter show, in general, that higher clean fuel consumption, energy prices, and investments decrease CO_2 emissions, while higher economic activity, energy consumption, fossil fuels and energy intensity increase CO_2 emissions. The model for energy sources indicates that a decline in fossil fuel consumption and an increase in electricity and natural gas usage generates lower CO_2 emissions. The model for output and production factors suggests that higher energy consumption should cause greater economic activity and higher levels of CO_2 emissions. This model indicates that the trends in CO_2 emissions and economic activity show a relative decoupling where the growth rate of CO_2 emissions is less than that of the economic activity, thus suggesting that manufacturing industries produce greater output with reduced CO_2 emissions. The model for energy prices indicates that higher energy prices generate lower CO_2 emissions, whereas higher energy consumption increases CO_2emissions. The last model denominates investments and demonstrates that manufacturing sectors with higher levels of investments achieve a greater decrease in CO_2 emissions.

Germany shows increases in economic indicators and decreases in energy and CO_2 emissions. These trends have been led by adequate policy instruments that have combined fiscal instruments.

In Colombia, as a developing country, the results indicate that CO_2 emissions and energy use have not decreased to the same degree as they have in the developed country studied. This finding suggests the great potential for this country to become a low-carbon economy.

References

1. Ang JB (2007) CO_2 emissions, energy consumption and output in France. Energy Policy 35:4772–4778
2. Ali M, Saidur R, Hossain M (2011) A review on emission analysis in cement industries. Renew Sust Energ Rev 15:2252–2261
3. Apergis N, Payne J (2009) CO_2 emissions, energy usage and output in Central America. Energy Policy 37:3282–3286
4. Ciais P, Paris J, Marlandw G, Peylin P, Piao S, Levin I, Pregger T, Scholz Y, Friedrich R, Rivier L, Houwellingk S, Schulze E (2010) The European carbon balance. Part 1: fossil fuel emissions. Glob Change Biol 16:1395–1408
5. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) (2003) Relationship between energy efficiency and economic development. (In Spanish)
6. Eichhammer W, Schlomann B, Kling N (2006) Energy efficiency policies and measures in Germany 2006. Monitoring of energy efficiency in EU 15 and Norway (ODYSSEEMURE). Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI)
7. Federal Ministry of economics and technology (BMWI) (2006) Energy efficiency policy in the face of Germany's upcoming EU presidency in the first half of 2007. Annual meeting of the Energy Efficiency Initiative of dena. 2H http://www.bmwi.de
8. Hamilton C, Turton H (2002) Determinants of emissions growth in OECD countries. Energy Policy 30:63–71
9. Hawksworth J (2006) The world in 2050. Implications of global growth for carbon emissions and climate change policy. http://www.pwc.com/gx/en/world-2050/pdf/world2050carbon.pdf
10. Hendricks L (2000) Equipment investment and growth in developing Countries. J Devel Econ 61:335–364
11. Homma T, Mori S, Akimoto K, Tomoda T, Murota Y (2008) A study of fuel substitution flexibility effects on economic impacts of carbon emission constraints using an energy-multi-sector-economy model. http://www.iioa.org/pdf/16th%20Conf/Papers/HOMMA.pdf
12. Im K, Pesaran M, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econometrics 115:53–74
13. Intergovernmental Panel on Climate Change (IPPC) (2001) Mitigation climate change: summary for policymakers. Third assessment report of the IPPC. Cambridge University Press
14. International Energy Agency (IEA) (2007) Tracking industrial energy efficiency and CO_2 emissions. In support of the G8 plan of action. Energy indicators. http://www.iea.org/textbase/nppdf/free/2007/tracking_emissions.pdf
15. International Energy Agency (IEA) (2008) Energy technology perspectives: scenarios and Strategies to 2050. http://www.iea.org/textbase/nppdf/free/2008/etp2008.pdf
16. Johansson M and Söderström M (2011) Options for the Swedish steel industry—energy efficiency measures and fuel conversion. Energy 36:191–198
17. Kao C, Chiang M (2000) On the estimation and inference of a cointegrated regression in panel data. Adv Econom 15:179–222
18. Kim C (2010) Environmental Performance Index (EPI). http://epi.yale.edu/
19. Luengen H, Endemann G, Schmöle P (2011) Measures to reduce CO_2 and other emissions in the steel industry in Germany and Europe. AISTech—Iron and Steel Technology Conference Proceedings

20. Mahadevan R, Asafu-Adjaye J (2007) Energy consumption, economic growth and prices: a reassessment using panel VECM for developed and developing countries. Energy Policy 35:2481–2490
21. Mukherjee K (2008) Energy use efficiency in U.S. manufacturing: a nonparametric analysis. Energy Econ 30:76–96
22. Niu S, Ding Y, Niu Y, Li Y, Luo G (2011) Economic growth, energy conservation and emissions reduction: a comparative analysis based on panel data for 8 Asian-Pacific countries. Energy policy 39:2121–2131
23. Pao H, Tsai C (2010) CO_2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy 38:7850–7860
24. Pao H, Tsai C (2011) Multivariate granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy 36:685–693
25. Pardo Martinez C (2011) Energy efficiency development in German and Colombian non-energy-intensive sectors: a non-parametric analysis. Energy Efficiency 4:115–131
26. Pardo Martínez C (2009) Energy efficiency developments in the manufacturing industries of Germany and Colombia, 1998–2005. Energy Sust Dev 13:189–201
27. Pedroni P (1999) Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bull Econ Stat 61(Special Issue Nov.):653–678
28. Pedroni P (2001) Purchasing power parity tests in cointegrated panels. Rev Econ Stat 83:727–731
29. Price L (2005) Voluntary agreements for energy efficiency or GHG emissions reduction in industry: an assessment of programs around the world. Ernest Orlando Lawrence Berkeley National Laboratory. Environmental Energy Technologies Division LBNL–58138
30. Ramos J, Ortege M (2003) Non-linear relationship between energy intensity and economic growth. ESEE Conference Frontiers 2
31. Speck S (2008) The design of carbon and broad-based energy taxes in European countries. In the reality of carbon taxes. In the 21st century. A Joint Project of the Environmental Tax Policy Institute and the Vermont Journal of Environmental Law Vermont Law School
32. Stock J, Watson M (1993) A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61:783–820
33. Takeda K, Anyashiki T, Sato T, Oyama N, Watakabe S, Sato M (2011) Recent developments and mid- and long-term CO_2 mitigation projects in ironmaking. Steel Res Int 82:512–520
34. The Gleneagles Communiqué (2005)http://www.unglobalcompact.org/docs/about_the_gc/government_support/PostG8_Gleneagles_Communique.pdf
35. Wagner J (2010) Exports and firm characteristics in German manufacturing industries. Discussion Paper No. 5244. Institute for the Study of Labor (IZA)

Strategic Land-Use Planning in a Changing Climate—Adapting to the Spatial Dynamics of Risk in Ho Chi Minh City

Harry Storch and Nigel Downes

Abstract For Asian cities situated within mega-urban coastal regions, such as Ho Chi Minh City, there is a pressing need for adaptation to climate change to focus on minimising exposure and reducing vulnerability by increasing urban resilience to the future impacts of climate extremes. Scientifically predicted are the direct impacts of climate change on populations (i.e. by urban flooding) and the indirect effects through impacts on climate-sensitive urban sectors (i.e. housing, energy supply systems). Geographic context gives rise to the biophysical exposure, which includes factors such as topography, connectivity and urban structures, all of which can be mediated by spatial planning or construction technologies. Further the urban fabric underlies the patterns of social vulnerability, including issues such as population density, levels of income and education as well as institutional capacities. Here spatial planning measures to enhance adaptive capacity should be directed towards decreasing biophysical exposures and the social vulnerability from the viewpoint of place-based risk assessments. Key urban impact and vulnerability indicators vary considerably from settlement to settlement and even within settlements. The location, the built urban structures, the dominant building types, the social-economic characteristics and institutional capacities are all highly dynamic factors with an important spatio-temporal dimension that affects ultimately the overall exposure, vulnerability and environmental performance of a settlement. Rapid urbanisation driven by fast changes in socioeconomic development conditions are the key factors influencing the future levels in both exposure and vulnerability to climate extremes. Our impact assessment study highlights, that the influence of non-climatic stressors—like urbanisation as the spatial manifestation of socio-economic processes is still widely under acknowledged. Traditionally only snapshots of the current urban situations have been partially integrated into risk assessments, resulting often, for highly dynamic urban regions, in an overestimation of climate extremes as a stressor of risk. An urgent need has arisen to readdress and improve the scientific methods and datasets to examine these key non-climatic drivers of future urban risk and to assess their relative importance for risk propagation compared to primary changes

H. Storch (✉) · N. Downes
Department of Environmental Planning, Brandenburg University of Technology Cottbus, Erich-Weinert-Str. 1, 03046 Cottbus, Germany
e-mail: storch@tu-cottbus.de

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_35,

in climate. The most significant issue here is the integration of the future dynamics of urban development processes.

The Spatial Dynamics of Risk in Ho Chi Minh City

The southern Vietnamese metropolis of Ho Chi Minh City (HCMC) represents one of the most dynamic examples of urban development and a megacity in the making. The city is precariously located on the banks of the Saigon River, 60 km inland from the South China Sea and northeast of the Mekong Delta, in an estuarine area of the Dong Nai River system. In a short space of time, the city has grown into Vietnam's most populous settlement, contributing a dominant share to the national economy. The official population of the city as of 2010 was 7.4 million, spread over a total administrative area of 2095 km^2 [5].

Over half of HCMC's population are concentrated in the 140 km^2 inner-city urban area with in an average population density of 260 inh/ha, and with highs of up to 800 inh/km^2 seen in many of the inner-city informal settlements (Fig. 1). The high-dense development of the inner city, additionally with coverage ratios of more than 60 % ground coverage and floor area ratios of 1.5 and above, is principally a manifestation of the necessary to adapt to the dominant flood risk situation of the city. Originally founded on relatively higher grounds, the city has densified through the infilling of open spaces or the redevelopment of existing buildings. However recently, great concern has been raised at the city's rapid expansion into the lower-lying and former wetland surroundings.

Elevation-Based Risk-Assessment for Urban Flooding

To assess the exposure to tidal-flooding and future SLR, our results provide an initial estimation of the exposure of HCMC to potential flooding from the current high tide level (1.5 m AMSL).The assessment results were based on the detailed mapping of the urban development of HCMC (Fig. 3). The scenario approach investigates how climate change is likely to influence HCMC's exposure to tidal flooding due to SLR (+1.0 m) up to the year 2100, alongside rapid urbanisation. Most of HCMC's area is distinctively low and flat. The terrain elevation varies from 0 to 32 m AMSL. It was calculated that 70 % of the whole urban area of HCMC is below 2 m AMSL.

Figure 2, graphically represents the development trend of HCMC from 1989 till the year 2007. Since 2000, the urban expansion of HCMC has taken place in the low-lying peripheral and suburban areas [7]. These areas were already known to be prone to flooding in high-tide events. Natural streams, channels, lakes, wetlands and vegetation structures were replaced by impermeable surfaces causing increased surface run-off and increased the risk of urban flooding. Our results document that

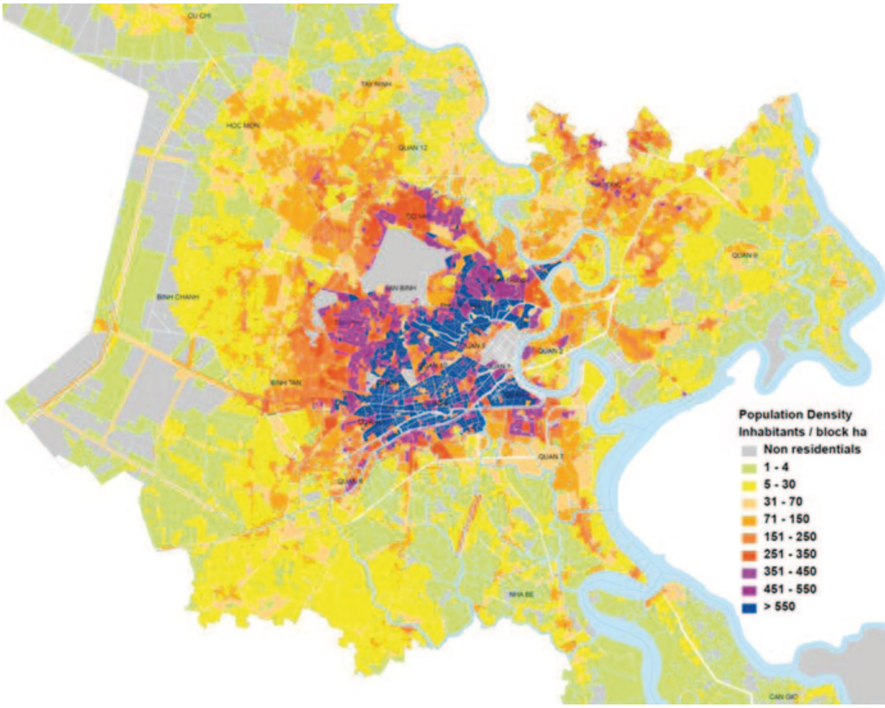


Fig. 1 The population density of HCMC in 2010

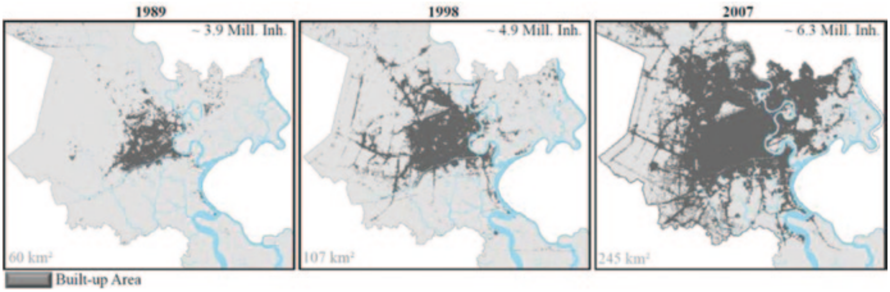


Fig. 2 The development of the built-up extent in HCMC from 1989 to 2007

HCMC, as a densely built-up area in a low lying region, is sensitive to climatic effects [12].

However our results also highlight that the vulnerabilities of lives and livelihood to climate-related environmental processes are primarily the result of the past inadequate and unsustainable urban planning practices [11]. To take into account future land-use changes, projected land-use changes were extracted from the official land-

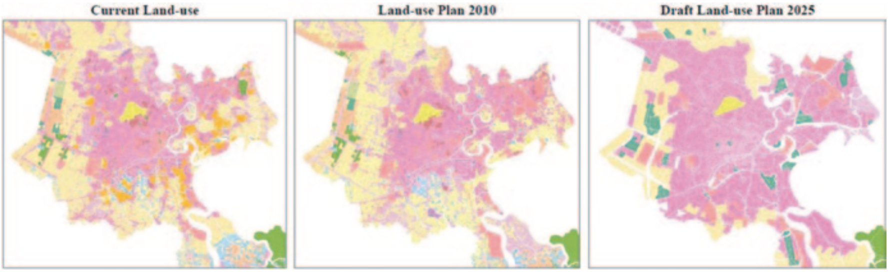


Fig. 3 The current land-use and official land-use plans for 2010 and up to 2025

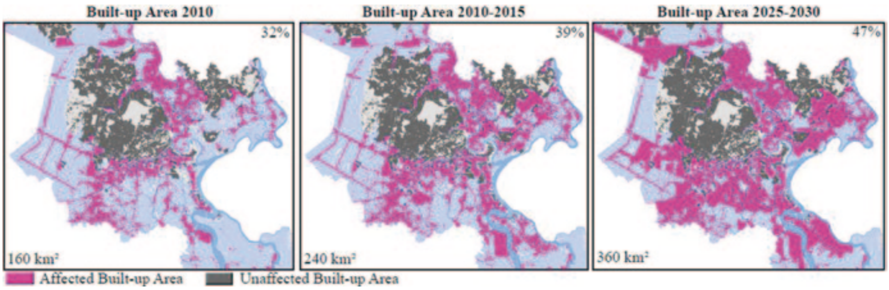


Fig. 4 The inundation risks for a max-tide water level of 1.5 m AMSL for HCMC's urban development scenarios

use plan up to the year 2010 and the draft version for the years up to 2025/2030, while, the current land-use was determined from the urban structure type classification for the entire HCMC urban area (Fig. 3).

For the purpose of this study built-up extent was defined as solely residential and industrial developments and derived from the aforementioned land-use plans (Fig. 3). The integration of the mapped built-up extents to the inundation risks at max-tide level, highlight that a significant proportion of the current built-up area (approximately 160 km^2 or 32 % of the total built-up 500 km^2) is exposed to potential inundation from a current max-tide water level of 1.5 m AMSL (Fig. 4). Implementing the draft land-use plans up to the year 2025/2030 would increase the total built up area to 750 km^2—an increase of 50 %, while at the current max-tide water level, the total built-up area at significant risk would increase twofold to around 360 km^2. However, when combining the effects of an extreme SLR of 1 m projected for 2100 [6] with the urban development scenarios, the total exposure can be seen to alarmingly grow to 450 km^2 (Fig. 5). This exposure would account to more than a threefold increase in relation to the current area at risk of present day tidal flooding.

Our assessments have highlighted that for exposure to tidal flooding, rapid urbanisation is proportionately more important for the emerging megacity HCMC, than projected SLR up to the year 2100 under a high-emission scenario [12]. Climate change was seen to contribute to less than one third of the total increase in

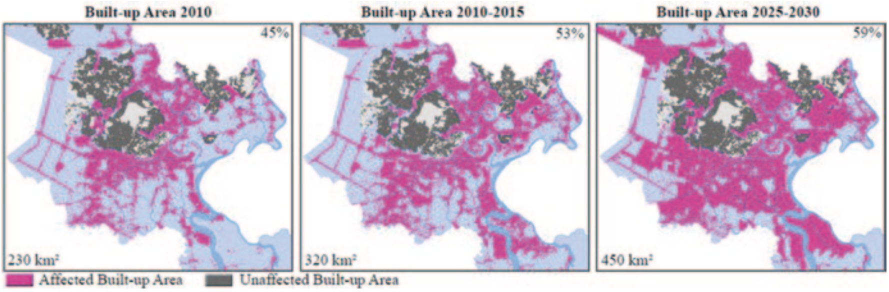


Fig. 5 The inundation risks form a current max-tide water level of 1.5 m and SLR 1 m (=2.5 m AMSL) for HCMC's urban development scenarios

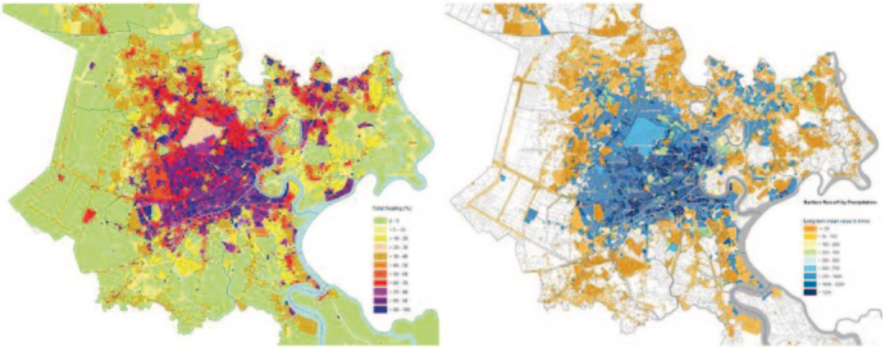


Fig. 6 The current imperviousness and modelled surface-runoff for HCMC in 2010

exposure of built-up areas, while the vast majority of exposure was seen to stem from the officially planned urbanisation up until 2025/2030.

The Impacts of Urbanisation on Stormwater Run-Off

In another step, to assess the impacts of urbanisation on the local hydrological system, a dedicated site specific risk assessment was carried out. One of the key environmental indicators for urban agglomerations is impervious surface coverage [2]. To determine the current impervious surface coverage of HCMC, the visual estimation from high resolution satellite imagery of the percentage of both built-up and non built-up sealed surfaces for each classified urban structure was undertaken [10]. An additional important consideration for the assessment of urban imperviousness is the varying proportions of different surface coatings for each urban structure. The results aggregated to the entire administrative area show that currently approximately 16 % is imperviously covered (Fig. 6).

Additonally annual surface-runoff was modelled. Here a suitable water balance model was selected which would utilise the estimated impervious surface coverage values [9]. The results have shown that from a mean annual precipitation input of 1,572 mm, 225 mm or approximately 14 % is unable to infiltrate or evaporate and converts into surface run-off (Fig. 6). With the implementation of the future development plans up to 2025/2030, the impervious coverage will be seen to double over the entire urban area of HCMC. This action significantly doubles the amount of surface-runoff—a current major cause of urban flood problems.

Strategic Land-Use Planning in a Changing Climate

To support the potentials of urban land-use planning for adaptation in HCMC, the focus has to shift towards the evaluation of land conditions and urban development potentials in a more spatially explicit manner. In the development of planning recommendations to assist master plan adjustments for both land-use and urban development, recommendations need to be grounded in realistic land-use and urban development scenarios. These need to in turn consider both the underlying land conditions and suitability for development and additionally are required to integrate the pressing climate-related issues into HCMC's existing urban planning framework [5].

The main factors affecting urban development activities are natural factors, like naturally flood-prone area, topography and soil conditions (Fig. 7), and artificial factors, like urban services (water supply, drainage, roads), accessibility to urban centres and land prices. The current urban development situation in HCMC is characterised by a high population density in the existing urban core area, mostly by low-rise housing structures. This has led to an extreme inherent urban compactness (Figs. 1, 6 and 7), which ensures due to location a good accessibility and short commuting times for the residents. At the sometime, however, low-density sprawling into the peri-urban fringe—partly caused by illegal development is visible, resulting in an ineffective infrastructure provision. The current development trends—a continued concentration and densification within city centre and along the major transportation corridors—is highly impractical, yet is mainly driven by small private development projects on the level of the single building or street block. This trend is worrying from an environmental standpoint, as without planning interventions of some degree, such small scale yet high-density developments fail to provide adequately for open space provision and environmental services. The assessment of HCMC's urban development strategy highlights a lack of effective planning and plan enforcement mechanisms for guiding urban growth orientated to the basic underlying natural conditions, against a backdrop of strong market mechanisms that have recently dictated the current development activities.

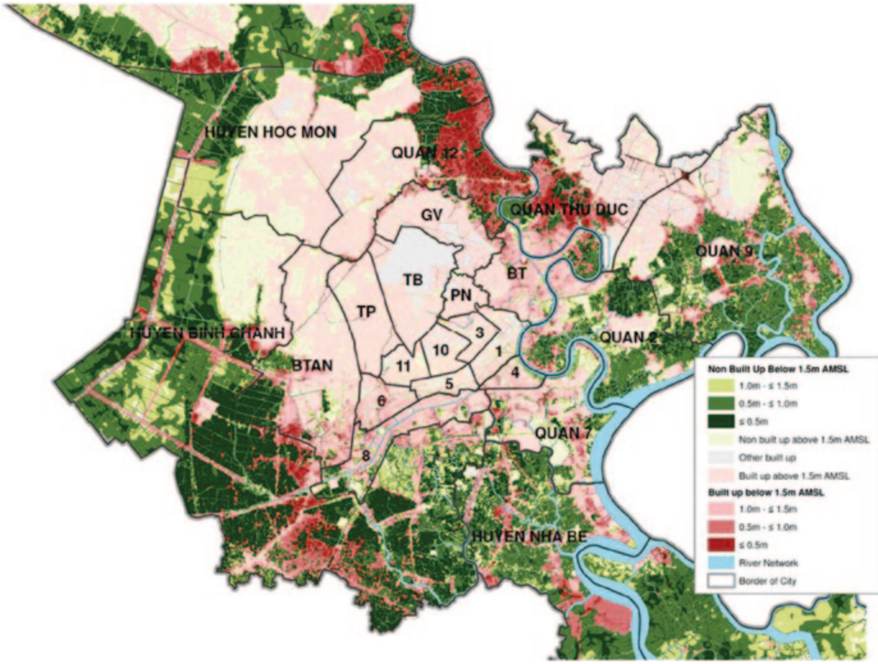


Fig. 7 HCMC's non built-up and built-up areas in flood-risk areas (areas below the current high-tidelevel of 1.5 m AMSL)

Development of Recommendations for Adaptation Planning

The rapid urban growth and expansion of cities into natural areas is not solely the problem of HCMC, but is a global phenomenon presenting an important challenge to both sustainability and adaptation planning [3]. Effective planning policies are required to stem the tide of increasing land-consumptive development in the high-risk flood-prone areas of HCMC. Here, without delay urban containment policies should be considered as a promising adaptation approach to address the current and unfolding spatial risk-patterns of HCMC.

Figure 7 highlights clearly that the current urban form and structure of HCMC is strongly influenced by and to some extent constrained by its underlying natural conditions. The few remaining open spaces surrounding the extremely dense core –mainly agricultural land–have an elevation below the current high-tide level of 1.5 m AMSL. These spaces currently act as a natural blue and green belt–akin to flood risk zoning by nature–and strongly influence the ongoing inner-city re-densification. Hence a genuine understanding the interrelationship between urban densification and adaptation processes to current flood risk can aid the guidance the spatial adaptation processes of HCMC in the uncertain times of rapid urban growth and climate change.

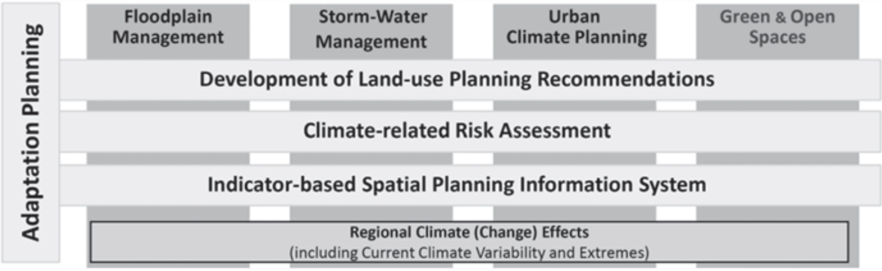


Fig. 8 The environmental planning tools and methods used for the integrated assessment of blue and green infrastructure for an adapted land-use planning in Ho Chi Minh City

Our developed planning recommendations for climate change adaptation focus on supporting the designation of natural flood-prone greenbelts (Fig. 7), the most restrictive form of urban containment policy. Utilising the existing flood-prone areas as greenbelts for current and future flood protection measures would additionally provide significant urban environmental benefits including recreational value, protection of open space, agricultural land, natural resources, all in additional to the highly important supporting ecosystem services for storm- and floodwater management. To be ultimately climate resilient, urban development planning need to reconcile these ecological services for adaptation planning. Supported by environmental planning methods and tools land-use planning can protect these environmental services in a systematic manner (Fig. 8).

For high-dense urban patterns, a larger blue and green infrastructure is in general beneficial to adaptation, as it provides space for urban agriculture, natural spaces for retention and detention of storm and flood water management, and areas to generate and transit cool and fresh air, lowering and offsetting the energy demands for cooling in cities with tropical climates.

Supporting Administrative Integration and Implementation

Land-use planning is seen as having a key role to play in developing strategies to climate-proof HCMC [13]. As such, our research has not been carried out in isolation but from the outset was foremost intended to assist the Department of Natural Resources and Environment (DONRE) with administrative policy making (Fig. 9). In making informed decisions underpinned by the latest assessment techniques [1]. The results presented in this paper show the apparent gravity of the grave challenges faced by DONRE with respect to climate proofing future urban development.

Ultimately, DONRE has the task to determine the overall land-use, spatial zoning and environmental quality of HCMC. As such, DONRE possesses executive powers over one of the most important instruments for the adaptation of HCMC to climate change, the steering and management of land-use. To their credit, DONRE has become very conscious of its responsibility in relation to climate change re-

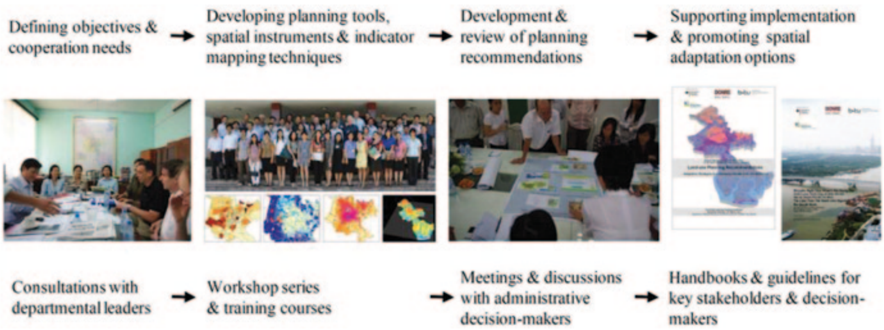


Fig. 9 The cooperation and joint research activities with DONRE in development and implementation of planning recommendations for adapting HCMC's land-use plan to climate change

sponses and the management of associated impacts. Externally, these matters have gained increasing acceptance and importance within the wider administrative structure of HCMC, while, internally they have reinforced the essential need to adapt their own planning [12]. Hever integrating climate change considerations into land-use planning in HCMC is inherently a complex decision-making problem, which requires the careful assessment of the current decision situation, related to place and space [13].

Summary and Conclusion

For high-dense Asian megacities, the complexity of risk and vulnerability requires high resolution spatial information in order to identify hazard patterns, vulnerabilities and risks at a scale that can provide guidance for urban land-use and development planning. Planning for risk and uncertainty for future urban growth will not just be a challenge for high flood prone areas; it will be a broader challenge impacting on the very nature and location of future urban development, particularly in planning for climate change [8]. Here land-use planning that takes into account disaster risks is the single most important adaptation measure for minimising future losses. The spatial planning framework and subsequent urban planning decisions, as currently applied, do not attach ample importance to the physical exposure and the rate of urban growth associated with the risk of disaster losses. Generally, urban governments are responsible and have a moral obligation for regulating either building or development in a way that reduces risks. Urbanisation does not necessarily have to lead to an increasing hazard portfolio and can, if managed properly, contribute towards risk reduction. However, there are a number of key characteristics of the urbanisation process that do directly contribute to the formation of risk [4]. Solely spatial and physical exposure alone does not explain nor directly lead to increased urban risk. If urban growth in risk-prone locations is directed by adapted land-use zoning and at the same time guided by adequate building standards, ensuring risk patterns can be effectively managed and mitigated.

Acknowledgments The authors would like to acknowledge the assistance and cooperation of the Ho Chi Minh City Department of Natural Resource and Environment. The contribution is based on results of the research project "Integrative Urban and Environmental Planning for Adaptation of Ho Chi Minh City to Climate Change" which is funded as part of the "Future Megacities" programme by the German Federal Ministry of Education and Research (BMBF). The authors would like to express their gratitude to Le Thanh Hoa, Thong Nhat Tran and Hendrik Rujner who partly supported the geoprocessing.

References

1. Downes N, Storch H (2010) Adaptation response to climate change at the Urban level—spatial information needs for climate-related decision support in Mega-Urban regions. Report of the German-Vietnamese Workshop held on 9th July 2010 at IMHEN in Hanoi, Vietnam. Cottbus. http://www-docs.tu-cottbus.de/megacity-hcmc/public/04_Results/Ger_Vn_Workshop_Hanoi_2010/Workshop_Report_090710.pdf, accessed 25/11/2013
2. Downes N, Storch H, Rujner H, Schmidt M (2011) Spatial indicators for assessing climate risks and opportunities within the Urban environment of Ho Chi Minh City, Vietnam. In: Isocarp (eds) E-Proceedings of 47th ISOCARP Congress 2011 "Liveable Cities Urbanising World, Meeting the challenge" Wuhan China, Case Study Platform www.isocarp.net and Congress CD, p 13. ISOCARP, The Hague
3. Fünfgeld H (2011) Introduction: approaches to climate change adaptation in cities. In: Otto-Zimmermann K (ed) Resilient cities: cities and adaptation to climate change, Proceedings of the Global Forum 2010, Local Sustain 1:399–400.Springer, Berlin. doi:10.1007/978-94-007-0785-6_40
4. Heinrichs D, Aggarwal R, Barton J, Bharucha E, Butsch C, Fragkias M, Johnston P, Kraas F, Krellenberg K, Vogel J, Lampis A, Ooi GL (2011) Adapting cities to climate change: opportunities and constraints. In: Hoornweg D, Freire M, Lee MJ, Bhada-Tata P, Yuen B (eds) Cities and climate change: responding to an urgent agenda. Publication from the Fifth Urban Research Symposium, World Bank
5. Labaeye A, Brugmann J, Nguyen Van P, Bao T, Ly Khanh Tam T, Nguyen Anh T, Storch H, Schinkel S (2012) Reality check: Ho Chi Minh city, Vietnam. In: Otto-Zimmermann K (ed) Resilient cities 2. Local Sustain 2:367–376, Springer, Berlin. doi:10.1007/978-94-007-4223-9_38
6. MoNRE (Ministry of Natural Resources and Environment) (2009) Climate change, Sea Level Rise Scenarios for Vietnam, Hanoi
7. Nguyen-Thanh S, Chi-Farn C, Cheng-Ru C, Li-Yu C, Bui-Xuan T (2012) Urban growth mapping from landsat data using linear mixture model in Ho Chi Minh city, Vietnam. J Appl Remote Sens 6(1). doi:10.1117/1.JRS.6.063543
8. Preston B, Kay R (2010) Managing climate risks in human settlements. In: Jubb I, Holper PN, Cai WJ (eds) Greenhouse 2009 Conference. pp 183–196
9. Rujner H (2011) GIS-based coupling of the water balance model ABIMO with Urban structure types of Ho Chi Minh City. In: German Academic Exchange Service (DAAD) (ed) (2011): "Future Megacities in Balance" Young Researchers Symposium in Essen, 9.–10. Oktober 2010, pp 58–63, Dok & Mat vol 66
10. Rujner H, Goedecke M, Storch H, Moon K, Downes N (2010) GIS-basierte Kopplung des Abflussbildungsmodells ABIMO mit dem stadtstrukturellen Planungsinformationssystem von Ho Chi Minh City (Vietnam). In: Strobl J, Blaschke T, Griesebner G (eds) Angewandte

Geoinformatik 2010, Beiträge zum 22. AGIT-Symposium, Salzburg. Wichmann, Heidelberg, pp 545–551

11. Storch H (2007) GIS-based sustainability assessment of housing and settlement structures within the metropolitan area of Ho Chi Minh city. In: Zeil P, Kienberger S (eds) Geoinformation for development. Bridging the divide through partnerships, Wichmann, Heidelberg, pp 65–75
12. Storch H, Downes NK (2011) A scenario-based approach to assess Ho Chi Minh city's Urban development strategies against the impact of climate change. J Cities 28(6):517–526. doi:10.1016/j.cities.2011.07.002 (Special Issue: Low Carbon Cities)
13. Storch H, Downes N, Katzschner L, Thinh NX (2011) Building resilience to climate change through adaptive land use planning in Ho Chi Minh city, Vietnam. In: Otto-Zimmermann K (ed) Resilient cities: cities and adaptation to climate change, Proceedings of the Global Forum 2010, Local Sustain 1:349–363. Springer, Berlin. doi:10.1007/978-94-007-0785-6_35

Neoliberalism and Spatial Adaptation

Lachlan McClure, Douglas Baker and Mellini Sloan

Abstract Human spatial environments must adapt to climate change. Spatial planning is central to climate change adaptation and potentially well suited to the task, however neoliberal influences and trends threaten this capacity. This paper explores the significance of neoliberal influences on urban planning to climate change adaptation. The potential form of spatial adaptation within the context of a planning environment influenced by neoliberal principles is evaluated. This influence relates to spatial scale, temporal scale, responsibility for action, strategies and mechanisms, accrual of benefits, negotiation of priorities and approach to uncertainty.

This paper presents a conceptual framework of the influence of neoliberalism on spatial adaptation. It identifies the potential characteristics, challenges and opportunities of spatial adaptation under a neoliberal frame.

The neoliberal frame does not entirely preclude spatial adaptation but significantly influence its form. Neoliberal approaches involve individual action in response to private incentives and near term impacts while collective action, regulatory mechanisms and long term planning is approached cautiously. Challenges concern the degree to which collective action and a long term orientation are necessary, how individual adaptation relates to collective vulnerability and the prioritisation of adaptation by markets. Opportunities might involve the operability of individual and local adaptation, the existence of private incentives to adapt and the potential to align adaptation with entrepreneurial projects.

L. McClure (✉) · D. Baker · M. Sloan
Science and Engineering Faculty, School of Civil Engineering and Built Environment,
Queensland University of Technology, Brisbane, Australia
e-mail: lachlan.mcclure@student.qut.edu.au

D. Baker
e-mail: d2.baker@qut.edu.au

M. Sloan
e-mail: mellini.sloan@qut.edu.au

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_36,

Introduction

Human spatial environments must adapt to the changing climate. Urban planning has a central role in bringing about spatial adaptation and established characteristics of planning make it potentially well suited to this task. However neoliberal trends in spatial governance have established parameters and reorientated the focus of planning. The overall capacity to facilitate adaptation and the particular form of adaptation in the spatial sphere is potentially influenced by neoliberalism.

This paper positions climate change adaptation within the context of neoliberal urban governance to explore the forms of spatial adaptation which may emerge in response to the spatial impacts of climate change and the favouring of market mechanisms of coordination. Literature on neoliberal geographies and spatial adaptation is reviewed to identify how adaptation paths align with neoliberal principles and how neoliberal influences prevent, support and direct the course of spatial adaptation. This paper provides a conceptual framework for understanding the influence of neoliberalism on spatial adaptation and presents evidence of this influence in key documents to outline the potential characteristics and difficulties of spatial adaptation under a neoliberal frame.

The Task of Adapting

Some climate change has already occurred and further climate change, as the result of past emissions, is beyond the scope of mitigation. Adapting human spatial environments is therefore necessary. Adaptation involves reducing vulnerability and increasing resilience to accommodate projected climate scenarios and can involve anticipatory and reactive, autonomous and planned action. Adaptation has long been identified by research and policy communities as a possible response to climate change, but has previously been sidelined in favour of focusing on emissions mitigation [38]. Similarly adaptation has been acknowledged in planning literature although aligned discourses of sustainable development have received greater attention. Adaptation is now the subject of emerging research and policy [38] and of significant concern for spatial planning [36].

Spatial planning involves the allocation of land and the design and control of spatial patterns. Spatial planning is frequently identified as being the most effective means of adapting settlements in response to climate change [24]. It provides the instrumental framework for adaptation [29] and operates as both a mechanism to achieve adaptation and a forum to negotiate priorities surrounding adaptation [13]. The acknowledged role of spatial planning in adaptation however has not translated into comparably significant consideration in planning literature [13, 24]. The discourse on adaptation specifically through spatial planning is described as '*missing*' and '*subordinate*' in national adaptation plans [19],'*underrepresented*' [35] and '*limited and disparate*' in planning literature [13]. Hurlimann and March [24] suggest this is due to limited experiences of adaptation in developed nations while Roggema et al. [36] and Crane and Landis [12] suggest it is because climate change is a wicked problem involving an unfamiliar problem, various frames of understanding and uncertain solutions.

A number of requirements and characteristics determine the capacity for spatial planning to facilitate adaptation. Systems must anticipate and respond to change, develop and implement contextually specific strategies and bridge the timescale between short term projects and long term plans [36]. Processes must also manage conditions of uncertainty and emerging information, competing interests, inequality and intergenerational equity and the long timescale of incremental change [13, 36]. Existing spatial planning systems and processes potentially meet these requirements. They are '*strategic, adaptive, results oriented, involve diverse stakeholders, and incorporate multiple scenarios*', furthermore planners are experienced working under conditions of uncertainty and coordinating collective action [12]. Hurlimann and March [24] identify characteristics making spatial planning well suited to adaptation:

1. Planning has the ability to act on and coordinate matters of collective concern or public good;
2. Planning can facilitate the consideration of competing interests;
3. Planning acts across various spatial, temporal and governance scales while understanding and acting on local circumstances;
4. Planning can reduce or modify uncertainty and provide mechanisms to deal with changing circumstances;
5. Planning has the capacity to be a repository for spatial knowledge sets;
6. Planning is oriented to the future and has the potential to coordinate the activities of a range of actors to achieve long term benefits.

These characteristics however are not invariable and the degree to which they are reflected in actual spatial planning processes is determined by the political, professional and ideological context. For example, Davoudi et al. [13] blames reformist and ecological modernisation approaches for constraining planning from effectively embedding climate change mitigation and sustainable development into spatial development frameworks and Brown [10] argues that spatial planning is restricted by the parameters of the dominant development paradigm.

Coordinated spatial adaptation has not occurred to a significant extent and spatial patterns demonstrate much lower levels of variability than required to accommodate climate change [34, 35]. Studies have assessed the projected spatial impacts of climate change while an emerging number of adaptation outcomes are achieved through disaster risk management and sustainable development projects [40]. Advanced impacts such as on urban flooding, water resources and coastal management have received particular attention while other conditions have not translated into spatial policy [41]. Policy approaches to adaptation are either based on a reformist position of supporting existing development patterns or a radical position of challenging the sustainability of such [10, 20].These distinct agendas underpin conflicting opinions of whether adaptation can be achieved through existing frameworks or requires radically different approaches.

A Neoliberal Frame

Neoliberalism is a doctrine of economic management and governance which holds that free markets and individual liberty is the most effective means of resource coordination and allocation [21]. Accordingly, any intervention is seen as distorting price signals, increasing transaction costs, challenging individual liberty and ultimately leading to suboptimal allocation. This ideology of economic liberalism is associated with conditions and processes of deregulation, privatisation, globalisation, capital mobility and accumulation [21]. Neoliberalism emerged in response to the Fordist-Keynesian form of post-war capitalism and revived tenants of classical economic liberalism. It developed as an intellectual project promoted by Friedrich Hayek and Milton Friedman before becoming mainstream economic doctrine in the United Kingdom and United States with the Thatcher and Regan Governments of the 1980s [21]. Neoliberal thought has spread globally to become a dominant ideological form of capitalism [32].

Neoliberalism has been described as 'an essential descriptor of the contemporary urban condition' [7] and 'an essential descriptor of the political trends and bureaucratic transformations forming the conditions under which planners work' [37]. Socio-spatial geographers have identified various neoliberal influences in spatial policy and reflected on the effects of neoliberal restructuring on spatial environments [37]. However the expression of neoliberal thought, the processes and products of neoliberal restructuring, are highly varied [31]. Neoliberalisation is the 'the prevailing pattern of market oriented, market-disciplinary regulatory restructuring' [32]. This process is highly path dependent and contextually embedded on pre-existing institutional arrangements [7], spatially diffuse and geographically uneven [8] and characterised by destructive and creative phases of institutional change [32]. These characteristics manifest various variegated and hybridised neoliberal experiences linked by a common market orientation and antipathy for central regulation.

Neoliberalism operates as an organising framework which structures the parameters of urban governance and as an ideology which influences expectations of the urban experience [8]. Spatial organisation itself plays a role in the articulation and reproduction of neoliberalism: '*spatial organisation is at once a foundation, an arena and a mechanism for the mobilisation of neoliberal political strategies*' [8]. The neoliberal reorganisation of broader economic systems has influenced spatial governance. Capital mobility forces regions to compete for economic resources by establishing favourable investment conditions focusing urban governance to the entrepreneurial pursuit of investment.

Neoliberal doctrine holds that allocation of land is optimally achieved by the market, while planning constitutes an intervention and is opposed or relegated to supporting market functions [2]. While neoliberalism limits the domain of planning [17], planning is tolerated in managing externalities where there is a mandate and clear benefits [2]. The neoliberal critique of planning as limiting individual choice and imposing unreasonable costs underscores recommended models of simple, flexible local planning.

The ideologically absolute deregulatory image of neoliberal planning does not however adequately represent the range of processes experienced. Neoliberal restructuring also involves the rollout of new market oriented and entrepreneurial forms of governance [31]. Peck et al. [32] identifies characteristics of neoliberal spatial governance to include the devolution of responsibilities, emergence of private sector alliances, privatisation of assets and services and growth oriented regimes. Neoliberal planning favours entrepreneurial concepts of highest and best use, private ownership and management of space, investment oriented projects, special development areas, urban regeneration and discourses of urban reinvestment [32].

Planning policies are identified by Sager [37] as being linked to neoliberalism by favoring private sector solutions, competitive governance, property rights and economic development. Urban economic development is pursued through city marketing, attracting creative capital, incentivising development and competitive resource allocation [37]. Infrastructure provision is characterised by public partnerships and private sector infrastructure development [37]. Commercial areas are managed through special enterprise areas, flexible land use zones, urban regeneration and privatisation of public space [37]. The housing sector has experienced liberalisation and privatisation of public stock, growth of closed neighbourhoods and quasi non-government organised urban redevelopment [37]. Neoliberalising trends have been observed in the governance of environmental systems [11, 23]. Climate change mitigation policy also courts neoliberal values in the market based technocentric solutions currently favoured [5].

Neoliberal Adaptation

Adaption takes place in the context of the prevailing neoliberal frame. However the link between spatial adaptation and the neoliberal context has received little attention despite growing literature in both areas. The following section considers how adaptation may be influenced by neoliberalism based on literature linking the themes and a conceptualisation of the relationship.

Literature Linking Neoliberalism and Adaptation

The link between adaptation and neoliberalism is part of a broader conversation about the capacity for sustainable development within the capitalist system. Unrestrained pursuit of economic value and unregulated environmental externalities are responsible for climate change. Some argue sustainability requires a new socio-environmental orientated system of '*beyond capitalism*' not dependant on endless growth [25, 39]. Others hold that capitalism and sustainability are not inconsistent but a reformed '*natural capitalism*' which captures environmental e is required [22, 33].

Neoliberalism has been linked to the production of vulnerability and reduced capacity for collective action. Vulnerability to climate change has been observed to correlate with patterns of social vulnerability originating from neoliberal globalisation [26]. Fieldman [15] links the operation of neoliberal systems of uneven accumulation and diminished social functions to radical inequality implicit in the production of climate vulnerability. Collective action through a well functioning state is important for effective adaptation [1]. Neoliberal practices limit the capacity for collective adaptation by reducing the role and resources of government while questioning its efficacy [6, 15]. Moreover, neoliberal institutions have been identified as emphasising individual adaptation [14, 20].

Neoliberalism has been linked to reformist approaches to sustainable development and the techno-scientific problematisation of adaptation. Grist [20] and Brown [10] argue that current adaptation is embedded within the dominant development paradigm and reformist model of sustainable development and employs approaches of ecological modernisation, market environmentalism and risk commoditisation. Similarly Oppermann [30] observes a techno-scientific problemisation of adaptation in policies which consider adaptation in terms of risk and decision making thereby legitimising a rationale of limited intervention.

These links all concern the broadly interpreted neoliberal political economy and the general field of adaptation. The subsequent section investigates the specific influence of neoliberal spatial planning on adaptation.

Conceptualisation of Neoliberal Adaptation

The potential capacity for adaptation through spatial planning has been identified, but is ultimately determined by the neoliberal context which imposes parameters and introduces a market orientation. Relating the requirements of spatial adaptation with the characteristics of neoliberal planning according to the themes of spatial scale, temporal scale, responsibility for action, strategies and mechanisms, accrual of benefits, negotiation of priorities and approach to uncertainty possible conflicts, alignments and partial links can be observed (Table 1).

Neoliberalism does not support a long term future orientation and commonly undervalues the environmental and social benefits of adaptation in market based resource allocation thereby reducing spatial adaptation capacity. However neoliberalism responds to the direct market incentives of localised benefits of adaptation and provides approaches to manage uncertainty thereby supporting spatial adaptation. Neoliberalism confines action to the local scale, emphasises individual responsibility and weakens regulatory controls while supporting strategic entrepreneurial intervention thereby influencing the form of spatial adaptation.

Following this conceptualisation, neoliberal spatial adaptation would be undertaken individually and locally by land owners and authorities prompted by near term impacts and tied to the private benefits of reduced risk exposure or to position the locality as a safe place for capital investment. Flagship adaptation projects

Table 1 Influence of neoliberal patterns of spatial planning on the capacity for and form of climate change adaptation

Theme	Requirement for adaptation	Ideal role of spatial planning	Neoliberal spatial planning	Interplay	Consequences for spatial adaptation
Spatial scale	Impacts occur across scales adaptation optimally involves multi-scale coordination but is operable and particularly important at the local scale	Involves various spatial scales while understanding and acting on local circumstances and particularities [24]	Questions the practicality, efficiency and relevance of action at large scales, favouring intervention only at the local scale in response to local conditions	Partially align/diverge	Spatial adaptation occurs through local spatial planning strategies which are highly responsive to local impacts but do not coordinate well across scales
Temporal scale	Impacts emerge incrementally but are highlighted by sudden weather events, adaptation must consider and act on long term future conditions	Oriented to the future and has the potential to coordinate the activities of a range of actors to achieve long term benefits [24]	Focuses on the reactive remediation of present externalities of development, future conditions are left to be considered and actions determined in individual decisions	Conflict	Spatial adaptation does not coordinate a response to long term impacts until events demonstrate their immediate consequence and that the market has failed to support autonomous adaptation
Responsibility for action	Climate change is a collective problem, but while mitigation hinges on a collective response, adaptation although most effectively advanced through collective action can be pursued individually	Has the ability to act on and coordinate matters of collective concern or public good [24]	Emphasises the importance and effectiveness of individual autonomy and voluntary association while remaining sceptical and limiting the capacity for central planning and collective action	Partially align/diverge	Spatial adaptation is positioned as an individual responsibility to manage risk supported by public good information. Maladaptation occurs where adaptation produces negative externalities and where individual benefits are marginal

Table 1 (continued)

Theme	Requirement for adaptation	Ideal role of spatial planning	Neoliberal spatial planning	Interplay	Consequences for spatial adaptation
Strategies and Mechanisms	Regulatory strategies are required to reduce future vulnerability while proactive adaptation is required to manage present vulnerability	Involves the strategic allocation and regulation of land uses and the design and control of spatial patterns	Reduces regulatory controls on development, relying on the disciplinary function of competitive markets. Favours entrepreneurial forms of investment focused governance	Partially align/ diverge	Spatial adaptation is pursued in flagship redevelopment and regeneration projects, while mainstream development continues to be poorly suited to emerging conditions
Accrual of benefits	Unlike mitigation where benefits are diffuse, the benefits of adaptation are highly localised so that those involved receive direct benefit from their actions	Works towards an equitable distribution of goods and benefits and the production of public goods	Requires actions to be motivated by creation of alienable value. Diffuse benefits or externalities provide little economic incentive for action	Align	Spatial adaptation is pursued by landowners and authorities as the direct benefits and returns related to risk reduction and metropolitan competitiveness is realised against increasingly severe impacts
Negotiation of priorities	Competing social, environmental and economic priorities and conflicting views of their relative value are inherent in adaptation decisions	Facilitates the consideration of competing interests and non-economic, social and environmental values [24]	Employs markets as the forum to negotiate priorities and allocate resources. Land use is determined by economic value or highest and best use and undervalues diffuse social and environmental goods	Conflict	Spatial adaptation is restricted by current markets which undervalue adaptation as a social and environmental good and do not allocate sufficient resources. Late term adaptation could conceivably follow more accurate valuation of adaptation

Table 1 (continued)

Theme	Requirement for adaptation	Ideal role of spatial planning	Neoliberal spatial planning	Interplay	Consequences for spatial adaptation
Approach to uncertainty	The nature, extent and timing of impacts are uncertain and the subject of a constantly emerging and improving body of information	Can reduce or modify uncertainty and provide mechanisms to deal with changing circumstances [24]	Models uncertainty as risk which is assessed through collective knowledge and bargaining of market actors and conveyed and managed through risk pricing mechanisms	Align	Spatial adaptation decisions under uncertainty and emergent information are based on established and effective risk assessment and risk pricing models

would lead while mainstream development would adapt later in line with consumer demand. Difficulties with this approach concern the degree to which collective action and a long term orientation are necessary, how individual adaptation relates to collective vulnerability, whether markets can regulate maladaptation and if adaptation can be appropriately prioritised through market mechanisms.

Neoliberal projects are extremely varied, seldom ideologically consistent [9, 32] and subject to negotiation and challenge [27]. Furthermore, climate change will prompt institutional change and reorientation of governance frameworks [28]. Thus, this conceptualisation provides a broad understanding of the potential characteristics of spatial adaptation under a neoliberal frame but does not represent a strict model.

Neoliberalism and Australian Adaptation Policy

The '*neoliberal heartland*' of the United Kingdom, United States and Australia has been subject to particularly strong processes of neoliberal restructuring [16]. Adaptation planning particularly in these contexts may have to navigate stronger neoliberal influences. Planning in Australia in particular has been identified as coming under the influence of strong neoliberal reform agendas [17]. Emerging climate change adaptation policy in Australia has been argued to be consistent with neoliberal principles of individual responsibility and the role of government [18]. Granberg and Glover [18] note that the Australian Government position paper *Adapting to Climate Change in Australia* [3] reasons that individuals and business are responsible for managing climate risk and that there are private incentives to do so.

It also describes the role of government *as* '*creating the right framework and in providing appropriate information to allow the private sector to make well-informed decisions*' consistent with neoliberal views. Likewise the Australian Government Productivity Commission report *Barriers to Effective Climate Change Adaptation* [4] states that that '*most adaptation would occur without the need for government involvement*'. It recommends that that adaptive capacity can be build be reforming taxes which distort the allocation of adaptation resources, reforming transfers which reduce incentives to adapt and reforming regulations which restrict or increase the cost of adapting. However these documents do broadly acknowledge that climate change adaptation is a task to which spatial planning must respond, the question is whether neoliberalism will play a significant part in shaping that response.

Conclusion

This paper has explored the potential form of spatial adaptation in the context of the prevailing tendency for neoliberal urban governance. The neoliberal frame does not entirely preclude spatial adaptation but has the potential to significantly influence its form. Likely approaches involve individual action in response to private incentives and near term impacts while collective action and regulatory mechanisms are limited and long term planning is approached cautiously. Challenges include overcoming limits to collective action, adopting a long term planning horizon and appropriately prioritizing adaptation through existing frameworks. Opportunities include the operability of individual and local adaptation, existence of private incentives, established risk management tools and the potential to align adaptation with entrepreneurial aims and projects. The neoliberal context will influence the practice of adapting spatial environments. Ultimately many influences will constrain a planner's efforts and should be contested while others can be exploited to advance the cause.

References

1. Adger N (2003) Social capital, collective action, and adaptation to climate change. Econ Geogr 79(4):387–404
2. Allmendinger P (2002) Planning theory. Palgrave, New York
3. Australian Government Department of Climate Change and Energy Efficiency (CCEE) (2010) Adapting to climate change in Australia. Retrieved from: http://www.climatechange.gov.au
4. Australian Government Productivity Commission (AGPC) (2012) Barriers to effective climate change adaptation—Draft Report. Retrieved from: http://www.pc.gov.au
5. Bailey I, Wilson G (2009) Theorising transitional pathways in response to climate change: technocentrism, ecocentrism, and the carbon economy. Environ Plann A 41(10):2324–2341

6. Bardsley D, Pech P (2012) Defining spaces of resilience within the neoliberal paradigm: could French land use classifications guide support for risk management within an Australian regional context? Human Ecol: Interdiscipl J 40(1):129–143
7. Brenner N, Theodore N (2002) Cities and the geographies of ‘actually existing neoliberalism’. Antipode 34(3):349–379
8. Brenner N, Theodore N (2005) Neoliberalism and the urban condition. City 9(1):101–107
9. Brenner N, Peck J, Theodore N (2010) Variegated neoliberalization: geographies, modalities, pathways. Global Networks 10(2):182–222
10. Brown K (2011) Sustainable adaptation: an oxymoron? Clim Dev 3(1):21–31
11. Castree N (2008) Neoliberalising nature: the logics of deregulation and reregulation. Environ Plann A 40(1):131–152
12. Crane R, Landis J (2010) Introduction to the special issue. J Am Plann Assoc 76(4):389–401
13. Davoudi S, Crawford J, Mehmood A (eds) (2009) Planning for climate change: strategies for mitigation and adaptation for spatial planners. Earthscan, London
14. Felli R, Castree N (2012) Neoliberalising adaptation to environmental change: foresight or foreclosure? Environ Plann A 44(1):1–4
15. Fieldman G (2011) Neoliberalism, the production of vulnerability and the hobbled state: systemic barriers to climate adaptation. Clim Dev 3(2):159–174
16. Geddes M (2008) *Neoliberalism and local governance - cross-national perspectives and speculations.* In: Davies, JS (ed) Journal of European Public Policy Series . London, UK: Routledge, pp. 123-142. ISBN 9780415420884
17. Gleeson B, Low N (2000) Revaluing planning: rolling back neo-liberalism in Australia. Progr Plann 53(2):83–164
18. Granberg M, Glover L (2011) Adapting Australian cities to climate change: is there a growing risk of maladaptation? Paper presented at the State of Australian Cities Conference, University of Melbourne
19. Greiving S, Fleischhauer M (2012) National climate change adaptation strategies of European states from a spatial planning and development perspective. Eur Plann Stud 20(1):27–48
20. Grist N (2008) Positioning climate change in sustainable development discourse. J Int Dev 20(6):783–803
21. Harvey D (2005) A brief history of neoliberalisim. Oxford University Press, New York
22. Hawken P, Lovins A, Lovins l (1999) Natural capitalism: creating the next industrial revolution. Little Brown, Boston
23. Heynen N, McCarthy J, Prudham S, Robbins P (2007) Neoliberal environments: false promises and unnatural consequences. Routledge, New York
24. Hurlimann A, March A (2012) The role of spatial planning in adapting to climate change. Wiley Interdiscipl Rev: Clim Change 3(5):477–488
25. Kovel J (2007) The enemy of nature: the end of capitalism or the end of the world? Zed Books, New York
26. Leichenko R, O’Brien K (2008) Environmental change and globalization: double exposures. Oxford University Press, New York
27. Leitner H, Peck J, Sheppard E (2006) Contesting neoliberalism: urban frontiers. Guilford Press, New York
28. Matthews T (2012) Responding to climate change as a transformative stressor through metropolitan regional planning. Local Environment
29. Meyer B, Rannow S, Loibl W (2010) Climate change and spatial planning. Landsc Urban Plann 98(3–4):139–140
30. Oppermann E (2011) The discourse of adaptation to climate change and the UK climate impacts programme: de-scribing the problematization of adaptation. Clim Dev 3(1):71–85
31. Peck J, Tickell A (2002) Neoliberalizing space. Antipode 34(3):380–404
32. Peck J, Theodore N, Brenner N (2009) Neoliberal urbanism: models, moments, mutations. SAIS Review 29(1):49–66
33. Porritt J (2007) Capitalisim as if the world matters. Earthscan, London

34. Roggema RE (2007) Spatial impact of adaptation to climate change in Groningen, move with time. Province of Groningen, Groningen, The Netherlands
35. Roggema R (2009) Adaptation to climate change: a spatial challenge. Springer, Dordrecht
36. Roggema R, Kabat P, van den Dobbelsteen A (2012) Towards a spatial planning framework for climate adaptation. Smart Sustain Built Environ 1(1):29–58
37. Sager T (2011) Neo-liberal urban planning policies: a literature survey 1990–2010. Progr Plann 76(4):147–199
38. Schipper L (2006) Conceptual history of adaptation in the UNFCCC process. Rev Eur Community Int Environ Law 15(1):82–92
39. Schweickart D (2010) Is sustainable capitalism possible? Procedia—Soc Behav Sci 2(5):6739–6752
40. Solecki W, Leichenko R, O'Brien K (2011) Climate change adaptation strategies and disaster risk reduction in cities: connections, contentions, and synergies. Curr Opin Environ Sustain 3(3):135–141
41. Wilson E (2006) Adapting to climate change at the local level: the spatial planning response. Local Environ 11(6):609–625

Part VI
Contamintation of Urban Waters and Its Effects

Occurrence, Sources and Pathways of Antimony and Silver in an Urban Catchment

Sophie Ayrault, Cindy Rianti Priadi, Pierre Le Pape and Philippe Bonté

Abstract The recently introduced and increasing uses of silver (Ag) and antimony (Sb) have resulted in an increasing concern on their impacts to the environment. Nevertheless, little information can be found about anthropogenic impacts on the geochemical behaviour of such trace metals in urban river. In the course of our studies dedicated to the Seine River basin, France (67,400 km^2), a large set of data was collected. Silver and antimony inputs to the Seine River Basin were estimated using three relevant sources: atmospheric deposition, waste water treatment plants effluents and combined sewer overflows. The Ag and Sb dissolved/solid partition in the river was also estimated on an annual basis. Results showed that Ag output river flux cannot be balanced with the input fluxes, unless to consider another source, which could be the erosion of contaminated soils. In opposite, the Sb budget is well balanced, with atmospheric deposition dominating the input fluxes to the river. The Ag and Sb geochemical behaviors (i.e., their dissolved/solid partition) are highly contrasted, especially for Sb, which dissolved/solid partition is even more fluctuant depending on the emission route.

S. Ayrault (✉) · C. R. Priadi · P. L. Pape · P. Bonté
Laboratoire des Sciences du Climat et de l'Environnement, UMR 8212,
CEA-CNRS-UVSQ/IPSL, 91198 Gif-sur-Yvette, France
e-mail: Sophie.ayrault@lsce.ipsl.fr

C. R. Priadi
Environmental Engineering Study Program, Civil Engineering Department,
Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
e-mail: cindy.priadi@eng.ui.ac.id

P. L. Pape
Laboratoire Interactions des Environnements de Surface, UMR 8148, Univ.
Paris Sud-CNRS, 91405 Orsay cedex, France
e-mail: pierre.lepape@lsce.ipsl.fr

P. Bonté
e-mail: philippe.bonte@cea.fr

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_37,

Introduction

While antimony (Sb) and silver (Ag) are not new pollutants *stricto sensus*, their recently introduced uses have resulted in an increasing concern on their impacts to the environment.

Antimony and its by-products have been listed as priority pollutants by the US Environmental Protection Agency (EPA). Indeed, during the last decade, Sb environmental behaviour has received an increasing attention due to the increasing uses of Sb compounds (semiconductors, lead alloys, flame retardant, pigments, medicine etc…) [7]. The basic concentration ratio of Sb to As in the earth's crust is 1/7.6, but this ratio has been found to be reversed in urban environments, probably due to the recent intensive use of Sb based materials to replace asbestos in vehicles brake pads [11].

Silver (nano)particles, increasingly used for their biocide properties, threaten the living organisms [9]. Although Ag is considered to be one of the highest recycled metals, up to 57 % [12], much is still emitted in the environment. Van de Velde et al. [25] suggest that the waste incinerators are a significant source of Ag to the atmosphere. In a global scale, tailings, leachates and direct dissipation to land may contribute to 30, 10 and 10 % of Ag waste emitted to the environment, respectively. The bioavailability and toxicity of Ag to aquatic life has been reviewed by Ratte [20].

Despite the sharply increasing number of studies recently devoted to the occurrence of Ag and Sb in environment, both their main sources and pathways in urban environment remain unclear, particularly in the water bodies. Large conurbations often developed close to a water system, river or harbor, allowing transportation of humans and material, and providing the city with water and as well as a place to evacuate liquid wastes. The Seine River, crossing the Paris conurbation deserves this description. As a consequence, this major French river may be susceptible to Ag and Sb contamination due to urban-linked activities.

In the course of our studies dedicated to the Seine River basin (67,400 km^2), a large set of data was collected (atmospheric deposition, urban river sediment and water, effluents from combined sewer overflows and waste water treatment plant effluents). This data set allows us to estimate the Ag and Sb:

1. Annual input from atmospheric deposition,
2. Annual riverine output due to discharge of sediment and dissolved fraction to ocean and
3. Annual inputs due to the discharge to the river of treated and untreated waste water.

The objectives of this work are to estimate those different annual fluxes of Ag and Sb at the regional scale and to demonstrate the anthropogenic impact of Paris conurbation on the geochemical behaviour of these trace metal in river. This study is also a first step to provide evidence on the most significant sources and pathways of Ag and Sb in urban environment.

Materials and Methods

Silver and antimony input to the Seine River Basin were estimated using three sources, including atmospheric deposition, WWTP effluents and combined sewer overflows. Based on a previous study of Cd, Cr, Cu, Ni, Pb, Zn and Hg budget in the Seine River [23], these three sources are considered sufficient to gain an insight to the contribution of Ag and Sb in the Seine River. Unless mentioned otherwise, all dissolved samples were acidified to 0.1 M ultrapure HNO_3 and stored at 4 °C until analysis.

Atmospheric Deposition

The exposure site is an area devoted to air monitoring, free from canopy cover, located 20 km-south of Paris intramuros [1]. The main pollution source is a motorway (100 m upwind from the sampling location), with an average of 67500 vehicles/day, including 5 % of heavy duty vehicles. At such a distance, the dry deposition fluxes due to the coarse particles emitted by the traffic have reduced to approximately urban conditions [21]. Several other sources, weaker and further away, also exist (urban, incinerators). Total deposition samples were collected in a HDPE conical collector with a diameter of 22.5 cm, 1.5 m above ground. The rain collection duration varied throughout the experiment, as a function of the rainfall intensities. The rain sample was transported back to the laboratory in a clean polyethylene bottle and immediately filtered using a 0.22 µm Minisart unit with 50 ml syringes on polyethylene flasks. The rain samples were analysed in duplicates by ICP-MS ($PQ2^+$, VG Elemental) without dilution, added with internal standards for signal drifts correction. Two sub-samples were analysed in the same batch, the third sub-sample being analysed in another batch. No difference between triplicates higher than 5 % was observed. The natural water reference material SRM-1640 from NIST (without any dilution and 10 times diluted) was checked during each batch. The field blank was constituted of ultra-pure water poured in the collector and immediately transported to the laboratory, filtered, acidified and stored as a sample. The limits of quantification (QL) were two standard deviation of the field blank determination on three replicates and reach 0.01 and 0.03 µg L^{-1} for Ag and Sb, respectively

WWTP Effluents (Seine-Aval)

Treated effluents from the Seine-Aval waste water treatment plant (WWTP) were sampled in April and December 2006 during a dry weather period [16]. This WWTP collects over 70 % of the dry weather (combined sewer) flows from the Paris metropolitan areas (11 million inhabitants). At the time of sampling and in this WWTP, raw wastewater was mainly treated using primary settling and aerobic activated sludge processes. Three 50-ml samples of water were immediately filtered using a 0.22 µm Minisart unit with 50 ml syringes on polyethylene flasks. One Litter of raw water was centrifuged to recover the particulate fraction. The digestion and the analytical procedures are similar to those described for the Seine River samples (see below).

Combined Sewer Overflow (CSO)

Samples were collected in the Clichy Combined Sewer Overflow, located downstream of the Paris Region before the Seine Aval WWTP. Overflow water was collected by vacuometric samplers installed by the Observatory of Urban Pollutants research program (OPUR) at the Clichy overflow facility. SPM recovery (100–250 ml), dissolved fraction filtration, digestion and analytical procedures are similar to those described for the Seine River samples (see below).

Seine River Water and Sediment

Three sites were chosen:

1. Marnay-sur-Seine, situated far upstream on the Seine River, non-affected by the Greater Paris region with a population density of around 15–30 inhabitants/km
2. Bougival, located 40 km downstream of Paris city, affected by Greater Paris without the influence of the major WWTP Seine-Aval
3. Triel-sur-Seine, located 40 km further downstream, which includes the influence of the "Seine-Aval" WWTP. Sampling was performed from October 2008 to October 2009. Details can be found in [17, 18]

The dissolved 0.45 µm fraction was obtained by filtering on-field and acidifying samples with 200 µl of pure HNO_3 65 % (Merck Suprapur). SPM was recovered by filtration of a 20 L volume of Seine River water through 0.45 µm Millipore cellulose filters. A sediment trap was also installed at each site. SPM were completely digested using a method adapted for the Seine River carbonated SPM using HNO_3, HF and $HClO_4$ separately. Major and trace metal concentration were determined using Inductively Coupled Plasma Quadrupolar Mass Spectrometry (ICP-QMS) (XIICCT-Series, ThermoElectron, France).

Results and Discussion

Atmospheric Deposition Fluxes

To validate the data upscaling issued from a single sampling site to the whole Seine River basin, the Zn values obtained at Saclay and expanded to the whole basin (680 t y^{-1}) were compared to Zn atmospheric deposition flux value (1135 t y^{-1}) published in [23]. These authors have evaluated the budget of several metals including Zn for the Seine River basin by using large databanks (sampling year: 2002). Zn was selected because its main source to the Seine River atmosphere, the roofs made of zinc plates, is supposed to be steady over time. In addition, Cu values compare similarly: 155 and 223 t y^{-1} for the atmospheric deposition derived from Saclay and [23], respectively. This comparison tends to prove that the fluxes evaluated at Saclay are underestimated and not representative for the whole basin fallout, considering the unverified hypothesis that atmospheric Ag, Cu, Sb and Zn have similar behaviours.

Ag concentrations in the digested deposition samples were all lower than the detection limit (DL) (0.01 µg L^{-1}). Applying the DL value to the samples allows to calculate that the silver annual atmospheric input for the whole basin is lower than 0.5 t y^{-1}, with a deposition rate < 0.02 µg m^{-2} d^{-1}. To our knowledge, this input data cannot be compared to any literature value.

In the opposite, Sb concentrations in the atmospheric deposition samples were significantly higher than the DL. The deposition rate was up to 0.55 µg m^{-2} d^{-1}. This value is lower than the deposition rate range reported for Munich city (1.2–13.1 µg m^{-2} d^{-1}, [5]). The antimony annual atmospheric input for the whole basin derived from the Saclay data was evaluated to 14 t y^{-1} (2002–2003).

Waste Water Treatment Plants Inputs

The composition of the two WWTP effluents varies from a sample to another (Table 1). Two effluents produced by the Seine-Aval WWTP under different plant operating conditions were sampled and analysed for Ag and Sb concentrations. As shown by [3], the WWTP operating conditions and the treatment processes strongly affect the metal loads (Cd, Co, Cr, Cu, Fe, Ni and Pb) in the effluents. Thus the effluent composition may vary over time for the same WWTP. Even though the Seine-Aval WWTP is from far the major WWTP discharging in the Seine River, another effluent composition for the other Parisian WWTP (Seine-Centre, Marne-Aval, etc…) cannot be excluded.

The results on two samples presented here are probably too few to catch the variability of the Ag and Sb concentrations in the WWTP effluents and to estimate properly the WWTP inputs to the Seine River. Nevertheless, the present data (Table 1) may be of some use to evaluate the WWTP impact. The particulate fraction percent-

Table 1 Composition of the Seine-Aval WWTP effluents

	SPM (mg L^{-1})	Ag			Sb		
Sampling date		Diss. (µg L^{-1})	Part. (mg kg^{-1})	Total	Diss. (µg L^{-1})	Part. (mg kg^{-1})	Total
April 2006	1	ND	50.8		0.96	23.4	
Input (t y^{-1})			0.05	>0.05	0.89	0.02	0.91
Dec. 2006	5	0.11	16.9		0.50	2.9	
Input (t y^{-1})		0.10	0.08	0.18	0.46	0.01	0.48

ND not determined

age was 44 % for Ag (Dec. 2006) and ranged between 2.4 and 2.8 % for Sb, for the April and December samples, respectively.

The annual WWTP discharge to the Seine River averaged 986 M m^3 between 1999 and 2010. As a consequence, the annual WWTP input to the Seine River can be evaluated to lie in the range <0.05–0.18 t y^{-1} for Ag and 0.5–0.9 t y^{-1} for Sb according to our data. In the San Francisco Bay, the Ag discharge from waste water was estimated to 20–27 mg per capita [15], which is equivalent to fluxes of 0.18–0.24 t y^{-1} for Ag considering the population in the area. This result is in agreement with the range evaluated through the analysis of the two Seine-Aval WWTP samples.

Combined Sewer Overflows Inputs

To validate the upscaling of the data issued from a single sampled event to an annual budget, the characteristics of the August 2008 event were compared to long term studies. The average particulate concentration in the August 2008 CSO effluents was 3.9, 541, 594 and 3271 mg kg^{-1} for Cd, Cu, Pb and Zn, respectively. These results are in agreement with those reported by Thévenot et al. [23], 3.1, 505, 525 and 3600 mg kg^{-1} for Cd, Cu, Pb and Zn, respectively. Indeed, the temporal homogeneity of the Parisian CSO composition has been previously noticed [6], as large urban areas act as a steady source of metals.

SPM concentrations in CSO effluents averaged 201 mg L^{-1} during the sampled events. The average concentrations of the CSO effluents were 9.7 mg kg^{-1} and 0.12 µg L^{-1}, for particulate and dissolved Ag concentrations, respectively, and 11.8 mg kg^{-1} and 1.01 µg L^{-1}, for particulate and dissolved Sb concentrations, respectively. The CSO dissolved Ag and Sb concentrations were in the same order of magnitude as in the WWTP effluents, while the particulate CSO concentrations were found to be lower than in the WWTP effluent. The Ag and Sb particulate fraction in the effluent was 92 ± 18 % and 64 ± 12 %, respectively. Taking as a hypothesis a total of CSO annual discharges up to 90 m^3 y^{-1}, the CSO input to the river can be evaluated to 0.22 t y^{-1} for Ag and 0.29 t y^{-1} for Sb.

Table 2 Average site composition of the Seine River water: median ± standard deviation, (min–max) values [22]

Sampling site	Ag		Sb	
	Diss. (µg L^{-1})	Part. (mg kg^{-1})	Diss. (µg L^{-1})	Part. (mg kg^{-1})
QL	0.003	0.005	0.001	0.1
Marnay	<QL	0.37 ± 0.14 (<QL–0.63)	0.11 ± 0.15 (0.06–0.30)	0.36 ± 0.09 (<QL–0.53)
Bougival	0.009 ± 0.277 (<QL–0.687)	3.54 ± 1.53 (2.14–6.55)	0.21 ± 0.01 (0.08–0.33)	1.22 ± 0.65 (<QL–1.99)
Triel	0.008 ± 0.005 (<QL–0.009)	2.38 ± 0.86 (0.95–3.83)	0.26 ± 0.01 (0.14–0.37)	1.10 ± 0.45 (<QL–1.65)
UCC (mg kg^{-1})		0.05		0.22

QL quantification limit, *UCC* upper continental crust

Seine River Water and Sediment Composition

The average concentrations of the dissolved and particulate fractions measured at the three sampling sites on the Seine River collected monthly between October 2008–2009 are summarized in Table 2. For both Ag and Sb, the upstream Seine (at Marnay) particulate concentrations are significantly lower than Bougival and Triel, downstream Paris. The difference between the two downstream Paris sites is only significant for particulate Ag concentration. The dissolved Ag concentration did vary significantly from upstream to downstream sites. In the opposite, the Sb dissolved concentrations increased from upstream to downstream sites while their variability decreased, suggesting that the urban conurbation acts as a steady state dissolved Sb source to the river. On the whole, the dissolved and particulate concentrations determined in the Seine River water are significantly lower than the concentrations determined in both WWTP and CSO effluents. On the other hand, at the most upstream site, the Ag particulate concentration is significantly higher than the reference UCC values [22], suggesting a widespread contamination of the Seine River basin [2], as already observed in Swedish lakes [10].

When possible (i.e., when the particulate and the dissolved concentrations are higher than the QL), the particulate fraction percentage has been calculated for the downstream sites. The median value was 84 ± 11 % for Ag and 4.3 ± 5.2 % for Sb. The literature on silver dissolved/particulate partition in freshwater is scanty. Silver sorption to soils showed a strong and irreversible sorption to organic matter, clays and iron oxides [12] that may explain the high Ag particulate fraction in the Seine River. The Sb partition observed in the Seine River agrees well with the literature which indicated that antimony is present almost exclusively in the dissolved phase [8, 14].

The particulate output of the Seine was estimated at 700,000 t y^{-1} in average (1994–2000) [23]. Using the Ag and Sb median concentrations at Triel-sur-Seine, the most downstream site, we estimate the particulate Ag output from the Seine River at 1.6 t y^{-1}, and 0.75 t y^{-1} for Sb particulate output. The Ag particulate flux

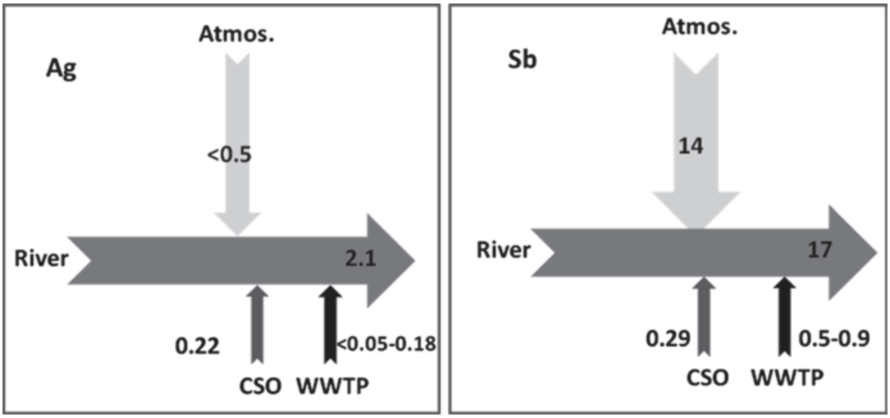


Fig. 1 Seine River basin annual budget of the inputs (atmospheric deposition (Atmos.), combined sewer overflows (CSO) and waste water treatment plants discharges (WWTP) and the river output, in t y^{-1}, for silver (Ag) and antimony (Sb)

determined here agrees with previously published data for the Seine River (1.7 and 1.7–2.0 t y^{-1} in Thouvenin et al. [24] and Ayrault et al. [2], respectively).

To estimate the total output fluxes, it is necessary to consider the dissolved flux. This flux cannot be monitored as the continuous monitoring of the dissolved concentrations over one year or more is not feasible. To overcome this difficulty, the dissolved flux is evaluated by combining the particulate flux and the solid/dissolved partition. The particulate fraction percentage has been calculated at Triel-sur-Seine. The median value was 78 ± 11 % (n = 5) for Ag and 4.3 ± 1.6 % (n = 6) for Sb. The total Ag and Sb output flux for the Seine River was finally estimated to 2.1 and 17 t y^{-1}, respectively (Fig. 1).

Silver Budget

Neither atmospheric deposition, nor combined sewer overflows and treated waste water discharge appear to dominate the silver fluxes in the Seine River basin. On another hand, the Ag concentration in the river at the most upstream, non-urbanized site is significantly higher than the reference background signal (*i.e.*, the upper continental crust composition). The catchment geology, mainly characterized by a succession of sedimentary rocks, could not explain such high concentration. The large contamination registered in the sediment archives [2] could explain this high concentration through widespread contamination of the basin soils. These soils may be the main source of Ag to the Seine River due to erosion. A recent study by Chon et al. [4] demonstrated through a mass balance, that resuspension of bed sediment could significantly contribute to the increase of metal loads in the water column. Furthermore, evidence of a large contribution of eroded bed sediments to the Seine River water column has been identified in previous studies, particularly for Zn [19].

Consequently, Ag inputs from soils and bed sediments could explain a part of the gap in the budget. Other sources could contribute to this gap. Indeed, previous metal budget in the Seine River [23] accounted leaks (sewage leaks mainly) to the Seine River to contribute up to 2 times as much metals as those contributed by the treated urban wastewater. This potential nonpoint leak of Ag to the Seine River could be a large source given the historical construction of Paris city and its sewage networks. The recent increasing use of Ag in the consumer goods as nano-particles [15] could also signify that WWTP samples dating back to 2006 should be verified with a more recent sample. Finally, other undetermined sources, such as industrial treated wastewater, may also be potential source to be considered in future budgets.

Antimony Budget

The Sb budget is dominated by the atmospheric deposition. The CSO and WWTP effluents only contributed to a minor contamination of the Seine River. In the Seine River, Sb was mostly identified under the dissolved speciation. Considering the uncertainties of the determination of the output dissolved flux, the antimony budget of the Seine River basin seems to be resolved, but minor Sb sources not explored here could also contribute to this budget.

Dissolved/solid partition of Sb display variability among untreated wastewater samples and river samples, $64 \pm 12\,\%$ and $4.3 \pm 1.6\,\%$, respectively. This may be a problem to flux calculation especially considering that dissolved metals were derived from average dissolved/solid partitioning value. Indeed, Sb in natural waters is found to be mostly in anionic form, thus mostly in the dissolved fraction [7, 13]. This is consistent with the relatively small partitioning of dissolved Sb in the Seine River. However, the higher particulate Sb fraction may be due to the specific physico-chemical conditions in the CSO (pH, presence of organic matter, Sb concentration). This large variation of Sb partitioning in various compartment suggests that average Sb partitioning should be calculated based on a larger set of data in furthers studies.

Conclusion

Ag demonstrates a high affinity for the particulate fraction in all the explored effluents and in the Seine River. The Ag output river flux cannot be balanced with the input fluxes explored here. However, the erosion of contaminated soils of the Seine River basin, which contribution is uneasy to evaluate could be another source to consider in future studies. The Sb budget drawn here seems to be well balanced, with the input fluxes dominated by atmospheric deposition. In the river, Sb is mainly in the dissolved form but its solid/dissolved partition in the treated and untreated waste water is very different, suggesting that complex solid-dissolved exchange processes may occur for this element in river. Altogether, this study highlights the real need to implement reliable monitoring techniques, which allow to quantify pollutant emissions at a large spatio-temporal scale, in order to establish a sustainable development of urbanization.

Acknowledgements The authors thank J. Gaspéri and G. Varrault (LEESU) and V. Rocher (SIAAP) for information on wastewater volumes, and the PIREN-Seine program for funding and fruitful discussions.

References

1. Ayrault S, Senhou A, Moskura M, Gaudry A (2010a) Atmospheric trace element concentrations in total suspended particles near Paris, France. Atmos Environ 44:3700–3707
2. Ayrault S, Priadi CR, Evrard O, Lefèvre I, Bonté P (2010b) Silver and thallium historical trends in the Seine River basin. J Environ Monitor 12:2177–2185
3. Buzier R, Tusseau-Vuillemin MH, Martin dit Meriadec C, Rousselot O, Mouchel JM (2006) Trace metal speciation and fluxes within a major French wastewater treatment plant: Impact of the successive treatments stages. Chemosphere 65:2419–2426
4. Chon HS, Ohandja DG, Voulvoulis N (2012) The role of sediments as a source of metals in river catchments. Chemosphere 88:1250–1256
5. Dietl C, Reifenhauser W, Peichl L (1997) Association of antimony with traffic—occurrence in airborne dust, deposition and accumulation in standardized grass cultures. Sci Total Environ 205:235–244
6. Estèbe A, Mouchel JM, Thévenot DR (1998) Urban runoff impacts on particulate metal concentrations in river seine. Water Air Soil Pollut 108:83–105
7. Filella M, Belzile N, Chen Y-W (2002a) Antimony in the environment: a review focused on natural waters I. Occurrence. Earth-Sci Rev 57:125–176
8. Filella M, Belzile N, Chen YW (2002b) Antimony in the environment: a review focused on natural waters. II. Relevant solution chemistry. Earth-Sci Rev 59:265–285
9. Garcia-Alonso J, Khan FR, Misra SK, Turmaine M, Smith BD, Rainbow PS, Luoma SN, Valsami-Jones E (2011) Cellular internalization of silver nanoparticles in gut epithelia of the estuarine polychaete Nereis diversicolor. Environ Sci Technol 45:4630–4636
10. Grahn E, Karlsson S, Karlsson U, Düker A (2006) Historical pollution of seldom monitored trace elements in Sweden—Part B: sediment analysis of silver, antimony, thallium and indium. J Environ Monit 8:732–744
11. Iijima A, Sato K, Yano K, Kato M, Kozawa K, Furuta N (2008) Emission factor for antimony in brake abrasion dusts as one of the major atmospheric antimony sources. Environ Sci Technol 42(8):2937–2942
12. Jacobson AR, McBridea MB, Baveyea P, Steenhuis TS (2005) Environmental factors determining the trace-level sorption of silver and thallium to soils. Sci Total Environ 345:191–205
13. Krupka KM, Serne RJ (2002) Geochemical factors affecting the behavior of antimony, cobalt, europium, technetium, and uranium in vadose sediments. Report of the Pacific Northwest National Laboratory (PNNL-14126), December 2002, p 95
14. Le Pape P, Ayrault S, Quantin C (2012) Trace element behavior and partition versus urbanization gradient in an urban River (Orge River, France). J Hydrol 472–473:99–110
15. Luoma SN (2008) Silver nanotechnologies and the environment: old problems or new challenges? Project on Emerging Nanotechnologies, Wilson Center and The Pew Charitable Trusts, Washington DC USA, September 2008, p 72

16. Pernet-Coudrier B, Varrault G, Saad M, Croué JP, Dignac MF, Mouchel JM (2011) Characterisation of dissolved organic matter in Parisian urban aquatic systems: predominance of hydrophilic and proteinaceous structures. Biogeochemistry 106:89–106
17. Priadi C, Ayrault S, Pacini S, Bont P (2011a) Urbanization impact on metal mobility in riverine suspended sediment: Role of metal oxides. Int J Environ Sci Tech 8(1):1–18
18. Priadi C, Bourgeault A, Ayrault S, Gourlay-Francé C, Tusseau-Vuillemin MH, Bonté P, Mouchel JM (2011b) Spatio-temporal variability of solid, total dissolved and labile metal: passive vs discrete sampling evaluation in river metal partitioning. J Environ Monitor 13:1470–1479
19. Priadi C, Le Pape P, Morin G, Ayrault S, Maillot F, Juillot F, Llorens I, Testemale D, Proux D, Brown Jr G (2012) EXAFS and SEM evidences for zinc sulphide solid phases in riverine suspended matter from the Seine River, France. Environ Sci Technol 46(7):3712–3720
20. Ratte HT (1999) Bioaccumulation and toxicity of silver coupounds: a review. Environ Toxicol Chem 18:89–108
21. Sabin LD, Lim JH, Venezia MT, Winer AM, Schiffa KC, Stolzenbach KD (2006) Dry deposition and resuspension of particle-associated metals near a freeway in Los Angeles. Atmos Environ 40:7528–7538
22. Taylor SR, McLennan SM (1985) The continental crust: its composition and evolution. Blackwell Scientific, Oxford, p 328
23. Thévenot DR, Moilleron R, Lestel L, Gromaire MC, Rocher V, Cambier P, Bonté P, Colin JL, de Pontevès C, Meybeck M (2007) Critical budget of metal sources and pathways in the Seine River basin (1994–2003) for Cd, Cr, Cu, Hg, Ni, Pb and Zn. Sci Total Environ 375(1–3):180–203
24. Thouvenin B, Boutier B, Chiffoleau JF, Gonzalez JL, Cossa D, Auger D, Averty B, Rozuel-Chartier E, Ménard D, Santini A, Olivier M (2005) Contribution à l'étude de la dynamique et de la spéciation des contaminants, Rapport d'activité 2004, Programme Seine Aval 3, 2005, p 46. http://seine-aval.crihan.fr/web
25. Van de Velde K, Barbante C, Cozzi G, Moret I, Bellomi T, Ferrari C, Boutron C (2000) A 200 year record of atmospheric cobalt, chromium, molybdenum, and antimony in high altitude alpine firn and ice. Atmos Environ 34:3117–3127

Urban Pollutant Plumes around Wushan and Dachang City in the Three Gorges Reservoir

Andreas Holbach, Lijing Wang, Hao Chen, Nina Schleicher, Wei Hu, Binghui Zheng and Stefan Norra

Abstract The Three Gorges Reservoir (TGR) in the Yangtze River was among other reasons meant to improve and strengthen socio-economic development of the involved regions. Considerable economic growth and urbanization now pose additional threat to the water quality of the TGR due to urban pollutant inflows. The changed hydrological conditions in the TGR have considerably altered pollutant transport dynamics now causing higher susceptibility of the backwater areas to eutrophication and algal blooms. The Yangtze River is also widely used as a source for drinking water production. The assessment of the urban impact on the water quality in the TGR is, thus, crucial for sustainable future development planning. Measurements with an underwater multi-sensor system (MINIBAT) were performed in the frame of the "Yangtze-Project" [1] around the cities of Wushan and Dachang on the Daning River in the backwater reaches of the TGR in December 2012. Hydrological conditions were stable at constant water level between 174–175 m.a.s.l and low discharge conditions in the TGR during sampling period. 3D distribution patterns of the parameters temperature, conductivity, and turbidity in the water bodies were modeled using geostatistics. Selected water samples from different depths were analyzed for dissolved and particulate constituents using ICP-MS. Results show plumes of higher temperature, conductivity and turbidity in the epilimnion around the investigated urban areas. The range of influence was larger for temperature and conductivity plumes. Significant increase of turbidity was detected around Dachang City during few hours. Urban impacts on the water quality were significant at the encountered conditions and need to be further investigated for risk assessment, especially concerning drinking water production and eutrophication problems.

A. Holbach (✉) · N. Schleicher · W. Hu · S. Norra
Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Adenauerring 20b, 76131 Karlsruhe, Germany
e-mail: andreas.holbach@kit.edu

L. Wang · H. Chen · B. Zheng
Chinese Research Academy of Environmental Sciences, No.8, Dayangfang, Anwai Beiyuan, Chaoyang District, 100012 Beijing, China

S. Norra
Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Reinhard-Baumeister-Platz 1, 76128 Karlsruhe, Germany

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_38,

Table 1 Pollutant sources in TGR [15]

	COD (t)	N (t)	P (t)
Industry	59300	4300	N/A
Urban areas	92600	13300	N/A
Ships	718	340	51
Agriculture	N/A	8700	1800

Introduction

The water quality in the Yangtze River Three Gorges Reservoir (TGR) upstream of the Three Gorges Dam (TGD) is of major concern since the first closure of the dam in 2003. The TGR serves as an important drinking water source for the local population. Thus, the increasing nutrient pollution causing eutrophication and algal blooms [6, 15] as well as pollution with heavy metals and organic compounds need to be carefully monitored. Changed hydrodynamics after the TGR impoundment may cause serious accumulation of pollutants in critical water bodies making them temporarily inappropriate for safe drinking water production. The very complex interactions in the TGR water bodies include seasonal discharge and water level fluctuations, tributary/main stream mixing dynamics [18], density currents [11, 14], thermal stratification development, as well as point and non-point source pollution. The resulting unique dynamics of water quality in TGR and the key driving forces for water quality distribution under different hydrological and ecological conditions are not yet understood. Besides others, discharges from urban areas are the main source for COD and N pollution in the TGR (Table 1). Their consideration for environmental studies in the TGR is, thus, crucial for a holistic understanding of proceeding pollution dynamics. Release of pollutants, e.g. heavy metals, from sediments and inundated former soils and urban areas is likely to occur, especially under the changing oxic conditions caused by water level fluctuations [10, 14].

The Sino-German environmental research program "Yangtze-Hydro Project" has been established and funded since 2010 [1] to conduct international and interdisciplinary research on the sustainable utilization and development of the newly created ecosystem in the TGR. Therein, the MINIBAT sub-project aims to monitor water quality distribution dynamics in 3D-space and time in critical areas throughout the

TGR region. The data presented in this paper is based on fieldwork conducted from 3rd to 6th December 2011 around the urban areas of Wushan City and Dachang City. Both cities are located in the TGR backwater affected water bodies of the Daning River and its confluence zone with the Yangtze River. The performed in-situ MINIBAT measurements and water sample analysis revealed significant pollutant plumes around these urban areas under the very serene hydrological conditions during the measurement period.

Material and Methods

Study Area and Hydrological Boundary Conditions

The Three Gorges Reservoir (TGR) formed after the impoundment of the Yangtze River by the Three Gorges Dam (TGD) [17]. After completion of the TGD in 2009 the TGR now has a length of more than 600 km at a mean width of 1.1 km, a total storage capacity of 39.3×10^9 m³ and an annual water level fluctuation between 145–175 m.a.s.l. caused by the reservoir management. The mean discharge of the Yangtze River is around 30.000 m³/s. Consequently, the hydrological conditions in the whole involved water bodies changed considerably from a river to a river-style reservoir. Depending on the shape of the riverbed in the backwater reaches and the current hydrological conditions, either lake-like or river-like conditions may form in different reservoir water bodies.

The Daning River is a tributary of the TGR entering the Yangtze River main stream through the Wushan Lake, which formed next to Wushan city after the impoundment by the TGD (Fig. 1). The Daning River has a length of 162 km, a watershed of 4170 km², and a mean discharge of 136 m³/s [4]. The backwater area reaches about 60 km upstream [5] and comprises the "Little Three Gorges", a famous National Park and scenic spot in China, and several wide lake-like structures. The two biggest lake-like water bodies are found close to the biggest urban areas in the region. The Wushan Lake formed close to Wushan City and the Dachang Lake close to Dachang City. Frequent algal blooms and low water quality due to high Total Phosphorous (TP) loads threaten the backwater areas of the Daning River since the impoundment of the TGR [15].

The hydrological boundary conditions were quite stable throughout the measurement period from 3rd to 6th December 2012. Water level did only rise slightly from 174.5 to 174.7 m.a.s.l. and the discharge in both the Daning River and the Yangtze River was comparably low with 6.85–6.93 m³/s and 6300–6700 m³/s, respectively [4].

Measurement of Physico-chemical Water Quality Parameters with the MINIBAT and Data Evaluation

The MINIBAT towed underwater multi-sensor system [2] is connected to a boat with a data transmission cable. Sensors on the applied instrument measure physico-chemical water quality parameters (temperature (T), conductivity (Cond normalized to 25 °C), turbidity (Turb), chlorophyll *a* (Chl*a*), oxygen saturation ($O_{2\%}$), and pH) with high spatial and temporal resolution. The MINIBAT can be used while driving the boat and meanwhile be steered to different depths. Vertical depth profiling can be performed when the boat does not move. Positioning and sensor data is recorded on-line by a computer.

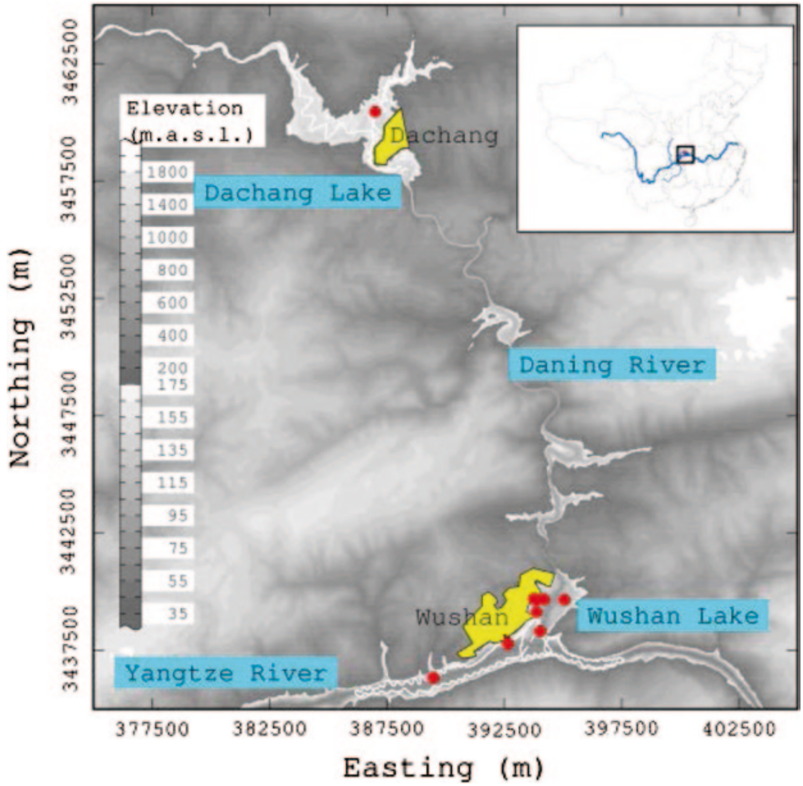


Fig. 1 Map of the study area in the TGR backwater reaches of the Daning River and its confluence zone with the Yangtze River. Red points mark water sampling locations. White lines mark MINIBAT measurement cruises. Upper right sketch map shows Yangtze River and outlines of provinces in China

During the measurement campaign in December 2011 measurement cruises were performed densely in the surface waters between 0–20 m depth at 40 m cable length using approximately sinusoidal diving course. Depth profiling was done at selected sites. A description of the geostatistical evaluation procedure for MINIBAT datasets can be requested from the authors.

Water Sampling, Sample Preparation, and Analysis

A Hydro-Bios FreeFlow Sampler was used for water sampling from different depths in the water column at selected sites. On 3rd—5th December, samples were taken around the Wushan City urban area (Fig. 1). Additionally, samples from two Waste Water Treatment Plant (WWTP1+2) discharge channels and two other untreated sewage water discharge locations (WSS1+2) were taken on 3rd December. The

WWTP1 channel contained unmixed water entering the Yangtze River over concrete cascades. Water from the WWTP2 channel was already leveled and mixed with Yangtze water. Samples were filtered (Sartorius stedim CAMembran, 0.45 µm, 25 mm) to separate dissolved from suspended particulate matter. Filtered water volumes were recorded. For cation and dissolved Phosphorus (DP) analysis, samples of 20 mL were acidified with 50 µl of 65 % HNO_3 (Merck, Suprapur) and stored at 5 °C in 20 mL PET bottles. Filters were air dried and sealed.

Prior to analysis, filters were digested using 65 % HNO_3 as oxidation agent, 40 % HF and 70 % $HCLO_4$ as digestion agents (all Merck, Suprapur) at 175–200 °C. HF and $HClO_4$ were fumed off and the residues were dissolved in 10 mL 1 % HNO_3 for analysis. DP, dissolved Cu, and dissolved Cd were analyzed from the acidified water samples. Particulate Phosphorus (PP), Cu, and Cd were analyzed from the filter digestions. An X-Series 2 ICP-MS (Thermo Fisher Scientific Inc.) was applied for analysis in collision cell mode to eliminate polyatomic clusters. ^{103}Rh and ^{115}In were used as internal standards and Phosphorus ICP Standard (Merck, CertiPUR) as calibration and cross check standard throughout the analysis procedure. Four blank filters were tested and revealed blank Phosphorus concentrations of 11.66 ± 0.46 µg/L in the digestion solution which was subtracted from all analyzed digestion samples. USGS GXR-2 [9] and IAEA SL-1 [16] geochemical standards were also digested four times and revealed Phosphorus recovery rates of 107 ± 8 % for GXR-2 and 118 ± 13 % for SL-1, respectively.

Results and Discussion

Water quality distribution patterns, geostatistically estimated from the in-situ and on-line MINIBAT measurements on 4th and 6th December, revealed plumes of higher temperature, conductivity, and turbidity around the urban areas of Wushan City and Dachang City. The plumes were only present in the epilimnion water bodies. Around Wushan City the epilimnion included the upper 65 m water column around Dachang City only 20 m. Pollutant concentrations in the water bodies revealed a similar pattern with higher epilimnetic concentrations around both urban areas.

Wushan City

Plumes around Wushan City On 4th December, the plume outlines at 5 m depth around Wushan City (Fig. 2) appeared very similar for the parameters T, Cond, and Chl*a*. However, the highest values for these parameters were found in different locations. T had its maximum values at the western shore within the Wushan Lake. There are parts of the Wushan harbor and untreated waste water discharges in this area. Maximum values for Cond and Chl*a* were also found in the similar area as for

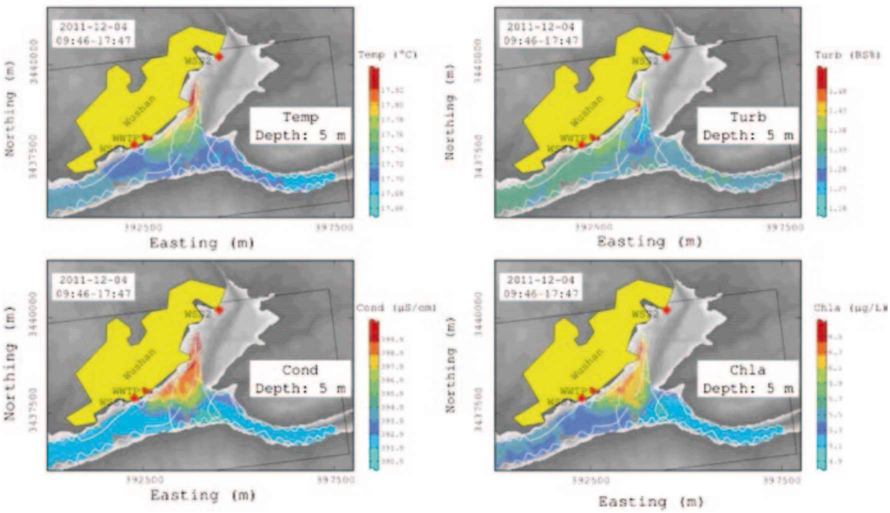


Fig. 2 Distribution of T, Turb, Cond (normalized to 25 °C), and Chl*a* at 5 m depth in the water bodies around Wushan City on 4th December 2012. White lines mark MINIBAT measurement cruises. Waste Water Treatment Plant (WWTP) and sampled discharge locations (WSS) are marked in red

T, but additionally in the vicinity of the WWTP discharge location. Turb showed a slightly different pattern and plume outline. Highest Turb values were found in front of the small headland at the Wushan Lake western shore. There was a huge construction site on that headland during the measurement time. A plume with significantly higher Turb around the WWTP discharge location could also be observed. Lowest Turb values were present along the deep central channel in the Wushan Lake Generally the Turb plume was more concentrated on the water bodies close to the Wushan City shoreline compared to T, Cond, and Chl*a*.

Pollutant concentrations in the water bodies around Wushan City Concentrations of TP as well as dissolved Cd and Cu from sampling locations in the surrounding of Wushan City revealed significantly higher concentrations of these elements in the epilimnion water bodies compared to hypolimnion waters on 3rd and 5th December (Fig. 3). Epilimnion TP concentrations (109 ± 14 µg/L) generally had very high levels according to German water quality standards for reservoirs where > 100 µg/L TP account for polytrophic water bodies [13].

Major parts of Cd (86 ± 8 %) and Cu (92 ± 4 %) in the water were present in the dissolved phase. Diss. Cd revealed outstandingly high concentrations (0.05–0.08 µg/L) in three epilimnion samples, diss. Cu only in one sample (9.1 µg/L) (Fig. 3). However, measured metal concentrations are very low compared to the threshold values of the WHO [20] and German guidelines [7] for Cd (3 µg/L) and Cu (2 mg/L) in drinking-water. Highest TP and Cu concentrations as well as 2nd highest Cd concentration were all found in the same sample originating from 50 m depth close to the river bed in front of the Wushan harbor. Both other samples with outstandingly high Cd concentrations also derived from the Wushan harbor area,

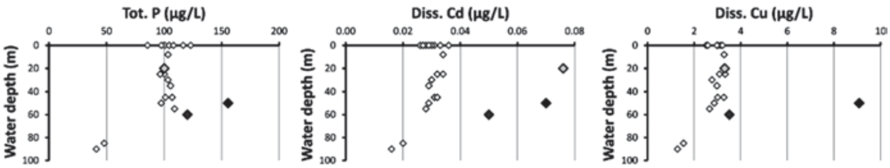


Fig. 3 TP, dissolved Cd, and dissolved Cu concentrations in water samples from different depths around Wushan City from 3rd and 5th December 2011. Corresponding samples with outstandingly high concentrations for one or more components are marked accordingly

one from 20 m depth in the middle of the water column and one from bottom water at 60 m depth. Water samples from selected Wushan City effluents revealed both higher and lower temperatures than the ambient water (Table 2). Cond was higher than ambient water in all three measured effluents.

The samples contained very different amounts of TP, diss. Cu, and diss. Cd. TP concentrations varied between ~2–30 fold of the epilimnetic TP concentrations. Both diss. Cu and Cd did not exceed the concentration range measured in the waters around Wushan City. However, concentrations were lowest in the WWTP effluents.

Interpretation of the observed scenario The plumes of higher T, Cond, and Turb in the water bodies around Wushan City appear to originate from the adjacent urban area. There were very serene hydrological conditions during the sampling period so that only little horizontal transport and mixing of water-borne substances happened. At hydrological conditions with higher discharge and changing water level this kind of plumes could not be observed in August 2011 (Data not shown here). There was also no effective mixing of epilimnion and hypolimnion water resulting in the enrichment of intruding substances in the epilimnetic water bodies.

MINIBAT observations identified the Wushan harbor as a major source for higher T and higher Cond in the water. However, the source could either be urban effluents but also warm water discharges from ships resting in the harbor. Both sampled WWTP effluents had a higher Cond (Table 2) than the surrounding water body and did, thus, contributed to higher epilimnetic Cond. The observed higher element concentrations of TP, diss. Cu, and Cd in the epilimnion can partly be explained by the sampled effluents from Wushan City. TP concentrations significantly exceeded the ones of ambient waters in three of four sampled effluents. But still, there are many more discharge locations that could not be sampled, yet, and they might serve as relevant pollution sources. Contaminated sediments and the inundated former urban area of Wushan City could also be a possible source of P, Cu, and Cd in the water [10, 12]. One sample with outstandingly high TP, Cu, and Cd concentrations derived from close to the riverbed. But, highest Cd concentrations were found in the middle of the water column. Water discharge from ships resting in the harbor area or discharged water layering at around 20 m depth might, therefore, also be reasonable Cd pollution sources. High turbidity seemed to be closely related to a huge construction site on the small headland in the Wushan Lake but also to the WWTP effluent. The Chl*a* content and, thus, algal activity was positively related to T, and

Table 2 T, Cond (normalized to 25 °C), TP, dissolved Cu and dissolved Cd concentrations in water samples from selected Wushan City effluents (for locations see Fig. 2)

	T (°C)	Cond (μS/cm)	TP (μg/L)	Cu (μg/L)	Cd (μg/L)
WWTP1	16.7	582	1150	1.09	0.012
WWTP2	18.3	467	469	2.17	0.014
WSS1	18.8	489	179	4.90	0.016
WSS2	N/A	N/A	3220	3.39	0.054

Cond. A significant part of this relation might, however, also be due the higher TP nutrient contents in the epilimnetic water around Wushan City.

Dachang City

On 6th December, plumes were also found around the urban area of Dachang City (Fig. 3). T and Cond showed very similar distribution pat-

terns with their maximum values south of Dachang city. Values of both parameters decreased significantly towards the upstream of both meeting rivers. Chl*a* on the other hand reached its maximum values north-west of the urban area. Turb values, showed a very significant increase around Dachang City during the course of the day (Fig. 4). Three measurement cruises (10:04–11:42; 11:42–13:33; 15:19–16:52) passing Dachang City were performed on 6th December. Initially, the highest Turb was found north-west of Dachang City in similar areas as the highest Chl*a*. Subsequently, increasing Turb was found all along the urban area shoreline.

Concentrations of TP, Cu, and Cd were also enriched in the epilimnetic water (Table 3) from the Dachang Lake sampling location (Fig. 1). TP

concentration is on lower levels compared to the samples from the Wushan area. Diss. Cu is in a similar concentration range, while Cd reaches much higher levels in the epilimnion at Dachang.

Interpretation of the scenario The main source for higher T and Cond must be in the southern part of Dachang City. There is no big harbor in that area but several urban water discharge locations. The initially highest Turb values were measured in an area where there was active gravel exploitation. Digging in the sediment could also cause nutrient release in this area and explain the highest Chl*a* concentrations, there. However, the significant increase in Turb along the urban shoreline during the day seems to be an impressing result of temporal urban discharge dynamics. The everyday work and water use cycle might be mirrored in the water turbidity.

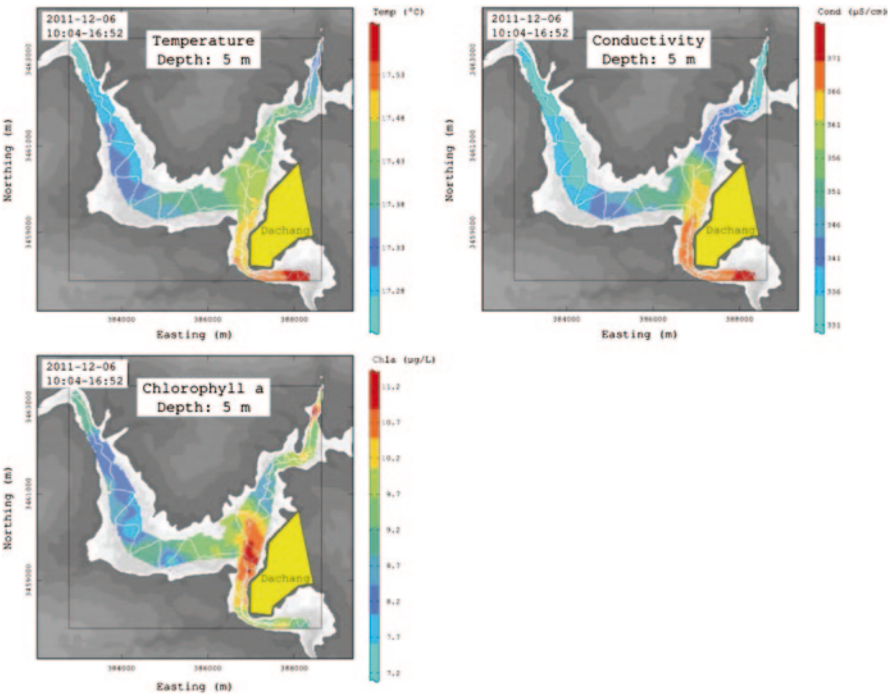


Fig. 4 Distribution of T, Cond (normalized to 25 °C), and Chl*a* at 5 m depth in the water bodies around Dachang City on 6th December 2012. White lines mark MINIBAT measurement cruises

Table 3. TP, dissolved Cu, and dissolved Cd concentrations in water samples from the Dachang Lake (Fig. 1) on 6th December 2011. Water depth was 42 m

Depth (m)	TP (µg/L)	Cu (µg/L)	Cd (µg/L)
0	69.8	2.65	0.09
15	66.9	3.22	0.12
40	14.8	0.73	0.02

Conclusion and Perspective

Urban pollutant impacts on the water quality in TGR could be successfully monitored with the applied MINIBAT instrument. Pollutants in selected water samples were obviously related to water quality parameter distribution. Consequently, the detection of urban point source pollution is possible with the applied techniques. Further fieldwork will focus on the coverage of different hydrological and ecological scenarios at different sites in TGR with similar sampling strategy. Evaluation of various impact factors, including urban, hydrological, meteorological, and land-use conditions, on water quality under varying boundary conditions is intended.

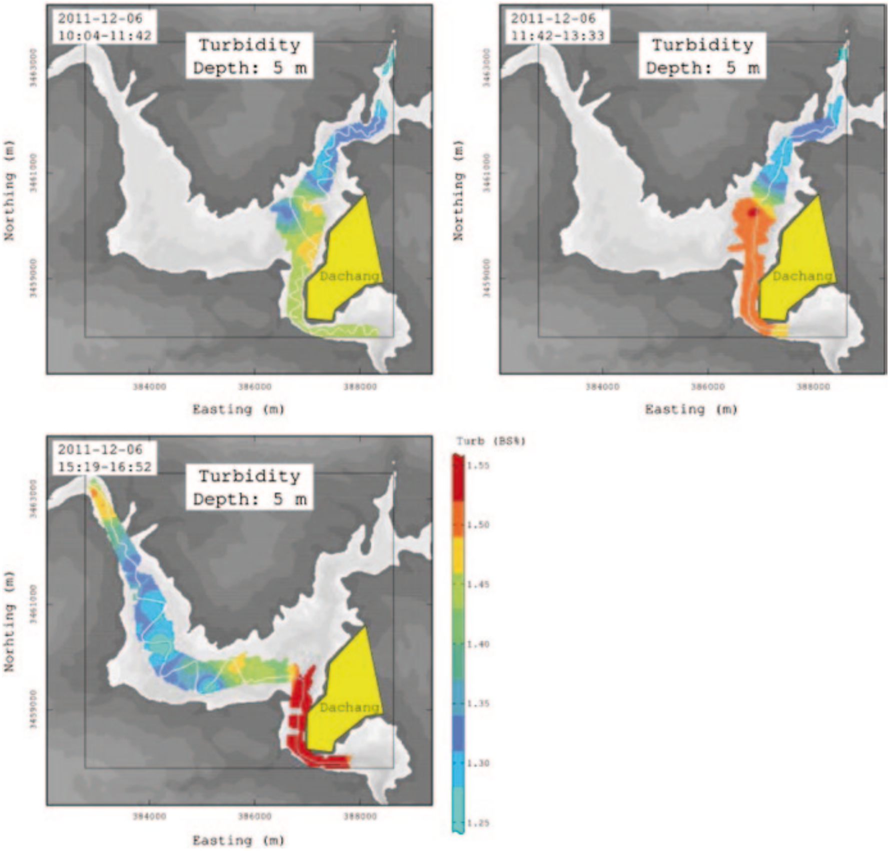


Fig. 5 Distribution of Turb at 5 m depth in the water bodies around Dachang City during 3 MINIBAT measurement cruises on 6th December 2012. White lines mark MINIBAT measurement cruises

Acknowledgments Thanks to Mrs. Liu, Mr. Wu, and our captain Mr. Ma from the environmental protection agency and the environmental monitoring station in Wushan, Chongqing, China, for their great infrastructural and personal support during the fieldwork.

Funding of the Yangtze-Project by the Federal Ministry of Education and Research (BMBF grant no. 02WT1131) of Germany and the International Science and Technology Cooperation Program of China (NO. 2007DFA90510) is gratefully acknowledged.

References

1. Bergmann A, Bi Y, Chen L et al (2012) The Yangtze-Hydro Project: a Chinese-German environmental program. Environ Sci Pollut R 19:1341–1344
2. Casagrande CE (1995) The MiniBAT - A miniaturized towed sampling system. Oceans 95 3:638–641. doi: 10.1109/OCEANS.1995.526904

3. Chongqing Water Resources Bureau, China (2010) Chongqing water function zoning revision report. url: http://www.cqwater.gov.cn/Pages/Home.aspx. (in Chinese)
4. Chongqing Water Resources Bureau, China (2011) Hydrological information - Rivers real-time water regime. url: http://www.cqwater.gov.cn/swxx/jrbssq/Pages/Default.aspx. Accessed 21-30 Aug 2011 (in Chinese)
5. Compilation Committee of Chongqing Atlas, China (2007) Chongqing Atlas. Xi'an Cartographic Publishing House. 92-93. isbn: 978-7-80748-069-3 (in Chinese)
6. Dai H, Zheng T, Liu D (2010) Effects of Reservoir Impounding on Key Ecological Factors in the Three Gorges Region. Procedia Environ Sci 2:15–24
7. Deutscher Verein des Gas- und Wasserfaches (2011) Erste Verordnung zur Änderung der Trinkwasserverordnung vom 3. Mai 2011- Nichtamtliche Vollversion. In: Bundesgesetzblatt Jahrgang 2011 Teil Nr. 21 (in German)
8. German Aerospace Center (2010) Shuttle Radar Topography Mission, 1 Arc Second scenes E1090000N300000_SRTM_1_DEM - E1100000N310000_SRTM_1_DEM. url: https://centaurus.caf.dlr.de:8443. Accessed 27 July 2012
9. Gladney ES, Roelandts I (1990) 1988 Compilation of elemental concentration data for USGS Geochemical Exploration Reference Materials GXR-1 to GXR-6. Geostandard Newslett 14(1):21–118. doi: 10.1111/j.1751-908X.1990.tb00065.x
10. Ho HH, Swennen R, Cappuyns V, Vassilieva E, Van Gerven T, Van Tran T (2012) Potential release of selected trace elements (As, Cd, Cu, Mn, Pb and Zn) from sediments in Cam River-mouth (Vietnam) under influence of pH and oxidation. Sci Tot Environ 435–436:487–498
11. Ji DB, Liu D, Yang ZJ, Yu W (2010) Adverse slope density flow and its ecological effect on the algae bloom in Xiangxi Bay of TGR during the reservoir impounding at the end of flood season. Shuili Xuebao (J Hydraul Eng) 41:691–696 (in Chinese)
12. Komárek M, Zeman J (2004) Dynamics of Cu, Zn, Cd, and Hg release from sediments at surface conditions. Bulletin of Geosciences 79(2):99–106
13. Länderarbeitsgemeinschaft W (2001) Gewässerbewertung - stehende Gewässer: Vorläufige Richtlinie für die Trophieklassifikation von Talsperren. isbn: 3-88961-237-7 (in German)
14. Luo ZX, Zhu B, Zheng BH, Zhang Y (2007) Nitrogen and phosphorus loadings in branch backwater reaches and the reverse effects in the main stream in Three Gorges Reservoir. China Environ Sci 27:208–212 (in Chinese)
15. Ministry of Environmental Protection of China (2012) Three Gorges Bulletin 2005-2011. Ministry of Environmental Protection - The People's Republic of China. url: http://english.mep.gov.cn/-standards_reports/threegorgesbulletin/. Accessed 31 July 2012
16. National Oceanic and Atmospheric Administration (1995) Standard and reference materials for Environmental Science. Technical Memorandum NOS ORCA 94. url: http://docs.lib.noaa.gov/noaa_documents/NOS/ORCA/TM_NOS_ORCA/nos_orca_94_pt1.pdf. Accessed 27 Aug 2012
17. Ponseti M, López-Pujol J (2006) The Three Gorges Dam Project in China: history and consequences. Revista HMIC, Número IV:151–187
18. Ran X, Yu Z, Yao Q, Chen H, Mi T (2010) Major ion geochemistry in the mixing zone of Changjiang (Yangtze) River and its tributaries in the Three Gorges Reservoir. Hydrol Process 24:2481–2495
19. USGS (2006) Shuttle Radar Topography Mission, 3 Arc Second scenes SRTM3N30E109-SRTM3N31E110. url: eros.usgs.gov. Accessed 27 July 2012
20. World Health Organization (2011) Guidelines for drinking-water quality. 4th edn. isbn: 978-92-4-154815–1

Contamination of Bottom Sediments of Small Rivers in Moscow (Businka and Tarakanovka rivers as examples)

D Kramer and I Tikhonova

Abstract In this study we observed bottom sediments of two Moscow small rivers: Businka and Tarakanovka. The observation was carried out in autumn, 2011. Upon our field observation of the rivers we choosed 9 sampling points on each river that could represent their contamination. In each sampling point we took sample of water and sample of bottom sediments from the surface layer (0–5 cm). We measured such parameters as heavy metals, petroleum products and extracted organic compounds (EOC) containment in bottom sediments. Heavy metals concentrations were measured by such methods as ICP and atomic absorption spectrometry, petroleum products were measured via IR-spectrometry and EOC were measured gravimetrically. The results of our observation showed that river Businka is more polluted than river Tarakanovka by all measured parameters with the main pollutants being Cu, Zn Cd and Sr. Organic contamination is mostly caused by petroleum products: the comparison between concentrations of petroleum products and EOC showed symbatic relation between these parameters.

Introduction

Bottom sediments (BS) are the most conservative part of the natural water bodies and provide information on pollution and watershed characteristics. Thus, BS can serve as an indicator to determine the composition, intensity and scale of industrial pollution, as their composition reflects the biogeochemical characteristics of catchment areas [4, 8]. Determination of heavy metals in the upper (1 cm) layer serves

D. Kramer (✉)
Department of Industrial Ecology, Faculty of Biotechnology and Industrial Ecology,
Mendeleev University of Chemical Technology of Russia, Zeleny Pr., 6-2-80,
Moscow, Russian Federation 111141
e-mail: dkramer@mail.ru

I. Tikhonova
Department of Industrial Ecology, Faculty of Biotechnology and Industrial Ecology,
Mendeleev University of Chemical Technology of Russia, Miusskaya Pl., 9,
Moscow, Russian Federation 125047
e-mail: iriti-may@yandex.ru

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_39,

as, taking into account peculiarities of sedimentation, characteristic of the annual process of accumulation of pollutants [5].

In autumn 2011 we carried out a survey of two Moscow small rivers: Tarakanovka and Businka. Particular emphasis was given to the analysis of sediment contamination, as well as identification of potential contaminants of these rivers.

The river Tarakanovka is situated in the north-west of Moscow, left tributary of the Moskva River, flows in an industrial zone. Length is 7.8 km (most lies in the collector). The basin area is 18.3 km^2. In the 1950–1960-ies the river was almost completely removed to the collector. Small open areas of the river remained near Horoshevskoe, Zvenigorodskoe highways and the Leningradskiy Prospect.

River Businka is located in the north of Moscow and Moscow region. The total length of the river is about 4.5 km, 1.4 km of which is in Moscow in the industrial area (part of the river lies in the collector). It is a right tributary of River Likhoborka, which in turn flows into the River Yauza.

Methodology and Field Observations

Field Observation and Sampling

At the beginning of the work we carried out a field observation of rivers Businka and Tarakanovka, which aimed at the description of the coast, vegetation and identification of possible sources of contamination of these rivers.

According to the results of field observations of the rivers 9 sampling points were selected from each river where water and BS samples were taken. Samples were taken from the surface layer (0–5 cm depth), and then we determined the petroleum products content, some heavy metals and total organic pollution in them.

Analyzing Procedures

List of priority heavy metals to determine was based on the screening analysis of BS samples, made with the help of ICP method at the Institute of Microelectronics Technology and High Purity Materials. Petroleum products content in the BS samples was determined by IR spectroscopy, and the content of selected heavy metals were determined by atomic absorption spectrometry.

Results and Discussion

To assess the pollution of rivers with heavy metals we used limit allowable concentrations (LAC) for heavy metals (HM) in the soil [2], as well as the background of

Table 1 Background concentrations (mg/kg) in BS of Moscow region rivers, watercourses of National Park "Losiniy ostrov" and rivers observed. *N/d*—not determined. Values that exceed LAC are bold

Metal	LAC in soils/Recommended norm [5]	Background concentration in BS in rivers of Moscow region and watercourses in NP "Losiniy ostrov" [6]			Mean concentration in BS of rivers	
		Background concentration in BS in the rivers of Moscow region	Background concentration in soils of park	Concentration in BS of park watercourses	Tarakanovka	Businka
Ni	80/20	11	23.1	23.4	10.1	17.6
Cu	132/27	35	27.4	36.7	27.3	*297.5*
Zn	220/50	37	58.2	62.3	136.3	*398.7*
Cd	2.0/0.3	0.3	–	–	0.38	*11.1*
Pb	130/26	19	21.2	15.6	13.1	39.4
Cr	90/46	29.0	33.3	39.2	29.2	*165.2*
Sr	no value/30	N/d	N/d	N/d	*314.3*	*241.0*

chemicals in the soil [3, 6]. Results of analysis of the content of HM in the bottom sediments of rivers are presented in Table 1.

Based on these results, we selected priority heavy metals—pollutants of small rivers Businka and Tarakanovka: copper, zinc, cadmium and strontium. Changes in the concentrations of these metals in parts of LAC by the sampling points can be seen in Fig. 1.

The presented figures show that in the sediments of the river Tarakanovka are enriched in Zn, whereas in the sediments of the river Businka there is a high content of Cd. It is worth noting the high Sr content in the sediment samples of both rivers.

The results of analysis of petroleum products in BS (Table 2, Fig. 2) indicate the intensity of their entry into the river and, just as importantly, allow us to identify the sources of pollution.

In the Tarakanovka river there is only one point that exceeds limit values, where the auto-technical center is situated. River Businka is more polluted with petroleum products, its basin contains several garage cooperatives.

In addition to the standard analysis for petroleum products we performed an analysis for extractable organic compounds (EOC) in the sediment samples of both rivers.

At first we tried to use spectrophotometric method that is used in work [7] to determine the concentration of EOC. Unfortunately, we found no correlation of the optical density and the concentration of the EOC during preliminary analyses at wavelengths from 250–600 nm. Further analysis for EOS was performed by gravimetric method.

Results analysis for EOC for both rivers show symbatically of EOC and petroleum products (PP) concentrations, which means that the organic pollution in rivers

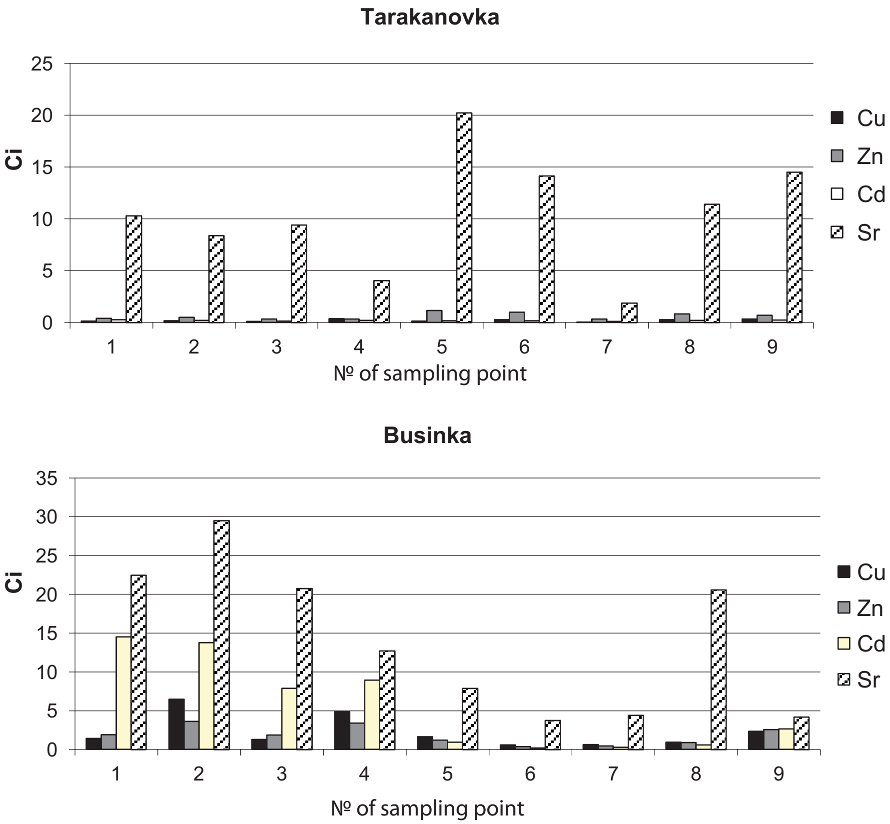


Fig. 1 Changes in concentration of HM (in parts of LAC, for Sr—in parts of recommended norm) in BS samples

is mainly due to petroleum products. Figure 2 and 3 show the ratio of concentrations of PP and EOC for p. Businka and Tarakanovka.

To assess the pollution of rivers we calculated contamination factor C_f that characterizes water pollution by separate substances, and their total impact by determining the degree of contamination C_d, qualifying total pollution of water body by observed substances [1].

To describe the water area pollution by toxic substances values contamination factors C_f are determined:

$$C_f = \frac{C^i_{0-5}}{C^i_n}$$

C^i_{0-5} — substance concentration;
i — heavy metals: Ni, Cu, Pb, Zn, Mn, Cd, Hg, As, Sr; petroleum products in surface layer (0–5 cm) of BS;

Table 2 Concentration of petroleum products in BS of River Businka, mg/kg. Values, that exceed recommended norm for petroleum products for Moscow region (1,000 mg/kg) are bold

No. of sample	1	2	3	4	5	6	7	8	9
r. Tarakanovka									
Concentration of petroleum products, mg/kg	768.0	*3470.6*	871.8	*4502.6*	*3111.1*	646.8	*1280.7*	*1928.2*	*5414.4*
r. Businka									
Concentration of petroleum products, mg/kg	*6835.5*	646.0	515.2	918.0	702.0	579.8	264.5	632.5	537.6

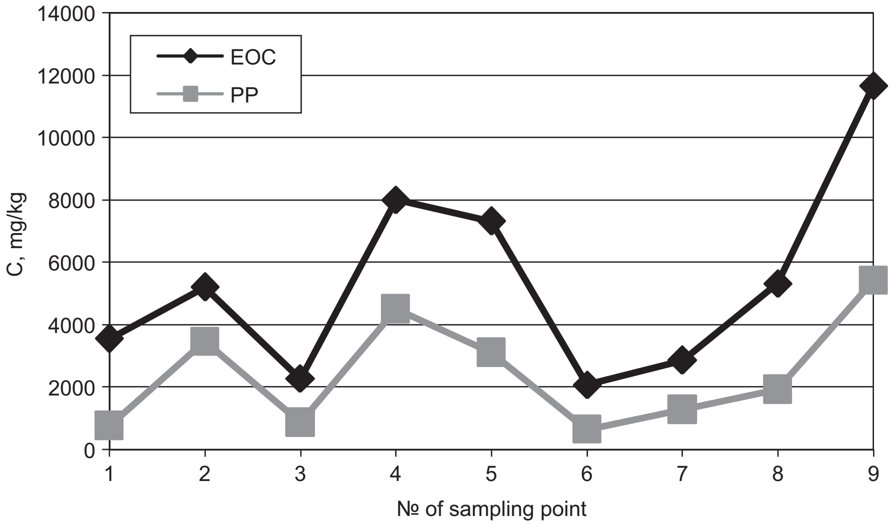


Fig. 2 Ratio of concentration of PP and EOC for river Businka

C_n^i — mean background concentration for BS.

The above-mentioned list of metals and petroleum products used to determine the intensity of the contamination due to the high toxicity of these substances to aquatic organisms, as well as the availability of data on these substances.

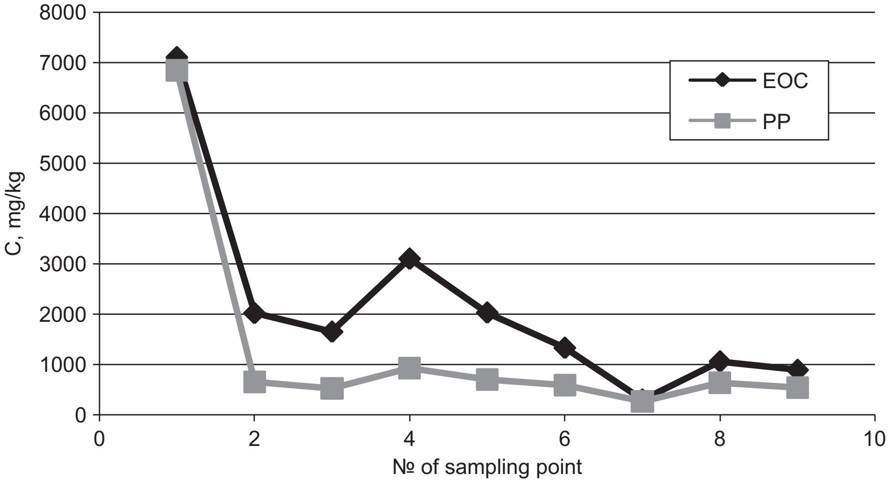


Fig. 3 Ratio of concentration of PP and EOC for river Tarakanovka

Contamination factor Cf is calculated for each pollutant separately:

$C_{0-5} > C_n$—substance can be described as polluting (or high concentration).
$C_{0-5} < C_n$—substance is not considered polluting.

In this approach to the following classification with the degree of pollution is adhered:

$C_f < 1$ as low
$1 \le C_f < 3$ as moderate
$3 \le C_f < 6$ as significant
$C_f \ge 6$ as high

Values of contamination factor for sediment pollution in the studied rivers are presented in Tables 3 and 4.

The degree of contamination C_d was determined as the sum of all factors of contamination Cf (HM/petroleum) for the river:

$$C_d = \sum C_f = \sum \frac{C_{0-5}^i}{C_n^i}$$

For the calculation of C_d sum of contamination factors for n substances is used. According to [1], the values of C_d are characterized as follows:

$C_d < n$—	a low level of contamination;
$n \le C_d < 2n$—	moderate;
$2n \le C_d < 4n$—	significant;
$C_d \ge 4n$—	high, serious pollution.

Table 3 C_f values in sediments of river Businka

No. of sample	Cr	Ni	Cu	Zn	As	Sr	Cd	Hg	Pb	PP
1	*11.94*	0.32	*7.01*	*8.41*	0.40	*22.44*	96.67	*6.67*	2.49	0.77
2	*6.76*	0.35	*31.68*	*15.95*	0.34	*29.50*	91.67	2.47	2.27	3.47
3	5.09	0.35	*6.34*	*8.23*	0.34	*20.77*	52.50	2.80	1.10	0.87
4	4.41	2.28	*23.93*	*14.96*	0.53	*12.73*	59.67	3.89	2.76	4.50
5	1.46	2.13	*8.15*	5.36	0.50	7.90	6.33	0.67	1.17	3.11
6	0.39	0.71	2.84	1.63	0.18	3.73	1.20	0.27	0.49	0.65
7	0.64	0.96	3.14	1.97	0.26	4.43	1.77	0.33	1.10	1.28
8	0.67	0.28	4.58	3.93	0.49	20.58	4.07	0.40	0.64	1.93
9	0.95	0.54	*11.49*	*11.36*	0.45	*4.20*	17.83	1.07	1.62	5.41

Table 4 C_f values in sediments of river Tarakanovka

No. of sample	Cr	Ni	Cu	Zn	As	Sr	Cd	Hg	Pb	PP
1	0.11	0.061	0.71	1.78	0.13	*10.29*	1.77	0.47	0.24	*6.83*
2	0.18	0.09	0.89	2.20	0.15	*8.38*	1.47	0.60	0.30	0.65
3	0.10	0.08	0.56	1.42	0.18	*9.41*	0.93	1.80	0.15	0.52
4	0.66	0.77	1.73	1.54	0.34	4.05	1.33	0.20	0.78	0.92
5	0.31	0.21	0.75	5.12	0.38	*91.97*	1.20	0.27	0.23	0.70
6	0.22	0.11	1.28	4.35	0.25	*14.15*	1.13	0.60	0.31	0.58
7	0.09	0.05	0.17	1.44	0.20	1.88	0.60	0.13	0.05	0.26
8	1.39	1.75	1.38	3.69	1.27	*11.40*	1.33	0.20	1.16	0.63
9	2.67	1.41	1.62	3.01	0.78	*14.49*	1.57	0.33	1.32	0.54

Table 5 Values of the degree of contamination C_d of bottom sediments

Cu	Zn	Pb	Cd	Ni	Cr	Hg	As	Sr	PP
r. Businka									
99.15	71.77	13.64	331.70	7.91	32.32	18.56	3.50	126.29	22.00
r. Tarakanovka									
9.09	24.55	4.54	11.33	4.54	5.73	4.60	3.68	166.02	11.63

To assess contamination by toxic substances in sediments of rivers Businka and Tarakanovka the values of contamination factor of nine HM (Cu, Zn, Pb, Cd, Ni, Gr, Hg, As, Sr) and the content of petroleum products were used, so to describe the degree of pollution of Cd next classification of values was used:

$C_d < 10$ as a low level of contamination10 $C_d < 20$ as moderate;
20 $C_d < 40$ as significant
$C_d \geq 40$ as high

The values of the degree of contamination of bottom sediments of rivers Businka and Tarakanovka are shown in Table 5 and Fig. 4.

On the river Businka there are high values of the contamination factor and degree of contamination for copper, zinc, cadmium, chromium, mercury, significant

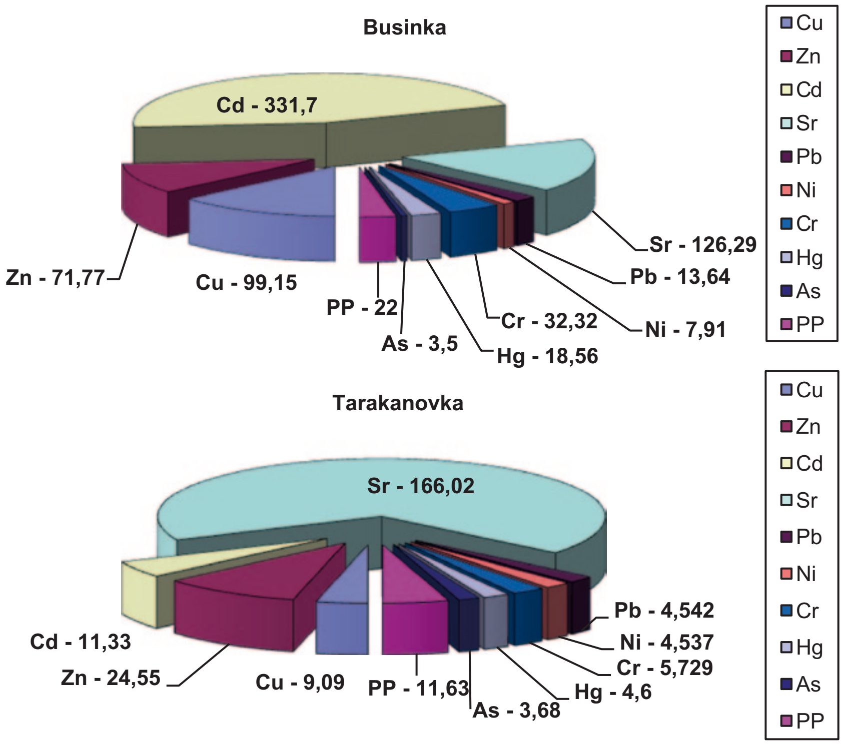


Fig. 4 Contamination degree of rivers Businka and Tarakanovka by heavy metals and petroleum products

for lead and petroleum products. Moderate values of the contamination factor and the low values of the degree of contamination occurred for nickel. In general, the degree of river contamination by heavy metals is high.

On the river Tarakanovka high values of the contamination factor has only Sr and PP in the first sampling point, a high degree of contamination for strontium, significant for zinc, moderate for cadmium and PP and low for chromium, nickel, copper, arsenic, mercury and lead.

Conclusion

The results of survey showed that the priority heavy metals polluting the rivers are copper, zinc, cadmium and strontium, and that Businka river is highly contaminated with heavy metals and organic compounds, while the river Tarakanovka has a lower degree of contamination of heavy metals and organic compounds. Contamination by organic compounds of both rivers is mainly caused by petroleum products.

References

1. Dauvalter VA (2006) Otsenka ecologicheskogo sostoyaniya poverhnostnyh vod po resultatam issledovaniya chimicheskogo sostava donnyh otlozhenii (Assessment of the ecological status of surface waters as a result of studies of the chemical composition of sediments). MGTU, Murmansk
2. GN 2.1.7.2041-06 Predelno dopustimye contsentracii (PDC) chimicheskih veshchestv v pochve (Hygienic norms GN 2.1.7.2041-06 Limit allowable concentrations (LAC) of substances in soil)
3. Metodika ischisleniyara zmera ushcherba, vyzyvaemogo zahlamleniem, zagryazneniem i degradatsiei zemel na territorii Moskvy (The method of calculating the amount of damage caused by cluttering, pollution and degradation of land in Moscow). Annex to the order of Mayor of Moscow from July 27, 1999 N 801-RM
4. Papina TS (2001) Transport i osobennosti raspredeleniya tyazhelyh metallov v ryadu “voda-vzveshennie veshchestva-donnie otlozheniya” rechnich ecosystem (Transportation and distribution characteristics of heavy metals in a range “water-suspended matter-sediments” of river ecosystems). GPNTB SO RAS, Novosibirsk
5. Pateev MR (2009) Mezhphaznyi i transgranichnyi perenos tyazhelyh metallov v pribrezhnyh i ustievyh zonah yuzhnyh morei Rossii (Interphase and transboundary transport of heavy metals in coastal and estuarine areas of the southern seas of Russia). Dissertation, Russian University of Fishery and Oceanography
6. Sokolova OV (2008) Eksperimentalnoe issledovanie i termodinamicheskoe modelirovanie migratsii tyazhelyh metallov v sisteme “voda-donnye otlozheniya” v zone antropogennogo vozdeistviya (Experimental observation and thermodynamic modeling of the migration of heavy metals in the system “water—sediment” in the area of human impact). Dissertation, Moscow State University
7. Vignati DAL, Burdino E, Congiu AM et al (2008) Quality evaluation of sediments from 24 tributaries of the Po River, Italy. Water Air Soil Pollut 190:129–141
8. Yanin EP (2002) Technogennie geohimicheskie assotsiatsii v donnyh otlozheniyah malyh rek (sostav, osobennosti, metody otsenki) (Technogenic geochemical associations in sediments of small rivers (the composition, characteristics, assessment methods)). IMGRE, Moscow

Assessment of Ground Water Quality as Influenced by Paper Mill Effluent in Namakkal District, Tamilnadu, India

S. Manorama and S. Paulsamy

Abstract Namakkal district in Tamilnadu, India is climatically semi-arid with low rainfall of ca.400 mm per year. Agriculture of sorghum and manihot through well irrigation in some localized areas is practiced in this district. In rivurine areas, cultivation of coconut, sugarcane and banana are also made. Effluents through sago industries, paper industries and sugarcane industries are generally polluting the soil and well water drastically in many parts of the district, which results in the soil not so fit for plant growth and well water not good for drinking and agriculture. Oddapalli is an agricultural belt in Namakkal district contains ca. 10,000 ha of farming land and most of it depends on well water for agriculture. Hence to asses the quality of ground water, the present study was attempted in the water samples collected from a well, located at Oddapalli where Seshasayee paper mill and Ponni sugar mill effluents are being discharged without proper treatment. The results of the study revealed that the samples contained significantly higher amount of total solids and dissolved CO_2, elements such as Mg, Ca and Fe and the nutrients such as NO_3, SO_4 and PO_4 than that of the standards prescribed by WHO. On the other hand, contents of dissolved O_2 was very low in the well water in comparison to that of standard. Further, it has been estimated that the chlorides and total solids are higher in the well water then that of the irrigation standard. The over all study shows that the well water of Oddapalli is not adequately suitable for drinking as well as agriculture. Hence proper treatment of effluent of paper and sugar mills is suggested before discharging so as to fit for all domestic and farming purposes which also keep the soil environment in healthy status at maximum extent.

Introduction

Water is an indispensable natural resource on earth. Safe drinking water is the primary need of every human being. Fresh water has become a scarce commodity due to over exploitation and pollution of water. Groundwater is the major source of drinking water in both urban and rural areas [3] and it is the most important source of water supply for drinking, irrigation and industrial purposes. Increasing popula-

S. Manorama (✉) · S. Paulsamy
Department of Botany, Kongunadu Arts and Science College, Coimbatore 641029, Coimbatore, India
e-mail: drsmanorama@gmail.com

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_40,

tion and its nesscities have lead to the deterioration of surface and sub surface water [2]. Water is polluted on all the surfaces of earth and Oddapalli village, Namakkal district, Tamilnadu, India is no exception to this phenomenon. Sugar mills, paper mills and sago factories are distributed almost all regions of Namakkal district and the effluents from these industries pollute the groundwater and soil considerably. All metabolic and physiological activities and life process of aquatic organisms are generally influenced by such polluted waste and hence, it is essential to study physico-chemical characteristics of water.

Materials and Methods

Study Area

The study area, Oddapalli village is situated in Tiruchengode thaluk of Namakkal district, Tamil Nadu, India at 11.265º N and 77.94º E Ponni sugar mill and Seshasayee paper mill are the two major industries situated in this village. The groundwater quality of Oddapalli is continuously degrading due to these industrial activities and the soils of the nearby fields are also being affected. Therefore, we have decided to analyze its groundwater so that some remedies for the improvement could be possible.

Methods

Groundwater samples were collected from ten different locations of Oddapalli during the post-rainy season (November, 2011). Borosilicate glasswares, distilled water and E-mark reagents were used throughout the testing. Samples were collected in sterilized screw-capped polyethylene bottles of one liter capacity and analyzed in laboratory for their physico-chemical parameters. The pH and dissolved solids of the water samples were determined on the spot using a pH meter and TDS meter. Various standard methods were used for the determination of other parameters [1]. The trace elements such as copper, lead, chromium and cadmium were analyzed by using AAS.

The parameters analyzed in the sample were compared with that of standards prescribed by BIS (Bureau of Indian Standards) for drinking water. The water quality data, sodium percentage was calculated as per the method of Wilcox [11].

Table 1 Physical and chemical parameters of the polluted well water in Oddapalli, Namakkal district, Tamil Nadu, India with drinking water standard, BIS, irrigation standard by using Na^+%

Parameter	Sample	BIS (Bureau of Indian Standards) standard
Physical		
Colour	Brownish	Colorless
Total Suspended solids (mg/L)	396.8	100
Total Dissolved solids (mg/L)	2,468.2 ± 96.5	2,100
Total solids (mg/L)	2,865 ± 26.5	500–2,000
Chemical		
pH	7.3 ± 0.5	6.5–8.5
Dissolved oxygen (mg/L)	6.83 ± 0.83	8.9–9.81
Dissolved carbon dioxide (mg/L)	11.20 ± 0.8	10.0
Phosphate (mg/L)	0.46 ± 0.07	0.1
Nitrate (mg/L)	3.58 ± 1.31	45–100
Silicate (mg/L)	1.00 ± 0.05	1.0
Iron (mg/L)	2.89 ± 0.98	0.3–1.0
Magnesium (mg/L)	145.0 ± 31.8	30–100
Chloride (mg/L)	333.7 ± 12.64	200–1,000
Calcium (mg/L)	165 ± 1.25	75–200
Fluoride (mg/L)	2.1	1.0–1.5
Sulphate (mg/L)	460	200–400
[a]*SODIUM (%)*	*68.12*	*200*
Copper (mg/L)	0.10 ± 0.002	0.05–1.5
Lead (mg/L)	0.11 ± 0.003	0.05
Chromium (mg/L)	0.11 ± 0.003	0.05
Cadmium (mg/L)	0.09 ± 0.002	0.01

[a] Irrigation standard as reflected by Na^+ % content (20–40 Na^+ % = "good" for irrigation, 40–60 Na^+ % = "permissible" for irrigation and 60–80 Na^+ % = "doubtfull" for irrigation) [7]

Results and Discussion

The physical, chemical and trace metal parameters of the polluted well water samples of Oddapalli village, Namakkal district, Tamil Nadu, India are given in Table 1. The physical parameter, colour of the samples was generally brownish which indicates the presence of various dissolved and suspended materials and the other colloidal substances in excess [6]. The total solids estimated in the samples were determined to be 2,865 mg/l, which is significantly higher than that of the BIS standards. The presence of excessive solids in water shows pollution which can lead to a laxative effect. The presence of excessive solids in water may be due to the industrial pollution and other agricultural activities [7].

Many chemical parameters analyzed were also not comparable to that of BIS standards. The pH of the samples was existing within the range prescribed by BIS. However, the pH 7.3 measured in the sample has certain potential health effects like disturbance to the mucus membrane, bitter taste and corrosion while using for drinking purpose [4, 5, 11].

The dissolved oxygen present in the samples was 6.83 mg/l, which is far lower than the standard proposed by BIS (8.9–9.81 mg/l). Oxygen in water is most essential not only for aquatic organisms but also for the stability of ecosystem by regulating the ecological process. The presence of very low content of dissolved oxygen indicates that the water is not so healthy and not fit for drinking purpose. The dissolved carbon dioxide present in the study samples was greater than that of the BIS standards i.e 11.20 mg/l against the BIS standard, 10 mg/l standard value. The higher content of carbon dioxide in the study sample is not providing condusive environment for phytoplanktons and other beneficial organisms in water, which naturally make the water unfit for drinking.

The phosphate content of the study samples was higher(0.46 mg/l) than the BIS standards(0.1 mg/l).The excess content of the phosphate leads to eutrophication and in turn results algal blooming, a factor causes lower BOD level in water. On the other hand the nitrate level in the Oddapalli well water was estimated to be lower (3.58 mg/l) than that of BIS standards. The fluoride and sulphate contents were higher (2.1 and 460 mg/l respectively) than the values prescribed by BIS. It has been reported that higher content of fluoride causes dental and skeletal florosis and non skeletal manifestations [4, 5, 11]. The greater sulphate content may also affect the taste of the water and causes gastrointestinal [4, 5, 11].

The heavy metals and trace elements such as iron, magnesium, copper, lead, chromium and cadmium were estimated to be significantly higher in the study samples (2.89, 145, 0.10, 0.11, 0.11, 0.09 mg/l respectively). It is known that all these metals exceed the permissible limit proposed by BIS. High heavy metals concentration values may cause kidney damage, carcinogenic, bone damage, nervous disorder and cancer [8]. The sodium percentage is a very usefull parameter to determine the use of water for irrigation [7]. Sodium percentage value (68 %) reflected under the category doubtful for irrigation for Oddapalli well water as per the water quality data of [9].

Conclusion

In the current study based on the physico-chemical parameters, heavy metal analysis and water quality data (Na %), thus concluded that the well water of Oddapalli village, Namakkal district is not fit for drinking, irrigation and fisheries owing to the poor quality water as majority of the important parameters not in accordance with the BIS standards. So it is suggested proper modern eco-friendly treatment must be given to well water before going for utilization. Further it is suggested that proper treatments must also be given to the effluents of paper industries and sugar industries so as to upgrade the quality of well water in Oddapalli area of Namakkal district, Tamil Nadu, India.

References

1. APHA (1992) Standard methods for analysis of water and wastewater, 18th ed. American Public Health Association, Inc., Washington DC
2. Dhiviyaa PTS, Venkatesa RT, Punithavathi L, Karunanithi S, Bhaskaran A (2011) Groundwater pollution in the palar river bed near Vellore, Tamil Nadu, India. Ind J Sci Technol 4(1):19–21
3. Gupta DP, Sunita, Saharan JP (2009) Physiochemical analysis of groundwater of selected area of Kaithal City (Haryana) India. Researcher 1(2):1–5
4. ICMR (1996) Manual of standards of quality for drinking water supplies, 2nd ed. Indian council for Medical research Govt of India, New Delhi
5. ISI (1991) Indian standard drinking water specifications. New Delhi, 5,16
6. Karunakaran K, Thamilarasu P, Sharmila R (2009) Statistical study on physicochemical characteristics of groundwater in and around Namakkal, Tamilnadu, India. E J Chem 6(3):909–914
7. Kaur R, Sing RV (2011) Assesment for different groundwater quality parameters for irrigation purposes in Bikaner city, Rajasthan. J App Sci Environ Sanit 6(3):385–392
8. Saravanakumar K, Ranjithkumar (2011) Analysis of water quality parameters of groundwater near Ambattur industrial area, Tamil Nadu, India R. 2011. Indian J Sci Technol 4(5):660–662
9. Wilcox LV (1995) Classification and use of irrigation water, US DA Circular, Washington, DC. US Department of Agriculture. 969
10. World Health Organization (WHO) (1993) Guidelines for drinking water quality, 2nd ed. Surveillance and control of community supplies. Geneva, Switzerland. 3
11. World Health Organization (WHO) (2004) International standards of drinking water. World Health Organization, Geneva. pp 55–79

Road Salt and Environmental Hazards—Identification of Vulnerable Water Resources

Kjersti Wike Kronvall

Abstract The Norwegian Public Roads Administration (NPRA) just finished a four year research and development project, entitled: "Salt SMART". The objective has been that the NPRA's effort to maintain ease of passage and traffic safety during winter, shall not result in unacceptable effects to the environment. To solve this, areas vulnerable to road salt within Norway has been identified. In this paper, a flowchart method to identify water resources vulnerable to road salt has been presented. Readily accessible data or methods, produced in the Salt SMART project have been used. The results have been processed and presented in a GIS (Geographic Information System).

Introduction

The EU Water Framework Directive (WFD) was implemented by law in Norway 2006 [19]. It is expected that the Norwegian Public Roads Administration (NPRA) take part and make necessary action regarding the WFD implementation. This is in accordance to the general principle in the Norwegian governmental policy, that all ministries and operational departments have a sectorial environmental responsibility [18]. In response to this, the Norwegian Public Roads Administration just finished a four year research and development project, entitled: "Salt SMART". Results from the project is presented in this paper.

Sodium chloride or road salt (NaCl) is widely used to improve winter road conditions, but concerns have been raised regarding environmental impacts. The amount of road salt applied annually on Norwegian roads has more than tripled since year 2000. During the winter 2010/2011, 238000 t road salt was spread [23] (Fig. 1).

Chloride concentrations can reach concentrations that are harmful to humans and aquatic biota in surface water, groundwater and drinking water wells [3, 12, 20, 21, 25, 26]. However, sodium chloride has variable impacts on aquatic environments which makes it difficult to generalize effects and establish water quality criteria for aquatic biota [6]. Insufficient oxygen levels measured in the bottom water layer in

K. W. Kronvall (✉)
Environmental Assessment Section, Norwegian Public Roads Administration,
PO Box 8142 Dep, 0033 Oslo, Norway
e-mail: Kjersti.kronvall@vegvesen.no

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_41,

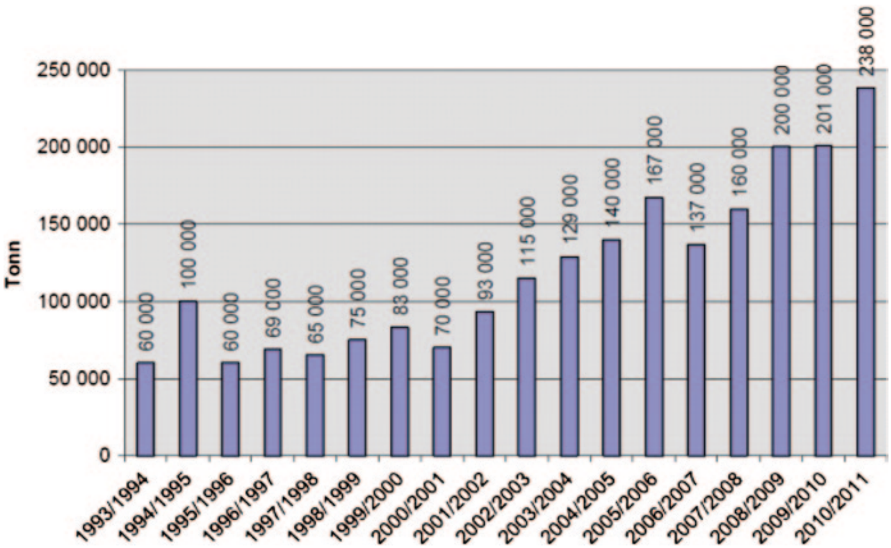


Fig. 1 Annual applied amount of road salt in Norway by the Norwegian Public Roads Administration (NPRA) as total amounts in tonne

lakes have been shown to be directly related to elevated salt concentrations caused by road salt [e.g. 1, 3, 20, 21, 26]. Increased salinity in surface waters can be caused by road salt application, but there are other potential chloride sources, including fertilizers, agriculture, landfills, wastewater treatment plants and leaching from marine sediments or supply from rain [13]. However, Thunqvist [27] has documented that road salt contributes to more than half of the total supply of chloride to surface water, while along the coast precipitation containing seawater and fertilizers in agricultural areas contributes to a large portion of the total amount of chloride [24].

For winter road maintenance in vulnerable areas special requirements need to be considered to avoid environmental impacts. Sampling of all Norwegian water resources is both time consuming and costly, and in this respect a flowchart method has been developed to identify areas were road salt may have negative impact to water resources adjacent to roads. The results from the flowchart method have been processed and presented in a GIS-map (Geographic Information System).

Data and Methods

The method to identify lakes vulnerable to road salt has consisted of (1) Data collection and (2) Identification of vulnerable water resources. The identification of vulnerable water resources was done by using already existing data, from studies in the Salt SMART project. The studies used in the flowchart method are detailed in the next section.

STEP 1: Data Collection

The data included in the method was digital maps showing roads and road salt consumption from the Norwegian Public Roads Administration (NPRA), lakes from Norwegian Institute for Water Research (NIVA), ground water from Geology for Society (NGU), municipal water works from Norwegian Food Safety Authority, estimated contribution of road salt in lakes based on estimated average stationary water balance, salt balance and salt concentration in lakes [16], estimated background concentration of chloride in freshwater lakes [10], method for risk classification of chemical stratification [3, 10] and method for risk classification of biological effects [11]. Data was collected and gathered in a digital database. All data were processed and presented in a GIS-map. Methodology used in the above mentioned studies are described in the respective references.

STEP 2: Identification of Vulnerable Water Resources

The water resources are divided into (1) Ground water, (2) Municipal water works and (3) Lakes. Occurrences of ground water and municipal water works closer than 200 m from salted road have been identified. For lakes, the method has been more complex. Two potential ways of causing damage to lakes because of road salt have been used; chemical stratification and biological effects.

Risk of Chemical Stratification

According to Bækken and Haugen [4] formation of salt gradients depends mainly on the added road salt quantity, road length in the catchment, lake morphology, runoff from the catchment and average annual daily traffic. The method used in this study, has been to classify lakes with an area less than 200 decare, situated closer than 200 m from a road with road salt consumption of more than 25 t/km, to be at risk for salt-induced stratification. Lakes with an area between 200–500 decare, situated closer than 200 m from a road with road salt consumption of more than 10 t/km, is classified to be possible at risk and lakes with an area less than 200 decare, situated closer than 200 m from a road with road salt consumption between 10–25 t/km is also classified to be possible at risk.

Haaland et al. [10] have developed a method to identify lakes possibly at risk for chemical stratification. The model takes into account (1) the contribution of road salt in lakes, which have been estimated by Kitterød et al. [16], (2) background chloride concentration, (3) a factor for wind exposure and (4) a factor for retention time. These variables have been used together with a tolerance limit, for when chemical stratification is developed.

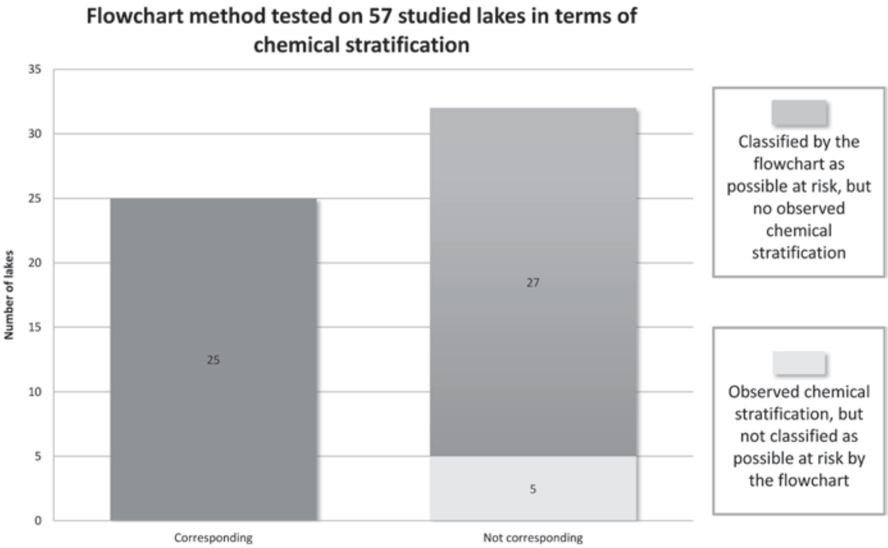


Fig. 2 Flowchart method tested on 57 studied lakes in terms of chemical stratification

Risk of Biological Effects

A survey performed by Haugen and Bækken [11] for biological effects caused by road salt has been used in this study. The results from the survey showed that lake algae communities in calcium-poor lakes become altered at chloride concentrations above 23–30 mg/L, whereas in calcium-rich lakes the chloride concentration has to exceed 40 mg/L in order to observe changes in the algae community. Based on these results, tolerance limits have been set to 25 mg Cl/L in calcium poor lakes, and 40 mg CL/L I calcium rich lakes.

Results and Discussion

Flowchart to Identify Vulnerable Water Resources

A flowchart to identify water resources vulnerable to road salt has been made in the project (Fig. 3). The flowchart is presented in a GIS. The flowchart method identifies all ground water and municipal water works closer than 200 m from salted roads.

For lakes a more complex method is shown in the flowchart. The method is divided into “risk of chemical stratification” and “risk of biological effects”. Fifty-seven lakes have been studied for chemical stratification caused by road salt [4].

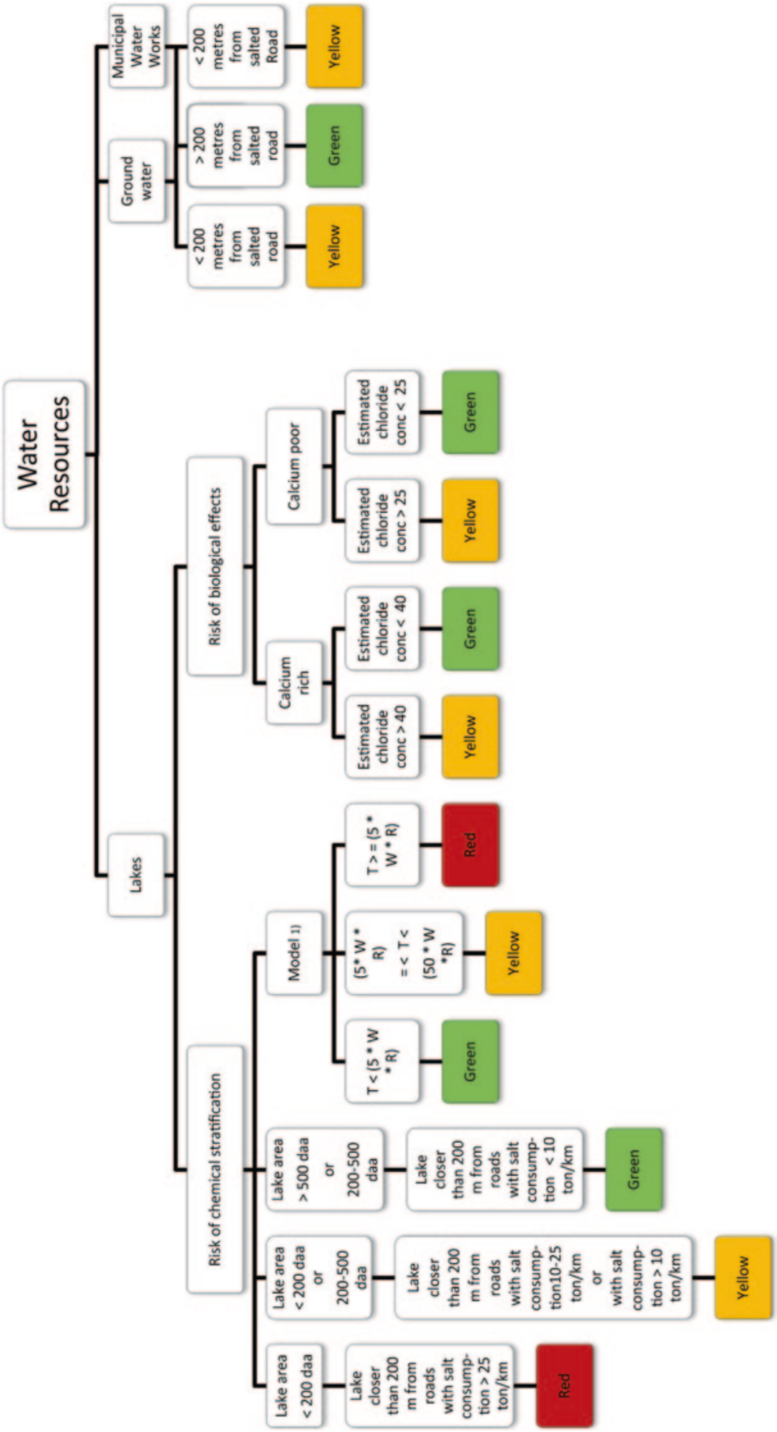


Fig. 3 Flowchart of a method to identify water resources vulnerable to road salt

The flowchart method has been tested on the 57 studied lakes to see whether they give the same results in terms of chemical stratification. The flowchart method and the study by Bækken and Haugen [3] appeared to be corresponding in 25 out of 57 cases (Fig. 2). The flowchart method has classified 27 out of 57 cases as possible at risk, but a chemical stratification is not observed in the study. This means that the flowchart method is overestimating the risk of chemical stratification currently. In five out of 57 cases, the flowchart method did not identify the lakes with observed chemical stratification.

Reasons why the flowchart method and the studied lakes do not always correspond include:

- The model used in the flowchart method shows a steady state situation, an equilibrium state where the concentration does not change and a constant supply of road salt. This means that if the salt supply to the lakes continues in the future, a chemical stratification might be observed in some of the lakes estimated to be possibly at risk, even if it's not observed any chemical stratification currently.
- In some areas the municipal salt consumption may be significant and can contribute to the chloride concentrations in lakes. In this study, the municipal salt consumption was not taken into account.
- The registration of the salt consumption might be inaccurate, because it is manual and contract dependent.
- Chloride can either origin from different anthropogenic sources, e.g. road salt, or from natural deposits of salt, such as relict salt, atmospheric deposition, weathering of minerals and seawater intrusion [17]. This means that some lakes might be affected by natural deposits which are not revealed by the model developed by Haaland et al. [10].
- A seasonal variation through the year would be expected since road salt is only used during winter season. Seasonal variation in chloride concentration is not taken into account in this study. In addition, the measured chloride concentration is based on only one measurement through one year Categories of vulnerable water resources.

Following the flowchart in Fig. 3, the user will end up in one of three different categories; green, yellow or red. The three categories are described in the next section.

- Green—The salt consumption does not lead to environmental damages.
- Yellow—The salt consumption causes medium risk of environmental damages or the risk of environmental damage is not clarified. Measurements are implemented or further studies are needed.
- Red—The salt consumption causes high risk of environmental damages. Measurements are implemented.

The Use of Methods to Predict Vulnerability

Tools or models to predict runoff from roads or vulnerable areas have been developed in a number of research projects [e.g. 5, 7, 9, 13, 15, 22, 27]. The spatial nature of diffuse sources, such as road salt, make the estimation of such pollutants well suited to models and integration in a GIS [e.g. 9, 17]. Among the problems that are recognized are creation of a database, including both collection of data and the assurance of proper database quality, which were also identified in this study. Errors and uncertainties can be managed by statistics in order to estimate the errors, but was not done in this study.

Academic researchers often use numerical models that involve large amounts of field data on watershed characteristics. Such models can be costly, cumbersome to use, and do not necessarily lead to more accurate predictions than simpler models [13]. Simpler models or methods can capture the main trends, which is used in this study.

Corsi et al. [6] stated that sodium chloride has variable impacts on aquatic environments which makes it difficult to generalize effects and establish water quality criteria for aquatic biota. In the flowchart method developed in this study, a study by Haugen and Bækken [11] has been used to identify risk of biological effects. Additional studies to identify risk of biological effects could be added to the flowchart method. This is an example of how the flowchart method can be improved.

Flowchart Method Presented in a GIS

The flowchart method has been presented in a GIS. Through the GIS-map vulnerable lakes, ground water and municipal water works can be identified visually. This can be a useful tool for management decisions in order to minimise environmental impacts and for the road maintenance contractor. An example of how the GIS-map looks like for a yellow lake is shown in Fig. 4. The red dotted line shows the lake catchment, while the green dotted line shows salted road in the lake catchment.

A Swedish study has focused on implementation of environmental requirement in Swedish road maintenance contracts [8].The study concluded that information and communication with the contractor, in addition to follow-up the contract are crucial factors in integrating environmental aspects into contracts.

Conclusions

The present paper presents a brief summary of a flowchart method to identify lakes, ground water and municipal water works vulnerable to road salt, developed by the Norwegian Public Roads Administration. The method has been presented in a GIS map. The flowchart method has been tested on studied lakes with observed chemi-

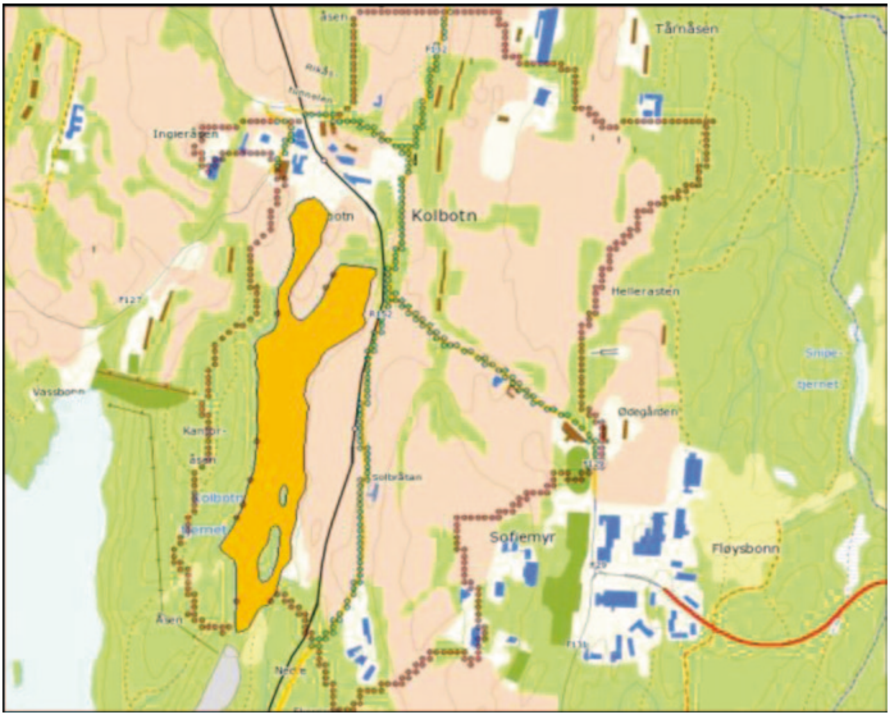


Fig. 4 Example of a GIS-map showing water resources vulnerable to road salt

cal stratification. The flowchart method and the studied lakes appeared to be corresponding in 25 out of 57 cases. The flowchart method classified 27 out of 57 cases as possible at risk, but a chemical stratification is not observed in the studied lakes. This means that the flowchart method is overestimating the risk of chemical stratification currently. In five out of 57 cases, the flowchart method did not identify the lakes with observed chemical stratification.

The method cannot replace measurements, but can give a rough indication of the water resources that should be further studied and it can show trend estimation. The generated maps provide a useful visual tool for management decisions in order to minimize environmental impacts and for the road maintenance contractor. As more data becomes available and the quality is improved, the methods and the results will be improved.

References

1. Amundsen C-E, Haaland S, French H, Roseth R, Kitterød N-O, Pedersen PA, Riise G (2010) Salt SMART: environmental damages caused by road salt -a literature review. Norwegian Institute for agricultural and environmental research and department of plant and environmental sciences, Norwegian University of Life Sciences
2. Bækken T, Færøvig PJ (2004) Effekter av vegforurensninger på vannkvalitet og biologi i Padderudvann. Publikasjon nr. 106. Teknologiavdelingen, Oslo
3. Bækken T, Haugen TO (2006) Chemical state in lakes near road (in Norwegian). Norwegian Institute for Water Research
4. Bækken T, Haugen TO (2012) Road salt and heavy metals in lakes along roads in Southern Norway 2010 (in Norwegian). Norwegian Public Roads Administration
5. Brencic M, Barbosa AE, Leitao T, Rot M (2012) Identification of water bodies sensitive to pollution from road runoff. A new methodology based on the practices of Slovenia and Portugal. Urban environment: proceedings of the 10th Urban Environment Symposium, pp 225–235
6. Corsi SR, Graczyk DJ, Geis SW, Booth NL, Richards KD (2010) A fresh look at road salt: aquatic toxicity and water-quality impacts on local, regional, and national scales. Environ Sci Technol 44(19):7376–7382
7. Crabtree B, Dempsey P, Johnson I, Whitehead M (2009) The development of an ecological approach to manage the pollution risk from highway runoff. Water Sci Technol 59(3):549–555
8. Faith-Ell C, Balfors B, Folkeson L (2005) The application of environmental requirements in Swedish road maintenance contracts. Royal Institute of Technology, Department of land and water resources engineering Stockholm, Sweden
9. Gontier M, Olofsson B (2003) Spatial vulnerability assessment for road contamination on groundwater. Division of land and water resources, Department of civil and environmental engineering, Royal Institute of Technology, Stockholm
10. Haaland S, Turtumøygard S, Gjemlestad L-J, Nytrø T-E (2012) Salt SMART road salt in lakes -threshold limits regarding chemical stratification. Norwegian Public Roads Administration
11. Haugen TO, Bækken T, Hasle HH, Skjelbred B (2010) Salt tolerance in lake phytoplankton -statistical analyses and toxicity tests (in Norwegian). ISBN No.: 978-82-577-5749-6 edn. Norwegian Institute for Water Research
12. Jackson RB, Jobbagy EG (2005) From icy roads to salty streams. Proceedings of the National Academy of Sciences of the United States of America 102(41):14487–14488
13. Jin L, Whitehead P, Siegel DI, Findlay S (2011) Salting our landscape: an integrated catchment model using readily accessible data to assess emerging road salt contamination to streams. Environ Pollut
14. Kelly VR, Lovett GM, Weathers KC, Findlay SEG, Strayer DL, Burns DJ, Likens GE (2008) Long-term sodium chloride retention in a rural watershed: legacy effects of road salt on streamater concentration. Environ Sci Technol 42(2):410–415
15. Kelting DL, Laxson CL, Yerger EC (2012) Regional analysis of the effect of paved roads on sodium and chloride in lakes. Water Res 46(8):2749–2758
16. Kitterød NO, Turtumøygard S, Aakerøy PA, Haaland S (2010) Estimation of the average saltfluks from road to water body (in Norwegian). Department of plant and environmental sciences, Norwegian University of life sciences and soil and environmental division, Norwegian Institute for agriculture and environmental research
17. Lundmark A (2003) Predicting environmental impact of deicing salt -a modeling approach. Division of land and water resources, Department of civil and environmental engineering, Royal Institute of technology, Stokcholm
18. Meland S (2010) Ecotoxicological effects of highway and tunnel wash water runoff. Norwegian University of Life Sciences, Ås

19. Ministry of the Environment (2006) FOR 2006-12-15 nr 1446: the Norwegian water framework regulations (FOR 2006- 12- 15 nr 1446: forskrift om rammer for vannforvaltningen)
20. Ramakrishna DM, Viraraghavan T (2005) Environmental impact of chemical deicers—a review. Water Air Soil Pollut 166(1–4):49–63
21. Rimmer A, Aota Y, Kumagai M, Eckert W (2005) Chemical stratification in thermally stratified lakes: a chloride mass balance model. Limnol Oceanogr 50(1):147–157
22. Scholes L, Revitt DM, Ellis JB (2008) A systematic approach for the comparative assessment of stormwater pollutant removal potentials. J Environ Manage 88(3):467–478
23. Sivertsen Ã (2010) Reporting of the road salt consumption winter 2009/2010 (in Norwegian). Technology Department, Norwegian Public Roads Administration, Oslo
24. Smart R, White CC, Townend J, Cresser MS (2001) A model for predicting chloride concentrations in river water in a relatively unpolluted catchment in north-east Scotland. Sci Total Environ 265(1–3):131–141
25. Thunqvist EL (2003) Estimating chloride concentration in surface water and groundwater due to deicing salt application. Royal Institute of Technology, Stockholm
26. Thunqvist EL (2003) Increased chloride concentration in a lake due to deicing salt application. Water Sci Technol 48(9):51–59
27. Thunqvist EL (2004) Regional increase of mean chloride concentration in water due to the application of deicing salt. Sci Total Environ 325(1–3):29–37
28. Tjøstheim H (2011) Spatial variation of atmospheric chlorid to Norwegian water sources. University of Life Sciences

Purification Practices of Water Runoff from Construction of Norwegian Tunnels—Status and Research Gaps

Hedda Vikan and Sondre Meland

Abstract This article describes origin and effects of manmade and natural sources of water-borne pollutants related to Norwegian tunnelling projects. These include particles, acidic runoff, heavy metals, radioactivity, alkalinity, nitrogen, oil, chemicals and polypropylene fibres. Common water purification methods are described. In order to ensure quality of tunnelling water, research and development is needed. The article is concluded by identifying key research and development areas.

Tunnelling in Norway

As in many other countries, traffic volumes in Norway have increased substantially during recent decades. This together with increased road construction activities may have significant effects on the aquatic environment. Norway has totally 1043 road tunnels, 34 of these are subsea. Every year 20–30 km new tunnel is built. The construction phase of these tunnels involves several manmade and natural sources of water-borne pollutants [22].

In Norway, EU's Water Framework Directive was implemented and entered into force in 2007. The directive aims to coordinate all relevant authorities and to achieve good ecological and chemical quality of waters and waterways within 2021. In effect, all Norwegian road construction projects must document the quality of water from site and the recipient's tolerance limit. This article describes water-borne pollutants related to tunneling, purification practices and research gaps.

H. Vikan (✉)
Tunnel- and Concrete Section, Norwegian Public Roads Administration,
PO Box 8142 Dep, N-0033, Oslo, Norway
e-mail: hedda.vikan@vegvesen.no

S. Meland
Environmental Assessment Section, Norwegian Public Roads Administration,
PO Box 8142 Dep, N-0033, Oslo, Norway
e-mail: sondre.meland@vegvesen.no

Department of Plant and Environmental Sciences, Norwegian University of Life Sciences,
PO Box 5003, N-1432, Ås, Norway

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_42,

Water Sources During Tunnelling

Tunnelling involves large water volumes that, unless countermeasures are taken, transport impurities into the recipient. The main water sources during construction of road tunnels are drilling water used for cooling of drill heads and removal of cuttings, natural leakage from solid rock and incidental water inflow occurring in connection with drilling.

The drill water volume depends on the type of drilling rig. A rig with three booms has a typical water consumption of approximately 300 L/min.

Natural leakage of ground water depends upon type of rock and tunnel and can be controlled by grout injection. Thresholds towards natural leakage are set in respect to the vulnerability of the nature and risk of groundwater lowering. A threshold value of 10–25 L/min per 100 m tunnel is often set, but threshold values as low as 4 L/min per 100 m tunnel have also been applied.

It is difficult to estimate incidental water inflow since rock mass is a discontinuous material with hydraulic characteristics varying widely from an impervious medium to a highly conductive zone. However, a value of 200 L/min has frequently been used for Norwegian projects. This water source will typically be diminished as the perforation is sealed [18].

Contaminants in Tunnelling Water

Suspended Particulate Matter

Tunnelling water will periodically contain large amounts of suspended fine particles such as clay and rock particles from drilling and blasting. Clay particles are rounded, while newly formed blast particles can be more edgy and splintery and thereby more harmful for biota. Detrimental effects of suspended particulate matter include reduced penetration of light, temperature changes, infilling of reservoirs and channels, altered spawning conditions, covering sources of fish food such as benthic invertebrates, and damages of fish gill tissue [4, 13, 18, 22].

According to guidelines for effects of naturally eroded particles on freshwater fish published by Alabaster and Lloyd [1] and adopted by the European Inland Fisheries Advisory Commission (EIFAC) 400 mg/L suspended solids (SS) will cause poor fishing (i.e. reduced fish stocks), 80–400 mg/L results in reduced fishing, 25–80 mg/L yields good or average conditions and less than 25 mg/L yields no detrimental effects.

Guidelines given by the Canadian Council of Ministers of the Environment specify that natural background levels must be considered as seen by Table 1.

Norwegian tunnelling water contains approximately 5,000–10,000 mg SS/L. The threshold value is often set to 400 mg/L. This is a performance based value that can be obtained by leading the water through sedimentation basins. However, in susceptible areas the threshold value may be lowered to 100 mg/L. In order to

Table 1 Water quality guidelines for total particular matter for protection of aquatic life (freshwater, estuarine, and marine environments) given by the Canadian Council of Ministers of the Environment [9]

	Guideline value
Clear flow	Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d)
High flow	Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10 % of background levels when background is > 250 mg/L

achieve this threshold value, the tunnel water must be added a coagulant before entering the sedimentation basin. Some systems include thereafter a filtration step. Acid (normally HCl) may be added in order to improve sedimentation, but also in order to avoid elevated pH of the recipient [22]. It should be stressed that the discharged tunnelling water and thus concentration of suspended solids will be diluted by the recipient. A dilution factor of 0.1, which is considered to be a worst case scenario, is for instance normal to use for lakes where no better data is available [18].

Natural Rock as Source of Acidic Runoff, Heavy Metals and Radioactivity

Natural rock may be a source of pollutants such as acidic runoff, heavy metals and radioactivity. Acidic rock drainage occurs naturally as part of the rock weathering process, usually within rocks with high contents of sulphide minerals. Acidic drainage is exacerbated by large-scale earth disturbances characteristic of large construction activities. After being exposed to air and water, oxidation of metal sulphides (often pyrite, FeS_2) within the rock generates sulphuric acid. This acidic runoff can wash out large quantities of aluminium (Al), iron (Fe) and other heavy metals that are detrimental or even lethal for aquatic organisms, e.g. fish [2, 14].

Precipitation of Al and Fe occurs when acidic water high in dissolved metals meets water with higher pH. Mixing zones may for instance occur as a stream runs into a lake. In effect, metal species, that may be highly toxic, are deposited onto fish grills [24]. Large volumes of fluffy sediments may, moreover, render receiving water unfit for other uses [14].

Marshes may also have high sulphide contents. Lowering of the water surface may oxidise sulphide to sulphuric acid with drainage of heavy metals as a consequence.

Alum shale is an example of rock that causes environmental and technical challenges in Norway. This type of black shale has high contents of FeS_2, heavy metals and uranium (U). Sulphuric acid is formed when alum shale reacts with water and oxygen causing expansion and decomposition of the rock followed by acidic runoff containing heavy metals and U. Uranium decomposes to radioactive substances including radium (Ra) and radon (Rd). Major effects of U on humans and mammals include specific organ toxicity, neurotoxicity, DNA damage/carcinogenicity, reproductive toxicity and immunotoxicity [10].

Deposits of alum shale are classified as radioactive by the Norwegian Radiation Protection Authority (NRPA). Correspondingly, special measures must be taken for handling and disposing of the rock. Environmental quality standard (EQS) value for natural radioactive masses is 1 Bq/g and permission must be given by the NRPA for handling masses with higher radioactivity values. Alum shale classified as radioactive can moreover not be freely handled and disposed of, but must be delivered to waste disposal site approved by the NRPA [20]. The NPRA has generally no guidelines for management of tunnelling and road projects within regions containing radioactive masses. Research and development is thus needed on this topic.

Alkaline Tunnelling Water

Use of cement based grout and shotcrete will elevate the tunnelling water pH. Periodic pH values up to 11–12 are not un-common for Norwegian tunnelling projects. Alabaster and Lloyd [1] have reported detrimental effects on salmon and perch exposed to pH above 9 for a long time span. pH above 11 is reported to be lethal. The tunnelling water will be diluted and the pH thereby reduced when discharged to the recipient. Oppositely, pH of acidic runoff will increase when diluted by for instance a lake as described in the previous chapter. Prediction of dilution factors and recipient's tolerance limit is thus of upmost importance.

Nitrogen, Ammonium and Ammonia from Shards with Undetonated Explosives

Explosives are a considerable source of nitrous compounds during the construction period. The fraction of undetonated explosives varies, but is often stipulated to be between 10 and 15 %. Even higher values are recorded for areas with difficult rock and tunnelling conditions [6].

Ammonium nitrate (NH_4NO_3) is commonly used as a tunnelling explosive. Undetonated ammonium nitrate is readily soluble in water and enters quickly into the process water as well as runoff from waste disposal sites.

Two issues are related to runoff with undetonated explosives in solution: Eutrophication of marine waters both by ammonium and nitrate and formation of toxic ammonia at elevated pH. The ammonium—ammonia equilibrium given in equation (1) is dependent on temperature, pH and salinity. Ammonium, opposed to ammonia is, not acutely toxic for aquatic organisms.

$$NH_3 + H_3O^+ \leftrightarrow NH_4^+ + H_2O \tag{1}$$

The influences of pH and temperature on percent unionized ammonia are illustrated by Fig. 1. Shotcrete will result in alkaline runoff and the ammonia-ammonium equilibrium is shifted towards formation of ammonia. Tolerance of ammonia varies between fish species. Tests have shown that salmon is responding to concentrations

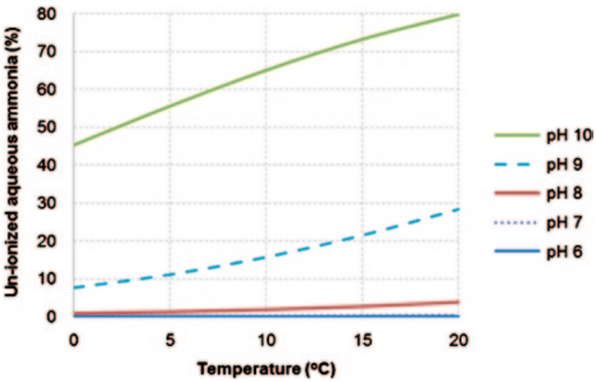


Fig. 1 Percent un-ionized aqueous ammonium as a function of temperature and pH [11]

as low as 12 µg/L NH_3 and that mortality among salmon juveniles occur at 37 µg/L (96 h LC_{50} values) [15]. Periodic ammonia concentrations above 4000 µg/L have been measured in Norwegian tunnelling water [7, 16].

Grouting Chemicals

Cement based permeation grouts do normally not have negative effects on tunnelling water apart from increased alkalinity. Numerous chemical grouts with varying chemical compositions are, however, available on the market. Some of these contain harmful substances. Examples of such substances are acrylamide and hormone mimicking substances such as phthalates from polyurethane products. Special focus was put on acrylamide in 1995–1997, as grouts with this substance were used for both Norwegian and Swedish tunnelling projects. Drainage water from the injection sites showed high concentrations of acrylamide and these emissions were seen in connection with severe neurological effects found on cattle downstream of a tunnelling project [5, 28]. Grouts containing acrylamide have since then been forbidden in Norway.

Oil and Chemical Spills

Tunnelling water contains oil contaminants originating from mineral oil in explosives, diesel spills and hydraulic oil from machinery. Oil products contain toxic components such as polycyclic aromatic hydrocarbons (PAH), lead, methyl-tert-butyl ether (MTBE) etc. [18]. The concentration of oil in tunnelling water varies. Concentrations up to 520 mg/L have been measured close to the face. This value was reduced to 22 mg/L after treatment by sedimentations pools and oil separators [16]. Norwegian pollution regulations set 50 mg/L as limiting value of oil emissions in sewage. Tunnelling water is, however, not directly mentioned in these regulations.

Water-borne Polypropylene Fibres

Polypropylene or steel fibres are added as reinforcement to shotcrete used during tunnelling to secure the rock surface. Polypropylene fibres are required for Norwegian subsea tunnels in order to avoid corrosion of the reinforcement [21]. Up to ten percent of the fibres are rebound during shotcreteing. Norwegian tunnelling projects have experienced that a considerable amount of such polypropylene fibres ends up along the coast. Some of the fibres are transported to the recipient together with the tunnelling water. Large fibre volumes may, however, free themselves from the solid masses and reach the water surface when tunnelling masses are used to stabilize or extend the roads in direct contact to the waterfront.

Plastic has a lifespan between hundreds and thousands of years. It will continuously be fragmented. Eventually, very durable fragments of microplastics are formed [19]. Small pieces of plastic are eaten as food by fish and birds. Norway is for instance far from the target set by OSPAR, that there should be less than 10 % of northern fulmars having more than 0.1 g plastic particles in the stomach [12]. Pieces of microplastic are moreover consumed by animals living on plankton [25].

Treatment Practices for Norwegian Tunnelling Water

Suspended Particles and Oil

Suspended particle concentration in water by the working face is normally estimated to be 5.000–10.000 mg/l. The tunnelling water is transported out from the working face via basins and pipework to a sedimentation area. Initial, crude sedimentation in the tunnel will increase the efficiency of the treatment system. Sedimentation close to the face can be achieved by building provisional thresholds in the tunnel ditches. Considerable amounts of sludge will sediment behind the thresholds and oil will be retained. The water is thereafter pumped to sedimentation pools (see Fig. 2).

Well dimensioned sedimentation pools can purify tunnelling water to approximately 400 mg/L SS. Particle contents below 100 mg/L can be obtained by addition of coagulation chemicals, often in combination with acid (HCl), at the inlet of the sedimentation pool or by aid of filters. Sludge from thresholds and other purification steps must be removed regularly and deposited at approved refusal sites.

Removal of oil that has not been retained by ditches and thresholds are retained by oil separators, normally positioned after the sedimentation basins.

Certain types of rock have high loadings of heavy metals. Water with high SS content may thus also have elevated content of heavy metals. Organic contaminants such as oil and PAH are also often particle bound. Removal of suspended particles from the tunnelling water is thus an important and relatively simple measure of water treatment. However, in a biological context the removal of particle bound

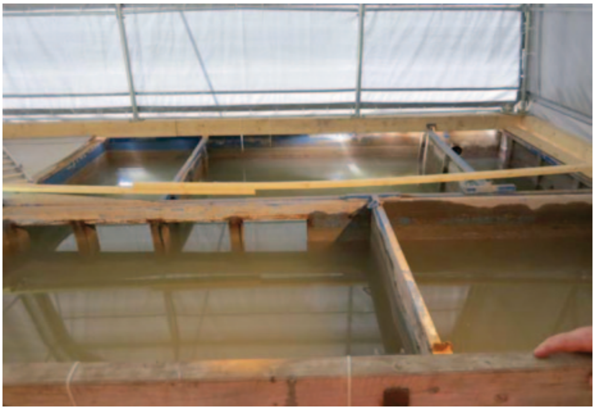


Fig. 2 Example of sedimentation pool constructed to enable minimal water turbulence and S-shaped flow

contaminants may not be sufficient as dissolved contaminants are considered more bioavailable and, thus, more detrimental to the aquatic biota [17].

Nitrogen—Ammonia—Ammonium

Technologies removing nitrogen from water include ion exchange and denitrification [27]. The NPRA has not gained practical experience with such technology on construction sites. The ammonia concentration can, however, be reduced by adjusting the alkalinity of the tunnelling water. Blasting rock can, moreover, be hosed down before deposition in order to reduce nitrogen runoff from disposal sites and reused masses. Such a solution involves, however, large amounts of water that must pass through purification systems and can thus be technically complicated.

pH Adjustment

Tunnelling water can periodically have pH up to 11–12, which is detrimental for aquatic organisms. Adjustment of pH, often by addition of HCl, may be performed with respect to aquatic life in the recipient and/or improved particle sedimentation. Maintenance of a stable pH by addition of acid demands thorough follow-up of the system. Addition of carbon dioxide is a more environmental friendly method of reducing the alkalinity. Norwegian construction sites have, however, not gained experience with this method.

Recirculation of Drill Rig Water

Recirculation of the drill rig water will result in reduced water quantities transported out of the tunnel. Particles in the water must be removed in order to avoid damage to the machinery, while the pH must be adjusted with respect to the working environment. Recirculation motivates the contractor to operate the installations optimally in order to avoid unnecessary maintenance costs of the machinery. As a consequence, dimensions of the water purification systems will be reduced and routines for follow-up of additional purification steps such as pH regulation or addition of coagulants will be better [22].

Retainment of Polypropylene Fibres

Filters may be installed in the water treatment systems to prevent polypropylene fibres to block the pumps and follow the tunnelling water to the recipient.

Polypropylene fibres are easily transported by water and wind due to its low specific weigh. Protective measures must thus be taken to prevent fibres from spreading when tunnelling masses are reused below water level. Deployment of silt-curtains have proven not be a successful measure to contain and collect fibres that find their way to the water surface. Containment booms may be more efficient as they are not as easily pulled below the surface as silt curtains. Finally, temporary dams made of blasting rock have proven to be very efficient in retaining fibres.

Conclusion

Purification of tunnelling water is viable. Technology and degree of water treatment varies from project to project depending on vulnerability of recipients, but also largely due to know-how of local authorities and technologists on the project. In order to ensure quality of tunnelling water, research and development is needed in terms of identifying pollutants and concentrations, biological effects and limits of tolerance (EQS), proper handling of naturally radioactive masses, as well as improved water purification systems in terms of particle sedimentation, removal of nitrogen/ammonia and pH regulation.

References

1. Alabaster JS, Lloyd R (1982) Water quality criteria for freshwater fish. Butterworths, London
2. Baker JP, Schofield CL (1982) Aluminium toxicity to fish in acidic waters. Water Air Soil Pollut 18:289–309

3. Barnes DK, Galgani F et al (2009) Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc Lond B Biol Sci 364(1526):1985–1998
4. Bilotta GS, Brazier RE (2008) Review. Understanding the influence of suspended solids on water quality and aquatic biota (2008). Water Res 42:2849–2861
5. Boholm Å LR (1999) Issues of risk, trust and knowledge: the Hallandsås tunnel case. Ambio 25(6):556–561
6. Bækken T (2005) Emission of tunnel water to Korten stream. Effects on sediments and biology in Korten stram, Homanns stream and Ilene nature reserve. NIVA report in Norwegian. ISBN: 82-577-4642–8
7. Bækken T (1998) Nitrogen runoff from tunnelling masses. NIVA report in Norwegian. ISBN: 82-577-3509–4
8. Bækken T (2000) Emission of tunnelling water to Maste stream Modum municipality. Effects on water chemistry, benthic organisms and fish. Final report. NIVA report in Norwegian. ISBN: 82-577-3917–0
9. Canadian Council of Ministers of the Environment (CCME) (1999/2002) Canadian water quality guidelines for the protection of aquatic life. Total particulate matter. http://ceqg-rcqe.ccme.ca/
10. Craft ES, Abu-Qare AW et al (2004) Depleted and natural uranium; chemistry and toxicological effects. J Toxicol Environ Health B Crit Rev 7:297–317
11. Emmerson K, Lund RV et al (1975) Aqueous ammonia equilibrium calculations: effect of pH and temperature. J Fish Res Board Can 32:2379–2383
12. Hals PI, Standal E et al (2011) Knowledge of marine litter in Norway. KLIF report TA 2753 (in Norwegian)
13. Hessen DO Biological effects of particles in water (1988) Limnos 3 (In Norwegian), ISSN 0333–3574, pp. 1–7
14. Hindar A (2010) Highway E18 Grimstad—Kristiansand; effects and quantification of acidic runoff from deposits of sulphide-bearing rock. NIVA report no. 5947-2010. ISBN: 978-82-577-5682–6
15. Knoph MB (1995) Toxicity of ammonia to Atlantic salmon (*Salmo salar* L.). Dissertation dr. scient, University of Bergen. ISBN: 82-7744–0170
16. Kruuse-Meyer R (2006) Tunnel run-off. Analyses of water and sludge samples during construction of tunnels with blasting operations. Master thesis NTNU
17. Meland S, Borgstrom et al (2010) Chemical and ecological effects of contaminated tunnel wash water runoff to a small Norwegian stream. Sci Total Environ 408(19):4107–4117
18. NFF Norwegian Tunnelling Society (2009) Technical Report 09, Treatment and emission of tunnelling water, in Norwegian
19. Ng KL, Obbard JP (2006) Prevalence of microplastics in Singapore's coastal marine environment. Mar Pollut Bull 52(7):761–767
20. Norwegian RProtectionA (2012) Bulletin (Stråleverninfo) 7:2012, Alum shale—source of radioactive waste and pollution, in Norwegian, www.nrpa.no
21. NPRA (2007) Håndbok 025 Prosesskode 1– Standard beskrivelsestekster for road contracts, process 33.4,
22. NPRA (2011) (VD) report No. 46, NORWAT—Nordic Road Water, Road and water pollution—A literature survey and identification of knowledge gaps
23. Song Y, Salbu B et al (2012) Early stress responses in Atlantic salmon (*Salmo salar*) exposed to environmentally relevant concentrations of uranium. Aquatic Toxicol 112–113:62–71
24. Teien H-C (2005) Transformation of aluminium species in unstable aquatic mixing zones—mobility and bioavailability towards fish. Dissertation dr. philos, UMB. ISBN: 82-575-0665–6
25. Teuten EL, Saquing JM et al (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philos Trans R Soc Lond B Biol Sci 364(1526):2027–2045
26. Thompson RC, Moore CJ et al (2009) Plastics, the environment and human health: current consensus and future trends. Philos Trans R Soc Lond B Biol Sci 364(1526):2153–2166

27. Tryland Ø (1977) Removal of nitrogenic compounds from waste water. Literature survey. Results from investigations at NIVA (in Norwegian). NIVA report FR–311
28. Vik EA, Sverdrup L et al (2000) Experiences from environmental risk management of chemical grouting agents used during construction of the Romeriksporten tunnel. Tunn Undergr Space Tech Constr Mater 15(4):369–378

Seasonal Trends in Bioaccumulation of Heavy Metals in Fauna of Stormwater Ponds

Diana Agnete Stephansen, Asbjørn Haaning Nielsen, Thorkild Hvitved-Jacobsen, Carlos Alberto Arias, Hans Brix and Jes Vollertsen

Abstract Fauna caught in three stormwater ponds, two receiving highway run-off and one receiving runoff from a center for trucks, was analyzed for copper, iron, zinc, cadmium, chromium, and lead. The fauna was monitored from March to October with 1-month intervals to evaluate seasonal trends in bioaccumulation. The results were compared with similar results from two natural shallow lakes of the same region. The study showed that there was some tendency for copper and also to some degree for other metals to be present in slightly higher concentrations in fauna of the ponds. There was, however, no clear seasonal trend in concentrations when looking at individual species or groups of species. The number of species caught in ponds and lakes was more or less identical, which together with an only slightly elevated heavy metal content of the fauna supported that stormwater ponds can contribute positively to the aquatic biodiversity of a region.

Introduction

Stormwater runoff is widely recognized as a major cause of nonpoint-source pollution. One approach to obtain proper management hereof is the use of stormwater detention ponds [12]. Such ponds are designed to detain stormwater runoff from impervious surfaces long enough to permit physical, biological and chemical treatment processes to take place [3]. A well-designed stormwater pond is efficient in retaining especially particle-bound pollutants by sedimentation, resulting in metals accumulating in the top layer of the sediments [6].

Even though it is seldom a criterion of design, a stormwater pond will over time serve as a wildlife habitat for plant and animal species. Scher et al. [8] argued that stormwater ponds could be viewed as biodiversity islands, contributing positively to the biodiversity of developed areas and along major roads. Le Viol et al. [5]

D. A. Stephansen (✉) · A. H. Nielsen · T. Hvitved-Jacobsen · C. A. Arias · J. Vollertsen
Department of Civil Engineering, Aalborg University, Sohngaardsholmsvej 57, 9000, Aalborg, Denmark

H. Brix
Department of Bioscience, Plant biology, Aarhus University, Ole Worms Allé 1, 8000, Aarhus C, Denmark
e-mail: dac@bio.aau.dk

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_43,

found that ponds treating highway runoff contributed positively to the biodiversity of aquatic macro-invertebrates. Stormwater ponds will in the future play an increasing role for stormwater management, and Tixier et al. [11] therefore discussed the ecological risks and benefits of such ponds and suggested a methodology to provide ecological quality goals and tools for assessment hereof.

Aquatic invertebrates take up metals through their diet or directly from the surrounding water [7, 13] and may therefore be exposed to elevated levels of metals when they inhabit a stormwater pond. So did for example Campbell [1] report that zinc, cadmium, nickel, and lead were present at 2–10 times higher concentrations in fish from stormwater detention ponds than in fish from natural lakes. For other water-dwelling animals, Stephansen et al. [10] reported that the content of several metals were somewhat elevated in animals from stormwater ponds compared to rural shallow lakes. Casey et al. [2] studied long-term temporal changes in heavy metal concentrations in sediments and macro-invertebrates from stormwater ponds to examine the potential bioaccumulation hereof. The variations in metal concentrations in water-dwelling invertebrates over the shorter term of a growth season stays, however, largely unknown.

This study has the objective to add to the knowledge on how pollutants are taken up by fauna living in stormwater detention ponds and to the debate on whether these man-made ponds can serve as “good quality” habitats for wildlife. It does so by investigating temporal trends of heavy metal accumulation in fauna of stormwater detention ponds and comparing these to corresponding accumulations in fauna from natural lakes. Three stormwater detention ponds and two shallow rural lakes unaffected by stormwater runoff were included in the study. Accumulation was followed for one growth season from spring to autumn by collecting fauna samples on a monthly basis.

Methodology

Water-dwelling fauna from 3 stormwater detention ponds (P1, P2, P3) located in Northern Denmark were sampled each month in the period from March to October, 2011. P1 received stormwater runoff from a highway service center for trucks, and P2 and P3 received runoff from a highway with average daily traffic (ADT) loads of 18,345 and 13,178, respectively. For comparison with naturally occurring levels of metals in water-dwelling fauna, two shallow lakes (L1, L2) located in the same region and not receiving urban or highway runoff were included in the survey. L1 is surrounded by agricultural land but somewhat shielded by trenches and shelterbelts, whereas L2 is located in a recreational heath and forest reserve of 170 ha. At an interval of a few years, organic matter is removed from L2 to ensure good condition for predator fish.

Samples were collected from the littoral zone and stored cold in 2.5 L plastic containers and transported to the laboratory. Within 24 hours the fauna was sorted according to groups of species, after which the samples were frozen (−20 °C). The samples were subsequently freeze-dried (ALPHA 1–2 LD plus, Martin Christ, Germany) at −55 °C at vacuum for 48 hours. The dried fauna samples were crushed using a glass spoon. Subsamples (approximately 0.5 g) were then transferred to Teflon vessels. Hereafter, the samples were digested using microwave assisted acid digestion according to EPA 3051. 10 ml concentrated nitric acid (67–69 % trace metal graded HNO_3, SCP Science, Canada) was added to the samples in the Teflon vessels and digested for 10 min in a microwave oven (Multiwave 3000, Anton Paar, Austria). After cooling, the digestates were diluted to volume with ultra-pure water (NanoPure Diamond UV, Barnstead, Thermo Scientific), transferred to plastic flasks and allowed to settle before analysis of metals.

Analysis and Quality Assurance

Copper (Cu), iron (Fe), zinc (Zn), cadmium (Cd), chromium (Cr) and lead (Pb) was measured in the fauna samples by Inductively Coupled Argon Plasma with Optical Emission Spectrometry detection (ICP-OES) (ICAP 6300 Duo View, Thermo Scientific). The elements were determined axially at two to three wavelengths. For all ICP-OES analyses, matrix-matched multi-element standards were used for external calibrations. The multi-element standards were prepared from single element standards (1000 µg ml-1, PlasmaCAL, SCP Science, Canada). To calibrate the ICP-OES for change in plasma intensity, scandium (Sc) was continuous injected. The applied analytical method was continuously verified using certified reference material (EnviroMAT—BE1, SCP Science, Canada). The reference material was included in each digestion batch (16 samples). Concentrations were within the tolerance of the reference material for Cu, Fe, Cd, Cr and Pb. For Zn, 1 reference of 24 did not match the tolerance interval of the reference material.

For each month's catch at a given site, the median concentration of metals was used to express the general bioaccumulation of metals in fauna from that site and date. Medians were used because the measured concentrations were generally not normal distributed. For the same reason, deviations were calculated as 25 and 75 % percentiles of the respective sample population.

Results and Discussion

The collected fauna was sorted into a total of 24 groups of species. Some groups contained only one species while others contained several species. The lumping of species was largely governed by the available fauna mass as the analytical procedure for determination of metals required 0.5 g of sample dry mass. The frequency of caught species in the three stormwater detention ponds and two shallow lakes is shown schematically in Table 1.

Table 1 Animals caught in ponds and lakes in the growth season of 2011

Species	Mar	Apr	May	June	July	Aug	Sep	Oct
Fry	L1	P2, P3, L1, L2	P2, P3, L1, L2	P2, P3, L1, L2	P2, P3, L1	P2, P3, L1, L2	P2, P3, L1	P2, P3, L1, L2
Naucore		P3, L1, L2	P2, P3, L1, L2	P2, P3, L2	P2, L1, L2	P2, P3, L1, L2	P2. P3, L1, L2	P2, P3, L1, L2
Dragonfly (Aeshnidae)		P1, P3, L1, L2	P3, L1, L2	P1, P2, P3, L2	P1, P3, L1, L2	P1, P2, P3, L1, L2	P1, P2, P3, L1, L2	P1, P2, P3, L1, L2
Dragonfly (Libellulidae)	P1	P1,L2	P1,L1	P3,L1, L2	P1, P2, P3, L1, L2	P3, L1, L2	P1,L1, L2	P1,L1
Snail (Radic balthica)	P1, L1	P1, L1	P1, P2, L1	P1, P2, L1	P1, P2, L1	P1, P2, L1	P1, P2, L1	P1, P2, L1
Snail (Lymnaea stagnalis)		P2, P3, L2	P3, L2	P3, L2	P3, L2	P3, L1, L2	P3,L1, L2	P3,L2
Snail (Planorbis planorbis)		P3, L2	P3, L2	P3, L2	P3, L2	P3, L2	P3, L2	P3, L2
Water beetle		P2, L1	P2, P3, L1	P2, L1	P2, P3, L1, L2	P2, P3, L1	P2, P3, L1	P3
Leech	P1	P1, L2	P1, L1, L2	P1, P2, L2	P1, P2, L1	P1	P1	P1, L1
Damselfly	P1, L1	P1, P3, L1	P1, P2, P3, L1, L2	P1, P2, P3, L1, L2	P1, P3	P1	P1, L1	P1, L1
Gammarus		P2, P3	P2, P3	P2, P3	P2	P2, P3	P2, P3	P2
Freshwater mussels		P1, P3, L2	P1, P3, L2	P1, P3, L1	P1, P3	P1, P3	P1, P3	P1, P3
Backswimmer		P2, L1		P2, P3, L1	P2, P3, L1, L2	P2, P3, L2	P1, P2, P3, L2	P1, P2, L2
Salamander		L2		P3	P1, P3, L1, L2	P1, L1		P2
Waterlouse	L1	P2, P3	P2					
Caddisfly		P2, L1, L2	P2, P3, L1, L2					
Tadpoles			P1, P2, P3, L1, L2	P1, P3, L2				
Water boatman			P2	P2				

Table 1 (continued)

Species	Mar	Apr	May	June	July	Aug	Sep	Oct
Water beetle (larvae)			P2	P2				
Mayfly		L2	L2					
Frog				P1	L2			
Backswim-mer (nymphs)				P2, L2				
Mosquito larvae		P1						
Water stick insect			L1					

Only 6 groups of species were detected in all aquatic systems, of which the dragonfly species Aeshnidae was most consistently caught. Comparing ponds and lakes as groups, also fry, naucores, the dragonfly Libellulidae, snails and water beetles were detected in both types of system. Most groups of species were not caught in each aquatic system at all times. Only fry, the three species of snails, leeches, damselflies and gammarus were found consistently in either a lake or a pond. For some animals the reason was obvious in terms of their life-cycle, for example mayflies and tadpoles. For most species, however, no obvious reason for lack of catch was identified.

Comparing the medians of the determined heavy metal contents for all fauna in all ponds and lakes at all times (Fig. 1), the animals from stormwater ponds P1 and P2 tended to have slightly higher metal contents than animals from pond P3 and the two lakes. However, for the Pb-content no difference could be seen between any of the aquatic systems, and for Fe it was animals from P1 and P3 which had the highest contents. Stephansen et al. [9] screened the fauna of 9 stormwater ponds and 11 lakes for heavy metals—here amongst the ponds and lakes of the present study. They saw similar differences between shallow lakes and stormwater detention ponds, with animals from ponds generally showing slightly higher metal contents than animals from shallow lakes. Karouna-Renier and Sparling [4] studied metal accumulation in odonates, molluscs and a composite group of invertebrates. They found that odonates from ponds receiving runoff from commercial catchments had increased contents of Zn and Cu compared to other land uses—here among open-space watersheds.

The general level of metals corresponded well with data reported by Karouna-Renier and Sparling [4] and with levels reported by Casey et al. (2006) who found 20–60 mg Cu $(kg\ DM)^{-1}$, 0.5–2 mg Pb $(kg\ DM)^{-1}$, and 70–170 mg Zn $(kg\ DM)^{1}$ in animals from stormwater ponds. Looking at the temporal trend of the data presented in Fig. 1, a weak tendency towards a seasonal variation is seen. For many of the 30 combinations of aquatic systems and metals, the content is highest in the spring period and declining during summer. However, the tendencies are in no way clear and differ from system to system and from metal to metal. For some combinations

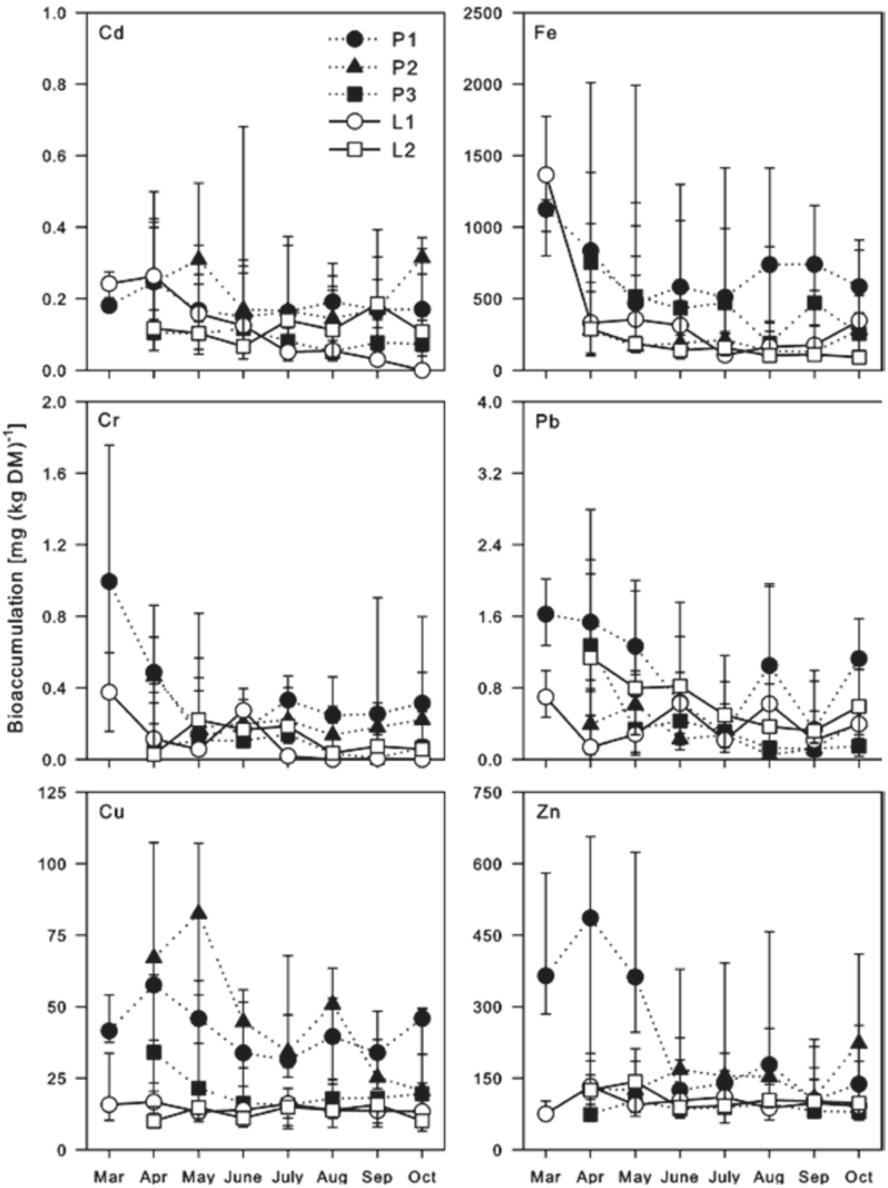


Fig. 1 Temporal trend in median heavy metals content of all animals caught

of metal and pond, the metal content again increases in the late summer, for some it stabilizes, and for some it continues to decrease.

An elevated metal content in the early spring can be due to numerous factors, chemical as well as biological. For example could the uptake of metals have been increased during the winter because some of the species hibernate in the sediments or seek lower towards the bottom of the water column to survive the cold water. In both cases they come in closer contact with the sediments where metals are present in manifold higher concentrations compared to the animal tissue [9].

Another explanation could be that metals may be more available for uptake by fauna during the winter due to a different metal speciation caused by differences in pH. In general the pH of ponds and lakes tend to be lower in winter compared to summer due to photosynthesis consuming carbonate from the bulk water.

A higher metal concentration could also be food related. Hibernation and absence of food can both cause loss of bodyweight. Poor excretion ability of the fauna towards the metals can in such case cause increased metal concentrations in the individuals. The metal concentrations would then drop when the growth season begins and the food becomes assessable again. A further explanation could be that some of the investigated species feed on algae of which some have higher affinity towards metals than others.

For the five aquatic systems the temporal variation in bioaccumulation of Cu and Zn was plotted for the most caught species groups (Fig. 2 and 3). For Cu the bioaccumulation was elevated in fauna from stormwater ponds compared to fauna from lakes, whereas the levels of Zn were somewhat the same for fauna in all aquatic systems. An exception was Zn in P1, which here occurred at up to five time higher concentrations than the other sites. This could be explained by the sediments of P1 comprising 2.5 times more Zn than P2 and 100 times more Zn than P3 [9].

No clear temporal trends were seen in the data set; neither as systematic fluctuations over the growth season, nor as correlation between the bioaccumulation of any metal in a specific fauna species. In some specific cases some tendencies could, though, be suggested. For example for the snail Radix Balthica living in the pond P1 an increasing concentration of Cu over the growth season was seen (Fig. 2). Additionally, the temporal trend for Cu in leeches from the same pond correlated well with the Cu in those snails, suggesting that maybe the leeches feed on those snails and thereby toke up Cu. However, the same seasonally tendencies could not be seen for the pond P2 and the lake L1 where this snail species was also collected. These tendencies may therefore well have be a matter of coincidence.

Even though this study was not intended to give a picture of the biodiversity of the studied lakes and ponds, the number of species caught at the different sites still gives some indication of the fauna diversity. From Table 1 it can be seen that it in general was possible to catch many different species in each of the aquatic systems. There was furthermore no systematic difference in which species were caught in ponds and which were caught in lakes. Furthermore was the number of different species caught in ponds versus lakes comparable. In combination with the observation that heavy metal concentrations in the ponds were not much above what was seen in the lakes, this study therefore supports the idea that stormwater ponds—although man-made—can become valuable aquatic ecosystems and contribute to the aquatic biodiversity of a region.

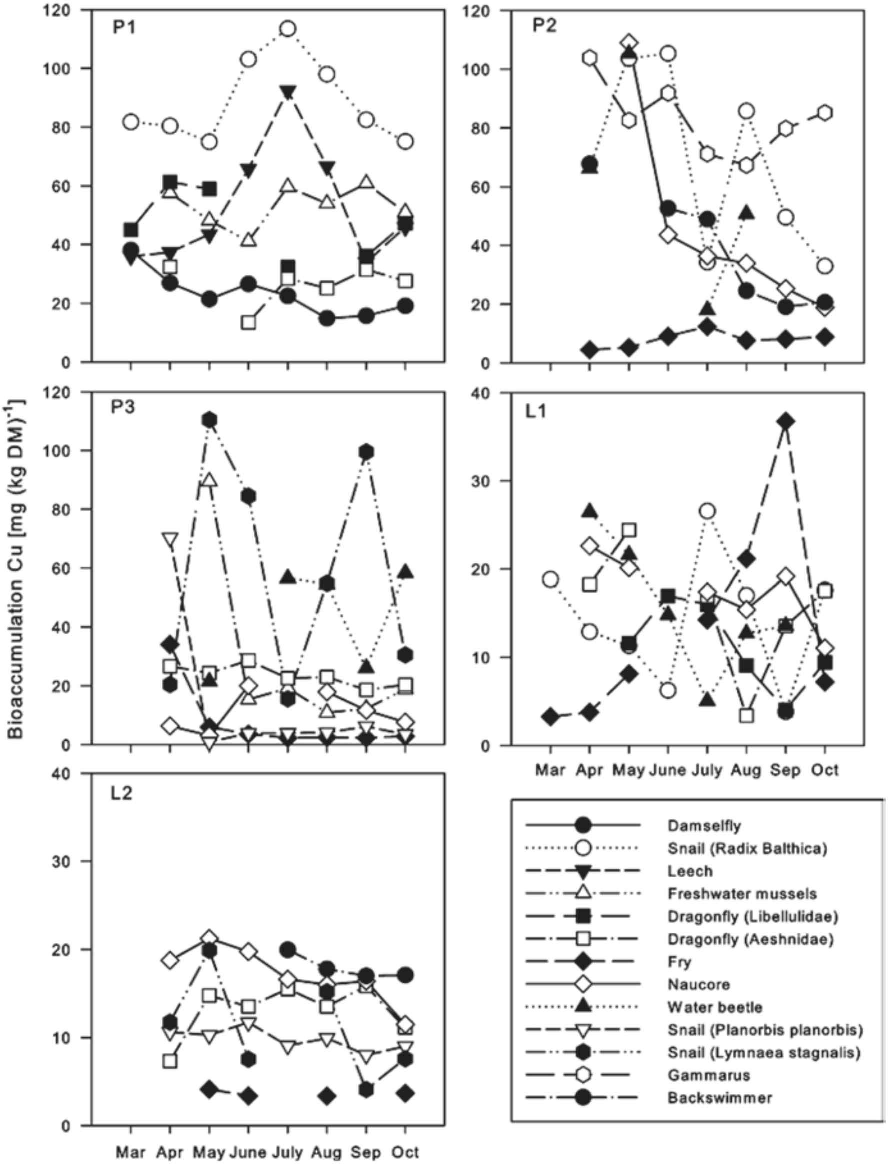


Fig. 2 Bioaccumulation of Cu in selected fauna species. Note different scales on the x-axes

Conclusion

Compared to fauna caught in two shallow lakes, fauna caught in three stormwater detention ponds had somewhat higher contents of copper and to some degree also slightly increased contents of other heavy metals. Contents of lead were, however,

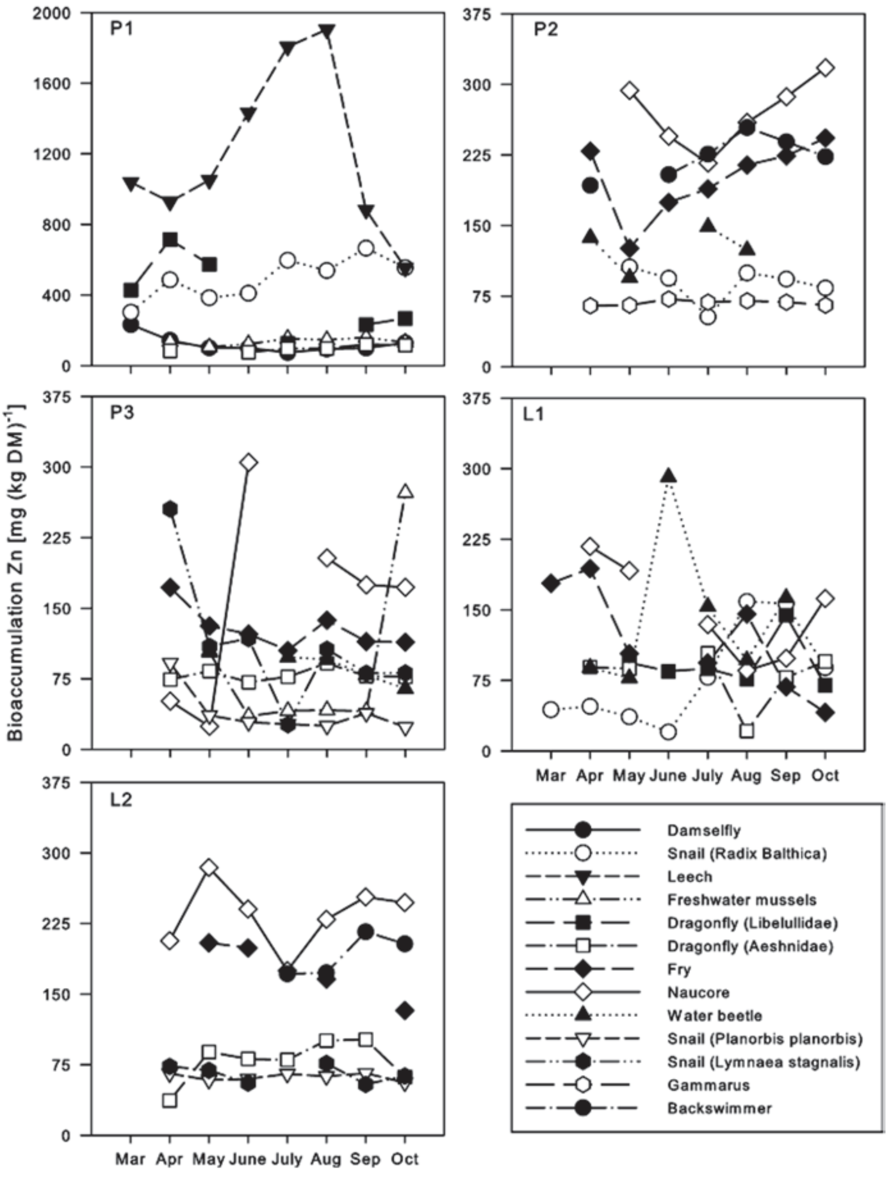


Fig. 3 Bioaccumulation of Zn in selected fauna species. Note different scales on the x-axes

indistinguishable for the two types of aquatic environments. The median of heavy metal concentrations for all caught fauna samples in a pond or a lake seemed to be highest in the early spring. However, when looking at individual species or groups of species that were caught more or less consistently over the whole growth season, such trend was not present.

The diversity of caught animals was comparable in the stormwater ponds and the shallow lakes, pointing towards stormwater ponds having ecological values similar to natural shallow lakes. This study therefore supports the concept of stormwater points contributing positively to fauna bisodiversity.

References

1. Campbell KR (1994) Concentrations of heavy metals associated with urban runoff in fish living in stormwater treatment ponds. Arch Environ Contam Toxicol 27:352–356
2. Casey RE, Simon JA, Atueyi S, Snodgrass JW, Karouna-Renier N, Sparling DW (2006) Temporal trends of trace metals in sediment and invertebrates from stormwater management ponds. Water Air Soil Pollut 178:69–77
3. Hvitved-Jacobsen T, Vollertsen J, Nielsen AH (2010) Urban and highway stormwater pollution. CRC Press, Taylor & Francis Group
4. Karouna-Renier NK, Sparling DW (2001) Relationships between ambient geochemistry, watershed land-use and trace metal concentrations in aquatic invertebrates living in stormwater treatment ponds. Environ Pollut 112:183–192
5. Le Viol I, Mocq J, Julliard R, Kerbiriou C (2009) The contribution of motorway stormwater retention ponds to the biodiversity of aquatic macroinvertebrates. Biol Conserv 142:3163–3171
6. Pontiera H, Williams JB, May E (2004) Progressive changes in water and sediment quality in a wetland system for control of highway runoff. Sci Total Environ 319(1–3):215–224
7. Rainbow PS (2002) Trace metal concentrations in aquatic invertebrates: why and so what? Environ Pollut 120:497–507
8. Scher O, Chavaren P, Despreaux M, Thiéry A (2004) Highway stormwater detention ponds as biodiversity islands? Arch Sci 57:121–130
9. Stephansen DA, Nielsen AH, Hvitved Jacobsen T, Vollertsen J (subm). Allocation of metals in fauna, flora and sediments of stormwater ponds. Submitted for Ecological Engineering
10. Stephansen DA, Nielsen AH, Hvitved Jacobsen T, Vollertsen J (2012). Bioaccumulation of heavy metals in fauna from wet detention ponds for stormwater runoff. In Highway and Urban Environment. Book Series: Alliance for Global Sustainability Series, vol. 19: 329–338. Editors: Rauch S, Morrison G M, ISBN 978-94-007-2539–3
11. Tixier G, Lafont M, Grapentine L, Rochfort Q, Marsalek J (2011) Ecological risk assessment of urban stormwater ponds: Literature review and proposal of a new conceptual approach providing ecological quality goals and the associated bioassessment tools. Ecological Indicators 11:1497–1506
12. Triboit F, Laffont-Schwob I, Demory F, Soulié-Märsche I, Rabier J, Despréaux M, Thiéry A (2009) Heavy Metal Lability in Porewater of Highway Detention Pond Sediments in South-Eastern France in Relation to Submerged Vegetation. Water Air Soil Poll 209:229–240
13. Walker CH, Hopkin SP, Sibly RM, Peakall DB (2006) Principles of Ecotoxicology. CRC Press, Taylor & Francis Group

Accumulation of Metals and Metalloids in Larvae of Insects and Frog Living in Wet Sedimentation Ponds Receiving Runoff from a Four Lane Motorway

Sondre Meland, Mari Bryn Damsgård, Lindis Skipperud and Lene Sørlie Heier

Abstract Road runoff, containing high concentrations of several contaminants, is a significant source of diffuse pollution. Much effort has therefore been done to mitigate the contamination of receiving waters, and the building of wet sedimentation ponds is a typical example. These ponds are inhabited by aquatic organisms which may experience exposures of high levels of e.g. metals. The present study investigated the concentrations of several metals and metalloids in water, sediment and aquatic insects obtained from wet sedimentation ponds. Most of the ponds were only moderately contaminated, however, the pond receiving tunnel wash water was highly contaminated by copper (Cu) and zinc (Zn). The metal and metalloid concentrations in water and sediment were only slightly correlated with metal and metalloid body burdens in the insects. Finally, metals and metalloids accumulated in a time-dependent manner in frog eggs and tadpoles sampled.

Introduction

Contaminated road runoff is considered world-wide as a significant threat towards the aquatic ecosystem. In that respect, several measures have been established to mitigate both peak runoffs and pollutant loadings. The by far most applied mitigation method is wet sedimentation ponds. As this type of pond is very similar to naturally occurring ponds, they seem to be an important habitat for several aquatic organisms such as aquatic insects and amphibians. Although organisms inhabiting wet sedimentation ponds may be exposed to elevated metal concentrations, their metal body burdens has, however, only rarely been documented [1, 2, 12].

S. Meland (✉) · M. B. Damsgård · L. Skipperud · L. S. Heier
Department of Plant and Environmental Sciences, Norwegian University of Life Sciences,
PO Box 5003, N-1432, Ås, Norway
e-mail: sondre.meland@vegvesen.no

S. Meland
Environmental Assessment Section, Norwegian Public Roads Administration, Dep,
PO Box 8142, N-0033, Oslo, Norway

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_44,

The present study aimed to document the accumulation of several traffic-related metals in insect larvae of damselflies (Zygoptera), dragonflies (Anisoptera) and mayflies (Ephemeroptera). In addition, the accumulation of metals in the developmental stages egg and tadpole of the amphibian common frog (*Rana temporaria*) was studied. Samples of animals, water and sediment were obtained from five sedimentation ponds receiving runoff from a motorway in Norway, as well as from two small ponds unaffected from traffic for comparison.

Materials and Methods

Study Sites

Five sedimentation ponds situated along the motorway E6 south of Oslo, Norway were used in the present study. Four of the ponds Skullerud (Sku: surface area: 978 m^2/annual average daily traffic: 53000), Taraldrud N (Tar N: 880 m^2/37000), Taraldrud (Tar: 1475 m^2/37000) and Taraldrud S (Tar S: 465 m^2/37000) receive ordinary road runoff, while the fifth, Vassum (Vas: 550 m^2/26000) also receives tunnel wash water runoff during cleaning of three tunnels. Two small ponds unaffected from traffic were included for comparison, one situated at the university campus (CtrC: 535 m^2) and another at a local farm (CtrF: 194 m^2).

Water, sediment and organism were sampled early May 2010. In addition, the sampling of frog eggs and tadpoles from Sku was conducted 24th and 30th April, 21st May and 11th June. In the ponds Sku, Tar N and Vas, samples were obtained from three sampling sites: centre of the ponds, inlets and outlets. In Taraldrud S the samples were obtained from inlet and outlet, while in Tar the samples were only obtained from the inlet. In the Ctr ponds the samples were obtained from one sampling site. Temperature, conductivity and pH in the water were measured *in situ* by using a handheld water quality sonde (Extech ExStik II EC510).

Metals and Metalloids in Water, Sediment and Biota

Water samples and digested upper-layer sediment samples were analysed and determined for the nine metals and metalloids aluminum (Al, only in water), antimony (Sb), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), cupper (Cu), iron (Fe, only in water), lead (Pb), nickel (Ni), zinc and (Zn) by using ICP-MS. The term "metal" will be used for metalloids (As and Sb) and metals hereafter.

Insect larvae and frog eggs and tadpoles were washed in MilliQ water to remove particles and contaminated water from their surface. In addition, the frog eggs were dissected, i.e. the gelatinous layer around the embryo was removed and excluded from the analysis. To secure enough tissue for the metal analysis, individuals of damselflies ($n=5$), mayflies ($n=15$), frog eggs ($n=40/20$) and tadpoles ($n=10$)

from each pond and sampling site were pooled. Individuals of dragonflies were measured singularly. Number of samples from each pond and site ranged from 1 to 5, depending on the availability of collected organisms. Digested biotic samples were analysed and determined for the same 11 metals as in the water samples by using ICP-MS.

Results and Discussion

Metal Concentrations in Water and Sediment

The metal concentrations in the water samples obtained from the various sedimentation ponds (Table 1) were comparable with measurements in other previous studies [3, 6]. According to the Norwegian Environmental Quality Standard System Cu, Zn, Ni and Pb were the metals of most concern. Especially in the Vas pond receiving tunnel wash water runoffs which were classified as highly polluted due to elevated concentrations of Cu and Zn. The internal variation of metals between the sampled ponds was described by conducting a redundancy analysis (RDA) with the various ponds as categorical explanatory variable. The results showed that the ponds significantly explained 87 % ($p = 0.002$) of the total variation and that all metals are positively correlated along the 1st axis. The RDA result is depicted in an ordination diagram and the distribution of the samples along the 1st axis can be considered as a pollution index increasing from left to right (Fig. 1A). Based on this classification the ranking of the ponds from low to high was CtrC < Tar N < Tar < CtrF < Tar S < Skul < Vas.

Opposite to the metal concentrations in the water, the sediment appeared to be less polluted according to the Norwegian EQS for metals in sediment. However, Zn and Cu (Table 2) were present at elevated concentrations in the sediment from the Vas pond which is very coherent with the concentrations of these two metals in the water. The presence of high concentrations of Cu and Zn, both in water and sediment, is observed in other studies as well [e.g. 7, 11, 15]. Tire and brake wear are believed to be the most important sources for these two metals [e.g. 8, 13, 14]. Generally, the metal levels in the sediment obtained from sedimentation ponds were in the same order of magnitude as the control ponds. The RDA revealed that using the ponds as categorical explanatory variable significantly explained 83 % of the total variation in the data ($p = 0.002$). As in the water data, the metals were positively correlated along the 1st axis (Fig. 1B). Ranking of the ponds on the 1st axis with increasing metal concentrations was Tar N < Tar S < Tar < Sku < CtrC < CtrF < Vas.

Metal Accumulation in Biota

The concentrations of metals in the various organisms are presented in Table 3, while the RDA using ponds and organisms as categorical explanatory variables is

Table 1 Metal concentrations (µg/L, mean ± st.dev) and water quality parameters from the ponds

Parameter	CtrC	CtrF	Sku	Tar	Tar N	Tar S	Vas
No. samp	1	1	3	1	3	2	3
Al	47	557	441 ± 99	159	172 ± 84	424 ± 454	1042 ± 589
As	0.24	0.48	0.18 ± 0.03	0.17	0.22 ± 0.02	0.21 ± 0.1	0.34 ± 0.1
Cd	0.0032	0.0053	0.025 ± 0.004	0.030	0.0053 ± 0.002	0.012 ± 0.01	0.042 ± 0.01
Co	0.074	0.24	0.25 ± 0.1	0.11	0.13 ± 0.1	0.28 ± 0.3	2.0 ± 0.2
Cr	0.17	0.58	3.3 ± 1.1	0.27	0.34 ± 0.1	1.0 ± 0.8	3.3 ± 2.3
Cu	0.64	2.2	10 ± 2.2	5.7	3.4 ± 1.2	6.4 ± 4.4	20 ± 4.2
Fe	208	1013	551 ± 113	254	299 ± 120	635 ± 655	1526 ± 620
Ni	0.89	1.3	1.2 ± 0.2	2.8	1.1 ± 0.8	0.97 ± 0.5	5.1 ± 0.1
Pb	0.053	0.29	0.80 ± 0.2	0.19	0.26 ± 0.1	0.71 ± 0.8	2.6 ± 1.1
Sb	0.09	0.07	0.86 ± 0.2	0.26	0.78 ± 0.03	1.2 ± 0.4	3.6 ± 0.7
Zn	2.3	1.6	24 ± 8.7	6.7	6.0 ± 2.2	47 ± 45	154 ± 53
Cond (µS/cm)	227	100	541 ± 14	649	362 ± 5	553 ± 11	1162 ± 303
Cl (mg/L)	21	8	105 ± 5	141	89 ± 1	149 ± 1	333 ± 122
pH (min-max)	8.9	7.9	7.4–8.1	n.a.	8.2 ± 8.8	7.9–8.0	8.1–8.5
TOC (mg/L)	4.9	5.1	5.1 ± 0.3	8.3	2.6 ± 0.1	2.6 ± 0.1	6.6 ± 1.5
Temp (°C)	18	9	6 ± 0.2	14	12 ± 0.2	12 ± 0.6	15 ± 0.7

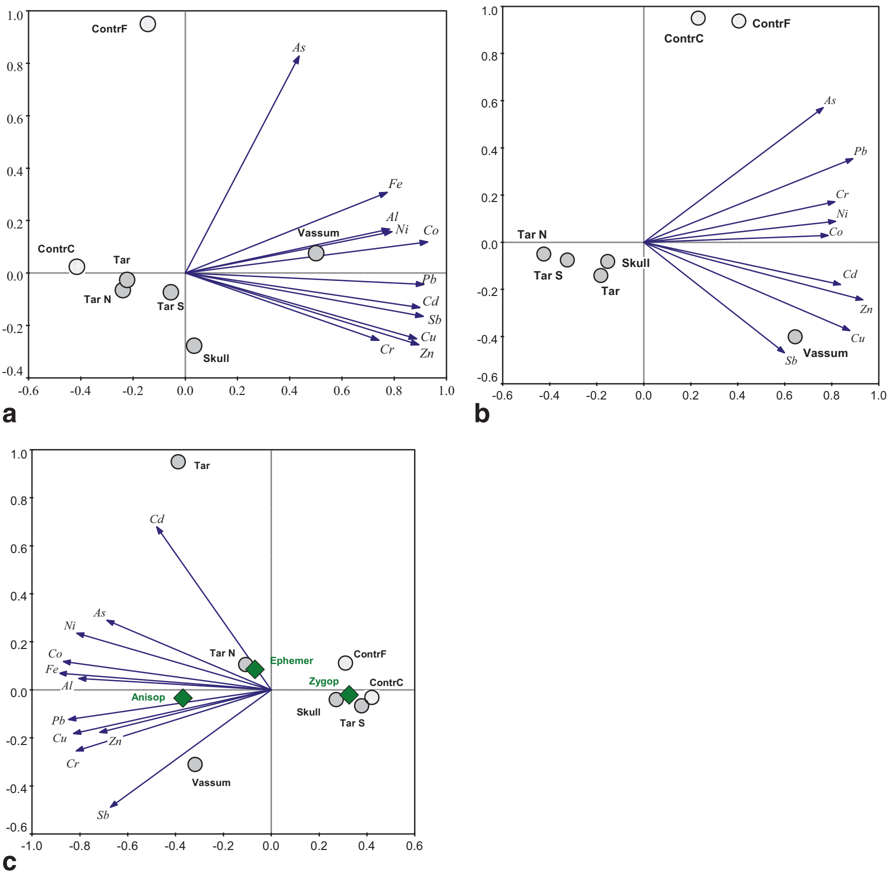


Fig. 1 Ordination diagram based on RDA depicting the relationship among the various ponds and metal concentrations in water (**a**), sediment (**b**) and biota (**c**). *Grey circles* (sedimentation ponds), *white circles* (control ponds) and *green squares* (organisms)

displayed in Fig. 1C. A general trend in the data material was that the metals were positively correlated with each other, and in addition, along the 1st RDA axis (60 %, $p=0.002$). The overall RDA model significantly explained 77 % ($p=0.002$) of the total variation of the metal accumulation.

Ranking the ponds along the 1st RDA axis with increasing metal accumulation was CtrC < Tar S < CtrF < Sku < Tar N < Vas < Tar. In addition, ranking the three different organism groups along the 1st RDA axis clearly indicates that the highest concentrations are found in dragonflies, followed by mayflies and damselflies.

It is well known from the literature that accumulation of metals in biota depends on the speciation which is largely influenced by water quality variables such as pH, ionic strength, redox potential and the presence of organic and inorganic ligands [10]. In addition, aquatic organisms also differ in their ability to accumulate metals from the surrounding environment depending on the particular physiology of the

Table 2 Metal concentrations (µg/g, mean ± st.dev) in sediment from the ponds

Parameter	CtrC	CtrF	Sku	Tar	Tar N	Tar S	Vas
No. samp	3	1	7	5	5	4	3
As	5.4 ± 0.1	5.9	1.9 ± 0.2	1.6 ± 0.5	1.07 ± 0.2	1.3 ± 0.5	2.9 ± 0.2
Cd	0.23 ± 0.01	0.21	0.25 ± 0.01	0.23 ± 0.1	0.068 ± 0.02	0.086 ± 0.02	0.36 ± 0.1
Co	9.1 ± 0.5	18	8.1 ± 1.9	8.8 ± 2.1	7.4 ± 1.2	9.3 ± 1.6	16 ± 3.7
Cr	60 ± 4.4	65	47 ± 14.5	30 ± 8.0	25 ± 6.6	42 ± 15.2	66 ± 11.2
Cu	16 ± 0.5	32	25 ± 9.1	23 ± 8.1	13 ± 3.7	16 ± 5.0	157 ± 18.7
Ni	29 ± 1	32	25 ± 5	21 ± 5	15 ± 2	23 ± 8	34 ± 5
Pb	31 ± 0.1	34	9.4 ± 3.1	7.0 ± 1.9	5.3 ± 0.9	7.3 ± 1.8	24 ± 2.9
Sb	0.0021 ± 0.001	0.0022	0.036 ± 0.03	0.0060 ± 0.01	0.0026 ± 0.002	0.0028 ± 0.0005	0.047 ± 0.03
Zn	142 ± 5	187	116 ± 43	65 ± 27	44 ± 7.9	97 ± 17	969 ± 132

Table 3 Metal concentrations in biota (µg/g wet weight, mean ± st.dev) from the various ponds. A = anisoptera (dragonfly) E = ephemeroptera (mayfly), Z = zygoptera (damselfly), Eg = frog egg, T = tadpole

Pond	Org	Al	As	Cd	Co	Cr	Cu
CtrC	E (1)	47	0.025	0.029	0.021	0.054	1.1
CtrC	Z (3)	33±7	0.024±0.003	0.019±0.005	0.014±0.01	0.057±0.01	1.3±0.1
CtrF	Z (5)	147±28	0.028±0.005	0.027±0.01	0.074±0.01	0.16±0.03	0.93±0.1
Sku	A (2)	178±13	0.016±0.002	0.012±0.004	0.076±0.01	0.45±0.07	4.1±1.5
Sku	Z (7)	81±26	0.030±0.01	0.034±0.01	0.032±0.01	0.21±0.04	1.6±0.3
Tar	A (5)	289±83	0.073±0.02	0.15±0.04	0.29±0.08	0.47±0.16	6.6±2.1
Tar N	E (13)	386±91	0.056±0.01	0.031±0.004	0.16±0.03	0.53±0.12	1.7±0.3
Tar S	E (1)	195	0.036	0.038	0.12	0.32	1.6
Tar S	Z (8)	35±16	0.024±0.01	0.021±0.005	0.035±0.01	0.074±0.03	1.3±0.2
Vas	A (14)	371±198	0.054±0.02	0.046±0.02	0.25±0.10	0.99±0.48	9.4±3.0
Vas	Z (4)	204±81	0.040±0.01	0.0094±0.002	0.11±0.04	0.37±0.15	2.7±0.6
Sku 1d	Eg (6)		0.023±0.002	0.0045±0.005	0.0079±0.0008	0.0039±0.0009	1.6±0.1
Sku 6d	Eg (5)		0.059±0.05	0.0062±0.001	0.014±0.003	0.023±0.02	1.5±0.2
Sku 27d	T (5)		0.16±0.03	0.038±0.01	0.40±0.07	2.9±0.6	6.4±1.3
Sku 48d	T (3)		0.22±0.01	0.080±0.01	0.52±0.05	3.5±0.3	10±0.3

organism, body size, age, sex and feeding habits [9] In fact, the accumulation may be different not only between groups of organisms but also between species within the same genus [4, 9]. Hence, an apparent weakness in the present study is therefore that the organisms were not determined to a species level, and, in addition, the invertebrate groups were not present in every pond. Hence, the variation in metal accumulation between the various ponds may not only be due to the pollution levels in these ponds, but also due to that different organisms were present in different ponds. Taking this into consideration, we applied a partial RDA (pRDA) on the data material to ascribe how much of the total variability could be assigned to the "pond factor" and the "species factor". The pRDA revealed that 21 % ($p=0.002$) and 9 % ($p=0.002$) of the total variability could be assigned to the "pond-factor" and "species factor", respectively. Forty seven % of the variability could not be separated between the two factors. Thus, differences between ponds are more important than the differences between the organisms in terms of describing the observed variation in metal accumulation in the present study.

The RDAs of the metal concentrations in sediment and water from the ponds indicated a strong linear trend in the material, i.e. increasing metal gradient. Hence, it was interesting to see if the concentrations of metals in sediment and water measured in the various ponds were correlated with the metal accumulation in the biota by using the RDA sample scores along axis 1 from the three RDA (sediment, water and organisms). The Pearson correlation coefficients (r) between "sediment and water", "sediment and organisms" and "water and organisms" were 0.7, −0.3 and −0.4, respectively. Only the former was significant. The rather weak and insignificant correlations may be explained from reasons such as:

1. Different accumulation between different organisms,
2. Food ingestion which may be a significant route of metal uptake [4] is not evaluated in the present study,
3. Nymphal molting will most likely have an significant effect on the total metal body burden as several metals will tend to accumulate in the exoskeleton [3, 4, 5] and
4. The bioavailable metal fractions in both sediment and water were not determined.

Nevertheless, performing an more in-depth correlation analysis using the metal concentrations in water and sediment together with the RDA sample scores from the organisms, revealed that Co (−0.5, $p=0.045$), Ni (−0.7, $p=0.009$), Cd (−0.6, $p=0.038$) and Sb (−0.6, $p=0.036$) concentrations in water and Zn (−0.6, $p=0.041$) concentrations in sediment were significant negative correlated (i.e. the increasing concentrations of these metals are associated to an increase in the metal accumulation in the organisms even at a high taxonomic level)

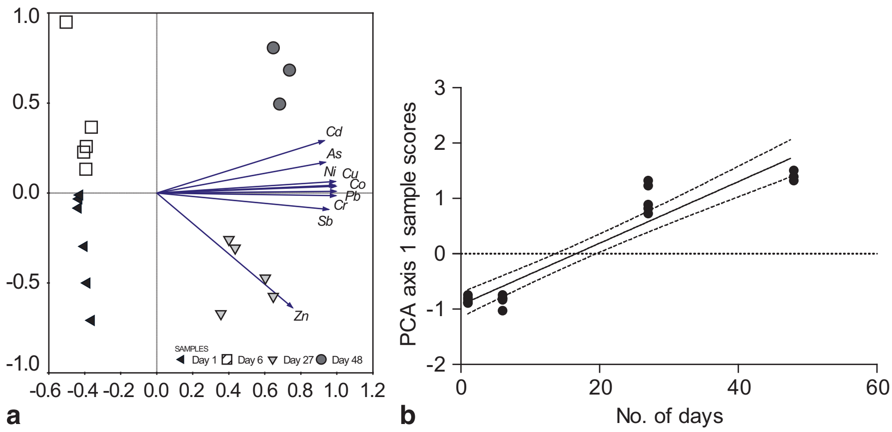


Fig. 2 **a** Ordination diagram based on a PCA depicting the time dependent uptake of trace elements in frog eggs and tadpoles. **b** One-way ANOVA with post test for linear trend between the days using the PCA sample scores ($r^2 = 0.8$, $p < 0.0001$)

Temporal Accumulation of Metals in Frog Eggs and Tadpoles

The concentrations of metals in egg and tadpoles are presented in Table 3, and the result of a principal component analysis (PCA) is depicted in Fig. 2A. All metals, beside Zn, appeared to increase during the studied period. The PCA axis 1 accounted for 91 % of the total variation in the data indicating a strong linear metal gradient. This was confirmed by a one-way ANOVA on the PCA sample scores (axis 1), which revealed significant time-dependent accumulation ($r = 0.8$, $p = 0.0001$) (Fig. 2B). The steepest increase was observed between the developmental stages egg and tadpole sampled day 6 day 27, respectively. This significant increase may reflect the fundamental physiological differences between the two developmental stages. Opposite to the "egg-stage" where metals only will accumulate passively, the "tadpole-stage" implies both active and passive uptake of metals through the ingestion of food, respiration through gills and passive diffusion through the body surface. Although the period between day 27 and 48 are of similar length (21 days) as between day 6 and 27, the accumulation rate for most of the metals seemed to flatten out. This may indicate that the metal body burdens approximated a threshold level under the prevailing conditions. Whether the observed metal accumulation has any toxicological implications are impossible to evaluate in the current study. However, a follow-up study which involves toxicological considerations has recently been commenced.

Conclusions

The present study has showed that water and sediment samples from sedimentation ponds only were moderately contaminated and not very distinct from the ponds unaffected by traffic. The pond receiving tunnel wash water was, however, contaminated by high levels of Cu and Zn both in water and sediment, and to some extent Ni and Pb in water. The metal concentrations in sediment and water were only marginally correlated with the metal body burdens of the sampled invertebrates. Finally, a significant time-dependent accumulation of metals in frog eggs and tadpoles was observed in a 48 days survey in Sku. Whether the observed metal body burdens in organisms inhabiting wet sedimentation ponds have any ecotoxicologial implications is not determined in the present study. However, the results may be considered as a baseline, being significant for future ecotoxicologial studies in such ponds.

References

1. Anderson BC, Bell T, Hodson P, Marsalek J, Watt WE (2004) Accumulation of trace metals in freshwater invertebrates in stormwater management facilities. Water Qual Res J Canada 39(4):362–373
2. Casey RE, Simon JA, Atueyi S, Snodgrass JW, Karouna-Renier N, Sparling DW (2007) Temporal trends of trace metals in sediment and invertebrates from stormwater management ponds. Water Air Soil Pollut 178(1–4):69–77. doi:10.1007/s11270-006-9132-z
3. Farm C (2002) Evaluation of the accumulation of sediment and heavy metals in a storm-water detention pond. Water Sci Technol 45(7):105–112
4. Scher O, Thiery A (2005) Odonata, amphibia and environmental characteristics in motorway stormwater retention ponds (Southern France) Hydrobiologia 551, 237–251
5. Hare L, Tessier A, Campbell PGC (1991) Trace-element distributions in aquatic insects—variations among generea, elements, and lakes. Can J Fisheries and. Aquatic Sciences 48(8):1481–1149
6. Lundberg K, Carling M, Lindmark P (1999) Treatment of highway runoff: a study of three detention ponds. The Science of The Total Environment 235(1–3):363–365
7. Maltby L, Forrow DM, Boxall ABA, Calow P, Betton CI (1995) The effects of motorway runoff on fresh-water ecosystems. 1. field-study. Environ Toxicol Chem 14(6):1079–1092
8. McKenzie ER, Money JE, Green PG, Young TM (2009) Metals associated with stormwater-relevant brake and tire samples. Science of The Total Environment 407(22):5855–5860. doi:10.1016/j.scitotenv.2009.07.018
9. Rainbow PS (2002) Trace metal concentrations in aquatic invertebrates: why and so what? Environ Pollut 120(3):497–507
10. Salbu B, Oughton DH (1995) Strategies of sampling, fractionation and analysis. In: Salbu B, Steinnes E (eds) Trace elements in natural waters. CRC Press, Boca Raton, pp 41–70
11. Scher O, Thiery A (2005) Odonata, amphibia and environmental characteristics in motorway stormwater retention ponds (Southern France), 237–251. doi:10.1007/s10750-005-4464-z
12. Stephansen D, Nielsen A, Hvitved-Jacobsen T, Vollertsen J (2012) Bioaccumulation of heavy metals in fauna from wet detention ponds for stormwater runoff. In: Rauch S, Morrison GM (eds) Urban Environment, vol 19. Alliance for global sustainability bookseries. Springer, Netherlands, pp 329–338. doi:10.1007/978-94-007-2540-9_30
13. Sternbeck J, Sjodin A, Andreasson K (2002) Metal emissions from road traffic and the influence of resuspension—results from two tunnel studies. Atmos Environ 36(30):4735–4744

14. Thorpe A, Harrison RM (2008) Sources and properties of non-exhaust particulate matter from road traffic: a review. Science of The Total Environment 400(1–3):270–282. doi:10.1016/j.scitotenv.2008.06.007
15. Wik A, Lycken J, Dave G (2008) Sediment quality assessment of road runoff detention systems in Sweden and the potential contribution of tire wear. Water Air Soil Pollut 194(1–4):301–314. doi:10.1007/s11270-008-9718-8

Mobility and Uptake of Antimony, Cadmium and Cobalt in Dragonfly Larvae (Odonata, Anisoptera) as a Function of Road Salt Concentrations—a Tracer Experiment

Lene Sørlie Heier, Mari Thanstrøm Nyheim, Lindis Skipperud and Sondre Meland

Abstract Road run off typically contains a variety of contaminants such as metals and road salt. Odonata larvae are important members in a variety of freshwater ecosystems which may receive road runoff. The objective of the present work was to investigate the uptake and excretion kinetics of cadmium (Cd), cobalt (Co) and antimony (Sb) in odonata larvae using radioactive tracer technique, and secondly how addition of road salt would affect the uptake. Larvae were individually exposed in beakers containing sediment spiked with ^{109}Cd, ^{60}Co and ^{125}Sb and water with different concentrations of road salt. The results showed that at higher salt concentrations more ^{109}Cd and ^{60}Co were mobilized from the sediments, however, the uptake in the larvae decreased. Antimony-125 was strongly bound in the sediment, and addition of salt did not affect the accumulation in the larvae significantly.

Introduction

Highway runoff typically contains a broad range of contaminants originating from various sources, both vehicle and non-vehicle sources. Vehicle sources may include inorganic and organic contaminants originating from brakes, tires, catalytic converters, vehicle body and combustion, while non-vehicle sources may include run-off from the road surface, de-icing and dust suppression chemicals, road equipment and detergents used in tunnel wash [1]. Metals and metalloids are a group of contaminants that origin from several of these sources. In the present paper focus

L. S. Heier (✉) · M. T. Nyheim · L. Skipperud · S. Meland
Department of Plant and Environmental Sciences, Norwegian University of Life Sciences,
PO Box 5003, 1432, Ås, Norway
e-mail: lene.sorlie.heier@umb.no

S. Meland
Environmental Assessment Section, Norwegian Public Roads Administration,
PO Box 8142, Dep, 0033, Oslo, Norway

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_45,

is put on three of these elements; cadmium (Cd), cobalt (Co) and antimony (Sb). Sources of Cd and Co are from tire wear and combustion, while Sb may originate from brakes and combustion (reviewed in Meland [6]).

In the northern hemisphere significant amounts of de-icing chemicals are being used to enhance friction and increase traffic safety during winter periods. In Norway most of the de-icing is done by applying sodium chloride (NaCl), and over the past few years the total use of NaCl has substantially increased. Thus, during runoff episodes the concentration of salt can be rather high and may impact ponds and lakes close to the roads. The high salt concentration may cause concern for several reasons including for example mobilization of trace elements through ion-exchange processes, altered circulation and oxygen depletion in lakes and ponds due to increased density of salt in the bottom dwelling layer.

Dragonfly larvae (Odonata, Anitoptera) are important species in many freshwater ecosystems. They can be predators on other invertebrates and can also be an important prey base for other aquatic organisms. Their life cycle predominantly occurs in the water phase with a generation time that varies between 2 months and 6 years. They are hemimetabolic insects having egg, nymphs and adult stage (imago). In cold temperate areas they are most often univoltine or semivoltine, thus generation time more than one year. The objective of the present study was to investigate the bioaccumulation and excretion of Cd, Co and Sb in dragonfly larvae exposed to spiked sediments using radioactive tracer techniques, and how addition of road salt would influence the uptake and excretion kinetics.

Material and Methods

Dragonfly larvae were collected in three different ponds, which were not affected by road run off or other point sources, in the vicinity of Oslo, Norway. The larvae were transported to the laboratory where they were kept in a beaker in a temperature controlled incubator at 10°C for 5 days before exposure start.

Sediment was collected in a pond at the university campus, which were not affected by any point sources. To model a moderately contaminated road runoff contaminated sediment, the sediment were spiked with stable Cd (0.74 µg/g) and Co (1.3 µg/g) using $CdCl_2$ and $CoCl_2$. Before exposure start the concentrations of Cd, Co and Sb were determined using ICP-MS (Perkin Elmer Elan 6000). The sediment were then spiked with ^{109}Cd (QSA Global GmbH, Braunschweig, Germany), ^{60}Co (Cerca Lea, France) and ^{125}Sb (Eckert & Ziegler, Valencia, California) and left stirring overnight before aliquots were transferred to exposure beakers. To study the binding properties of ^{109}Cd, ^{60}Co and ^{125}Sb to the sediment, a simplified sequential extraction procedure [8] based on the method of [10] was performed. In brief, four extraction solutions were used; (1) MQ water (2) 1M NH_4Ac (pH 7) (3) 1M NH_4Ac (pH 5) and (4) 7M HNO_3.

Salt solutions were made by dissolving road salt (40 % Na, 60 % Cl) in distilled water to nominal concentrations of 500, 5000 and 10000 mg NaCl/L. Actual concentrations were determined using ICP-OES (Perkin Elmer Optima 5300 DV).

The larvae were exposed in small glass beakers which were added about 5 g of spiked sediment and 50 mL water with the different salt concentrations including one without salt, with eight replicates for each salt solution. Each beaker housed one larva which was measured for radioactivity after 1, 3, 7, 14 and 21 days of exposure. After 21 days the larvae were moved to a new beaker containing tap water to investigate the excretion kinetics of the elements. Activity in larvae was then measured after 1, 7 and 15 days. Detection of activity in larvae were done by removing them from the exposure beaker, quickly rinse them in tap water before placing them in a 20 mL vial with 10 mL of tap water for detection of gamma activity. After measurement the larvae were carefully placed back in their exposure beaker. Water samples (1 mL) were collected at all exposure times, and sediment samples were collected after 1 and 21 days of exposure.

The gamma activity of ^{109}Cd, ^{60}Co and ^{125}Sb in sediment, water and larvae were detected using a NaI detector (Wizard, Perkin Elmer), and results are given as counts per minute (cpm). pH and conductivity were measured (WTW inoLab pH/Cond 720) in the water. Larvae for digital autoradiography was put on cleaned autoradiography imaging plate (Imaging plate, Molecular dynamics), and placed in a protective cassette reducing the impact of external radiation. After exposure the imaging plate was scanned in an Image plate scanner (Typhoon 8600, Molecular dynamics).

Graph Pad Prism and Minitab 16 were used for statistical calculations.

Results and Discussion

Exposure Characterization

Sediments were spiked with stable and radioactive isotopes of Cd, Co and Sb before adding dragonfly larvae to the different exposures. The concentrations of the different elements in the sediment after spiking were 1.2, 7.9 and 0.01 µg/g dw for Cd, Co and Sb respectively. The activity at exposure start (cpm/g sediment) was 5581, 2139 and 2490 for ^{109}Cd, ^{60}Co and ^{125}Sb, respectively. Only activity levels will be further discussed. Water pH was measured at each sampling and varied between 6.1–6.8. Conductivity was measured at the end of the experiment (Day 21) and was 2.6, 950, 9400 and 19900 in the 0, 500, 5000 and 10000 mg/L NaCl respectively. Actual concentrations of NaCl were 0.0, 500, 4700 and 9400 mg/L in the different exposures.

During the exposure some mortality of the larvae were observed. As the mortality was randomly distributed in the different exposure groups, this is probably attributed to the exposure conditions (i.e no feeding, repeated measurements of individual larvae) rather than chemical effects. During the experiment 8 of the larvae also went through molting.

Sequential Extraction of Sediments

To assess the binding strength and the mobility of the elements in the sediment, sequential extraction was performed at the start and end of the exposure and distribution coefficients (Kd) were calculated. For ^{109}Cd and ^{60}Co similar results were obtained in the sequential extraction, where the elements in majority were identified in the NH_4Ac (pH 5) and NH_4Ac (pH 7) fractions (Fig. 1), thus being relatively mobile. At the lowest salt concentrations, there is no major difference between the start and the end of the experiment in the NH_4Ac (pH 5), however at the high salt concentrations there is an increase in this fraction of approximately 10%. At the start of the experiment no correlation was identified between concentrations of salt and activity in the water and NH_4Ac (pH7) fraction, however, at day 21 a significant correlation between these was found for both ^{109}Cd ($r=0.991$, $p=0.009$) and ^{60}Co ($r=0.966$, $p=0.034$). Thus, at higher salt concentrations the binding strength of the metals was decreasing, and the mobile fractions increased. For ^{125}Sb however, the results are different with the residual fractions being the largest, followed by the HNO_3 fraction. Thus, the added ^{125}Sb was strongly bound in the sediment which also increased as a function of time. No significant correlations between the water soluble and the NH_4Ac (pH7) fractions was observed for ^{109}Cd and ^{60}Co. Strong binding of Sb is also observed in other studies with soils and sediments [1].

Activity Concentrations in Water

In the water phase the activity levels varied as a function of time, salt concentration and element (Fig. 2). A positive correlation between concentration of salt and activity in the water-phase was identified for ^{109}Cd ($r=0.686$, $p=0.000$) and ^{60}Co ($r=0.425$, $p=0.000$), while for Sb the opposite, a negative correlation ($r=-0.492$, $p=0.000$) was observed. Thus, salt mobilized sediment associated ^{109}Cd and ^{60}Co to the water phase, while ^{125}Sb was more strongly bound.

Distribution Coefficient (Kd)

Based on the activity concentrations in water and sediments the distribution coefficient (Kd) were determined. The Kd values ranged from 13–300 for the different exposures, and the highest values were found for ^{109}Cd without salt at the end of the experiment. For ^{109}Cd and ^{60}Co, the Kd increased as a function of time in the exposures without salt, however at the high salt concentrations the opposite is observed. Thus, at high salt concentrations the metals were less strongly bound which is in accordance with the sequential extraction results. For ^{125}Sb however, there is no difference in Kd with time in the exposures without salt, and at the lowest salt

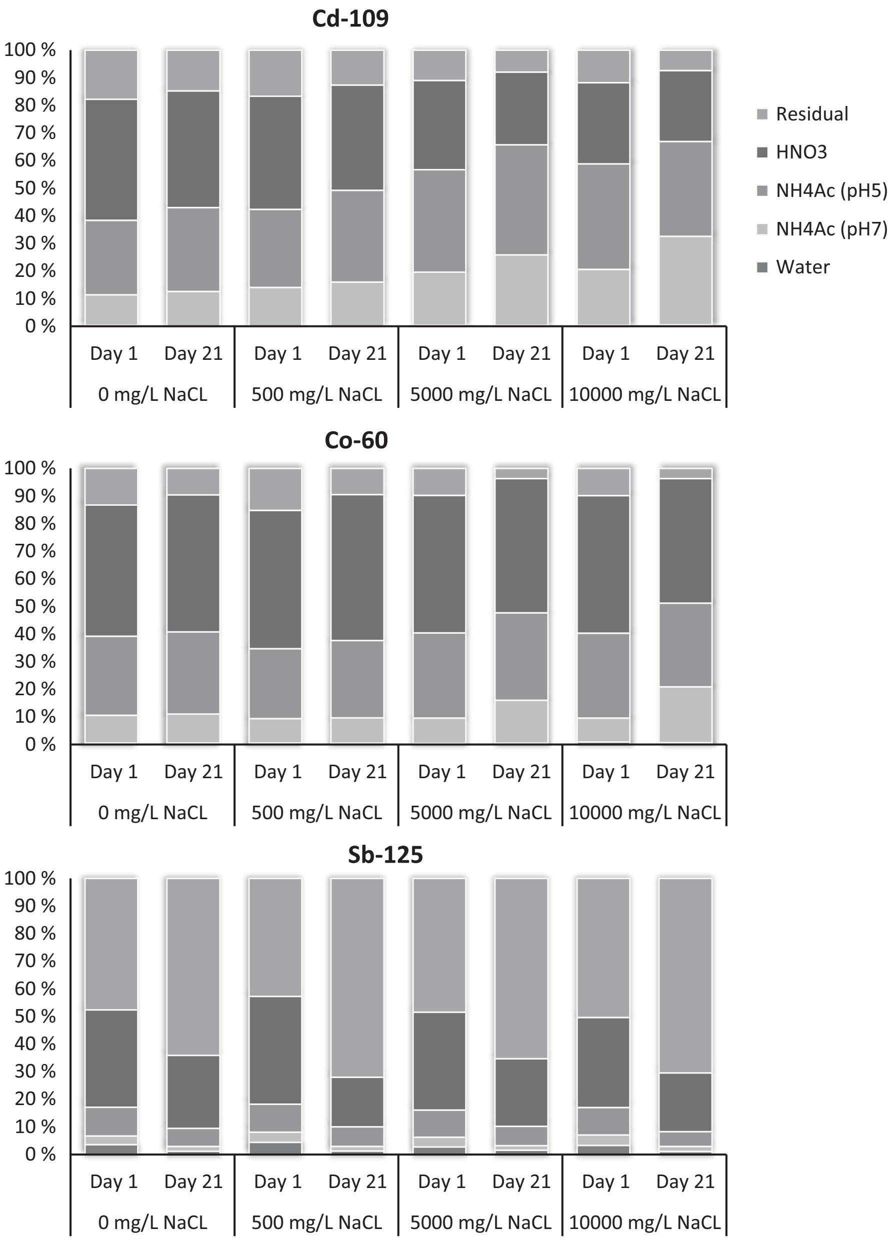


Fig. 1 Sequential extraction of sediments after 1 and 21 days of exposure in the different exposure groups ($n = 1$)

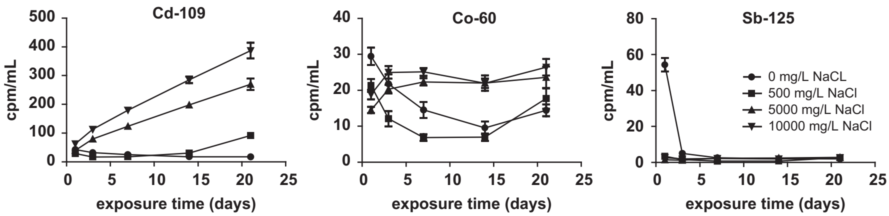


Fig. 2 Activity (cpm/mL) of ^{109}Cd, ^{60}Co and ^{125}Sb in the water phase as a function of time and NaCl added to the water. Each point represent mean values ± SEM (n=7–8)

concentrations there is an increase in Kd, while at the highest concentrations Sb follow the same trend as ^{109}Cd and ^{60}Co with a decreased Kd at the end of the exposure.

Bioaccumulation of ^{109}Cd, ^{60}Co and ^{125}Sb in Odonata Larvae

Aquatic insects may accumulate trace elements either from ingested food or via water [5]. In general, there is not extensive literature on metal accumulation and toxicity in members of the order Odonata. In the studies that are available Cd, Cu, Zn and Pb are amongst the metals that are most studied [7, 11]. In the larvae exposed to ^{109}Cd, ^{60}Co and ^{125}Sb an uptake of all elements was identified (Fig. 3). In the exposures without salt the highest uptake was identified in larvae exposed to ^{60}Co, which had a BCF (mL/g) in the range 42–110 (min–max) after 21 days of exposure. For ^{109}Cd and Sb the uptake was lower with BCF's in the range 11–77 and 3–6 (min–max) for ^{109}Cd and ^{125}Sb respectively. For ^{109}Cd the BCF levels are in agreement with a study on freshwater isopodes [12].

A linear uptake (function of time) was identified for both ^{109}Cd and ^{60}Co, where ^{109}Cd seemed to reach steady state after 14 days of exposure, while ^{60}Co did not seem to reach steady state in the current experimental setup. The uptake kinetics of ^{125}Sb was different from the other elements, with a rapid initial uptake which reached steady state after 3 days of exposure. When the larvae were transferred to clean water, ^{109}Cd was excreted following first order kinetics with a half-life of 5.1 days. The toxicokinetics of ^{109}Cd was somewhat similar to a study of Cd uptake and excretion in the stonefly *Pteronarcella badia* [2], however, the excretion kinetics in the present study was not as rapid. On the other side, no depuration of Cd was observed in *Hyella Azteca* during a 5 day elimination period [9]. The excretion of trace elements depends on several factors such as for example the metabolic rate which is temperature dependent. Thus, the variation in depuration kinetics may be large in different environments and among different species.

The larvae exposed to ^{125}Sb also followed one phase decay with an estimated half-life of 5.2 days, while ^{60}Co, however, was not significantly excreted in the 15 days the larvae were housed in tap water. The lack of excretion of ^{60}Co under the experimental conditions indicates that the biological half-life may be very long.

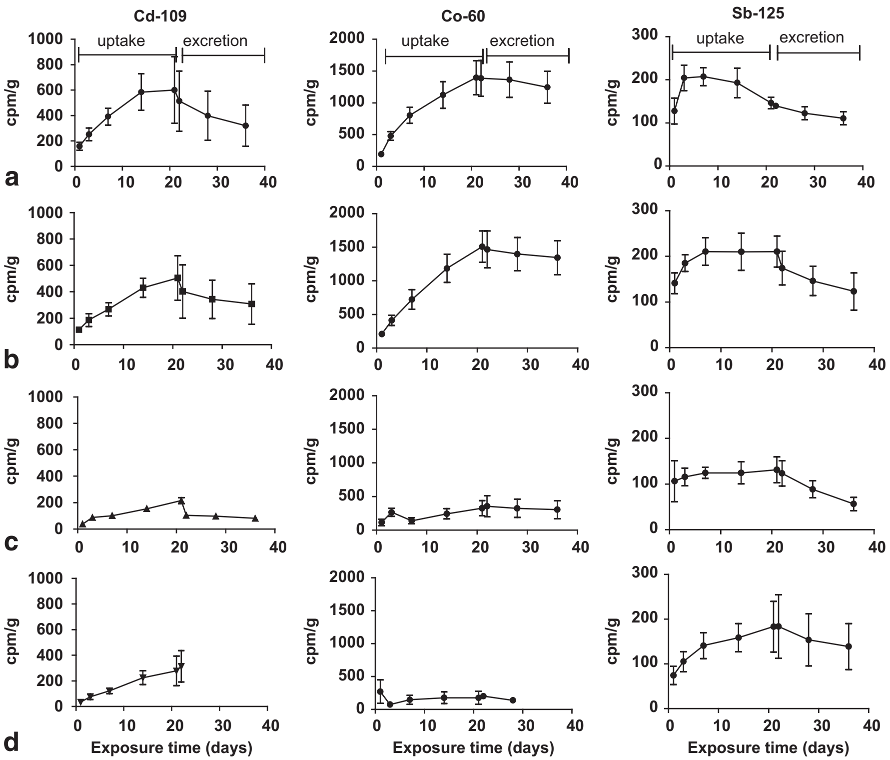


Fig. 3 Uptake and excretion of 109Cd, 60Co and 125Sb in odonata larvae as a function of exposure time (days) and salt concentration. A=0 mg NaCL/L, B=500 mg NaCl/L, C=5000 mg NaCL/L and D=10000 mg NaCl/L. Each point represents mean ± SEM (*n*=3–8)

This implies that Co may cause an effect on the larva itself but also be a significant source of Co for predators.

Tollet [11] investigated the toxicity of Cd to Odonata larvae and found that they were very tolerant to high body burdens of Cd. However, even if the larvae itself can handle high body burdens larvae be a source of metals for their predators which might not be as tolerant.

Very few studies are available on accumulation of Sb in invertebrates. A couple of recent field studies have studied Sb accumulation in different freshwater compartments including invertebrates [3, 4]. In the study of Culioli et al. [3], they found that of the accumulation of Sb was highest in the macroinvertebrates and was decreasing with trophic level. The low BCF of Sb found in the present study could imply that Sb do not pose a threat to members of Odonata, but this has to be tested in a toxicity study.

Autoradiography was used on some larvae to determine if the activity was found on the exoskeleton and/or in the internal organs/tissues. The result indicated that the activity had accumulated in both the exoskeleton and in the visceras (Fig. 4) for

Fig. 4 Autoradiography of larvae (*right*) where the internal organs are dissected out (*left* picture) exposed to ^{109}Cd and ^{60}Co. Cd = 24 cpm, Co 390 cpm

^{109}Cd and ^{60}Co. In the ^{125}Sb exposed larvae it was difficult to see the results due to low activity in the samples.

Effect of Road Salt on Accumulation of ^{109}Cd, ^{60}Co and ^{125}Sb in Odonata Larvae

Increased concentrations of salt may increase mobility, remobilization and potentially the bioavailability of metals. Dissolved salt increases the ionic strength and the composition of ions in the water, which may influence sorption processes of metals in sediments and to other ligands in water. In general, metal uptake in aquatic organisms is inversely related to salinity, which in turn is related to metal speciation and uptake pathways in organisms as reviewed in Wright [13]. In general the low molecular mass cationic metal species are assumed to be the most bioavailable to aquatic organisms. Addition of high concentrations of Cl may lead to the formation of various chloride complexes which again may be less bioavailable. Biotic factors may include access to binding sites, and competition between the metal and e.g sodium and chloride ion transport channels regulating osmolarity.

The present results show that adding salt increases the solubility of the ^{109}Cd and Co (Fig. 2), however the uptake in the larvae decreased (Fig. 3). At the highest concentrations of salt the uptake of ^{109}Cd was lower, however, still significant linear responses was identified. However, for ^{60}Co there was no significant linear response in accumulation at the high salt exposures. Cd and Co may form hydroxyl chloride complexes which potentially are less bioavavailable than their free ions. In the present study we did not determine the speciation of the elements in the water phase. The BCF after 21 days of exposure (Table 1) is significantly lower for ^{109}Cd in all the groups added salt, while for ^{60}Co the BCF are only lower in the two highest salt concentrations. Thus, road runoff containing high amounts of salt may mobilize Cd and Co from sediments, however due to complexing reactions in the water phase the metal burden in the Odonata larvae does not necessarily increase due to the specia-

Table 1 Distribution coefficients (Kd) and concentration factors (CF_{sed}—organism:sediment and BCF_{water}—organism:water) in the different exposure group after 1 and 21 days of exposure

	NaCl (mg/L)	Kd Day 1	Kd Day 21	CFsed Day 1	CFsed Day 21	BCF Day 1	BCF Day 21
^{109}Cd	0	128	300	0.029	0.11	4.1 ± 1.2	35 ± 21
	500	183	55	0.021	0.10	4.5 ± 0.85	4.6 ± 1.5
	5000	124	18	0.0075	0.044	0.95 ± 0.12	0.74 ± 0.062
	10000	79	13	0.0071	0.055	0.62 ± 0.20	0.72 ± 0.36
^{60}Co	0	70	140	0.093	0.68	7.1 ± 0.80	79 ± 19
	500	90	109	0.11	0.77	11 ± 2.1	68 ± 17
	5000	120	72	0.066	0.19	8.7 ± 4.0	12 ± 4.4
	10000	102	73	0.14	0.091	17 ± 12	5.2 ± 2.7
^{125}Sb	0	28	30	0.083	0.13	2.6 ± 0.85	4.4 ± 0.70
	500	44	129	0.087	0.11	4.2 ± 0.85	16 ± 2.5
	5000	166	54	0.059	0.12	11 ± 3.8	6.5 ± 1.0
	10000	148	60	0.047	0.12	12 ± 3.6	7.7 ± 2.3

tion of the metals. The lack of accumulation may also be due to competition of Na and Cl with Cd and Co in cellular ionic transport channels.

For ^{125}Sb the trend is different, where the highest BCF is obtained at 500 mg/L NaCl. This suggest that salt increase the uptake in the lower concentrations, however, at high concentrations of salt the uptake is only slightly higher than in the control group (no salt).

Conclusions

Odonata larvae were exposed to sediments spiked with ^{109}Cd, ^{60}Co and ^{125}Sb which were added water with different concentrations of NaCl. Cd and Co were less strongly bound in the sediment than ^{125}Sb, and addition of salt increased the mobility of ^{109}Cd and ^{60}Co, contradictory to ^{125}Sb which was more strongly bound. Under the current experimental conditions the uptake of ^{60}Co was higher than ^{109}Cd followed by a low uptake of ^{125}Sb. Addition of salt increased the mobility of ^{109}Cd and ^{60}Co from sediments, however, this did not result in increased uptake of the metals in the larvae. In recipients affected by road salt, mobilization of metals may occur, however, it does not necessarily lead to increased bioaccumulation.

Acknowledgments This work was financed by the Norwegian Public Roads Administration. We thank Cato Wendel for assistance on autoradiography.

References

1. Carvalho PCS, Neiva AMR, Silva M (2009) Geochemistry of soils, stream sediments and waters close to abandoned W-Au-Sb mines at Sarzedas, Castelo Branco, central Portugal. Geochem-Explor Environ Anal 9(4):341–352. doi:10.1144/1467-7873/09-208

2. Clubb RW, Gaufin AR, Lords JL (1975) Acute cadmium toxicity studies upon 9 species of species of aquatic insects. Environ Res 9(3):332–341. doi:10.1016/0013-9351(75)90013-4
3. Culioli J-L, Fouquoire A, Calendini S, Mori C, Orsini A (2009) Trophic transfer of arsenic and antimony in a freshwater ecosystem: a field study. Aquatic Toxicol 94(4):286–293. doi:10.1016/j.aquatox.2009.07.016
4. Duran M, Kara Y, Akyildiz GK, Ozdemir A (2007) Antimony and heavy metals accumulation in some macroinvertebrates in the Yesilirmak River (N Turkey) near the sb-mining area. Bull Environ Contam Toxicol 78(5):395–399. doi:10.1007/s00128-007-9183-x
5. Hare L (1992) Aquatic insects and trace-metals—bioavailability, bioaccumulation, and toxicity. Crit Rev Toxicol 22(5–6):327–369
6. Meland S (2010) Ecotoxicological effects of highway and tunnel wash water runoff. Norwegian University of Life Sciences, Ås
7. Meyer W, Harisch G, Sagredos AN (1986) Biochemical and histochemical aspects of lead exposure in dragonfly larvae (Odonata Anisoptera). Ecotoxicol Environ Saf 11(3):308–319. doi:10.1016/0147-6513(86)90104-1
8. Oughton DH, Salbu B, Riise G, Lien H, Ostby G, Noren A (1992) Radionuclide mobility and bioavailability in Norwegian and Soviet soils. Analyst 117(3):481–486. doi:10.1039/an9921700481
9. Shuhaimi-Othman M, Pascoe D (2007) Bioconcentration and depurationof of copper, cadmium, and zinc mixtures by the freshwater amphipod Hyalella azteca. Ecotoxicol Environ Saf 66(1):29–35. doi:10.1016/j.ecoenv.2006.03.003
10. Tessier A, Campbell PGC, Bisson M (1979) Sequential extraction procedure for the speciation of particulate trace-metals. Anal Chem 51(7):844–851. doi:10.1021/ac50043a017
11. Tollett VD, Benvenutti EL, Deer LA, Rice TM (2009) Differential toxicity to Cd, Pb, and Cu in dragonfly larvae (Insecta: Odonata). Arch Environ Contam Toxicol 56(1):77–84. doi:10.1007/s00244-008-9170-1
12. van Hattum B, van Straalen NM, Govers HAJ (1996) Trace metals in populations of freshwater isopods: influence of biotic and abiotic variables. Arch Environ Cont Toxicol 31(3):303–318
13. Wright DA (1995) Trace-metal and major ion interactions in aquatic animals. Marine Pollut Bull 31(1–3):8–18. doi:10.1016/0025-326x(95)00036-m

Hydrodynamic Modelling of Microbial Water Quality in a Drinking Water Source

Ekaterina Sokolova, Thomas J.R. Pettersson, Olof Bergstedt and Malte Hermansson

Abstract The presence of faecal contamination in drinking water sources can cause waterborne disease outbreaks. The aim of this article was to study the influence of wastewater discharges from a wastewater treatment plant on microbial water quality in a drinking water source—the river Göta älv in Sweden. To fulfil this aim, the fate and transport of the faecal indicators *E*. coli and somatic coliphages in the river Göta älv were simulated using a three-dimensional hydrodynamic model. The validation of the hydrodynamic model confirmed a good model performance: the correlation coefficient was 0.99; the absolute mean difference between the simulated and measured water surface elevation was 0.03 m, which is 11.1 % of the standard deviation of the measured data. The modelling results revealed that during overflow events at the wastewater treatment plant, discharges of untreated wastewater contributed more to the concentrations of faecal indicators at the water intake than discharges of treated wastewater. The hydrodynamic modelling of microbial water quality proved to be a useful tool to estimate the contribution of different sources to the total contamination of raw water used for drinking water supply and, therefore, to provide decision-support information for preventive and mitigative risk-reduction measures.

Introduction

The faecal contamination of drinking water sources is a common cause of waterborne disease outbreaks [4, 7]. Faecal contamination often enters a drinking water source from a variety of contamination sources, such as wastewater treatment plants

E. Sokolova (✉) · T. J. Pettersson · O. Bergstedt
Water Environment Technology, Chalmers University of Technology, 412 96, Gothenburg, Sweden
e-mail: ekaterina.sokolova@chalmers.se

O. Bergstedt
Göteborg Vatten, Göteborgs Stad, Box 123, 424 23, Angered, Sweden

M. Hermansson
Department of Cell and Molecular Biology, Microbiology, University of Gothenburg, 405 30, Gothenburg, Sweden

S. Rauch et al. (eds.), *Urban Environment*, DOI 10.1007/978-94-007-7756-9_46,

(WWTPs), on-site sewers, sewer overflows, as well as surface runoff from urban and agricultural areas. To prevent and mitigate the faecal contamination of drinking water sources, estimation of the contribution of different sources to the total contamination is required.

To estimate the contribution of different sources to the total contamination of a water source at a certain location, hydrodynamic modelling of the microbial water quality can be used. Hydrodynamic modelling proved to be useful to simulate the fate and transport of faecal contamination within the water source, e.g. [5, 6, 9, 10, 12, 14, 16].

The aim of this article was to study the influence of wastewater discharges from a wastewater treatment plant on the water quality in the river Göta älv at the water intake of a drinking water treatment plant in Gothenburg, Sweden. For this purpose, a three-dimensional hydrodynamic model was set up and validated in order to simulate the fate and transport of faecal indicators (*E. coli* and somatic coliphages) within the river.

Materials and Methods

Study Area

Göta älv is a river that drains Lake Vänern into the strait Kattegat at the city of Gothenburg on the west coast of Sweden. The total catchment area of the river Göta älv is 50,233 km^2, which constitutes approximately 10 % of the area of Sweden. The part of the catchment area that is located downstream of Lake Vänern is approximately 3500 km^2. The length of the river between the outflow from Lake Vänern and the mouth of the river is 93 km. The vertical drop of the river is approximately 44 m. The water flow in the river Göta älv is regulated by several hydropower stations and varies strongly; the average and the maximum water flows are approximately 550 and 1000 m^3/s, respectively. Upstream of the island Hisingen, the river splits into two branches; the northern branch—Nordre älv—transports from 2/3 to 3/4 of the total water flow, the southern branch keeps the name Göta älv and runs towards the city of Gothenburg [3].

The river Göta älv is used for many various purposes, among which are drinking water production, transportation, hydropower, fish farming and sport fishing. The river is used as a water source for the drinking water supply of approximately 700,000 consumers in several municipalities, among which Gothenburg with approximately 500,000 consumers. Along the river there are five raw water intakes; the water intake for the drinking water treatment plants in Gothenburg (Lackarebäck and Alelyckan) is called Lärjeholm.

Between Lake Vänern and the Lärjeholm water intake the river Göta älv receives wastewater from approximately 100,000 persons. Approximately 95 % of this wastewater is treated at municipal wastewater treatment plants, while 5 % is treated by on-site sewer systems [3]. On the stretch between Lake Vänern and the Lärjeholm water intake, there are eight wastewater treatment plants that use the river Göta älv as a recipient of wastewater. The wastewater treatment plant Älvängen in the municipality of Ale treats wastewater from approximately 6200 people and is located approximately 24 km upstream of the Lärjeholm water intake.

The wastewater treatment at the Älvängen WWTP consists of mechanical, biological and chemical treatment steps [17]. The mechanical treatment includes a bar screen, grit chamber and primary sedimentation. The biological treatment includes an aeration tank and two sedimentation tanks. The chemical treatment involves chemical dosage, flocculation tanks and sedimentation tanks [17]. During heavy rainfalls, the overflows from this wastewater treatment plant can occur due to stormwater intrusion into sewer networks, i.e. the incoming wastewater can be discharged to the river Göta älv after only passing the primary sedimentation treatment step (partly treated wastewater) or occasionally even without any treatment (untreated wastewater).

In order to study the influence of wastewater discharges from the Älvängen WWTP on the raw water quality at the Lärjeholm water intake, the model was set up to cover the approximately 60 km long river stretch located between Lilla Edet (downstream of the hydropower station) and the Gothenburg harbour in the Kattegat. The length of the river stretch between Lilla Edet and the Älvängen WWTP is approximately 20 km and between Lilla Edet and the Lärjeholm water intake—approximately 44 km.

Model Implementation

To simulate the hydrodynamic conditions in the river Göta älv, the three-dimensional time-dependent hydrodynamic model MIKE 3 FM [2] was used. This hydrodynamic model is based on the numerical solution of three-dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure [2]. The model consists of continuity and momentum equations and is closed by a turbulent closure scheme [2]. The water density was assumed to be homogenous (barotropic formulation).

The modelling domain was approximated with prisms (triangles in horizontal plane) using a flexible mesh approach. The length of the triangles' sides varied from approximately 50 to 90 m. In vertical direction, the river was divided into 10 layers with a thickness that could vary depending on the depth and water surface elevation in the river (sigma-layers).

The initial conditions in the river were defined by the observed water surface elevation (Table 1). The upstream and downstream boundary conditions were defined by time-series of data regarding the water flow through the hydropower station in Lilla Edet, the water flow in the northern branch of the river—the river Nordre älv and the water surface elevation at the Gothenburg harbour (Table 1). On the land boundary the normal component of velocity was set to zero.

Table 1 Input data used for setup and validation of the hydrodynamic model of the river Göta älv

Type of data	Resolution	Source
Bathymetry	10 m	SGI[a]
Bathymetry	20 m	Sjöfartsverket[b]
Wind speed and direction	1 h	Göteborgs Stad
Precipitation	1 day	SMHI[c]
Water flow in tributaries	1 day	SMHI[c]
Water surface elev. and flow at Lilla Edet	1 h	Vattenfall
Water surface elev. at Lärjeholm water intake	1 h	Göteborg Vatten
Water surface elev. at Gothenburg harbour	1 h	SMHI[c]

[a] Swedish Geotechnical Institute. Data covered the part of the river between Lilla Edet and the mouth of the river Säveån

[b] Swedish Maritime Administration. Data covered the part of the river between the mouth of the river Säveån and the Gothenburg harbour

[c] Swedish Meteorological and Hydrological Institute

The model was set up to account for the hydrometeorological conditions (wind and precipitation on the river surface) and the inflow to the river from the tributaries with catchment areas greater than 50 km^2 (tributaries Gårdaån, Lärjeån, Grönån, Säveån, Hältorpsån and Mölndalsån; Table 1). The horizontal and vertical eddy viscosities were simulated using Smagorinsky and Log law formulations, respectively [2]. The bed resistance was described by a constant roughness height of 0.05 m. The model was run with default parameterisation [2].

The fate and transport of faecal indicators in the river Göta älv were simulated using the microbial water quality model ECO Lab [1], which was coupled with the hydrodynamic model of the river. The microbial water quality model used flow fields from the hydrodynamic model to calculate the faecal indicator concentrations in the river.

In the microbial water quality model, the decay of faecal indicators was described according to Eq. 1:

$$\frac{dC}{dt} = -k \cdot C \qquad (1)$$

where k is the decay rate of faecal indicators in the water, t is the time and C is the faecal indicator concentration.

The decay coefficient for *E. coli* and somatic coliphages in the river was described by Eq. 2 [8, 13]:

$$k = k_0 \cdot \theta_I^{Int} \cdot \theta_T^{(Temp-20)} \qquad (2)$$

where k_0 (1/day) is the decay rate at 20 °C for a salinity of 0 ‰ and darkness; θ_I is the light coefficient; *Int* (kW/m^2) is the light intensity integrated over depth; θ_T is the temperature coefficient; *Temp* (°C) is the water temperature.

The coefficients in Equation 2 for *E. coli* and somatic coliphages were experimentally determined in the microcosm trials performed in different seasons for the conditions of Lake Rådasjön in Sweden [13]. The coefficients k_0, θ_I and θ_T were set to 0.76, 1 and 1.04 for *E. coli* and to 0.25, 1 and 1.08 for somatic coliphages, respectively.

Validation of Hydrodynamic Model

To assess the performance of the hydrodynamic model, validation was performed by comparing the simulated and measured water surface elevation at the Lärjeholm water intake (Table 1). In order to capture different hydrodynamic conditions, validation was performed on four time periods, which were selected based on the water flow in the river during year 2011: low and stable (1–31 May), low and varying (15 June–16 July), high and stable (25 August–25 September), as well as high and varying (10 November–11 December). The validation showed that the model described the measured data very well—the Pearson correlation coefficient was 0.99 ($p < 0.001$). The absolute mean difference between the simulated and measured water surface elevation was 0.03 m. This absolute mean difference and its standard deviation were 11.1 % and 13.8 % of the standard deviation of the measured data, respectively. An example of the congruence between the simulated and measured data during one of the selected periods is shown in Fig. 1.

Simulations

During year 2011, several overflow events from the Älvängen WWTP into the river Göta älv occurred (Fig. 2). Several of these overflow events coincided in time with peaks of measured *E. coli* concentration at the Lärjeholm water intake (Fig. 2). Based on the data on overflow events and peaks in *E. coli* concentration in raw water, two time periods were selected to be simulated to study the influence of overflow events from the Älvängen WWTP on the raw water quality at the Lärjeholm water intake: 7–21 January (event I) and 4–24 September (event II). In the simulations of these two periods, the discharges of different types of wastewater were assigned constant concentrations of faecal indicators (Table 2) and the water temperature for event I and event II was specified as 4 °C and 18 °C, respectively.

The simulation of event I was also performed with the assumption that there was no decay of faecal indicators.

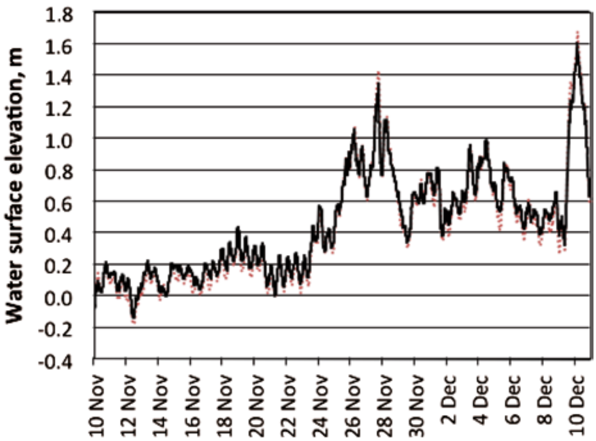


Fig. 1 Measured (*red dotted line*) and simulated (*black line*) water surface elevation at the Lärjeholm water intake

Results

The simulation of event I with no decay of *E. coli* and somatic coliphages resulted in up to 68 % and 9 %, respectively, higher values than the simulation with decay described based on the experimental measurements (Fig. 3).

The modelling results showed that, in case of both event I and event II, discharges of untreated wastewater from the Älvängen WWTP contributed the most to the concentrations of faecal indicators at the water intake in comparison to partly treated and treated wastewater (Figs. 4 and 5). The contribution of discharges of partly treated and treated wastewater to faecal indicator concentrations at the water intake was relatively small (Figs. 4 and 5).

According to the modelling results, it took between 26 and 31 hours in case of event I (Fig. 4) and 13 and 25 hours in case of event II (Fig. 5) before the discharges of untreated wastewater from the Älvängen WWTP caused peaks of faecal indicator concentrations at the Lärjeholm water intake.

Discussion and Conclusions

In this study a hydrodynamic model of the river Göta älv was set up and successfully validated (Fig. 1; cf. [16]). This hydrodynamic model was then used to simulate the fate and transport of the faecal indicators *E. coli* and somatic coliphages in the river, in order to evaluate the influence of wastewater discharges from the Älvängen WWTP during two overflow events on the microbial water quality at the Lärjeholm water intake. The model illustrated that during two studied events the discharges of untreated wastewater accounted for most of the Älvängen WWTP's contribution to the contamination at the Lärjeholm water intake (Figs. 4 and 5).

Table 2 Concentrations of faecal indicators E. coli and somatic coliphages in wastewater discharges from wastewater treatment plant. a Concentrations used in the model were calculated as median values of the concentrations measured at the Arvidstorp WWTP (municipality of Trollhättan, Sweden).

Wastewater	E. coli, CFU/100 mL (No of measurements)	Somatic coliphages, PFU/100 mL (No of measurements)
Treated	34,000 (17)	11,000 (14)
Partly treated	120,000 (13)	32,000 (12)
Untreated	450,000 (16)	100,000 (13)

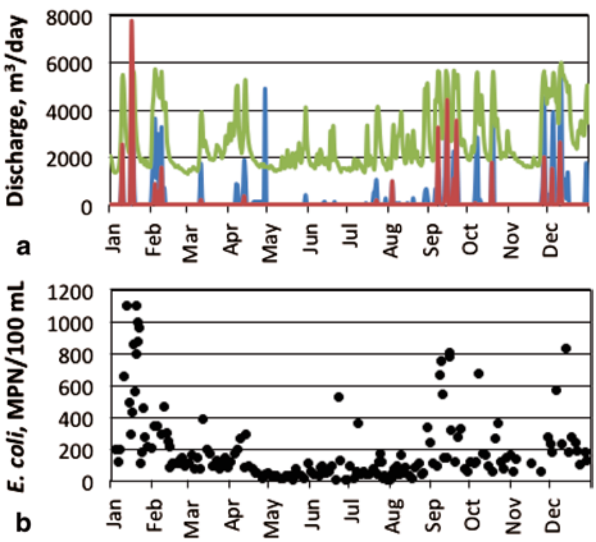


Fig. 2 **a** Discharges of untreated (*red line*), partly treated (*blue line*) and treated (*green line*) wastewater from the Älvängen WWTP (data provided by the municipality of Ale, Sweden) and **b** *E. coli* concentrations in raw water at the Lärjeholm water intake (data provided by Göteborg Vatten)

Although the discharges of untreated wastewater from the Älvängen WWTP coincided in time with high measured concentrations of *E. coli* at the Lärjeholm water intake (Fig. 2), the modelling results showed that only a small part of this faecal contamination at the water intake can be attributed to the influence of discharges from the Älvängen WWTP (Figs. 4 and 5). Along the river Göta älv there is a number of other faecal contamination sources, which, most likely, release faecal contamination during the same time periods as the Älvängen WWTP and contribute to the faecal contamination at the Lärjeholm water intake.

Pathogens are often very persistent in water sources [11, 15]. To estimate the infection risks related to the presence of pathogens in raw water, somatic coliphages, due to their slower decay, constitute a more suitable indicator than *E. coli*. This was shown by the simulations with the assumption that there was no decay of faecal indicators (Fig. 3). Detection of low *E. coli* concentrations may lead to underestimation of infection risks, as high levels of pathogens may still be present in the absence of *E. coli*.

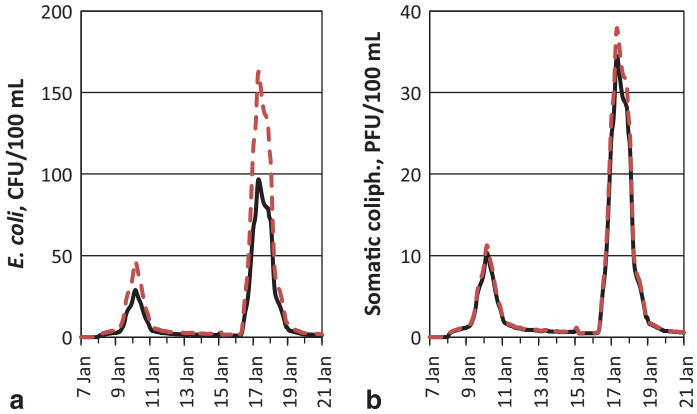
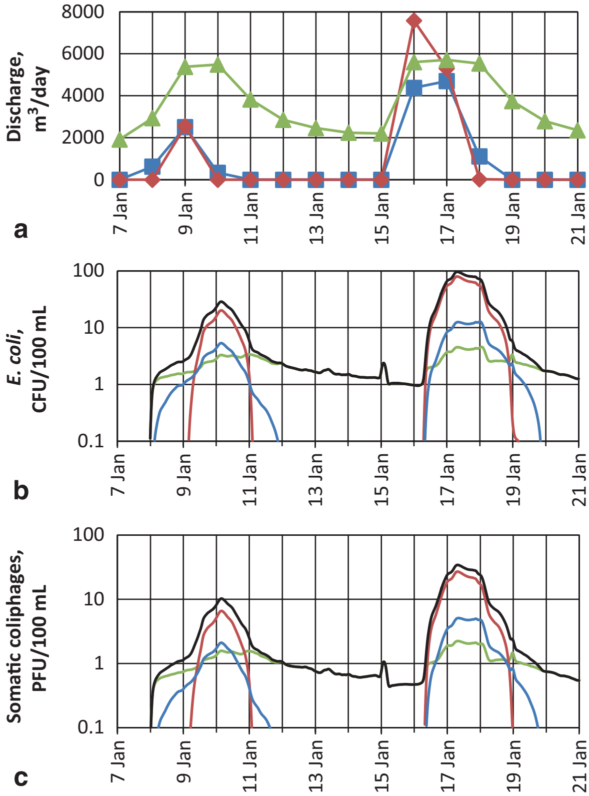


Fig. 3 Simulated *E. coli* (**a**) and somatic coliphages (**b**) concentrations in raw water at the Lärjeholm water intake during event I, assuming decay (*black line*) and assuming no decay (*red dotted line*)

Fig. 4 Graph (**a**) shows discharges of untreated (*red line*), partly treated (*blue line*) and treated (*green line*) waste water from the Älvängen WWTP into the river Göta älv. Graphs (**b**) and (**c**) represent the simulated contribution of untreated (*red line*), partly treated (*blue line*) and treated (*green line*) waste water discharges to the *E. coli* (**b**) and somatic coliphages (**c**) concentrations in raw water at the Lärjeholm water intake during event I. The total contribution from the Älvängen WWTP is represented by the *black line* in graphs (**b**) and (**c**)



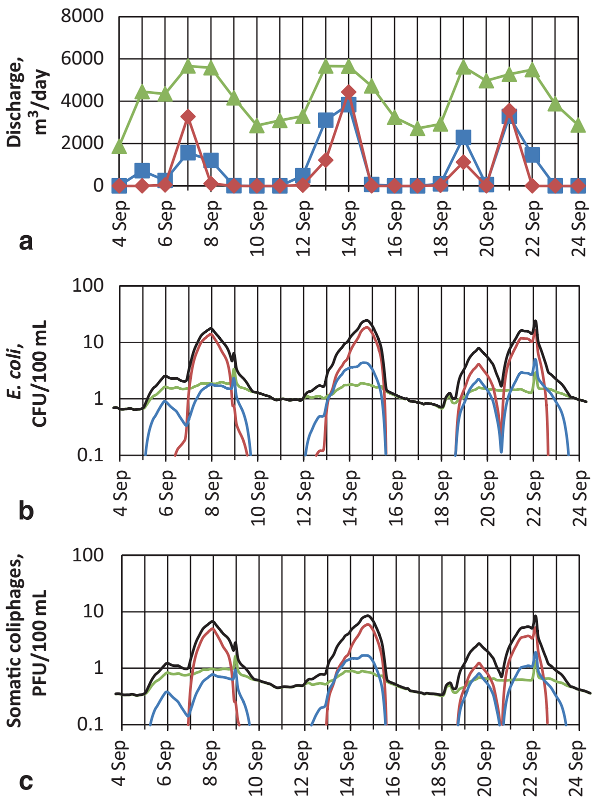


Fig. 5 Graph (**a**) shows discharges of untreated (*red line*), partly treated (*blue line*) and treated (*green line*) waste water from the Älvängen WWTP into the river Göta älv. Graphs (**b**) and (**c**) represent the simulated contribution of untreated (*red line*), partly treated (*blue line*) and treated (*green line*) waste water discharges to the *E. coli* (**b**) and somatic coliphages (**c**)

The hydrodynamic modelling of the microbial water quality proved to be a powerful tool to determine the contribution of different sources to the total contamination at the water intake. It can also provide information about the time that it takes for the peak of concentration to reach the water intake (Figs. 4 and 5). This type of modelling can be used to simulate various scenarios and situations, in order to estimate and predict the influence of different contamination events on the microbial water quality under various conditions. Therefore, hydrodynamic modelling can facilitate decision-making regarding risk-reduction measurements in the context of the faecal contamination of drinking water sources.

Acknowledgements The authors are grateful for the funding provided by the EU project VISK (Interreg IV A program); the Graduate School on Environment and Health (Forskarskolan Miljö och Hälsa) of the Chalmers University of Technology and the University of Gothenburg, Sweden; the Swedish Water and Wastewater Association (Svenskt Vatten). The authors are also grateful for the data provided by the Swedish Geotechnical Institute (SGI), the Swedish Maritime Administration (Sjöfartsverket), the Swedish Meteorological and Hydrological Institute (SMHI), Göteborgs Stad, Göteborg Vatten, Vattenfall, the municipalities of Ale and Trollhättan. Thanks are also due to Niels Markwat for his help with the statistical analyses.

References

1. DHI (2004) MIKE 21/3 Ecological modelling: MIKE21/3 ECO Lab FM short description. DHI Water & Environment, Horsholm
2. DHI (2011) MIKE 21 & MIKE 3 Flow model FM hydrodynamic and transport module—scientific documentation. DHI Water & Environment, Horsholm
3. GÄVVF (2006) Facts about the river Göta älv: a description of the river Göta älv and its surroundings 2005. (In Swedish: "Fakta om Göta älv: en beskrivning av Göta älv och dess omgivning 2005"). Göta älvs Vattenvårdsförbund (GÄVVF)—water management association of the river Göta älv, Gothenburg
4. Hrudey SE, Hrudey EJ (2004) Safe drinking water: lessons from recent outbreaks in affluent nations. vol 3. IWA Publishing, London
5. Kashefipour SM, Lin B, Falconer RA (2006) Modelling the fate of faecal indicators in a coastal basin. Water Res 40(7):1413–1425
6. Liu L, Phanikumar MS, Molloy SL, Whitman RL, Shively DA, Nevers MB, Schwab DJ, Rose JB (2006) Modeling the transport and inactivation of E. coli and enterococci in the near-shore region of Lake Michigan. Environ Sci Technol 40(16):5022–5028
7. Mac Kenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Peterson DE, Kazmierczak JJ, Addiss DG, Fox KR, Rose JB, Davis JP (1994) A massive outbreak in Milwaukee of Cryptosporidium infection transmitted through the public water supply. New Engl J Med 331(3):161–167
8. Mancini JL (1978) Numerical estimates of coliform mortality rates under various conditions. J Water Pollut Control Federation 50(11):2477–2484
9. Riou P, Le Saux JC, Dumas F, Caprais MP, Le Guyader SF, Pommepuy M (2007) Microbial impact of small tributaries on water and shellfish quality in shallow coastal areas. Water Res 41(12):2774–2786
10. Sanders BF, Arega F, Sutula M (2005) Modeling the dry-weather tidal cycling of fecal indicator bacteria in surface waters of an intertidal wetland. Water Res 39(14):3394–3408
11. Seitz SR, Leon JS, Schwab KJ, Lyon GM, Dowd M, McDaniels M, Abdulhafid G, Fernandez ML, Lindesmith LC, Baric RS, Moe CL (2011) Norovirus infectivity in humans and persistence in water. Appl Environ Microbiol 77(19):6884–6888
12. Sokolova E, AsÌtröm J, Pettersson TJR, Bergstedt O, Hermansson M (2012) Estimation of pathogen concentrations in a drinking water source using hydrodynamic modelling and microbial source tracking. J Water Health 10(3):358–370
13. Sokolova E, Åström J, Pettersson TJR, Bergstedt O, Hermansson M (2012) Decay of Bacteroidales genetic markers in relation to traditional fecal indicators for water quality modeling of drinking water sources. Environ Sci Technol 46(2):892–900
14. Thupaki P, Phanikumar MS, Beletsky D, Schwab DJ, Nevers MB, Whitman RL (2010) Budget analysis of Escherichia coli at a southern Lake Michigan Beach. Environ Sci Technology 44(3):1010–1016
15. Walker Jr FR, Stedinger JR (1999) Fate and transport model of Cryptosporidium. J Environ Eng 125(4):325–333
16. Zhu X, Wang JD, Solo-Gabriele HM, Fleming LE (2011) A water quality modeling study of non-point sources at recreational marine beaches. Water Res 45(9):2985–2995
17. Åström J, Pettersson TJR (2007) Wastewater discharges and microbial contamination in a drinking water source the river Göta älv (In Swedish: "Avloppsutsläpp och mikrobiologisk påverkan i råvattentäkten Göta älv"). Svenskt Vatten Utveckling, Stockholm