

Green Chemistry and Sustainable Technology

Series Editors

Liang-Nian He

State Key Lab of Elemento-Organic Chemistry, Nankai University, Tianjin, China

Robin D. Rogers

Department of Chemistry, The University of Alabama, Tuscaloosa, USA

Dangsheng Su

Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China

Pietro Tundo

Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Venice, Italy

Z. Conrad Zhang

Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China

The series Green Chemistry and Sustainable Technology aims to present cutting-edge research and important advances in green chemistry, green chemical engineering and sustainable industrial technology. The scope of coverage includes (but is not limited to):

- Environmentally benign chemical synthesis and processes (green catalysis, green solvents and reagents, atom-economy synthetic methods etc.)
- Green chemicals and energy produced from renewable resources (biomass, carbon dioxide etc.)
- Novel materials and technologies for energy production and storage (bio-fuels and bioenergies, hydrogen, fuel cells, solar cells, lithium-ion batteries etc.)
- Green chemical engineering processes (process integration, materials diversity, energy saving, waste minimization, efficient separation processes etc.)
- Green technologies for environmental sustainability (carbon dioxide capture, waste and harmful chemicals treatment, pollution prevention, environmental redemption etc.)

The series Green Chemistry and Sustainable Technology is intended to provide an accessible reference resource for postgraduate students, academic researchers and industrial professionals who are interested in green chemistry and technologies for sustainable development.

More information about this series at <http://www.springer.com/series/11661>

Justyna Płotka-Wasyłka · Jacek Namieśnik
Editors

Green Analytical Chemistry

Past, Present and Perspectives

 Springer

Editors

Justyna Płotka-Wasyłka
Department of Analytical Chemistry
Gdańsk University of Technology
Gdańsk, Poland

Jacek Namieśnik (Deceased)
Department of Analytical Chemistry
Gdańsk University of Technology
Gdańsk, Poland

ISSN 2196-6982

ISSN 2196-6990 (electronic)

Green Chemistry and Sustainable Technology

ISBN 978-981-13-9104-0

ISBN 978-981-13-9105-7 (eBook)

<https://doi.org/10.1007/978-981-13-9105-7>

© Springer Nature Singapore Pte Ltd. 2019

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

This book is dedicated in honour and memory of Prof. Jacek Namieśnik (10 December 1949–14 April 2019), a visionary analytical chemistry leader and a mentor to so many. You will be missed.

Preface

Care about global climate change, pollution of environment and hazards to human health have increased significantly. These fears have led to a call for changes in the field of chemistry science and chemists' action including those that are connected with chemical analysis. Analytical chemistry is a central science that provides the evolution in other chemical fields. There is no doubt analytical laboratories have an essential role to play in environmental protection through monitoring of pollutants in air, water or soil. On the other hand, analytical activities involve the use of many reagents and solvents, thus generating toxic residues. For these reasons, Green Analytical Chemistry (GAC) was introduced in 2000 to reduce or remove the side effects of analytical practices on operators and the environment.

This idea has attracted a great deal of interest among chemists, particularly those concerned with making laboratory practices in analytical chemistry environmentally friendly. As it is a great challenge to reach an acceptable compromise between increasing the quality of results and improving environmental friendliness of analytical methods, it is important to follow the guidelines and principles of Green Analytical Chemistry which have been introduced, and provide a framework for GAC.

All this makes the appearing field of Green Analytical Chemistry a "hot topic" not only in academia but also in industrial and governmental laboratories. This book starts by introducing the history of Green Analytical Chemistry as well as laws and principles that are based on the GAC ideology. Another important issue that will determine the future of Green Analytical Chemistry is education of this concept in the society; thus, the subject connecting with teaching of GAC based on several examples is also discussed. It then goes on to present the trends and future perspectives of the analytical laboratories. Developments and new achievements in such fields as direct techniques of detection and determination of trace analytes, extraction of trace constituents, and nature of the derivatization process and green chromatographic techniques are widely discussed. Flow injection analysis towards Green Analytical Chemistry as well as remote monitoring of environmental pollutants is presented. The book also contains chapters which are focused on the smart

sorption materials and new types of solvents used in the field of analytical chemistry.

As the greenness of analytical procedure is multivariable aspect, many greenness criteria should be taken into consideration. From the other side, modern analytical chemistry offers dozens of analytical methodologies, based on different methods and techniques, which are used for determination of analytes in a given matrix. Due to such complex decision-making processes, multi-criteria decision analysis tools are applied as systematic approach to deal with complex decisions. In this book, the reader will find the description of step-by-step approach to application of three multi-criteria decision analysis tools as Green Analytical Chemistry systems. In addition, several tools that can be applied to evaluate the developed analytical procedures are presented.

The book concludes with a discussion of how GAC is both possible and necessary. The final chapter summarizes contemporary problems and gives future perspectives of Green Analytical Chemistry. Green Analytical Chemistry is aimed at managers of analytical laboratories but will also interest teachers of analytical chemistry and green public policy-makers.

This book aims to celebrate the advancements in Green Analytical Chemistry, which encompasses all measurement techniques for all types of applications that minimize or eliminate the generation of chemical waste. We believe that this book will allow the reader to identify that GAC can operate in all contexts, not only in environmental application but also in the industrial and the sanitary. We hope that this book contributes to move from the theory to the practice; therefore, editors and authors are convinced of the necessity of this book.

We would like to express our thanks to the personnel of Springer who have offered all the time their support, especially June Tang and Sunny Guo for their help to make this book possible. The generosity, patience and good work of all the authors are acknowledged. We are convinced that this book is the starting point for future cooperation in a new analytical chemistry.

Gdańsk, Poland

Justyna Płotka-Wasyłka

Contents

1	History and Milestones of Green Analytical Chemistry	1
	Justyna Płotka-Wasyłka, Magdalena Fabjanowicz, Kaja Kalinowska and Jacek Namieśnik	
2	Teaching Green Analytical Chemistry on the Example of Bioindication and Biomonitoring (B & B) Technologies	19
	Bernd Markert, Eun-Shik Kim, Stefan Fränzle, Simone Wünschmann, Meie Wang, Romy Djingova, Mira Aničić Urošević, Shirong Liu, John Hillman, Jean-Bernard Diatta, Susanta Lahiri, Ivan Suchara, Piotr Szefer, Guntis Tabors, Jörg Rinklebe, Stefano Loppi, Harry Harmens, Peter Hooda, Maria Waclawek, Filipe Tack, Svetlana Gorelova, Anna Knox, Józef Pacyna, Elias Baydoun, Marina Frontasyeva, Adnan Badran, Alexander Lux, Silvia De Marco, Erik Meers, Andrzej Kłós and Jerome Nriagu	
3	Teaching Green Analytical and Synthesis Chemistry: Performing Laboratory Experiments in a Greener Way	45
	Arabinda Kumar Das, Ruma Chakraborty and Miguel de la Guardia	
4	Mass Spectrometry-Based Direct Analytical Techniques	75
	Renata Marcinkowska, Klaudia Pytel and Bożena Zabiegała	
5	New Achievements in the Field of Extraction of Trace Analytes from Samples Characterized by Complex Composition of the Matrix	103
	Katarzyna Owczarek, Natalia Szczepańska, Justyna Płotka-Wasyłka and Jacek Namieśnik	
6	Greening the Derivatization Step in Analytical Extractions: Recent Strategies and Future Directions	151
	Muhammad Sajid	

7	Smart Sorption Materials in Green Analytical Chemistry	167
	Francesc A. Esteve-Turrillas, Sergio Armenta, Salvador Garrigues and Miguel de la Guardia	
8	Ionic Liquids and Deep Eutectic Solvents in the Field of Environmental Monitoring	203
	Inês S. Cardoso, Augusto Q. Pedro, Armando J. D. Silvestre and Mara G. Freire	
9	Green Chromatography and Related Techniques	241
	Alshymaa A. Aly and Tadeusz Górecki	
10	Flow Injection Analysis Toward Green Analytical Chemistry	299
	Anita Martinović Bevanda, Stanislava Talić and Anita Ivanković	
11	Remote Monitoring of Environmental Pollutants	325
	Jacek Gębicki and Bartosz Szulczyński	
12	Comparative Greenness Evaluation	353
	Marta Bystrzanowska, Aleksander Orłowski and Marek Tobiszewski	
13	Quantitative Assessment	379
	Piotr Konieczka and Małgorzata Rutkowska	
14	QuEChERS—A Green Alternative Approach for the Determination of Pharmaceuticals and Personal Care Products in Environmental and Food Samples	395
	Christina Nannou, Anna Ofrydopoulou, David Heath, Ester Heath and Dimitra Lambropoulou	
15	Green Analytical Chemistry: Summary of Existing Knowledge and Future Trends	431
	Justyna Płotka-Wasyłka, Agnieszka Gałuszka and Jacek Namieśnik	

Contributors

Alshymaa A. Aly Department of Chemistry, University of Waterloo, Waterloo, Canada;

Department of Analytical Chemistry, Faculty of Pharmacy, Minia University, Minya, Egypt

Mira Aničić Urošević Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia

Sergio Armenta Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Adnan Badran Arab Academy of Sciences, Beirut, Lebanon

Elias Baydoun Department of Biology, American University of Beirut, Beirut, Lebanon

Anita Martinović Bevanda Department of Chemistry, Faculty of Science and Education, University of Mostar, Mostar, Bosnia and Herzegovina

Marta Bystrzanowska Department of Analytical Chemistry, Chemical Faculty, Gdańsk University of Technology (GUT), Gdańsk, Poland

Inês S. Cardoso CICECO—Aveiro Institute of Materials, Chemistry Department, University of Aveiro, Aveiro, Portugal

Ruma Chakraborty Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Arabinda Kumar Das Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Jean-Bernard Diatta Department of Agricultural Chemistry and Environmental Biogeochemistry, Poznan University of Life Sciences, Poznań, Poland

Rumy Djingova Faculty of Chemistry, University of Sofia, Sofia, Bulgaria

Francesc A. Esteve-Turrillas Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Magdalena Fabjanowicz Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Stefan Fränze Department of Biological and Environmental Sciences, University of Dresden, Zittau, Germany

Mara G. Freire CICECO—Aveiro Institute of Materials, Chemistry Department, University of Aveiro, Aveiro, Portugal

Marina Frontasyeva Department of Neutron Activation Analysis, Joint Institute for Nuclear Research, Dubna, Russia

Agnieszka Galuszka Geochemistry and the Environment Div., Institute of Chemistry, Jan Kochanowski University, Kielce, Poland

Salvador Garrigues Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Jacek Gębicki Department of Process Engineering and Chemical Technology, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Tadeusz Górecki Department of Chemistry, University of Waterloo, Waterloo, Canada

Svetlana Gorelova Department of Biology, Natural Science Institute, Tula State University, Tula, Russia

Miguel de la Guardia Department of Analytical Chemistry, University of Valencia, Valencia, Spain

Harry Harmens Centre for Ecology and Hydrology, Environment Centre Wales, Bangor, UK

David Heath Department of Environmental Sciences, Jožef Stefan Institute, Ljubljana, Slovenia

Ester Heath Department of Environmental Sciences, Jožef Stefan Institute, Ljubljana, Slovenia;
Jožef Stefan International Postgraduate School, Ljubljana, Slovenia

John Hillman James Hutton Institute, Invergowrie, UK

Peter Hooda School of Geography, Geology and the Environment, Kingston University London, London, UK

Anita Ivanković Faculty of Agriculture and Food Technology, University of Mostar, Mostar, Bosnia and Herzegovina

Kaja Kalinowska Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Eun-Shik Kim Department of Forestry Environment and Systems, College of Forest Science, Kookmin University, Seoul, South Korea

Andrzej Klos Chair of Biotechnology and Molecular Biology, Opole University, Opole, Poland

Anna Knox Department of Environmental Science and Biotechnology, Savannah River National Laboratory, Aiken, USA

Piotr Konieczka Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Susanta Lahiri Department of Chemical Sciences Division, Saha Institute of Nuclear Physics, Kolkata, India

Dimitra Lambropoulou Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki, Greece

Shirong Liu Department of Forest Ecology and Hydrology, Chinese Academy of Forestry, Beijing, People's Republic of China

Stefano Loppi Department of Life Sciences, University of Siena, Siena, Italy

Alexander Lux Department of Plant Physiology, Comenius University Bratislava, Bratislava, Slovakia

Renata Marcinkowska Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Silvia De Marco Department for Biology, Faculty of Exact and Natural Sciences, Universidad Nacional de Mar del Plata, Mar del Plata, Argentina

Bernd Markert Environmental Institute of Scientific Networks, Haren-Erika, Germany

Erik Meers Department of Green Chemistry and Technology, University of Ghent, Ghent, Belgium

Jacek Namieśnik Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Christina Nannou Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki, Greece

Jerome Nriagu School of Public Health, Center for Human Growth and Development, University of Michigan, Ann Arbor, MI, USA

Anna Ofrydopoulou Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki, Greece

Aleksander Orłowski Department of Management, Faculty of Management and Economics, Gdańsk University of Technology (GUT), Gdańsk, Poland

Katarzyna Owczarek Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Józef Pacyna Department of Energy and Fuels, AGH University of Science and Technology, Krakow, Poland

Augusto Q. Pedro CICECO—Aveiro Institute of Materials, Chemistry Department, University of Aveiro, Aveiro, Portugal

Justyna Plotka-Wasyłka Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Klaudia Pytel Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Jörg Rinklebe Department of Soil- and Groundwater-Management, University of Wuppertal, Wuppertal, Germany

Małgorzata Rutkowska Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Muhammad Sajid Center for Environment and Water, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Armando J. D. Silvestre CICECO—Aveiro Institute of Materials, Chemistry Department, University of Aveiro, Aveiro, Portugal

Ivan Suchara Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Průhonice, Czech Republic

Natalia Szczepańska Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Piotr Szefer Department of Food Sciences, Medical University of Gdansk, Gdansk, Poland

Bartosz Szulczyński Department of Process Engineering and Chemical Technology, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland

Guntis Tabors Faculty of Biology, University of Latvia, Riga, Latvia

Filipe Tack Department of Applied Analytical and Physical Chemistry, Ghent University, Ghent, Belgium

Stanislava Talić Department of Chemistry, Faculty of Science and Education, University of Mostar, Mostar, Bosnia and Herzegovina

Marek Tobiszewski Department of Analytical Chemistry, Chemical Faculty, Gdańsk University of Technology (GUT), Gdańsk, Poland

Maria Wacławek Department of Biotechnology and Molecular Biology, Opole University, Opole, Poland

Meie Wang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China

Simone Wünschmann Environmental Institute of Scientific Networks, Haren-Erika, Germany

Bożena Zabiegała Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, Gdańsk, Poland