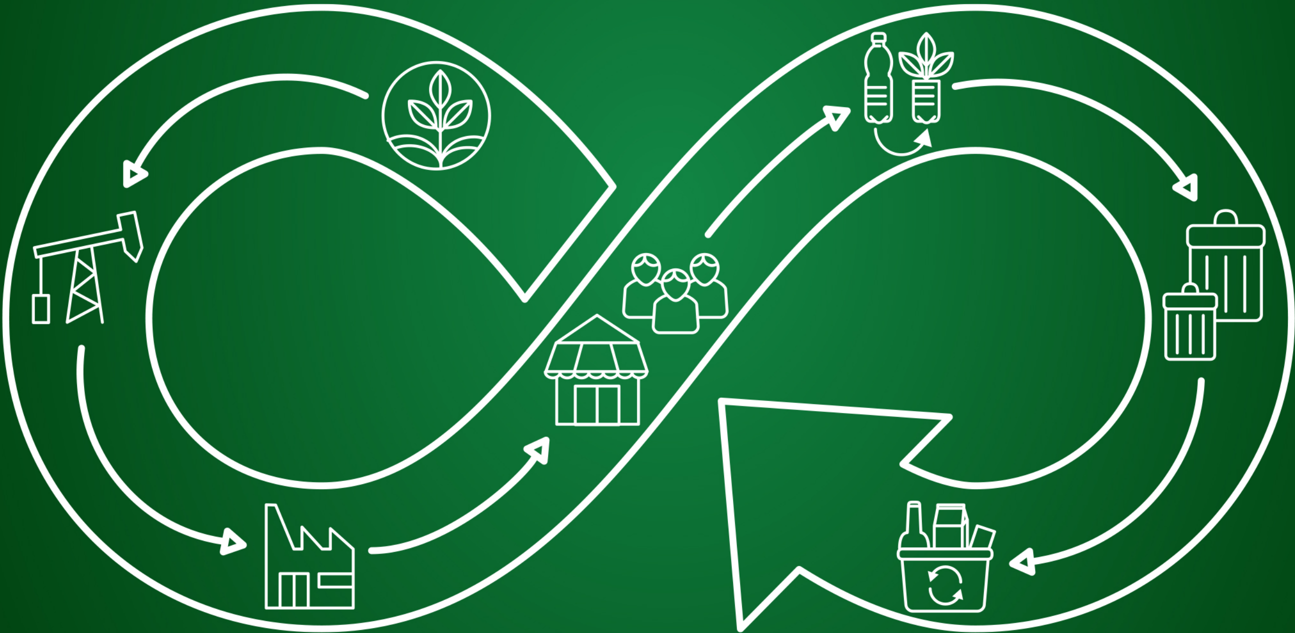
CIRCULAR ECONOMY AND SUSTAINABILITY

ENVIRONMENTAL ENGINEERING

VOLUME 2



EDITED BY

ALEXANDROS STEFANAKIS

IOANNIS NIKOLAOU

ELSEVIER

Circular Economy and SUSTAINABILITY

VOLUME 2

Circular Economy and
SUSTAINABILITY

VOLUME 2

Environmental Engineering

Edited by

ALEXANDROS STEFANAKIS
Assistant Professor, Environmental Engineering and Management Laboratory, School of Chemical and Environmental Engineering, Technical University of Crete, Greece

IOANNIS NIKOLAOU
Associate Professor, Business Economics and Environmental Technology Laboratory, Department of Environmental Engineering, Democritus University of Thrace, Greece

ELSEVIER

Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Notices
Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN 978-0-12-821664-4

For information on all Elsevier publications
visit our website at https://www.elsevier.com/books-and-journals

Publisher: Candice Janco
Acquisitions Editor: Marisa LaFleur
Editorial Project Manager: Barbara Makinster
Production Project Manager: Paul Prasad Chandramohan
Cover designer: Matthew Limbert

Typeset by STRAIVE, India

Contents

Contributors *xv*
Preface *xxiii*

1. Circular economy approach in the water and wastewater sector **1**
Marzena Smol
1. Introduction 1
2. Research framework 3
3. Results 4
4. Conclusions 15
References 16

2. Integrating circularity to achieve sustainability: Examples of various wastewater treatment systems **21**
Tamara Avellán, Nidhi Nagabhatla, Ishita Jalan, and Danielle Liao
1. Introduction 21
2. Case study 1: Sustainability assessment for wastewater treatment systems in Latin America 24
3. Case study 2: Decision making framework for wastewater treatment in New Delhi 25
4. Discussion and conclusion 26
Appendix 28
References 34

3. Risks associated with the circular economy: Treated sewage reuse in agriculture **37**
Ana María Leiva, Benjamín Piña, and Gladys Vidal
1. Limitations of the circular economy in sewage treatment 37
2. Antibiotics as a potential risk factor for treated sewage reuse in agriculture 39
3. Potential impacts on human health and in the environment 43
Acknowledgments 45
References 46

4. Wastewater reuse for agricultural irrigation in Greece: Review of guidelines under the prism of the latest European Union's policy developments 49

Charikleia Prochaska and Anastasios Zouboulis

1. Introduction 49
2. Wastewater treatment status in Greece 51
3. Wastewater reuse status in Greece 53
4. EU policy developments 54
5. Future trends and conclusions 58

References 60

5. A circular model for sustainable produced water management in the oil and gas industry 63

Alexandros I. Stefanakis

1. Introduction to PW 63
2. Constructed wetlands technology 66
3. Constructed wetlands in the oil and gas industry 67
4. A circular model to close the loop of waste in PW management 68
5. Conclusions 73

References 74

6. College of engineering Pune hostel campus: An Indian experience of sustainable wastewater treatment and reuse 79

F. Masi, R. Bresciani, A. Rizzo, and D. Panse

1. Introduction 79
2. Material and methods 80
3. Results and discussion 85
4. Conclusion 94

References 95

7. Wastewater treatment and sludge management strategies for environmental sustainability 97

Manisha Sharma, Ankush Yadav, Mrinal Kanti Mandal, Shailesh Pandey, Supriya Pal, Hirok Chaudhuri, Sandip Chakrabarti, and Kashyap Kumar Dubey

1. Introduction 97
2. Sludge management 99
3. Sustainability aspects 105
4. Conclusion 107

References 108

8. Recovery of nutritional resources of urban sewage sludge in lettuce production 113

T.N. Moraes, D.O. Guilherme, P.S. Cavalheri, and F.J.C. Magalhães Filho

1. Introduction 113
2. Methodology 114
3. Results 117
4. Conclusion 125

References 125

9. Sludge drying reed beds: A key ecotechnology for a sustainable sanitation infrastructure in Brazil 129

André Baxter Barreto, Gabriel Rodrigues Vasconcellos, and Breno Henrique Leite Cota

1. Humankind and agriculture as unbalanced geological forces 129
2. Sewage treatment in Brazil 132
3. Sludge drying reed beds: A key ecotechnology for a sustainable sanitation infrastructure in Brazil and similar countries 143
4. Conclusion 155

References 157

10. Manure treatment and recycling technologies 161

Renjie Dong, Wei Qiao, Jianbin Guo, and Hui Sun

1. Introduction 161
2. Solid-liquid separation 161
3. Composting 164
4. Anaerobic digestion 167
5. Land application of manure and digestates 170
6. Environmental risks control 174

References 177

11. Circular economy in the Mesopotamian Marshes: The Eden in Iraq Wastewater Garden Project 181

Davide Tocchetto, Meridel Rubenstein, Mark Nelson, and Jassim Al-Asadi

1. Introduction: Historical and ecological context 181
2. The wastewater project 185
3. Eden in Iraq and the circular economy 191
4. Conclusions 194

References 196

12. Design concept and performance of a constructed wetland system engineered for the circular economy 199

A.O. Babatunde

1. Introduction 199
2. Materials and methods 206
3. Results and discussion 207
4. Conclusions 212

References 213

13. Valorization of solid waste in subsurface flow constructed wetlands based on renewable modular structures: A contribution to a circular economy 215

Henrique J.O. Pinho and Dina M.R. Mateus

1. Introduction 215
2. Case study description 217
3. Perspective for future applications 229
4. Conclusions 230

Acknowledgments 231
References 231

14. Nature-based solutions for socially and environmentally responsible new cities: The contribution of green roofs 235

Cristina Sousa Coutinho Calheiros, Beatriz Castiglione, and Paulo Palha

1. Introduction 235
2. Green roofs as nature-based solution 237
3. Green roofs strategy for cities 244
4. Case study—Porto City Council 249
5. Highlights for the future 252

Acknowledgments 253
References 253

15. Constructed wetlands' application for flower farms wastewater treatment in developing countries: Case study in Kenya 257

Gilbert Atuga and Tsuma Jembe

1. Description of constructed wetlands 257
2. Constructed wetlands for Naivasha flower farms' wastewater treatment 259
3. Sustainability of constructed wetlands 264

4. Benefits associated with CWs in Naivasha flower farms' wastewater treatment 265
References 268

16. Ecotoxicity evaluation of diclofenac potassium in vertical flow constructed wetlands as posttreatment of septic tank effluent 271

P.S. Cavalheri, M.A. Mello, A.L. Pereira, T.R. Marques, T.N. Moraes, G.H. Cavazzana, and F.J.C. Magalhães Filho

1. Introduction 271
2. Materials and methods 274
3. Results and discussion 277
4. Conclusion 280

References 280

17. Searching for sustainability in organic matter and nitrogen removal by integrating constructed wetlands and microbial fuel cells 283

Daniela López, Thaís González, Gloria Gómez, Juan Pablo Miranda, José Contreras, and Gladys Vidal

1. Constructed wetlands from a circular economy perspective 283
2. Organic matter and nitrogen transformation and elimination processes in constructed wetlands 285
3. Integration of a microbial fuel cell into a constructed wetland to control methane emissions 289
4. Conclusions 293

Acknowledgments 294
References 294

18. Creative approaches in engaging the community toward ecological waste management and wetland conservation 297

Aaron Julius M. Lecciones, Kevin Roy B. Serrona, Ma. Catriona E. Devanadera, Amy M. Lecciones, and Jeongsoo Yu

1. Introduction 297
2. Research methodology 299
3. Wetland management 301
4. Regulatory framework 303
5. Waste pollution in wetlands 305
6. Interventions 307
7. Discussion 313
8. Conclusions 314

References 315

19. Circular economy in the building sector: Towards a holistic framework for implementing circular business models 319

Fatima Khitous, Andrea Urbinati, Davide Chiaroni, and Raffaella Manzini

1. Introduction 319
2. Literature review and research questions 320
3. Methodology, research framework and empirical analysis 322
4. Results 326
5. Conclusion, limitations, and directions for future research 333

References 334

20. Improving circular building under uncertainty and complexity: Exploring recent trends in the Netherlands 337

Jannie Coenen

1. Introduction 337
2. Theoretical and practical background 339
3. Research methodology 343
4. Results 344
5. Discussion 352
6. Conclusions, future research, and limitations 354

Acknowledgments 356

References 356

21. Circular materials—An essay on challenges with current manufacturing and recycling strategies as well as on the potential of life cycle integrated designs 359

Ludovic F. Dumée

1. Introduction 359
2. Enablers and barriers to circular design 361
3. Producing sustainable circular secondary raw materials 363
4. Producing circular products—Redesigning for easy dismantling and recycling 367
5. Conclusions and perspectives 370

References 370

22. Waste to energy at the neighborhood microscale in the urban regeneration of Madrid peripheries: Towards effective circular neighborhoods 373

Francisco Javier González, Susana Moreno, and Lourdes Rodriguez

1. Introduction: Changes in urban regeneration processes within vulnerable peripheries 373
2. Towards "circular neighborhoods" on the outskirts of Madrid: A model of sustainable urban regeneration that finds its resources in the intervention itself 375

3. Waste to energy processes at the neighborhood microscale 381
4. Opportunities and barriers in the implementation of waste to energy processes in the context of urban regeneration in the airport neighborhood of Madrid 383
5. Conclusions 390
References 391

23. Optimization of surface mining operation based on a circular economy model 395

F. Pavloudakis, C. Roumpos, and P.M. Spanidis

1. Introduction 395
2. Environmental aspects of surface mining 396
3. The circular resource flows in a surface mining project 399
4. Circular resource modeling 404
5. Conclusions 416
References 417

24. Sustainability assessment of bioleaching for mineral resource recovery from MSWI ashes 419

Valerio Funari

1. Municipal waste treatments call for sustainability 419
2. Waste-Bioleaching Nexus 428
3. Bioleaching Sustainability Assessment 438
References 441

25. Circular economy for the sustainability of the wood-based industry: The case of Caraga Region, Philippines 447

Raquel M. Balanay, Rowena P. Varela, and Anthony B. Halog

1. Introduction 447
2. Status and progress of circular economy initiatives across Asia (with emphasis on East and Southeast Asia) 448
3. Looking into the potentials of the circular economy for forestry development 452
4. The science-based initiatives on improving the wood-based industry in the Caraga Region 454
5. The development agenda for the sustainability of the wood-based industry 456
6. Developing the wood-based industry roadmap to sustainable development 458
7. Conclusion 459
References 459

26. Equilibrium modeling and statistical analysis of struvite precipitation for nutrient recovery from corn-ethanol downstream process 463

Ravi Kanani

1. Introduction 463
2. Literature review 465
3. Materials and methods 466
4. Results and discussion 470
5. Conclusion 487

Acknowledgment 488
References 488

27. Food processing wastes as a potential source of adsorbent for toxicant removal from water 491

Son Van Tran, Khai Manh Nguyen, Ha Thi Nguyen, Alexandros I. Stefanakis, and Phuong Minh Nguyen

1. Introduction on waste generated from food processing industries 491
2. Food processing wastes as potential adsorbents and their application in water and wastewater treatment 493
3. Advantages and obstacles of using food processing wastes as a valuable source of adsorbents for water treatment 498
4. Technological and policy solutions for supporting the application of food processing wastes as adsorbents in the water treatment industry 501

References 503

28. Sustainable circular economy design in 2050 for water and food security using renewable energy 509

Seeme Mallick

1. Introduction 509
2. Five technological possibilities 511
3. Sustainability, circular economy, and food security in the year 2050 518
4. Conclusion 519

References 520

29. Towards circular economy in e-waste management in India: Issues, challenges, and solutions 523

Biswajit Debnath, Ankita Das, and Abhijit Das

1. Introduction 523
2. Methodology 527
3. Circular economy practices in India 527

4. Existing technologies for e-waste management in India 528
5. New and upcoming technologies for e-waste management 530
6. Case studies 532
7. Findings and discussion 534
8. Conclusion and future direction 539
Acknowledgment 540
References 540

Index *545*

This page intentionally left blank

Contributors

Jassim Al-Asadi
Director of Nature Iraq NGO, El Chibaish, Iraq

Gilbert Atuga
Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

Tamara Avellán
Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), United Nations University, Dresden, Germany

A.O. Babatunde
School of Civil Engineering, University of Leeds, Leeds, United Kingdom

Raquel M. Balanay
College of Agriculture and Agri-Industries, Caraga State University, Ampayon, Butuan City, Philippines

André Baxter Barreto
Wetlands Construídos Ltda, Belo Horizonte, Brazil

R. Bresciani
IRIDRA Srl, Florence, Italy

Cristina Sousa Coutinho Calheiros
Interdisciplinary Centre of Marine and Environmental Research (CIIMAR/CIMAR), University of Porto, Novo Edifício do Terminal de Cruzeiros do Porto de Leixões, Matosinhos; Portuguese National Association of Green Roofs, Maia, Portugal

Beatriz Castiglione
Portuguese National Association of Green Roofs, Maia, Portugal

P.S. Cavalheri
Dom Bosco Catholic University, Campo Grande, Brazil

G.H. Cavazzana
Dom Bosco Catholic University, Campo Grande, Brazil

Sandip Chakrabarti
Amity Institute of Nanotechnology, Amity University, Noida, India

Hirok Chaudhuri
Department of Physics, National Institute of Technology, Durgapur, India

Davide Chiaroni
The Polytechnic University of Milan, School of Management, Milan, Italy

Jannie Coenen
Institute for Management Research (IMR), Radboud University (RU), Nijmegen, The Netherlands

José Contreras
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

Breno Henrique Leite Cota
Wetlands Construídos Ltda, Belo Horizonte, Brazil

Abhijit Das
Department of Information Technology, RCCIIT, Kolkata, India

Ankita Das
MCA Department, Heritage Institute of Technology, Kolkata, India

Biswajit Debnath
Department of Chemical Engineering, Jadavpur University, Kolkata, India; Department of Mathematics, ASTUTE, Aston University, Birmingham, United Kingdom

Ma. Catriona E. Devanadera
Department of Community and Environmental Resource Planning, College of Human Ecology, University of the Philippines, Los Baños, Laguna, Philippines

Renjie Dong
National Center for International Research of BioEnergy Science and Technology, College of Engineering, China Agricultural University, Beijing, China

Kashyap Kumar Dubey
Bioprocess Engineering Laboratory, School of Biotechnology, Jawaharlal Nehru University, New Delhi; Bioprocess Engineering Laboratory, Department of Biotechnology, Central University of Haryana, Mahendergarh, India

Ludovic F. Dumée
Khalifa University, Department of Chemical Engineering, Abu Dhabi, United Arab Emirates

F.J.C. Magalhães Filho
Dom Bosco Catholic University, Campo Grande, Brazil

Valerio Funari
National Research Council of Italy (CNR), Department of Earth System Sciences and Environmental Technologies, Institute of Marine Sciences (ISMAR-CNR), Bologna Research Area, Bologna, Italy

Gloria Gómez
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

Francisco Javier González
Architecture Department, School of Architecture, Engineering and Design, Universidad Europea, Madrid, Spain

Thaís González
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

D.O. Guilherme
Dom Bosco Catholic University, Campo Grande, Brazil

Jianbin Guo
National Center for International Research of BioEnergy Science and Technology, College of Engineering, China Agricultural University, Beijing, China

Anthony B. Halog
School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD, Australia

Ishita Jalan
Council on Energy, Environment, and Water, New Delhi, India

Tsuma Jembe
Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

Ravi Kanani
Lamar University, Beaumont, TX, United States

Fatima Khitous
Carlo Cattaneo University (LIUC), School of Industrial Engineering, Castellanza, Italy

Aaron Julius M. Lecciones
College of Architecture, University of the Philippines Diliman, Quezon City, Philippines

Amy M. Lecciones
Society for the Conservation of Philippine Wetlands, Inc., Pasig City, Philippines

Ana María Leiva
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

Danielle Liao
Institute for Water, Environment and Health (UNU-INWEH), United Nations University; Department of Biology, McMaster University, Hamilton, ON, Canada

Daniela López
School of Engineering and Sciences, Universidad Adolfo Ibáñez, Viña del Mar; Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

Seeme Mallick
Freelance Consultant Environmental Macroeconomics, Islamabad, Pakistan

Mrinal Kanti Mandal
Department of Chemical Engineering, National Institute of Technology, Durgapur, India

Raffaella Manzini
Carlo Cattaneo University (LIUC), School of Industrial Engineering, Castellanza, Italy

T.R. Marques
Dom Bosco Catholic University, Campo Grande, Brazil

F. Masi
IRIDRA Srl, Florence, Italy

Dina M.R. Mateus
Centre for Technology, Restoration and Art Enhancement (Techn&Art), BIOTEC.IPT, Polytechnic Institute of Tomar, Tomar, Portugal

M.A. Mello
Dom Bosco Catholic University, Campo Grande, Brazil

Juan Pablo Miranda
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

T.N. Moraes
Dom Bosco Catholic University, Campo Grande, Brazil

Susana Moreno
Architecture Department, School of Architecture, Engineering and Design, Universidad Europea, Madrid, Spain

Nidhi Nagabhatla
Institute for Water, Environment and Health (UNU-INWEH), United Nations University; School of Geography and Earth Science, McMaster University, Hamilton, ON, Canada

Mark Nelson
Wastewater Gardens International, Santa Fe, NM, United States; Institute of Ecotechnics, London, United Kingdom

Ha Thi Nguyen
Faculty of Environmental Sciences, University of Science, Vietnam National University, Hanoi, Viet Nam

Khai Manh Nguyen
Faculty of Environmental Sciences, University of Science, Vietnam National University, Hanoi, Viet Nam

Phuong Minh Nguyen
Faculty of Environmental Sciences, University of Science, Vietnam National University, Hanoi, Viet Nam

Supriya Pal
Department of Civil Engineering, National Institute of Technology, Durgapur, India

Paulo Palha
Neoturf espaços verdes Lda, Senhora da Hora; Portuguese National Association of Green Roofs, Maia, Portugal

Shailesh Pandey
Department of Chemical Engineering, National Institute of Technology, Durgapur, India

D. Panse
Ecosan Services Foundation, Pune, India

F. Pavloudakis
Public Power Corporation, Department of Mining Engineering, Athens, Greece

A.L. Pereira
Dom Bosco Catholic University, Campo Grande, Brazil

Benjamín Piña
Institute of Environmental Assessment and Water Research, Barcelona, Spain

Henrique J.O. Pinho
Smart Cities Research Center (Ci2), BIOTEC.IPT, Polytechnic Institute of Tomar, Tomar, Portugal

Charikleia Prochaska
Laboratory of Chemical and Environmental Technology, School of Chemistry, Faculty of Science, Aristotle University of Thessaloniki, Thessaloniki, Greece

Wei Qiao
National Center for International Research of BioEnergy Science and Technology, College of Engineering, China Agricultural University, Beijing, China

A. Rizzo
IRIDRA Srl, Florence, Italy

Lourdes Rodriguez
Envirobat España, S.L., Madrid, Spain

C. Roumpos
Public Power Corporation, Department of Mining Engineering, Athens, Greece

Meridel Rubenstein
Eden in Iraq Wastewater Garden Project, School of Sustainability, Arizona State University, Tempe, Arizona; Wastewater Gardens International, Santa Fe, NM, United States

Kevin Roy B. Serrona
Prince George's County Government, Department of the Environment, Resource Recovery Division, Largo, MD, United States

Manisha Sharma
Bioprocess Engineering Laboratory, Department of Biotechnology, Central University of Haryana, Mahendergarh, India

Marzena Smol
Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland

P.M. Spanidis
ASPROFOS Engineering SA, Division of Project Management, Athens, Greece

Alexandros I. Stefanakis
Environmental Engineering and Management Laboratory, School of Chemical and Environmental Engineering, Technical University of Crete, Greece

Hui Sun
National Center for International Research of BioEnergy Science and Technology, College of Engineering, China Agricultural University, Beijing, China

Davide Tocchetto
Wastewater Gardens International, Santa Fe, NM, United States; Institute of Ecotechnics, London, United Kingdom

Andrea Urbinati
Carlo Cattaneo University (LIUC), School of Industrial Engineering, Castellanza, Italy

Son Van Tran
Faculty of Environmental Sciences, University of Science, Vietnam National University, Hanoi, Viet Nam

Rowena P. Varela
College of Agriculture and Agri-Industries, Caraga State University, Ampayon, Butuan City, Philippines

Gabriel Rodrigues Vasconcellos
Wetlands Construídos Ltda, Belo Horizonte, Brazil

Gladys Vidal
Engineering and Environmental Biotechnology Group, Environmental Science Faculty & Center EULA-Chile, University of Concepción, Concepción, Chile

Ankush Yadav
Bioprocess Engineering Laboratory, Department of Biotechnology, Central University of Haryana, Mahendergarh, India

Jeongsoo Yu
Department of International Environmental and Resources Policy, Graduate School of International Cultural Studies, Tohoku University, Sendai, Japan

Anastasios Zouboulis
Laboratory of Chemical and Environmental Technology, School of Chemistry, Faculty of Science, Aristotle University of Thessaloniki, Thessaloniki, Greece

Preface

Circular economy is today a rising and widely discussed topic among professionals, academics, and the public. The trigger for this increasing attraction to this new concept is the gradual realization that the way our economies and societies have grown over the last 50 years has caused global environmental problems. We have experienced an unforeseen and continuous increase in materials extraction and consumption in our societies, doubled the production of goods, and quadrupled our economic development, reaching the smallest ever recorded percentage of people living under the poverty threshold. However, this much-desired growth and improvement of our global living standards has also resulted in 90% biodiversity loss, increasing water stress and greenhouse gas emissions, and ever-progressing climate change.

While the necessity to tackle these global environmental issues effectively is now recognized, we are still trying to identify the means to do that, i.e., to reach the goal of a truly sustainable society. While the discussion on sustainable society and economy is ongoing, it is clear that we need a new narrative, i.e., a new direction and scientific and epistemological theoretical frameworks. Circular economy is essentially an upcoming concept that could create the conditions to overcome the limitations of the existing linear economic model (take–produce–dispose) and focus on more efficient use of materials and flow optimization through engineering advances to preserve natural resources.

However, to achieve feasible sustainable solutions, the interface between economy, policy, and engineering, and implementation and production should be viewed from a different angle. A single environmental or technical approach is not sufficient, and a wider view is needed of the way we deal with environmental issues and industrial processes, to include goals such as social justice, poverty alleviation, and global and local connections. Hence, to get the answers and the solutions we seek, we see circular economy as a necessary vehicle to achieve the concept of sustainability, i.e., we believe that these two terms go hand-in-hand, thanks to social equity, economic growth, and environmental protection.

The new concept of circular economy and sustainability should be built on three main pillars: (i) environmental engineering, (ii) business, management, and economy, and (iii) society. The challenge now is to investigate the interconnections, interrelations, interactions, and synergies between these three pillars and how these relations are or can be realized in the real world. This is exactly the main motivation and the rationale behind this book. With this book we wanted to explore this new approach of circular economy and sustainability through chapters that would touch on and discuss different solutions and concepts to implement circular economy, viewed from multiple different angles.

The response was excellent, with more than 100 chapter proposals received. Therefore, we consulted Elsevier and they happily agreed to publish a second volume of this book, so that more chapters could be accepted. Thus, after the initial screening of the chapter proposals, the overall outcome is impressive: 63 chapters written by 198 authors from 33 different countries from all continents. The separation into two volumes was based on the contents: the first volume of the book includes chapters that focus more on the management and policy aspects, while the second volume deals mostly with the engineering and technology aspect. This two-volume book is the first to present an integrated approach of circular economy in various fields and disciplines, and to relate it to the goal of a sustainable society.

We hope that the readers, including professionals, academics, engineers, consultants, researchers, scientists, government agency employees, industrial stakeholders/entities, and students, will find the information provided here valuable for their work and tasks and useful for the fulfillment of their goals. We also hope that this book will contribute to a better understanding of the circular economy concept and to a clear definition of its contents.

Alexandros Stefanakis
Ioannis Nikolaou

CHAPTER 15

Constructed wetlands' application for flower farms wastewater treatment in developing countries: Case study in Kenya

Gilbert Atuga and Tsuma Jembe
Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

1. Description of constructed wetlands

Constructed wetlands (CWs) are naturally designed systems that utilize ecological processes such as physical, biological, and chemical processes. The CWs' components such as wetland plants, soil, and associated macrocosms influence these processes to strip pollutants from wastewater (EPA, 2000; Kadlec et al., 2000).

1.1 Classification of constructed wetlands

Constructed wetlands are classified based on: hydrology (open water surface and subsurface); plant growth (submerged, emergent floating leaved plants, and free-floating plants); and the flow path of water (horizontal or vertical) (Gorgoglione and Torretta, 2018; Kadlec et al., 2000).

Based on the above classification, CWs are of four different types. They include; (i) free water surface (FWS), which are shallow wetland water areas dominant with submerged and floating plants (Fig. 1A); (ii) vegetative submerged bed (VSB), which are subsurface flow wetlands with plants rooted on surface gravel with wastewater flowing through the gravel (Fig. 1B); (iii) hybrid systems, which are a combination of different types of CWs; and (iv) floating CWs systems (Fig. 1C), which encompass free-floating macrophytes (Kadlec et al., 2000; Tilley et al., 2014; Zhang et al., 2014).

1.2 General overview of application of constructed wetlands

Constructed wetlands technologies have been applied in different types of wastewater treatment. They include:

1. Secondary treatment of domestic and municipal wastewater where water is introduced to constructed wetlands after mechanical pretreatment for removal of debris, rags, and coarse suspended matter (Kadlec et al., 2000; EPA, 2000; Wu et al., 2008).

Circular Economy and Sustainability, Volume 2
https://doi.org/10.1016/B978-0-12-821664-4.00004-2

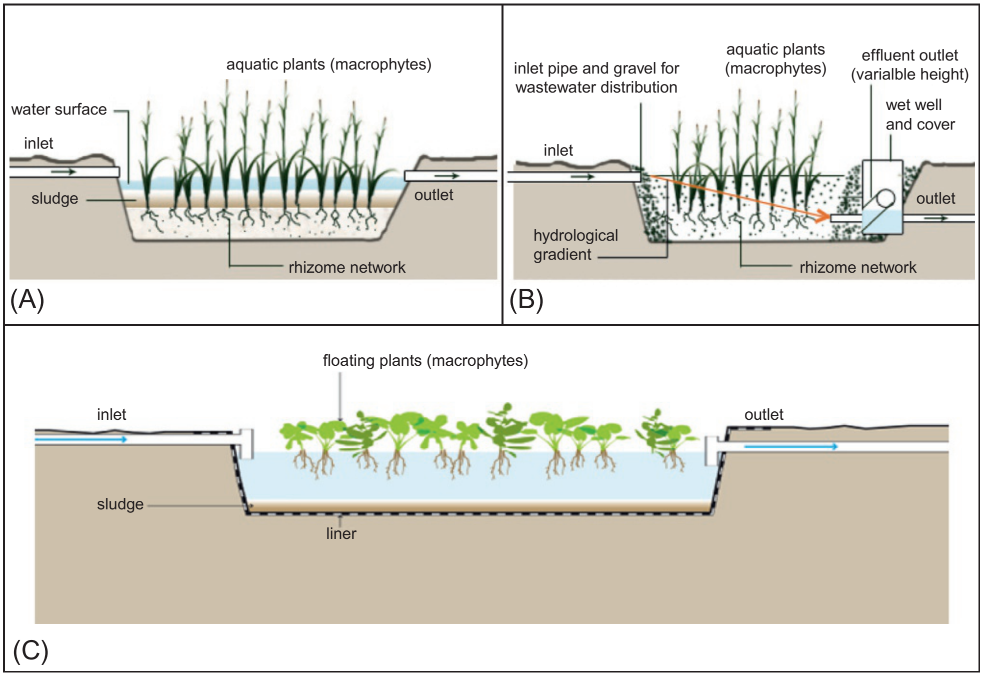


Fig. 1 (A) Free water surface constructed wetland; (B) subsurface flow treatment wetland (SSF); (C) floating CWs systems (Tilley et al., 2014).

In this application, CW is mainly used to remove major pollutants such as , total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and fecal coliforms (FC) (Kadlec et al., 2000; EPA, 2000).

2. Sewer overflow treatment, especially during rainy seasons, where excess sewer flow due to rainwater is channeled through a normal domestic flow to constructed wetlands. The principal contaminants in this wastewater are pathogenic bacteria and suspended solids, which are reduced before release to the receiving water bodies (Kadlec et al., 2000; EPA, 2000).
3. Stormwater originating from a variety of land sources have also been channeled to constructed wetlands for the removal of pollutants. Biochemical processes are used to remove targeted pollutants (Kadlec et al., 2000; Persson et al., 1999).
4. Metal amine waters, i.e., water from lead, zinc, silver, gold, copper, nickel, and uranium mines (Kadlec et al., 2000; Stefanakis, 2018; Noller et al., 1994; O'Sullivan et al., 2000).
5. Wastewater from food processing such as vegetables and meat (Bustillo-Lecompte and Mehrvar, 2015; Kadlec et al., 2000; Puchlik, 2016).

6. Petroleum industry for the treatment of refinery effluents, spills, and water from natural gas pipelines, oil, and sand processing water (EPA, 2000; Kadlec et al., 2000; Stefanakis, 2020).
7. Wetlands have also been utilized in pulp and paper industry effluent treatment (Abira, 2009; Choudhary et al., 2011; EPA, 2000; Kadlec et al., 2000).
8. In Kenya, it has been applied in wastewater treatment from Naivasha flower farms (Kimani et al., 2012).

2. Constructed wetlands for Naivasha flower farms' wastewater treatment

2.1 Naivasha's description, environmental setting, and economies

Lake Naivasha is a shallow freshwater tropical lake located in a semiarid environment with scarce surface and underground water resources. It is an important tourism and ecological site due to its biodiversity, and is the main economic resource for horticultural production. The lake supports a thriving fishery, extensive flower-growing industry, and geothermal power generation (Otiang'a-Owiti and Abiya, 2007). The Naivasha Basin is home to a wide range of aquatic and terrestrial flora and fauna, including birds, fish, mammals, and vegetation. The basin plays a very important role in Kenya's national development, contributing about 70% of Kenya's flower exports, 15% of Kenya's electric power, and is home to attractive tourist sites (Otiang'a-Owiti and Abiya, 2007). The area adjacent to the lake is ideal for horticulture, which plays a crucial role in the development of both the local and national economies, employing more than 30,000 people (Otiang'a-Owiti and Abiya, 2007).

Apart from contributing to the gross domestic product and foreign exchange earnings, approximately 60 flower farms line the entire lakeside providing employment and amenities to communities through their employees and families (Bolo, 2008). Handling of Lake Naivasha as a free "common pool" resource is considered the cost of the lake's sustainability and relates to the corporate image of the commercial farms. There is, therefore, need for sustainable management of the lakes' water resources. Ennis Killen (1999) suggests that a valuable resource such as freshwater cannot simply be left untapped, as the ability to develop and utilize water resources is linked to a nation's ability to develop and prosper (Walmsley, 2002).

Kenya's cut-flower industry is recognized as an economic success, which contributed 70% of Kenyan export value over the period 1996–2005 (Mekonnen et al., 2012). The total virtual water related to the export of cut flowers from the Lake Naivasha Basin was 16 Mm^3/yr, during the period 1996–2005 (22% green water; 45% blue water; 33% grey water) (Mekonnen et al., 2012).

2.2 The problems in Lake Naivasha's ecosystem

Rapid growth in population, human settlement, intensive commercial farming, tourism, and geothermal production have put intense pressure on natural resources, thereby threatening the sustainability of the Lake Naivasha Basin (Otiang'a-Owiti and Abiya, 2007). Increased demand for scarce environmental resources such as water and biomass has led to the increased abstraction of surface and groundwater resources, depletion of forestry resources, pollution of water bodies, and siltation of the lake (Mireri, 2005).

The Lake Naivasha ecosystem is acknowledged as fragile and faces increasing threats from irrigated agriculture, water abstraction, and a fast-growing human population (Otiang'a-Owiti and Abiya, 2007). The irrigated horticultural area consists of an estimated 4467 ha, with approximately 20,000 m^3 of water being extracted from the lake each day for use by nearby flower farms. Excess water abstraction—both from the lake itself and throughout its wider catchment area—is often perceived to be the most important conservation issue for this habitat (Mekonnen et al., 2012). The commercial farms have been blamed for causing a drop in the lake level, polluting the lake, and for possibly affecting the lake's biodiversity. Research has shown that, although the decline in the lake level can be attributed mainly to the commercial farms around the lake, both the commercial farms and the smallholder farms in the upper catchment are responsible for lake pollution due to nutrient loads (Mekonnen et al., 2012; Mireri, 2005).

A summary of these challenges concludes that severe environmental problems as a result of pollution from agricultural effluents and urban water surface runoff, uncontrolled water abstraction, improper land-use practices in the catchment area, and proliferation of invasive wetland species are the most pressing issues (Otiang'a-Owiti and Abiya, 2007). It has been observed that these problems are exacerbated and compounded by changes in climate and inadequate conservation interventions. In 2002, pollution from organochlorines, organophosphates, and DDT (which is illegal) was identified in Lake Fauna (Gitahi et al., 2002). These problems are further exacerbated by climate change and inadequate conservation interventions (Kimani et al., 2012). To control this problem, CWs have been used by Naivasha flower farms as a sustainable option for flower farm wastewater treatment (Kimani et al., 2012).

2.3 CW a preferred option to address pollution problems in Lake Naivasha

We provide a case study of environmental challenges being addressed through CW interventions. The Naivasha scenario involves a freshwater lake receiving agricultural effluents emanating from intense flower farming activities, with uncontrolled water abstraction, which services irrigated farms, geothermal power generation, and the urban populations' domestic needs. In addition to effluents, urban water surface runoff adds to pollution, while in the upper reaches, improper land-use practices provide additional nutrients, pesticides, and sediments.

Fig. 2 Flower farm in Salokidogo.

To mitigate against pollution, flower farms have adopted constructed wetland technologies for effluent treatment before release back into the lake's ecosystem (Fig. 2). In one of these scenarios, Home Grown Limited's CW demonstrates improved water quality (inlet to outlet) released back into the lake. In this scenario, the Kingfisher CW was designed to receive approximately 45 m^3/day of wastewater. The Kingfisher wetland is a combined (hybrid) system of a subsurface flow system known as gravel bed hydroponics (GBH) section, and a surface flow system with three sequential treatment cells. It uses a variety of aquatic plants including hyacinth (*Eichhornia crassipes*), *Cyprus papyrus*, and *Typha domingensis* for treating wastewater. The final treated water is used to culture fish in a fish pond. In this effort, the larger commercial farms are becoming more sustainable through the use of hydroponics and irrigation systems which decrease water consumption, thus increasing economic benefits.

2.4 Design types of the CWs in Lake Naivasha flower farms

Among constructed wetland types observed in Naivasha, horizontal subsurface flow wetlands are most widely used (Fig. 3), followed by surface flow and hybrid wetlands. Most of the reported hybrid wetlands (like Kingfisher CW) are reported to be more efficient. Some studies have been done on Naivasha flower farms CWs, which indicate that they are efficient in removal of organic matter (biochemical oxygen demand and chemical oxygen demand) and suspended solids (Mekonnen et al., 2015). Despite this telling situation, Mekonnen et al. (2015) opines that nutrient removal efficiency appears low.

Fig. 3 Horizontal CW in Naivasha, hyacinth and salvinia plants in use.

2.5 Effectiveness of CWs in Naivasha flower farms: Case study—Kingfisher CW

Some of the key functions of constructed wetlands include mitigating against increased conductivity, total dissolved solids (TDS), TSS, biological oxygen demand (BOD), chemical oxygen demand (COD), TN, TP, and toxic metals, which would otherwise be harmful to humans and other aquatic organisms including eutrophication of the recipient water bodies. A study conducted between October 2009 and March 2010 measuring water quality parameters at Kingfisher CW demonstrated that constructed wetlands are highly efficient in wastewater effluent treatment by significantly reducing the levels of most physical-chemical constituents, nutrients, and heavy metals from the wastewater (Kimani et al., 2012). The effectiveness of the CW in wastewater treatment became most visible when temporal variation in concentration of most parameters was compared. Most parameters showed wide temporal variations in their concentrations at inlet but stabilized at the outlet throughout the study period. The temporal variations of pollutants at the inlet were attributed to heightened farm activities and prevailing weather conditions (Kimani et al., 2012).

Table 1 shows the inlet to outlet water quality parameters changes. The table shows that Kingfisher CW effluents meet most of the East African discharge standards. On heavy metals, lead effluents concentrations changed from undetectable to 0.15 ± 0.13 mg/L with no significant variation in mean concentrations. Copper concentrations rarely exceeded 0.08 mg/L with means of 0.06 ± 0.03 mg/L with a slight general decrease

Table 1 Inflow and outflow water quality parameters at King Fisher flower farm CW.

Parameter	Inflow (mg/L)	Outflow (mg/L)	*P*-Values	East African Standards (EAS) effluents discharge limits (mg/L)
TSS	233 ± 26.47	23 ± 3.94	<0.05	100
BOD	138 ± 15.09	72 ± 5.49	<0.05	30
TDS	357 ± 30.92	260 ± 7.06	<0.05	2000
COD	569 ± 175	186 ± 62	<0.05	60
TN	5.1 ± 0.65	2.0 ± 0.34	<0.05	10
TP	5.5 ± 0.82	2.6 ± 0.24	<0.05	5
Lead (Pb)	0.04	0.03	<0.05	0.01
Copper (Cu)	0.06	0.03	<0.05	0.5
Manganese (Mn)	0.26	0.07	<0.05	–
Other parameters				
Conductivity	722 μS/cm	514 μS/cm	<0.05	–
PH	6.81 ± 0.17	6.65 ± 0.10	<0.05	6.0–9.0
Temperature	$23.1 \pm 0.35°C$	$18.3 \pm 0.38°C$	<0.05	–

East African Standards (2012).

in outflow concentration at 0.03 mg/L, and manganese outlet concentrations averaged 0.07 ± 0.01 mg/L (Kimani et al., 2012).

2.6 What next on application of CW on Naivasha flower farms?

A Previous study shows that constructed wetlands are an important intervention strategy in dealing with the pollution threats of Lake Naivasha from the estimated 300 horticulture farms (Kimani et al., 2012). The study emphasizes the need to encourage other flower farms to adopt the Kingfisher constructed wetland technology to deal with their wastewater (Kimani et al., 2012). In addition to these efforts, the World Wildlife Fund has launched a massive "payments for watershed services" (PWS) program designed to promote sustainable agriculture programs in the hills surrounding Lake Naivasha. By 2018, two major flower-grower associations had joined the program, but it will have to be scaled up tenfold to achieve meaningful results.

In terms of managing pollution, the flower growers have formed Flower Business Park Management Limited (FBP), which handles common issues for eight flower growers. Members of FBP are green certified for application of CWs in wastewater treatment. However, there is need to expand membership to strengthen the implementation of environmental protection activities. There are efforts to encourage farmers to adopt techniques such as biological controls of pests on flower farms, to reduce their reliance on potentially dangerous chemicals. Through incentive schemes put in place to encourage farmers to utilize "greener" practices, more farms are utilizing artificially constructed wetlands for wastewater treatment.

Furthermore, Kimani et al. (2012) propose that the efficiency of the constructed wetlands in treating the flower farms' wastewater can be improved and be used in resolving pollution challenges and help in establishing national guidelines.

3. Sustainability of constructed wetlands

Constructed wetlands are most useful for small communities and remote locations. Key factors to consider for the sustainability of a CW include the plant species, substrate type, water depth, hydraulic load, hydraulic retention time, and feeding mode. These factors define the benefits of using CWs as opposed to conventional wastewater treatment, which mainly results in low-energy use, and reduced operational and maintenance requirements. In evaluating the cost-benefit and sustainability of a typical CW, factors to consider should further include land acquisition, investment and operation costs, energy consumption, and ecological benefits.

Plant species used in both FWS CWs and SSF CWs Naivasha flower farms are sourced locally, hence being readily available and adapted to the environment. The most commonly used plant species in Naivasha flower farms are *Phragmites australis*, *Typha domingensis*, and *Cyperus papyrus* (emergent plants), and *Eichhornia crassipes* and *Salvinia molesta* (free-floating).

According to Saeed and Sun (2012), the capacity of uptake by plants differs according to system configuration, retention times, loading rates, wastewater types, and climatic conditions. The CW plant species are utilized to remove nitrogen, phosphorus, and other nutrients, while removing toxic elements such as heavy metals and antibiotics in wastewaters. For CWs' sustainability, selected plants have to be the most tolerant and most efficient in pollutants removal. While there are great differences in ammonia tolerance among plant species, *Typha latifolia* is stressed by ammonia concentrations averaging 160–170 mg/L (Surrency, 1993). Further evidence suggests that high COD levels (>200 mg/L) could disrupt the normal metabolism of *Phragmites australis* (Xu et al., 2010), this plant, however, tolerates and removes antibiotics concentrations typically found in wastewater.

Wang et al. (2010) have evaluated substrate types and state that hydraulic permeability increases the capacity to absorb pollutants and ensures long-term removal and performance of CWs. Substrate materials mostly consist of natural materials, artificial media, and industrial by-products. Albuquerque et al. (2009), Saeed and Sun (2012), Chong et al. (2013), and Yan and Xu (2014) have listed gravel, sand, clay, calcite, marble, vermiculite, slag, fly ash, bentonite, dolomite, limestone, shell, zeolite, wollastonite, activated carbon, and lightweight aggregates as commonly used substrates. Dynamic experiments have demonstrated that the adsorbing capacity of combined substrates is normally higher than that of single substrates (Lai and Lamb, 2009) and that increasing the proportion of decomposed granite in a substrate mix may enhance the phosphorus sorption capacity considerably.

Aguirre et al. (2005) established that the relative contribution of different metabolic pathways varied with water depth. In their experiments, it was noted that beds at depths of 0.27 m removed COD and ammonia and dissolved reactive phosphorus better than 0.5 m. The hydraulic loading rate (HLR) and hydraulic retention time (HRT) have to be optimized due to their importance in removal efficiency in CWs. Ammonium and TN concentrations are known to reduce dramatically with increasing HRT in CWs (Huang et al., 2000). Zhang et al. (2012) have shown that the feeding mode may influence the oxidation-reduction conditions and oxygen transfer and diffusion in wetland systems, thereby modifying the treatment efficiency.

Despite the advantages and CWs' advancement indicated herein, research on CWs needs more focus especially on enhancing technologies (artificial aeration, microbial augmentation, external carbon addition), operations (optimization of hydraulic conditions, manipulation of loading mode), design aspects (plant selection, substrate selection), and maintenance (plant harvest strategies, reclamation, and recycling of plant resources) (Wu et al., 2015).

4. Benefits associated with CWs in Naivasha flower farms' wastewater treatment

4.1 Circular economy/cleaner production

Constructed wetlands promote sustainable development within countries by ensuring the challenges of declining water quality and quantity are addressed. CW benefits countries by: (i) reducing pollution from industries, municipalities and agricultural activities; (ii) enhancing fish catches and other aquatic organisms through improved habitats and sustained fish biodiversity; (iii) reduced eutrophication and improved aquatic health; (iv) reduced land and catchment degradation that may lead to low land productivity; and (v) reduced sediment loading into receiving water bodies.

Adoption of CW technologies and modernizing the processes ensures reduced pollution, thereby greening the production units and making them not only green/sustainable but also competitive through lowered production costs. CWs may play a central role as a key tool for achieving a circular economy and provide enterprises a tool for environmental compliance.

In most developing countries where environmental compliance is low due to untreated industrial discharges, resource efficient and cleaner production (RECP) technologies may be complemented with CWs to achieve low COD and BOD levels. This ensures improved environmental performance and compliance. Apart from the capacity to manage industrial discharges, CWs can handle hospital and cosmetic wastewater as opposed to conventional wastewater treatment plants.

As a tool for managing effluents, CWs are much cheaper to manage and operate compared to conventional wastewater management systems. Such systems are easier to understand due to less complexity and fewer procedures. They are, therefore, accessible to communities, who have had an ever-increasing role in waste management.

4.2 Impact on markets

Utilization of green growth instruments by engaging private sector support for more sustainable agricultural supply chains of enterprises is particularly crucial in capital markets, especially for essential agricultural and commercial commodities like flowers, sugar, tea, coffee, fish, dairy, mango, honey, leather, paper processing, etc. Local and overseas market responses to products from noncompliant industries are detrimental to industrial success. Evidence points to increasing compliance as environmental regulators shift from traditional command and control (CAC), to market-driven instruments and information disclosure initiatives.

4.3 Impact on biodiversity

Effluents are known to impact negatively on receiving water bodies, especially due to toxic and organic substances. The ability of CWs to remove such substances ensures that habitat integrity is restored and encourages biodiversity in water bodies. The water bodies also support other businesses/industries relying on heavy use of local natural resources (i.e., greening the value chain).

4.4 Impact on the environment

One of the most common challenges in industrialization is pollution to the environment. Efforts to reduce pollution to the environment are boosted through utilization of CWs, with reduced effects of pollutants to all other life forms (humans, macro- and microorganisms, higher animals, and plants). Communities living in riparian water bodies are also less impacted by pollution from wastewater discharge that is treated before release to the environment.

4.5 Wetland products

The harvesting of wetland plants has been carried out for a long time and is embedded in tradition and cultures in many parts of the world. Wetland products include medicinal plants, various food types, furniture, building materials, and artifacts (Fig. 4). There exists a robust business in the region of the Naivasha flower farm wetlands, where markets are generally supported by wetland products and household incomes are enhanced.

Fig. 4 Examples of wetland products (Courtesy, Jembe).

4.6 Compliance to policies, regulations, and standards

For most countries, monitoring and enforcement by regulators and compliance of industries with existing standards and regulations are not achievable. The problem is generally associated with inadequate environmental policies or regulations, inadequate capacity, deficiencies in operational budgets and lack of trained personnel amongst regulators, and costs of wastewater treatment by industries. To mitigate against these challenges, East

African countries have combined three approaches to improve compliance and reduce environmental pollution. The augmentation of command and control (CAC) approaches with market-based instruments (MBI) has not had the desired effect, with noncompliance still high. The introduction of the public disclosure model has had a more profound impact, with most industries struggling to avoid being listed. However, the cost of treating wastewater remains the biggest challenge in developing countries. The proposal to use constructed wetlands offers lower costs in managing wastewater and increases compliance with existing policies, regulations, and standards.

References

Abira, M.A., 2009. A Pilot Constructed Treatment Wetlands for Pulp and Paper Mill Wastewater. CRC Press, Taylor & Francis, NW.

Aguirre, P., Ojeda, E., García, J., Barragán, J., Mujeriego, R., 2005. Effect of water depth on the removal of organic matter in horizontal subsurface flow constructed wetlands. J. Environ. Sci. Health A 40, 1457–1466.

Albuquerque, A., Oliveira, J., Semitela, S., Amaral, L., 2009. Influence of bed media characteristics on ammonia and nitrate removal in shallow horizontal subsurface flow constructed wetlands. Bioresour. Technol. 100, 6269–6277.

Bolo, M.O., 2008. The Lake Naivasha cut flower cluster in Kenya. In: Knowledge, Technology, and Cluster-Based Growth, p. 37.

Bustillo-Lecompte, C.F., Mehrvar, M., 2015. Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: a review on trends and advances. J. Environ. Manage. 161, 287–302.

Chong, H.L., Chia, P.S., Ahmad, M.N., 2013. The adsorption of heavy metal by Bornean oil palm shell and its potential application as constructed wetland media. Bioresour. Technol. 130, 181–186.

Choudhary, A.K., Kumar, S., Sharma, C., 2011. Constructed wetlands: an option for pulp and paper mill wastewater treatment. Elec. J. Environ. Agric. Food Chem. 10 (10), 3023–3037.

East African Standards, 2012. For Industrial and Municipal Effluents Discharged Into Public Sewers and Water Bodies—Maximum Permissible Limits.

Ennis Killen, A.L., 1999. The Ramsar Convention on Wetlands: The Lake Naivasha Riparian Association (LNRA), Kenya. Interview With Chairman Andrew Lord Enniskillen, by Catherine Mgendi and Susan Matindi. http://www.ramsar.org/award/key_awards99_interview_lnra.htmHubble.

EPA, D.M., 2000. Constructed Wetlands Treatment of Municipal Wastewaters (EPA/625/R-99/010). EPA Office of Research and Development, Cincinnati, OH.

Gitahi, S.M., Harper, D.M., Muchiri, S.M., Tole, M.P., 2002. Organochlorine and organophosphorus pesticide concentrations in water, sediment, and selected organisms in Lake Naivasha (Kenya). Hydrobiologia 488 (1–3), 123–128.

Gorgoglione, A., Torretta, V., 2018. Sustainable management and successful application of constructed wetlands: a critical review. Sustainability 10 (11), 3910.

Huang, J., Reneau, R., Hagedorn, C., 2000. Nitrogen removal in constructed wetlands employed to treat domestic wastewater. Water Res. 34, 2582–2588.

Kadlec, R., Knight, R., Vymazal, J., Brix, H., Cooper, P., Haberl, R., 2000. Constructed Wetlands for Pollution Control: Processes, Performance, Design, and Operation. IWA Publishing.

Kimani, R.W., Mwangi, B.M., Gichuki, C.M., 2012. Treatment of flower farm wastewater effluents using constructed wetlands in Lake Naivasha, Kenya. Indian J. Sci. Technol. 5 (1), 1870–1878.

Lai, D.Y., Lamb, K.C., 2009. Phosphorus sorption by sediments in a subtropical constructed wetland receiving stormwater runoff. Ecol. Eng. 35, 735–743.

Mekonnen, M.M., Hoekstra, A.Y., Becht, R., 2012. Mitigating the water footprint of export cut flowers from the Lake Naivasha Basin, Kenya. Water Resour. Manage. 26 (13), 3725–3742.

Mekonnen, A., Leta, S., Njau, K.N., 2015. Wastewater treatment performance efficiency of constructed wetlands in African countries: a review. Water Sci. Technol. 71 (1), 1–8.
Mireri, C., 2005. Challenges facing the conservation of Lake Naivasha, Kenya. In: FWU Topics of Integrated Watershed Management—Proceedings. vol. 3, pp. 89–98.
Noller, B.N., Woods, P.H., Ross, B.J., 1994. Case studies of wetland filtration of mine wastewater in constructed and naturally occurring systems in Northern Australia. Water Sci. Technol. 29 (4), 257–265.
O'Sullivan, A.D., Murray, D.A., Otte, M.L., 2000. Development of constructed wetlands for treatment of sulfate-enriched water originating from (Pb/Zn) mine tailings. Landbauforsch. Völkenrode Sonderh. 218, 81–84.
Otiang'a-Owiti, G.E., Abiya, O.I., 2007. Human impact on lake ecosystems: the case of Lake Naivasha, Kenya. Afr. J. Aquat. Sci. 32 (1), 79–88.
Persson, J., Somes, N.L., Wong, T.H.F., 1999. Hydraulics efficiency of constructed wetlands and ponds. Water Sci. Technol. 40 (3), 291–300.
Puchlik, M., 2016. Application of constructed wetlands for treatment of wastewater from fruit and vegetable industry. J. Ecol. Eng. 17 (1), 131–135.
Saeed, T., Sun, G., 2012. A review of nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions, and supporting media. J. Environ. Manage. 112, 429–448.
Stefanakis, A.I. (Ed.), 2018. Constructed Wetlands for Industrial Wastewater Treatment. John Wiley & Sons.
Stefanakis, A.I., 2020. Constructed wetlands for sustainable wastewater treatment in hot and arid climates: opportunities, challenges and case studies in the Middle East. Water 12 (6), 1665.
Surrency, D., 1993. Evaluation of aquatic plants for constructed wetlands. In: Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL, pp. 349–357.
Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., Zurbrügg, C., 2014. Compendium of Sanitation Systems and Technologies. Eawag.
Walmsley, J., 2002. Framework for measuring sustainable development in catchment systems. Environ. Manage. 29 (2).
Wang, R., Korboulewsky, N., Prudent, P., Domeizel, M., Rolando, C., Bonin, G., 2010. Feasibility of using an organic substrate in a wetland system treating sewage sludge: Impact of plant species. Bioresour. Technol. 101, 51–57.
Wu, Y., Chung, A., Tam, N.F.Y., Pi, N., Wong, M.H., 2008. Constructed mangrove wetland as a secondary treatment system for municipal wastewater. Ecol. Eng. 34 (2), 137–146.
Wu, H., Zhang, J., Ngo, H.H., Guo, W., Hu, Z., Liang, S., Fan, J., Liu, H., 2015. A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. Bioresour. Technol. 175, 594–601.
Xu, J., Zhang, J., Xie, H., Li, C., Bao, N., Zhang, C., Shi, Q., 2010. Physiological responses of *Phragmites australis* to wastewater with different chemical oxygen demands. Ecol. Eng. 36, 1341–1347.
Yan, Y., Xu, J., 2014. Improving winter performance of constructed wetlands for wastewater treatment in Northern China: a review. Wetlands 34, 243–253.
Zhang, D.Q., Tan, S.K., Ginsberg, R.M., Zhu, J., Sadreddini, S., Li, Y., 2012. Nutrient removal in tropical subsurface flow constructed wetlands under batch and continuous flow conditions. J. Environ. Manage. 96, 1–6.
Zhang, D.Q., Jinadasa, K.B.S.N., Ginsberg, R.M., Liu, Y., Ng, W.J., Tan, S.K., 2014. Application of constructed wetlands for wastewater treatment in developing countries—a review of recent developments (2000–2013). J. Environ. Manage. 141, 116–131.

This page intentionally left blank