Ecohydrology and ecohydrological biotechnologies as environmentally friendly remediation approaches for contaminated ecosystems

Magdalena Urbaniak
We are living in the Anthropocene Era when almost 80% of our usable ecosphere has been conditioned, converted, and consumed by humans, usually without understanding the full consequences of our actions.

Columbus Declaration EcoSummitt 2012
First principle of Ecohydrology

Quantification of processes – water cycle and dynamics of POPs

Zalewski et al., 1997; Zalewski, 2009
Ecohydrology was defined in a frame of the UNESCO International Hydrological Programme (IHP). Ecohydrology is a transdisciplinary and applied science. It uses the understanding of relationships between hydrological and biological processes at the catchment scale to achieve water quality improvement, biodiversity enhancement and sustainable development.

**4-step approach to solve environmental problems**

1. **Identification of threats**
2. **Analysis of cause-effect relationships**
3. **Development of methods and tools for reduction of identified threats**
4. **Elaboration of systemic solutions at catchment scale**
Practical Experiments Guide for Ecohedology

Book (2006) of 118 pp. 21 Chapters. Aiming to contribute to the dissemination of the Ecohedology concept in different types of aquatic ecosystems, the book proposes a series of practical experiments, mostly requiring non-sophisticated laboratory equipment and conditions. The experiments proposed will provide to the water science students a practical knowledge of the methods to identify, analyse and design solutions to water and biodiversity degradation. For further discussions, questions or suggestions readers may use the book webpage. See by chapters or download the entire book.

International Environmental Technology Centre (IETC)

The celebrated its 10th anniversary in 2004 and reviewed its area of work to ensure that its programme reflects current global environmental priorities and is closely linked to the outcomes of the World Summit on Sustainable Development (WSSD) - More.

European Regional Centre on Ecohedology (ERCE)

Established under the auspices of UNESCO, in Lodz (Poland), as an international institute of the Polish Academy of Sciences (International Centre for Ecohedology) in cooperation with the University of Lodz, in the framework of the International Hydrological Programme (IHP). ERCE promotes integrative multidisciplinary ecohedological research at a catchment scale for sustainable management, protection and restoration of aquatic resources. Basic research includes: Hydrology, hydrobiology, environmental chemistry, landscape processes, soil ecology, phytomonitoring, environmental toxicology and genetics, population studies and mathematical modelling. - More.

International Centre on Coastal Ecohedology (ICCE)

Established under the auspices of UNESCO, located within the University of Algarve (UALG), in Faro, Portugal, the Centre promotes science, education and public awareness in areas of expertise, specialty for Africa and Mediterranean regions. - More.


IHP-VIII WATER SECURITY

Responses to Regional and Global Challenges (2014-2021)

THEME 5: ECOHYDROLOGY – ENGINEERING HARMONY FOR A SUSTAINABLE WORLD

Focal Area 5.2 - Hydrological dimension of a catchment - identification of potential threats and opportunities for sustainable development

Focal Area 5.3 - Shaping the catchment ecological structure for ecosystem potential enhancement - social, agricultural productivity and biodiversity

Focal Area 5.4 - Urban Ecohedology – storm water purification and retention in the city landscape, potential for improvement of health and quality of life

Focal Area 5.5 - Ecohedological regulation for sustaining and restoring continental to coastal connectivity and ecosystem functioning

WATER-RELATED DISASTERS AND HYDROLOGICAL CHANGE

GROUNDWATER IN A CHANGING ENVIRONMENT

ADDRESSING WATER SCARCITY AND WATER QUALITY

WATER AND HUMAN SETTLEMENTS OF THE FUTURE

ECOHYDROLOGY ENGINEERING HARMONY FOR A SUSTAINABLE WORLD

EDUCATION, KEY TO WATER SECURITY

WATER SECURITY, ADDRESSING LOCAL, REGIONAL AND GLOBAL CHALLENGES
FIELD STUDIES

1) Impact of **DAM RESERVOIR** on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum

2) Impact of **HYDROLOGY** on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum

3) Impact of **WTPs** on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum
Study area

Baltic Sea catchment

Pilica River catchment

Water and sediment sampling stations located at Pilica River

Treated wastewater sampling stations located at WTP outlets
**Spatial distribution of dioxins and dioxin-like compounds along large reservoirs of different catchment land use**

<table>
<thead>
<tr>
<th>Large/agriculture, urban, industrial catchment</th>
<th>Large, prevailing agriculture/urban catchment</th>
<th>Large, prevailing agriculture catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiłczański Reservoir</td>
<td>Jeziorsko Reservoir</td>
<td>Sulejowski Reservoir</td>
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<table>
<thead>
<tr>
<th>Concentration [ng/kg d.w.]</th>
<th>Toxicity [ng TEQ/kg d.w.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>middle</td>
<td>dam</td>
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<td><img src="chart1.png" alt="Chart" /></td>
<td><img src="chart2.png" alt="Chart" /></td>
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</tbody>
</table>

During the transport of dioxins and dioxin-like compounds along the reservoir, reduction of sediment toxicity occurred.

PCDD, PCDF, dl-PCB

- Results relevant statistically Wilcoxon Test
- Results relevant statistically ANOVA Friedman
Impact of dam reservoir on river water quality

Bottom sediments

River water

Concentration [pg/L]

Zb. Sulejowski

Przepływy wezbraniowe
Przepływy średnie

Limit 1 pgTEQ/L wg JEQS

Impact of point sources of pollution on river water quality

Concentration of PCDDs/PCDFs & dl-PCBs

 Loads of PCDDs/PCDFs & dl-PCBs

Spała WTP Small

Nowe Miasto WTP Medium

Tomaszów Maz. Large

Urbaniak et al., 2014; Urbaniak & Kiedrzyńska, 2015
Insufficiently treated wastewater

Contaminated sewage sludge

Contaminated bottom sediments
Sequential Model Biofiltration System at Rozprza WTP outlet
Purification of wastewater on limestone, coal and sawdust deposits, and in the "constructed wetland"
Case study: Sokołówka Sequential Sedimentation-Biofiltration System

Stormwater inflow

Suspended matter sedimentation in sedimentation zone – anaerobic zone

Biogeochemical barrier for reduction of phosphate in water and binding heavy metals with calcium and phosphorus

$\text{Ca}_3(\text{PO}_4)_2$↓

Biofiltration zone – assimilation of nitrogen by macrophytes and minarelization processes, phytoremediation and rhizoremediation of micropollutants

The role of biotechnology in enhancement of purification efficiency

Outflow of purified water
The restoration water quality resilience, biodiversity, and ecosystem services for society in urban Sokółwka River at the City of Łódź

Tree Development rehabilitation rzeki, filtracja wód burzowych


Staw Wasiaka (2009/2010)

Staw Dolny

Zb. Zgierska

Zb. Teresy

Zb. Pabianka

Park Sokółwki

Marina filtracja wód burzowych
EH-REK: Ecohydrologic rehabilitation of recreational reservoirs "Arturówka" (Łódź) as a model approach to rehabilitation of urban reservoirs.

Project UE, LIFE+ Environment Policy and Governance Programme, LIFE08 ENV/PL/000517

Scientific coordinator: prof. dr hab. Maciej Zalewski, Project coordinator: dr Tomasz Jurczak
Case study: Arturówek
Harmonization of hydrotechnical & biological solutions

BSS
Biofiltration sedimentation system

Biological processes regulation

Biofiltration zone
Biogeochemical barrier
Sedimentation zone
System leading the stormwater into the BSS

UNDERGROUND SYSTEM OF SEPARATORS AND SEDIMENTATION TANKS
Elimination of petroleum substances in lamel separators and suspended matter in swirl tanks

Rain water
STREET suspended matter, petroleum substances, Heavy metals, dioxins, nutrients

Gradient of water quality
HIGH
LOW
The following represents the structure of rehabilitation measures, including their visualisations for the Bzura River and Arturowek recreational reservoirs.

Construction of buffer zones including biogeochemical barriers as well as construction of floating islands in order to reduce nutrients.

Ecohydrological adaptation of the reservoirs in order to intensify the process of water self-purification.

Construction of the biofiltration sequential system (BSS) in order to reduce the hazard posed by rainwater.

Ecohydrological adaptation of small retention reservoirs in terms of intensification of river self-purification capacity.
Transformation of the upper part of Arturowek upper reservoir’s bowl, which currently operates as a sedimentation tank within the sedimentation-biofiltration system.

V.2012

IV.2013

V.2013

VI.2013

Temp 23.7°C, TP 0.19, NO₂ - 0.000, NO₃ - 0.23, NH₄⁺ - 0.02 mg/l,

Temp 17.7°C, TP 1.22, NO₂ - 0.004, NO₃ - 2.16, NH₄⁺ - 0.82 mg/l.
Construction of buffer vegetation zones in the spots of point rainwater inflow in order to reduce surface run-off, and construction of buoyant vegetation mats.
Use of ecohydrology based systemic solutions for reduction of siltation, eutrophication and dioxin-induced toxicity in the Asella BioFarm Park lake, Ethiopia

- Absorption of nutrients and micropollutants and their conversion into loess toxic forms
- Use of sediments for bioenergy production
- Restitution of eroded land by application of biodegradable geofibres and phytoremediation
- Use of biodegradable geofibres for erosion control
- Stock watering site and use of manure collected at the site as a fertilizer
- Construction of the sequential biofiltration system for turbidity, eutrophication and dioxin toxicity reduction in the Asella BioFarm Park lake

**Dioxin toxicity reduction in the Asella BioFarm Park lake**

- Inflow
- Wetland I
- Wetland II
- Outflow
- Odphyw

Dioxin toxicity levels:
- 0
- 1
- 2
- 3
- Toxicity [ng TEQ/kg d.w.]

**Diagram Elements**

- Inflow
- Wetland I
- Wetland II
- Outflow
- Stock watering site
- Use of manure
- Bioenergy delivery
- Sedimentation
- Bioenergy plantation
- Fertilizing
- Infiltration dam
- Geofibre control
- Phyto remediation
- Manure collection
- Nutrient and micropollutant absorption
- Detoxification
- Biofiltration system
Insufficiently treated wastewater

Contaminated sewage sludge

Needs
Challenges
The National (Polish) Program of Urban Wastewater Treatment requires any agglomeration producing wastewater with a pollution load equivalent to the amount of wastewater generated by 2000 adults, (p.e. more than 2000), to be equipped with a wastewater collection and treatment system appropriate to local conditions and needs.

50% increase of sludge production during last 20 years

Among the new EU members (EU-12), Poland is the greatest sludge producer, producing almost 42% of total sludge amounts.
According the Sewage Sludge Directive (SSD) (86/278/EEC), the reuse of sewage sludge for direct agriculture application and compost is the principal method for its management in Europe. The Urban Waste Water Treatment Directive (91/271/EEC) recommend to maximize the reuse of produced sewage sludge.

In the case of EU27, the sewage sludge disposal methods include agricultural use (41%), incineration (19%), landfill (17%), compost (12%) and others (11%).

SSD and national regulations oblige the monitoring of sewage sludge content in terms of:
- dry matter, organic matter, pH, nitrogen, phosphorous, Cd, Cr, Cu, Hg, Ni, Pb, Zn

A huge amount of non-monitored compounds such as toxic persistent organic compounds, pharmaceuticals, emerging contaminants, etc.

Risk for human health and ecosystem well-being
Insufficiently treated wastewater
Contaminated sewage sludge
Contaminated bottom sediments
Europe-wide, the volume of dredged material is very roughly estimated at 200 million cubic metres per year.

http://en.ekorob.pl/barkowice-laka-demo-site
Study aims cont.

1) Impact of DAM RESERVOIR on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum

2) Impact of HYDROLOGY on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum

3) Impact of WTPs on PCDDs/PCDFs and dl-PCBs content and distribution along the river continuum

4) PHYTOREMEDIAION of PCDDs/PCDFs and dl-PCBs contaminated RESERVOIR SEDIMENTS AND SEWAGE SLUDGE

Plant cultivation: willow, zucchini, cucumber

Reservoir bottom sediments

Sewage sludge from WTPs
Solution: Sewage sludge can be utilized as a fertilizer of energetic plants.

Need for sludge utilization

Sewage sludge

NON-FOOD FERTILIZER

Willow plantation = green energy production + sludge-born pollutants removal

Problems / questions

Impact of sewage sludge amendment on soil properties

Impact of willow cultivation on soil properties

Impact of sewage sludge amendment on willow growth and metabolism
Experiment design

**Study area:** Protected Zone of a Lodz Wastewater Treatment Plant (WTP) (60 ha) used for willow biomass production (willow plantation).

**Used soil:** The soil was of poor quality (VI class) and mainly composed of loose sands.

**Used swage sludge:** The sewage sludge was obtained from the three WTPs located in Central Poland, selected according to the following size criterion: small (class I), medium (class II), large (class III).

**Used doses of sewage sludge:** The obtained sewage sludge was used as a fertilizer in quantities analogous to 3 and 9 tons per hectare (t/ha), reflecting the maximum allowable dose of sewage sludge according to the Regulation of the Polish Minister of Environment (Journal of Laws of 2015, item 257).
Soil characteristics

Changes in soil TOC and FH and total humic and fluvic content during 20 weeks of the experiment

Urbaniak et al., 2017

TOC and total fulvic and humic fractions – the effect of sludge amendment
Bacterial abundance— the effect of sludge amendment

Changes in bacterial abundance during 20 weeks of the experiment

Urbaniak et al., 2017
Changes in total phytotoxicity of soil during 20 weeks of the experiment (measured using Phytotoxkit test and three test plant species)

- Without willow
- With willow

Urbaniak et al., 2017
Soil characteristics

Changes in PCDDs/PCDFs TEQ concentration during 20 weeks of the experiment (measured using isotope dilution method and HRGC/HRMS)

PCDDs/PCDF TEQ concentrations — the effect of sludge amendment

Urbaniak et al., 2017
Biomass of the willow – the effect of sludge amendment

Willow condition

Urbaniak et al., 2017
Willow condition

Biometric parameters – the effect of sludge amendment

Average surface area of willow leaves

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>S 3</th>
<th>S 9</th>
<th>M 3</th>
<th>M 9</th>
<th>L 3</th>
<th>L 9</th>
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Average length of willow leaves

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<th>Control</th>
<th>S 3</th>
<th>S 9</th>
<th>M 3</th>
<th>M 9</th>
<th>L 3</th>
<th>L 9</th>
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</table>

Urbaniak et al., 2016
Willow condition

Physiological parameters of the willow – the effect of sludge amendment

Chlorophyll content [mg/g f.w.]

Chlorophyll a + b

Control  S 3  S 9  M 3  M 9  L 3  L 9

Urbaniak et al., 2017

10 weeks
20 weeks
The total GST activity (GST; EC 2.5.1.18) (Edwards and Dixon, 2004) determined with 1-chloro-2,4-dinitrobenzene (CDNB) by a method modified from Habig et al. (1974).
Need for sludge and sediments utilization

Application of *Cucurbitaceae* for POPs removal from sewage sludge and sediments

- Thanks to 17kDa protein (encoded by MLP-Gr gene) they have unique properties that enable them to take up POPs from soil and translocate them into the stems and leaves (*phytoremediation*)
- Fast-growing (only 4-5 weeks)
- Easy to cultivate (no specific needs)
- Thanks to PSMs excreted to soil they promote growth of soil microbiota (*rhizoremediation*)
Inhibition of root growth of *Lepidium sativum*, *Sinapis alba* & *Sorghum saccharatum* cultivated in soil amended with sewage sludge

**Decrease in root growth inhibition as an phytoremediation effect of *Cucumis sativus* L. cultivation** (after 5 weeks)

Morphology of *Cucumis sativus* L. grown in sludge amended soil

**PCBs removal efficiency**

Wyrwicka, Steffani, Urbaniak, 2014
Application of *Cucurbitaceae* for POPs removal from sewage sludge and sediments

A

![Graph A](image)

- **Total concentration of PCDDs/PCDFs [ng/kg d.w.]**
  - Control
  - 3 t/ha of SS
  - 9 t/ha of SS
  - 18 t/ha of SS

- **without plants**
- **after 5-weeks of zuccini cultivation**
- **after 5-weeks of cucumber cultivation**

B

![Graph B](image)

- **TEQ concentration [ng TEQ/kg d.w.]**
  - Control
  - 3 t/ha
  - 9 t/ha
  - 18 t/ha

- **without plants**
- **after 5-weeks of zuccini cultivation**
- **after 5-weeks of cucumber cultivation**

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**Urbaniak i Wyrwicka, 2016**

**Wyrwicka & Urbaniak, 2016**
Response of *Cucurbitaceae* to sewage sludge and sediments application

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**APx Activity**

<table>
<thead>
<tr>
<th>Experimental variant</th>
<th>Control</th>
<th>1.8</th>
<th>5.4</th>
<th>10.8</th>
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<tbody>
<tr>
<td>APx activity [kat/mg protein]</td>
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<tr>
<td>Control</td>
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<td>25</td>
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<td>1.8</td>
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<td>5.4</td>
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<td>10.8</td>
<td>25</td>
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<td>55</td>
<td>45</td>
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**POx Activity**

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<td>10.8</td>
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<td>60</td>
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**α-Tocopherol Concentration** [μg g⁻¹ fresh weight]

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<th>Experimental variant</th>
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<td>α-Tocopherol concentration [μg g⁻¹ fresh weight]</td>
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<td>10.8</td>
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**GST Activity** [kat/mg protein]

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<td>5.4</td>
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<tr>
<td>10.8</td>
<td>1</td>
<td>2</td>
<td>2.5</td>
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</table>
The choice of varieties was followed by the criterion of biomass and branching of the plant; Different biomass production of particular varieties, influences the ability to take up hydrophobic compounds from the substrate; The concentration of accumulated pollutants is proportional to the biomass of individual plant organs (White, 2002).
Potential of soil/rhizosphere bacteria to PCDDs/PCDFs degradation

**TCEA1**
Dehalogenase

Control – no PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

100 ng TEQ PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

500 ng TEQ PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

Positive control

**DXNA1**
Dioxygenase

Control – no PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

100 ng TEQ PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

500 ng TEQ PCDDs/Fs
- No plants
- Scyra
- Atena
- NimbA

Positive control
Potential of zucchini cultivars to take up PCDDs/PCDFs from soil

Roots

MLP-GR3 (471 bp)

Stems

Leaves

Protein 17 kDa in xylem sap

Control Soraya Atena Nimba
Concentration of PCDDs/PCDFs in roots, stems and leaves of zucchini cultivars
Concentration of PCDDs/PCDFs in stems and leaves of zucchini cultivars

Dry biomass of zucchini cultivars

![Graph showing dry biomass of zucchini cultivars](image)

Concentration of TEQ PCDDs/PCDFs per plant stems leaves (ng/plan)

![Graph showing concentration of TEQ PCDDs/PCDFs per plant stems](image)

![Graph showing concentration of TEQ PCDDs/PCDFs per plant leaves](image)
Removal efficiency of PCDDs/PCDFs
Conclusions

Our findings, derived from field studies, present the levels of PCDD, PCDF and dl-PCB pollution occurring in the Pilica River, but more importantly, they indicate the processes and factors (hydrotechnical construction, hydrology, point sources of pollution related to human activity) that influence the measured concentrations. This is an important issue associated with the implementation of EU directives intended to obtain, and maintain, good ecological status for the waters in Poland.

Our results emphasise the need to take steps to mitigate the risks associated with inadequate wastewater treatment, the production of contaminated sludge by the sludge purification process and accumulation of PCDDs, PCDFs and dl-PCBs in sediments of the reservoir.

This need became the basis for the laboratory experiments aimed at assessing the effectiveness of willow and selected cucurbits in removing PCDDs, PCDFs and dl-PCBs from contaminated sludge and sediments.

The use of both field and laboratory studies constitutes a holistic approach to addressing the problem of PCDD, PCDF and dl-PCB pollution in rivers.

This approach, based on understanding the role of complex interactions occurring in the river catchment, allows enhancement in our understanding of ecological processes to protect water resources and for sustainable development in the catchment.
Acknowledgements

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1) The Polish Ministry of Science and Higher Education Project No. NN305 365738,
2) The Polish Ministry of Science and Higher Education project under the name “Iuventus Plus” for the years 2015–2017 No. IP2014 049273
3) The National Science Centre, Poland, Project No. 2015/19/B/ST10/02167;
4) The European Structural and Investment Funds, OP RDE-funded project 'CHEMFELLS4UCTP' (No. CZ.02.2.69/0.0/0.0/17_050/0008485)"
Team that I work with......
Dziękuję za uwagę!!!