GeoPlanet: Earth and Planetary Sciences

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Treatment Wetlands for Environmental Pollution Control

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GeoPlanet: Earth and Planetary Sciences

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The GeoPlanet: Earth and Planetary Sciences Book Series is in part a continuation of Monographic Volumes of Publications of the Institute of Geophysics, Polish Academy of Sciences, the journal published since 1962 (http://pub.igf.edu.pl/index.php).

ISSN 2190-5193 ISSN 2190-5207 (electronic)
GeoPlanet: Earth and Planetary Sciences
ISBN 978-3-319-13793-3 ISBN 978-3-319-13794-0 (eBook)
DOI 10.1007/978-3-319-13794-0

Library of Congress Control Number: 2014956489

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Preface

Water and wastewater management in urbanized areas has been resolved, although sewage sludge created in the course of sewage treatment causes problems. Against this background rural areas, particularly in areas characterized by dispersed distribution of households suffer from the lack of wastewater treatment systems. The problem is aggravated by the increasing use of water due to rising civilization standards. The problem has grown to a scale that no doubt must be resolved in the near future. The most serious faults caused by untreated wastewater being discharged into the environment is pollution of surface and groundwater, and eutrophication of water bodies even in the touristically attractive regions.

In Europe, a substantial proportion of households in rural areas have the so-called dispersed infrastructure (in Poland 26 % of households are separated from each other by 100 m or more). Construction of a sewerage system in such areas is economically ineffective. Moreover, when constructed the sewerage systems suffer from high operation costs.

Also, collecting sewage in septic tanks is unpractical due to odors, costs, and danger, as on puncturing the surrounding soil is polluted. These are the reasons why on-site systems are gaining in interest. One such method that has been developing in the last four decades is a method based on adapting the natural conditions and treatment processes taking place in marsh ecosystems. Treatment wetlands are engineering facilities that tend to follow these natural conditions but in a more controlled way. Wastewater is treated when flowing through the matrix that consists of soil-like substrate and roots and rhizomes as well as microorganisms. The main treatment processes including adsorption, filtration, ion exchange, biodegradation, take place in the gravel filtration medium, however, they are supported by plants that supply oxygen and uptake some minor part of nitrogen. Thanks to the activity of hydrophytes and their ability for gas transfer and release of oxygen to the root zone various types of bacteria can exist and conduct the treatment processes. The method is attractive also because it fits well into the natural type of landscape. Both wastewater and sewage sludge can be utilized in treatment wetland systems (hydrophyte facilities). These facilities are inexpensive to be constructed and operated. The principles of operation are understandable, in particular to farmers and other inhabitants of rural areas.

Experience gained so far clearly shows that facilities composed of a septic tank and treatment wetland can treat wastewater effectively in the rural areas. However, the development of hydrophyte systems has led to complex facilities enabling efficient removal of not only organic matter and nutrients, but xenobiotics as well. Treatment wetland systems have been applied with success to purposes as distant from the original application as dewatering and stabilization of sewage sludge, treatment of landfill leachate, treatment of reject waters from sewage sludge processing, treatment of surface run-off, treatment of industrial water and wastewater, and others.

In this book, all these applications are described based on the authors' own experience and the literature review. The one subject that is not directly related to treatment is generation of humic-like substances that are produced in the course of treatment of wastewater in treatment wetland systems and traditional plants.

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Abbreviations

$A_{2/3}$	Value of quotient at wave lengths: 260 and 320 mm
$A_{4/6}$	Value of quotient at wave lengths: 465 and 665 mm
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
coli MPN	coli Most Probable Number
DM	Dray matter
HA	Humic acids
HSSF	Horizontal Subsurface Flow
HTWs	Hybrid Treatment Wetlands
IR	Infra-Red
MRR	Mass Removal Rate
MSS	Mineral Suspended Solids
$MUCT_{system}$	Modification of University Caption Town System
NK	Kjeldahl Nitrogen
pe	Person equivalent
SFs	Surface Flow systems
SFTW	Single Family Treatment Wetland
SSF	Subsurface Flow Solids
SSFs	Subsurface Flow systems
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
TW	Treatment Wetlands
TWSs	Treatment Wetlands systems
uv	Ultraviolet
vis	Visible light

VSSF	Vertical Subsurface Flow
VSSs	Volatile Suspended Solids
WWTPs	Wastewater Treatment Plants systems

Abstract

The idea of wastewater treatment in artificial and natural wetland systems (TWSs) has been developed for the last 30 years. These systems simulate aquatic habitat conditions of natural marsh ecosystems. In Europe about 10,000 constructed wetland treatment systems (TWTs) exist. In Germany about 3,500 systems are in operation. In other European countries, there are also numerous TWSs in operation, for example in Denmark 200–400, in Great Britain 400–600, and in Poland about 1,000. Most of the existing systems serve as local or individual household treatment systems. TWTs are simple in operation and do not require specialized maintenance. No biological sewage sludge is formed during treatment processes. The TWSs are robust to fluctuations of hydraulic loads. For this reason TWSs are in use mostly in rural areas as well as in urbanized areas with dispersed habitats, where conventional sewer systems and central conventional wastewater treatment plants (WWTPs) are avoided due to high costs. TWSs are usually applied at the second stage of domestic wastewater treatment, after mechanical treatment and/or at the third stage of treatment in order to secure polishing of effluent from conventional biological reactors and renaturalization. New application of TWSs is used for rainwater treatment as well as industrial wastewater and landfill leachate treatment. It is possible due to specific TWSs characteristics that have the potential to remove not only organic matter and nitrogen compounds, but also trace metals and traces of persistent organic pollutants and pathogens.

Based on the gathered practical information, results of new research processes and mechanisms of pollutants removal, and advances in the systems properties and design, TWSs are under continuous development. The aim of this volume is to present an overview of up-to-date knowledge concerning functioning, application, and design of TWSs in order to improve protection of surface water from contamination.

Chapter 1
Introduction

In Poland, there is a considerable interest in natural methods of wastewater treatment. The explanation is simple: constructing sewer systems in rural areas is not justified from the economical point of view.

This leads to insufficient treatment (usually only mechanical) or a lack of sewage treatment in villages and small towns, and a lack of methods of pollutant removal from surface runoff.

Rural areas in Poland, with a population of 14.6 million (38 % of the total population), are exposed to the inflow of pollutants from household sewage. Farms are supplied with water from a central water supply system or individual wells. Only 8.2 % of them, however, are equipped with sewer systems. Due to farms being scattered around, central wastewater treatment plants (WWTPs) cannot be a satisfactory solution. Moreover, water consumption per capita in rural areas is substantially smaller than in cities. It usually ranges from 50–100 l/day as compared to 120–150 l/day in cities. Therefore, contaminants in rural wastewaters are more concentrated and more difficult to treat in conventional systems. It is estimated that approximately 25 % of the sewage produced in rural areas in Poland is drained directly to the ground and surface water. In 2014 about 20 % of sewage generated in rural areas were collected, while only 7.0 % were treated before discharging to the recipient.

The problems mentioned above can be solved by treatment wetland (TW) systems. The systems simulate hydraulic and habitat conditions of natural marsh ecosystems. Organic substances, nutrients as well as heavy metals and organic micropollutants are removed in natural processes, supported by heterotrophic microorganisms and hydrophyte plants grown in specially designed soil filters or ponds. It is estimated that over 10,000 systems are in operation all over Europe including some 1,000 systems in Poland.

Treatment wetland systems in Poland are mainly used to provide the secondary treatment of domestic wastewater, after mechanical pre-treatment, and for the protection of surface waters. There are also attempts to use TWs for the treatment of landfill leachate. Due to climatic conditions, subsurface submerged beds (SSF) are

H. Obarska-Pempkowiak et al., *Treatment Wetlands for Environmental Pollution Control*, GeoPlanet: Earth and Planetary Sciences,
DOI 10.1007/978-3-319-13794-0_1

mostly used for wastewater and leachate treatment. For water protection, systems with a surface flow systems (SFs) or with a mixed flow are more often used.

Differences in the operation of treatment wetlands result from physical, chemical and biological conditions, which directly influence transformations in the whole aquatic matrix-plant environment. Depending on the quantity of inflowing organic matter load and the rate of biological processes, pollutants could be removed or/and retained in the system. Thus, the facility should be designed and operated in such a way that the highest possible removal of discharged pollutants is ensured.

The aim of this volume is to present an overview of knowledge concerning the application and functioning of treatment wetland systems for water and wastewater treatment.

Chapter 2
Characteristics of the Hydrophytes Method

Hydrophyte wastewater treatment plants are designed on the basis of the systems known as “treatment wetland”, introduced in western and North Europe, North America and Australia. These systems simulate aquatic and habitat conditions of natural marsh ecosystems. The term “wetland” refers to the areas where the water level is higher than the ground level for most of the year, which results in soil saturation with water, and causes the growth of characteristic plants species. The hydrophyte method of wastewater treatment is a biological process which proceeds in the presence of various microorganisms, and aquatic and hydrophytes plants grown in specially designed soil filters or ponds. Due to specific conditions enabling the development of hydrophytes, the intensification of alternative oxidation and reduction processes, accompanied with sorption, sedimentation and assimilation processes removing the majority of pollutants from wastewater, can be observed.

Initially, there was some difficulty with accepting the term “wetland”, that is why several terms describing water treatment plants were used e.g. hydro-botanic plant, soil-plant, hydrophytes plant, macrophytes plant, reed plant, marsh plant, root plant and others. Thus, it seemed necessary to choose one of the terms or introduce a new one. Taking into account the basic role of hydrophytes in the treatment process, the selected name for that process is “treatment wetland systems” (or treatment plants).

Plants most often used in such types of systems are reed (*Phragmites australis*) and willow (*Salix viminalis*). Reed is used because of its extended system of rhizomes and roots. The stalks and leaves of reed contain an extended porous and gaseous tissue called aerenchyma. Oxygen from the atmosphere goes through that tissue to the underground parts of the plants, where aerobic micro-zones (with O_2) around roots and rhizomes are created (Fig. 2.1). Those micro-zones are surrounded by anaerobic micro zones (without O_2, however, in the presence of NO_3^-). Outside them there are anoxic micro-zones (without both O_2 and NO_3^-). This results in forming conditions which allow the development of heterotrophic microorganisms taking part in a biochemical transformation of supplied pollutants. Reed is also resistant to frost and extensive summer heat.

Willow is a hydrophite plant which is often used because of its fast growth related to the intense consumption of biogenic compounds. Hydrophites plants do not

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DOI 10.1007/978-3-319-13794-0_2

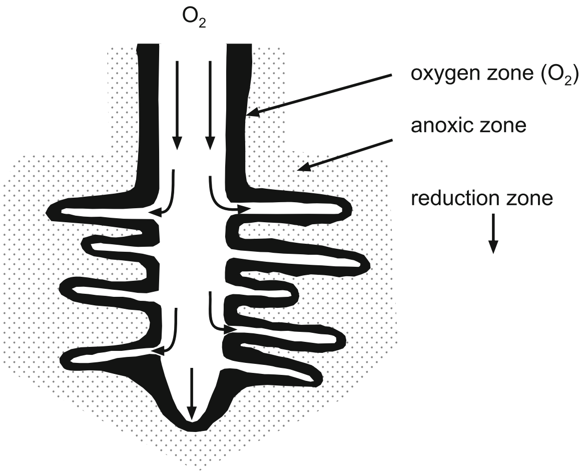

Fig. 2.1 Redox conditions around rhizomes of hydrophytes (Obarska-Pempkowiak et al. 2010)

transport oxygen to the ground. They grow in the environment of marsh ecosystems. To construct the treatment system for wastewater, the properties of these plants must be taken into account, and conditions for oxygen diffusion must be created.

The main advantages of treatment wetland systems are: simple maintenance, robustness to irregular inflow of wastewater, and lower cost of maintenance in comparison with conventional treatment systems. Moreover, their natural appearance better suits the natural environment. Treatment wetland systems, contrary to traditional biological plants, do not produce secondary sewage sediments and allow the simultaneous removal of biogenic compounds of nitrogen and phosphorus as well as the removal of specific pollutants, for example heavy metals. The main disadvantages of these systems are the following. They need a lot of area, and it takes up to 2–3 years to fully develop the rhizosphere of the plants. Treatment wetland systems are in use mostly in rural areas as well as in urbanized areas with dispersed habitats development, where conventional sewer systems and a central conventional WWTP are avoided because of high costs.

Up till now treatment wetland systems have been used:

1. for removal pollutants from point sources such as domestic wastewater, industrial sewage and landfill leachate,
2. as buffer plant zones for the removal of pollutants from surface runoff,
3. as specially constructed systems for the dewatering and stabilization of sewage sediments.

Reference

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Chapter 3
Types of Treatment Wetlands

The removal of pollutants in treatment wetland systems is the result of the sorption of biochemical pollutants, redox reactions, and a biological activity of microorganisms as well as hydrophytes plants. Sewage inflowing to a treatment wetland should be pre-treated in order to remove suspension (sand and other mineral and organic solids), and floating (e.g. fats, or substances originated from oil derivatives) substances. Thus, sewage directed to treatment wetlands should be pre-treated in Imhoff tanks, septic tanks or retention ponds. In the case of floating substances, separators of mud and oil, lamellar separators or coalescence separators are used (Fig. 3.1) (Kowalik and Obarska-Pempkowiak 1997).

Small towns with the quantity of sewage below 380 m^3/day should be fitted with a simple system of primary treatment, which precedes the treatment wetland system. Most often septic tanks (when the number of users, pe—person equivalent, is below 50), or Imhoff tanks (for settlements above 50 pe) are used.

Primary treatment in Imhoff tanks, septic tanks or separators leads to the production of sewage sludge, which can be discharged to reed beds or to willow plantations for sludge dewatering. If there is no primary treatment, wastewater must be transported to the central treatment system—most often to the municipal or local sewage treatment plants. In Europe, numerous treatment wetlands have screens installed on the wastewater inflow. Solid impurities separated there emit odours, which do not pose a problem when a treatment wetland is located at distance from human habitats. Larger amounts of wastewater require the installation of more complicated primary settling tanks connected to systems ensuring sludge processing (mainly digestion and mechanical dewatering). In the case of industrial wastewater, which contains enormously high loads of pollutants, primary treatment should take place in anaerobic reactors.

Treatment wetlands are usually used for wastewater treatment just after mechanical treatment or after the first stage of treatment, often carried out in conventional WWTPs (Wastewater Treatment Plants).

H. Obarska-Pempkowiak et al., *Treatment Wetlands for Environmental Pollution Control*, GeoPlanet: Earth and Planetary Sciences,
DOI 10.1007/978-3-319-13794-0_3