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Short communication

Green wastewater treatment technology for agritourism business in Romania

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ABSTRACT

This article describes the first implementation of green treatment technology for wastewater from agritourism facilities in Romania. The general concept was based on the principles of a nature-based treatment system (NBTS) developed, tested and successfully operated in cold climate in Norway. Two NBTSs, each constituting a three-element system equipped with a septic tank, a pre-treatment section and a filter/wetland bed, were constructed and set in full operation in Mara and Vadu Izei villages (Maramures County, Northern Romania, Carpathian Mountains). Both systems revealed sufficient adaptation to wastewater treatment during the first year of operation. The highest removal rates of BOD_5, COD_{Cr}, N_{tot} and P_{tot} reached 93–97%, 94–98%, 97–98% and 98–99%, respectively. In addition, these parameters did not exceed their permitted values in effluents discharged to water bodies. Both systems demonstrate integrated measures of ecological engineering implemented as "treatment gardens" perfectly suited to the tourist facilities, rural surroundings and cultural landscape of the region.

1. Introduction

The term "green wastewater technology" indicates a course toward sustainable, ecological and environmental approaches in wastewater treatment. In Norway, it applies to any manmade facility that mimics a natural ecosystem with respect to its function in environmental pollution control through several mechanical, chemical and biological processes. In practice, such treatment system operates through a complex of synergies between soil, water, vegetation and atmosphere (Paruch et al., 2016), and it is, therefore, more specifically named a nature-based treatment system (NBTS).

Three groups of NBTSs (soil infiltrations, sand filters, and filter beds) have been implemented in Norway. Various filter beds have been applied in constructed wetlands (CWs) for over a quarter of a century in Norwegian cold climate conditions and they have a proven, stable efficiency for the purification of water and wastewater originating from different pollution sources (point and non-point/diffuse). For instance, surface flow CWs have typically been applied for the management of stormwater, agricultural and urban runoffs, and landfill leachates (Blankenberg et al., 2015; Blankenberg et al., 2016; Haarstad et al., 2016; Paruch et al., 2017), while sub-surface flow systems, especially horizontal sub-surface flow constructed wetlands (HSSFCWs), have commonly been employed for the decentralised management and treatment of domestic wastewater in on-site systems (Paruch et al., 2016). To provide efficient treatment during the cold season, the on-site wastewater treatment systems have been upgraded with an additional section, an aerobic pre-filter (biofilter), implemented between a septic tank and filter bed/CW. This supplementary pre-treatment section supports operation by supplying air, enhancing the nitrification processes, and decreasing the organic matter load, which all lead to sustaining stable and efficient treatment performance.

The advantages derived from the NBTSs features (mostly, the diverse treatment options for different pollution sources, and the high and stable efficiency in varying climate conditions) strongly advocate for adaptation of these systems to other sites, conditions, and pollution problems outside of Norway (Paruch et al., 2011). The most recent example of such an adaptation is shown in a practical implementation of the Norwegian-like NBTSs throughout the project *"Greening the Agro-Tourism Business in Romania"* (http://comunitateverde.ro/home-en.html). The focus was on rural, decentralised settlements where cost-effective, highly efficient and sustainable treatment and management of wastewater was in high demand. In addition, the tourist destinations

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and activities in these areas gave opportunities to broadly highlight the new approaches for solving pollution problems through green wastewater technology showcases. This article reports the project achievements and presents the general design criteria, construction principles, operation, and treatment efficiency of the newly implemented systems. To the best of our knowledge, this is the first description of wastewater management through NBTSs adapted to the needs and conditions of agritourism facilities in Northern Romania.

2. Materials and methods

2.1. Study sites

To select the most representative sites for the project and for further scientific investigations, we focused on choosing places that comply with two primary criteria: 1) locations characterised by cold climate conditions, and 2) locations with well-established and fully-operating agritourism facilities. Following these criteria, we concentrated on Northern Romania, particularly Maramures County, situated in Northern Carpathian Mountains, where wetter and colder weather reveals a strong influence of Scandinavian-Baltic climate conditions (Sabău et al., 2018). We contacted the owners of two year-round active tourist facilities in Mara and Vadu Izei villages (Maramures County) who were willing to upgrade their purification technology, and possessed enough area for construction of the on-site wastewater treatment system. Both areas are within the basins of the Mara and Iza Rivers, where the vast majority of soils are alluvial deposits with sand, silt, clay, gravel and small boulders.

2.2. Design strategy of treatment systems

As the overall climatic, topographical and geological features of the selected agritourism businesses in Mara and Vadu Izei corresponded to the relevant conditions describing a number of sites with well-established on-site purification systems in Norway, the design strategy of the green wastewater treatment was primarily based on the Norwegian guidelines (NORVAR, 2001a; NORVAR, 2001b) for decentralised purification technologies with a pre-treatment section (pre-filter/biofilter) in three main options: 1) an integrated infiltration biofilter, 2) an integrated trickling biofilter, and 3) a separate trickling biofilter (Fig. 1). For both locations, two individual NBTSs, each equipped with a septic tank, a pre-filter, and a filter bed/CW, were planned with particular consideration to Romanian legislation regarding water supplies (SR 1343-1, 2006) and wastewater discharges (SR 1846-1, 2006).

2.3. Treatment efficiency control

Treatment performances of the Romanian systems were evaluated based on the results from chemical and microbiological analyses conducted on raw wastewater samples collected at the septic tank inlet and purified effluent samples collected at the outlet of each system. The sampling was conducted in the initial operation year of the systems, through both cold (January – March) and warm (May, August and September) seasons of the year. There were some practical difficulties in assembling wastewater samples during the cold season; therefore, the concentrations of chemical parameters in wastewater measured during the construction process were applied as background values for the assessment of treatment performance. All samples were collected by personnel from the Heifer International Romania/OPEN FIELDS Foundation (the Project Promoter), and further processed by Romanian accredited laboratories. Common chemical parameters describing the concentration of organic pollutants expressed as biochemical- and chemical oxygen demand (BOD_5 and COD_{Cr}, respectively) and the main elements causing eutrophication problems, i.e. total nitrogen and phosphorus (N_{tot} and P_{tot}, respectively), were measured. The hygienic status of the discharged effluent was generally assessed based on microbiological tests of *Escherichia coli* (*E. coli*) counts in samples collected only during the cold season.

Wastewater analyses were conducted by Laboratorul de Monitorizare a Factorilor de Mediu Cluj Napoca (Laboratory for Monitoring of Environmental Factors in Cluj Napoca) in accordance with the following national and international procedures: SR EN 1899-1 (2003), SR ISO 6060 (1996), and Photometry/Merck Method (14537 and 14848), respectively for BOD_5, COD_{Cr}, N_{tot}, and P_{tot}.

The chemical tests on effluents were performed by Laboratorul APELE ROMÂNE Maramures (Romanian Waters Laboratory in Maramures) in accordance with the following national and international standards: SR EN 1899-2 (2002), ISO 15705 (2002), SR EN ISO 11905-1 (2003), and SR EN ISO 6878 (2005), respectively for BOD_5, COD_{Cr}, N_{tot}, and P_{tot}. The microbiological analyses in effluents were conducted by Laboratorul S.C. VITAL S.A. Baia Mare (Water and Wastewater Service Laboratory in Baia Mare) in accordance with the standard procedure SR EN ISO 9308-1 (2004).

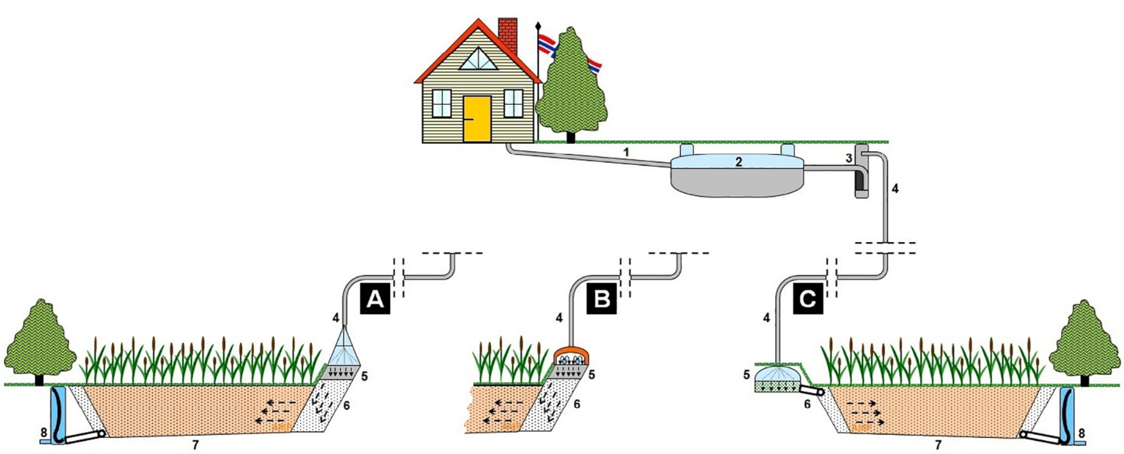

Fig. 1. Layout of a typical nature-based treatment system for domestic wastewater in Norway with three options for pre-filter design: A – an integrated trickling biofilter, B – an integrated infiltration biofilter, and C – a separate trickling biofilter. Components within the system are marked as follows: 1 – inlet (domestic wastewater), 2 – septic tank, 3 – pump well, 4 – effluent pipe from the well, 5 – pre-filter (biofilter in option A, B and C), 6 – effluent release from the biofilter (in vertical flow in option A and B, and drainage pipe in option C), 7 – filter/wetland bed, and 8 – outlet well (effluent discharge from the entire system). Graphic by Adam M. Paruch.

Table 1
Overview of the projected parameters of the Romanian treatment systems in Vadu Izei and Mara, and modifications (underlined) in comparison to the original design of the Norwegian on-site/decentralised three-step treatment technology.

Parameters	Vadu Izei system	Mara system	Norwegian design
Person equivalent (pe)	28	30	5–50
Hydraulic load	120 l/pe	120 l/pe	200 l/pe
1st treatment step	2 septic tanks (14–15.5 m^3)	1 septic tank (14–15.5 m^3)	1 Septic tank (14–15.5 m^3)
2nd treatment step	Prefilter	Prefilter	Prefilter
- distribution	Pump	Pump	Pump
- pre-filter type	Sheltered bed	Tanks	Domes/tanks/shelters
- porous media	Filtralite NC	Filtralite NC	Filtralite NC
- grain size	4–10 mm	4–10 mm	4–10 mm
3rd treatment step	Constructed wetland	Constructed wetland	Filter/wetland bed
- filter media	Filtralite P	Perlite	Filtralite P/shell sand
- porous media	0.5–4 mm	0–5 mm	0.5–4 mm
- liner	Polyetylene geomembrane	Polyetylene geomembrane	Polyetylene geomembrane
- vegetation	*Phragmites australis*	*Phragmites australis*	*Phragmites/Typha* spp.

3. Results and discussion

3.1. Treatment system in Vadu Izei

The NBTS in Vadu Izei was constructed to treat domestic wastewater from four small households (14 permanent residents and 14 visitors/tourists). An adjustment was implemented to the original design through reusing an existing septic tank (which originally collected wastewater from three households) and installing an additional tank for the fourth (new) building. Both septic tanks are two chambers instead of a single three-chamber septic tank as in the Norwegian design. As a result, the entire system consists of two septic tanks followed by an aerobic pre-filter (unsaturated biological section with vertical flow sheltered bed) and a subsequent saturated HSSFCW (Table 1).

The treatment performance outcomes reveal relatively high removal of pollutants during the initial operation period (Table 2). For the organic contamination, the removal was between 81% and 97% for BOD_5 and from 87% to over 98% for COD. The highest values detected in the effluents did not exceed 13 mg O_2/l and 30 mg O_2/l for BOD_5 and COD, respectively. They were far below the permitted limits for BOD_5 (25 mg O_2/l) and COD (125 mg O_2/l) in the Romanian legal discharge standard (NTPA-001, 2005). For the nutrients limiting eutrophication and algal blooms in waterbodies, N concentrations were quite stable, and the removal reached 94–98%. The highest effluent concentration (4.1 mg N/l) was much lower than the allowed discharge value of 10 mg N/l (NTPA-001, 2005). For P, relatively unstable values were observed during the first winter months. This must have been related to the difficulties with sampling during the cold season, hence the application of background measures for efficiency assessment that was already mentioned earlier. Therefore, these values cannot entirely be trusted for evaluation of the system performance as it is quite unexpected that concentrations in the effluent (final discharge after treating of wastewater) exceeded values in the influent (raw, untreated streams of domestic wastewater). The results obtained during spring and summer showed great contrasts to the winter P concentrations. At that time, P removal reached 95–99% and the maximum effluent value (0.41 mg P/l) was substantially lower than the Romanian legal discharge limit of 1 mg P/l (NTPA-001, 2005).

Microbial contamination was not tested in wastewater samples; thus, the removal efficiency of microbes could not be entirely evaluated. However, faecal indicator bacteria (FIB) was only detected in the first effluent sample (800 *E. coli*/100 ml) and, after that, the bacterial counts were always below the detection limit. Normally, large bacterial loads are carried in human faecal matter, e.g. 10^9 *E. coli*/g (Paruch and Paruch, 2018), therefore undetectable concentrations in the tested samples indicate the high hygienic status of effluents from the treatment system in Vadu Izei.

3.2. Treatment system in Mara

The NBTS in Mara was constructed to treat domestic wastewater from one agritourist facility (10 permanent residents, 4–6 tourists and 10–20 daily visitors). The original design of this system was modified by the implementation of perlite filter media (materials available in Romania and proven in environmental applications) in the HSSFCW. This NBTS consists of a three-chamber septic tank followed by an aerobic pre-treatment section (10 trickling unsaturated biofilters constructed in tanks with vertical flow) and a subsequent saturated perlite bed (Table 1).

Treatment efficiency was satisfactory but quite variable through the first year of system operation (Table 3). The most variation was observed in the cold season when the lowest removal rates of organic pollutants (46% and 63% for COD and BOD_5, respectively) and nutrients (15% and 55% for P and N, respectively) were observed. In

Table 2
Concentrations (mg/l) of selected pollutants in the influent and effluent from the treatment system in Vadu Izei, and total removal (%) occurring in the cold (January – March) and warm (May, August and September) seasons of the first operational year.

Pollutants	Influent – Effluent Removal					
	I	II	III	V	VIII	IX
Biochemical oxygen demand	73.1–4.6	73.1–1.9	73.1–4.1	107–12.5	83.8–9.6	69–13
BOD_5 (mg O_2/l)	94	97	94	88	89	81
Chemical oxygen demand	245.5–14.4	245.5– < 5	245.5–15.8	420–30	139.2–14.4	166–21
COD_{Cr} (mg O_2/l)	94	> 98	94	93	90	87
Total nitrogen	100.2–2.4	100.2–3	100.2–3.3	64.3–4.1	21.8–0.8	21.6– < 1
N_{tot} (mg N/l)	98	97	97	94	97	> 95
Total phosphorus	9.74–2.88	9.74–12.5	9.74–0.13	8.28–0.41	3.12–0.04	2.01–0.07
P_{tot} (mg P/l)	70	negative	99	95	99	96

Table 3
Concentrations (mg/l) of selected pollutants in the influent and effluent from the treatment system in Mara, and total removal (%) occurring in the cold (January – March) and warm (May, August and September) seasons of the first operational year.

Pollutants	Influent – Effluent Removal					
	I	II	III	V	VIII	IX
Biochemical oxygen demand	30.8–6.9	30.8–2.2	30.8–11.4	148.5–22.4	59.2–18.3	95.8–18.1
BOD_5 (mg O_2/l)	78	93	63	85	69	81
Chemical oxygen demand	85–19.2	85– < 5	85–46	990–60	144–28.8	203–26
COD_{Cr} (mg O_2/l)	77	> 94	46	94	80	87
Total nitrogen	6.4–2.2	6.4–2.3	6.4–2.9	55.9–6.6	33.3–0.9	28.2–7.8
N_{tot} (mg N/l)	65	65	55	88	97	72
Total phosphorus	0.33–2.01	0.33–18.7	0.33–0.28	8.31–0.76	4.88–0.08	3.11–0.69
P_{tot} (mg P/l)	negative	negative	15	91	98	78

particular, P concentrations in effluent samples were questionable as they were much higher than P content in the influent. This observation was similar to that in the Vadu Izei treatment system, and, therefore, must have been related to the same factors limiting the evaluation of system performance during the first operational months. More stable values characterise the warm season, with removal ranges of 69–85% for BOD_5, 80–94% for COD, 72–97% for N, and 78–98% for P. During that period, the highest contamination with organic matter was 22.1 mg O_2/l and 60 mg O_2/l for BOD_5 and COD, respectively. As for the nutrients, the maximum concentrations were 7.8 mg N/l and 0.76 mg P/l (Table 3). These values indicate that none of the tested parameters exceeded the permitted values according to the Romanian legal discharge standard (NTPA-001, 2005) limiting BOD_5, COD, N and P to 25 mg O_2/l, 125 mg O_2/l, 10 mg/l and 1 mg/l, respectively.

The effluent microbial content was tested irregularly. During the cold period, the maximum numbers of faecal bacteria reached 8700 *E. coli*/100 ml. This was unexpectedly high in comparison to the numbers reported from similar systems in the Nordic countries (Jenssen et al., 2010).

3.3. Comparative system assessment

By comparing the treatment efficiency of the system in Vadu Izei with the one in Mara, the former showed greater removal values. This is likely due to two factors that distinguish these systems: 1) the construction site of the pre-treatment section and treatment bed, and 2) the filter media used in the HSSFCW. Regarding the first factor, the Mara system was constructed right beneath a hilly slope, where massive surface runoff and drainage water was sporadically observed, e.g. after heavy and long-lasting precipitation. This caused uncontrolled water flow and flood over the treatment bed.

Concerning the second factor, the Vadu Izei system was constructed with the Norwegian filter media that had proven their applicability and effectivity in the treatment of domestic wastewater under cold climate conditions for over 25 years (Paruch et al., 2016). In contrast, the HSSFCW bed in the Mara system was filled in with locally available material – perlite. This material has never been tested solely in full-scale domestic wastewater treatment in Norwegian-like NBTSs; therefore, it is quite interesting to follow up on the treatment efficiency of perlite in a real-scale application.

The initial set-up of a new NBTS into operational condition requires several weeks for the mechanical, chemical and biological mechanisms to function properly in the removal of various contaminants. The major purification processes are based on establishing a complex biofilm in the filter media and cross-interactions through the filter-water-vegetation-atmosphere matrix. Therefore, it can even take some months before the system achieves a stable performance and the effluent quality normalises. This can explain the variations in chemical and microbiological contaminant levels, hence also the removal rates, observed in the Romanian NBTSs during the initial operating period.

4. Concluding remarks

The NBTSs in Vadu Izei and Mara exemplify practical implementation of sanitary engineering integrated with ecological approaches adapted to local environmental conditions. Both NBTSs act as “treatment gardens” perfectly suited to the rural surroundings, traditional architecture, and cultural landscape of the Maramures region. The NBTSs were promoted as best practices for other agritourism facilities in Romania and were proudly introduced and explicated to tourists, school groups and other visitors.

The initial performance of these systems reveal a quite comparable treatment efficiency to the proven high-performance of Norwegian NBTSs operating under cold climate conditions. The highest removal rates in the Romanian systems reached 97% BOD_5, 98% COD_{Cr}, 98% N_{tot} and 99% P_{tot}. However, there were some variations in the removal efficiency resulting from an early stage of operation, hence with undeveloped mechanisms of natural purification processes. There were not enough data on *E. coli* counts, therefore the quality of discharged effluents through the cold and warm seasons was not assessed. As for the other contaminants, none exceeded the limiting concentrations defined in the Romanian legal discharge norms.

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Declaration of Competing Interest

None of the authors have conflicts of interest.

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