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Challenges and Perspectives of Nature-Based Wastewater Treatment and Reuse in Rural Areas of Central and Eastern Europe

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Abstract: In Central and Eastern Europe, about one-third of the population lives in small settlements (<2000 PE). Since the current European Urban Wastewater Treatment Directive (91/271/EEC) does not clearly regulate the collection and treatment of wastewater from these settlements, countries solve the problem individually. Simple and robust technologies such as nature-based treatment systems could be the solution and are widely applied in many EU countries. In this paper, the status of wastewater collection, treatment, and reuse in rural areas of 14 countries in Central and Eastern Europe is presented together with the spread of different nature-based treatment systems. The results show that in the last decade, connection to wastewater treatment plants has increased from 9% to 19% of the total population in small settlements. The use of treated water is rarely applied. Sequencing batch reactors and other types of activated sludge systems predominate in treatment technologies. Nature-based treatment systems (mainly treatment wetlands) are used in all the countries studied. Their implementation is slowly increasing, hampered by lack of acceptance by authorities, lack of good case studies, and misdesigned or misoperated examples from the past. More awareness, formalized training on nature-based treatment systems, and supportive legislation are needed to promote sustainable sanitation solutions in small settlements.

Keywords: nature-based solutions; sustainable sanitation; treatment wetland; small and individual treatment systems; ecosystem service

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1. Introduction

Wastewater collection and treatment in small and scattered settlements is a challenge in many developed and developing countries. In Central and Eastern Europe (CEE: Bulgaria, Czechia, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Slovakia, Slovenia, and Ukraine), more than 42 million people live in settlements with less than 2000 population equivalents (PE), representing one-third of the population [1]. Previous studies indicate that only about 9% of this population is connected to wastewater treatment plants (WWTP) [1] and the discharge of untreated wastewater results in dispersed pollution of surface and groundwater bodies.

The connection of rural population to WWTP is difficult to assess because data on the number and type of public and private WWTP with a capacity of less than 2000 PE are usually limited and scattered among local water utilities and authorities. Even in developed countries, there are often no national databases on small WWTP (e.g., Austria [2]).

Since the European Urban Wastewater Treatment Directive (UWWTD) [3] came into force in 1991, the collection and treatment of wastewater in agglomerations of more than 2000 inhabitants has improved considerably, resulting in an improvement in the quality of European freshwater sources [4]. Despite significant improvements over the last 30 years, the percentage of the population connected to WWTP in CEE is still relatively low (50–80%) and has not improved significantly in recent years [5]. Wastewater collection and treatment in small settlements with less than 2000 PE is not clearly addressed in the UWWTD, and this gap is now specified in the proposal for a revised UWWTD. The revised UWWTD will require states to establish wastewater collection systems also in communities under 2000 PE. It will also strengthen regulations for the design, permitting, and control of small private wastewater treatment systems (called individual or other appropriate systems) [6].

Simple and robust technologies such as nature-based solutions (NBS), which refer to solutions inspired and supported by nature [7,8] and have low operation and maintenance requirements and costs, are recognized as the most suitable solutions for small communities [2]. NBS for wastewater treatment are already widely used worldwide, the most common being various types of treatment wetlands (TW), waste stabilization ponds, and soil infiltration. These are engineered systems that mimic functioning ecosystems and take advantage of their benefits with minimal reliance on electrical equipment [9]. NBS integrate plants, porous media, soil, microorganisms, and other natural elements and processes to remove pollutants such as organics, suspended solids, nutrients, pathogens, and various contaminants of emerging concern such as personal care products, pharmaceuticals, and hormones [10–12]. Additionally, resource depletion, water scarcity, and climate change require a shift from linear to circular wastewater management, in which decentralized NBS in rural areas may have certain advantages as they provide reclaimed water and treatment products close to where they are used [13], allowing easy connection with agriculture. Furthermore, NBS provide more ecosystem services (such as temperature and humidity regulation, plant biomass production, aesthetic appearance) compared to conventional activated sludge treatment systems, which is important for increasing the climate resilience and quality of the environment [14]. Finally, NBS have much lower operating costs compared to conventional systems [15], which can be particularly beneficial in economically less developed regions with a decentralized population distribution.

It is therefore of the utmost importance that countries lacking wastewater collection and treatment choose appropriate solutions that are also consistent with integrated water resources management, are climate resilient, and are cost-effective. NBS for wastewater treatment are a group of technologies that meet all the above requirements, but their recognition and implementation in countries with low connectivity to WWTP is still low [1,13], and this needs to be studied and addressed.

The aim of this paper is to present the current situation of wastewater collection and treatment in small settlements in CEE, the use of NBS, and the barriers to the implementation of NBS and water reuse systems as part of integrated water resources management.

2. Materials and Methods

Data on the current situation of wastewater collection and treatment and the use of NBS in small settlements in the CEE countries were collected by contacting sanitation and NBS experts from the region. First, mapping of the experts from the region was performed using the Sustainable Sanitation Task Force organized by the Global Water Partnership Central and Eastern Europe (GWP CEE). The Sustainable Sanitation Task Force of GWP CEE brings together small-scale sanitation experts from the majority of countries in the region. In addition, the study area was extended beyond GWP CEE to the Balkan countries by contacting the International Sava River Basin Commission and other networks. In total, experts from 18 countries were identified (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czechia, Estonia, Hungary, Kosovo, Latvia, Lithuania, Moldova, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, and Ukraine) and one expert per country was selected as the main contact person according to their activities in the stated networks.

Next, an online survey was prepared that included information on experts (affiliation, sector), countries (demographics, water consumption), wastewater collection and treatment (including individual systems, monitoring requirements, and discharge limits), NBS implementation (number, capacity, technology, challenges), and use of reclaimed water and nutrients (type of reuse, legislation, challenges). The full questionnaire is available in the Supplementary Materials section. The survey was emailed to identified experts in the summer of 2021. Additional updates to the data were made in 2022 and 2023, as needed.

The results of the survey were analyzed using Microsoft Excel. Data were grouped by topic and country, sorted, filtered, averaged, and counted where appropriate. For qualitative feedback, texts were examined and keywords extracted. The results were summarized in tables and figures. In case of doubtful answers, the experts were subsequently contacted to clarify the data. After analyzing the results, an elicitation workshop was organized to which all experts who had participated in the survey were invited. At the workshop, the results of the survey were presented, followed by a compilation of the needs and activities for sustainable sanitation in the region and a possible way forward for a broader implementation of NBS.

3. Results and Discussion

The total population of the CEE region is 152 million and that of the Western Balkans is 20 million, which together account for almost a quarter of the European population [16]. Of the experts from 18 countries contacted, 14 (78%) responded (Figure 1). The common denominator of all 18 countries is similar economic, political, and social development in the past, which is reflected in the current situation. It should be noted that both EU and non-EU countries were included in this study. While compliance with EU directives is mandatory for EU countries, non-EU countries also often take EU directives as guidelines for their national strategies.

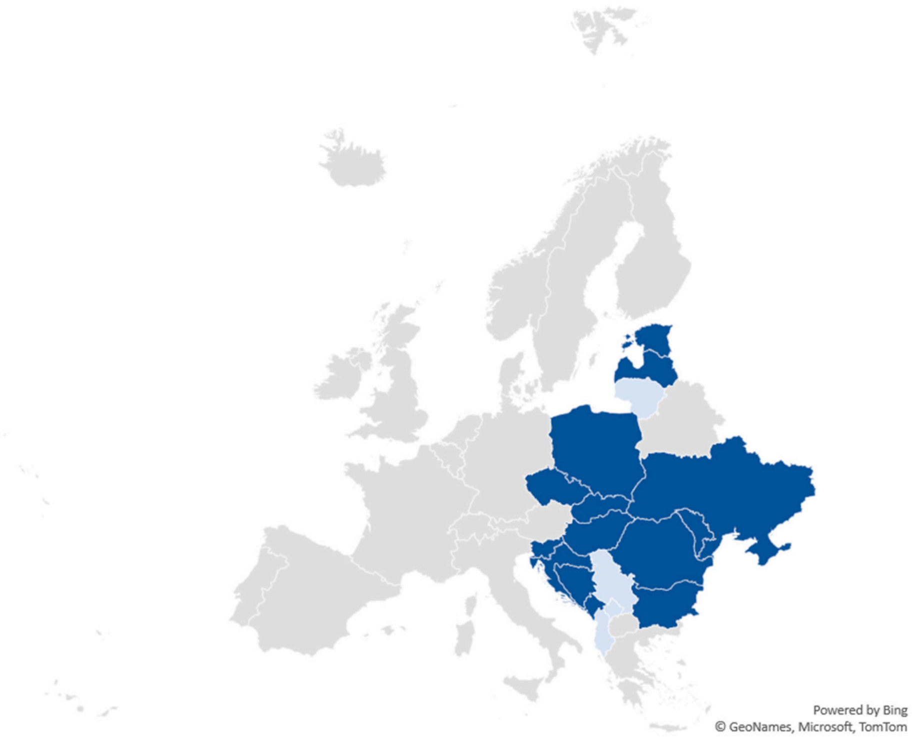

Figure 1. Map of Europe showing countries invited to the survey (dark and light blue). Countries that did not respond to the survey are marked with light blue and countries that did respond are marked with dark blue.

The respondents were sanitation or water professionals from different sectors, namely non-governmental organizations (2 respondents), national authorities (4 respondents), universities (4 respondents), and private companies (4 respondents).

One-third (37 million) of the total population of the countries studied live in settlements with less than 2000 inhabitants (Table 1), indicating a strong rural character of the region. Only in Moldova and Romania does the population appear to be more centralized, with about 10% of the population living in small settlements.

Table 1. Demographic characteristics of the countries studied and population connected to WWTP with a capacity of less than 2000 PE. The percentage of connected population is calculated based on the total number of inhabitants living in small settlements in each country. The population connected to WWTP includes both public WWTP and individual systems. For countries where only data on public systems are available, the character > is used to indicate that there are also uncounted individual or private systems.

Country	Population (Million)	Settlements below 2000 Inhabitants			
		Population (Million)	Population (%)	Population Connected to WWTP (Million)	Population Connected to WWTP (%)
BiH *	3.3	1.3	40	0.0059	0.5
Bulgaria	6.9	1.8	26	No data	No data
Croatia	4.3	1.7	39	0.02	1
Czechia	10.5	2.9	27	>1.92	>66
Estonia	1.3	0.4	31	0.10	25
Hungary	9.9	1.7	17	0.74	45
Latvia	1.9	0.8	43	0.09	11
Moldova	2.0	No data	No data	No data	No data
Montenegro	0.6	0.1	20	0.0025	2
Poland	37.7	10.0	27	No data	No data
Romania	19.2	1.9	10	0.16	8
Slovakia	5.5	1.6	30	0.41	25
Slovenia	2.1	1.1	52	>0.20	>18
Ukraine	41.3	13.1	32	>0.78	>6
Average/sum	143.2	>37.2	>29	>4.23	>19

* BiH—Bosnia and Herzegovina.

In both integrated water resources management and circular economies, the top priority is to avoid unnecessary treatment of wastewater; therefore, household water consumption and wastewater production are critical factors [17–19]. The average water consumption in the countries studied was 109 L/person·day, well below the European Union average of 128 L/person·day [20]. There are also quite large differences between countries, ranging from 50 L/person·day in Moldova to 200 L/person·day in Montenegro. According to the results of a similar study from 2012 [21], we can draw a comparison for seven countries, i.e., water consumption decreased in Hungary, Slovakia, and Slovenia, while it increased in Poland and Romania and remained almost the same in Bulgaria and Latvia.

The percentage of the total population connected to the public drinking water supply is higher than the percentage of the population connected to public WWTP. The average difference between connection to public water supply and to public WWTP is about 20%. Exceptions are Estonia and Latvia, where the percentage of the two connections is almost equal. Since the UWWTD came into force in 1991, the percentage of the population connected to public WWTP has gradually increased. The construction of wastewater networks and treatment plants has also been supported by various EU funds, but the support has been concentrated in agglomerations with more than 2000 PE. Leaving smaller settlements behind is now seen as a stagnation in the further improvement of wastewater collection and treatment in many countries studied [5].

Over the past decade, connection to WWTP in settlements <2000 PE has increased from 9% to 19% of the total population living in small settlements; however, information on private or individual systems (<50 PE) is not available in any country, so the actual percentage is somewhat higher. The differences between countries are large, ranging from a very low connection rate in Bosnia and Herzegovina (0.5%), Croatia (1%), and Montenegro (2%) to a connection rate of about half of the population in Hungary (45%) and Czechia (66%) (Table 1). The average connection to WWTP in the region is still much lower compared to developed countries; therefore, construction of WWTP in communities up to 2000 PE should be a current priority in most of the countries studied.

3.1. Number of Small and Individual Wastewater Treatment Systems

Construction of wastewater systems and WWTP for very small and scattered settlements <50 PE can be costly and often even economically infeasible. In such cases, individual sanitation systems, i.e., private treatment plants, with capacities ranging from 3 to 50 PE are used. The number, capacity, and technology of private treatment systems are not centrally recorded in most of the countries studied, and it is difficult to obtain accurate data, as a time-consuming inquiry and data search at water utility companies, municipalities, or regional authorities in each country should be conducted. Data can also be estimated based on the number of units sold by individual distributors and suppliers. It is also important to note that private systems in many countries include septic tanks with infiltration that provide limited treatment, while in other countries only watertight septic tanks used for wastewater collection are allowed (e.g., Slovenia). In many cases, septic tanks with infiltration are not a suitable solution due to limited treatment [22], while watertight septic tanks may be economically unviable due to regular emptying and transportation of the accumulated water and sludge to the central WWTP. In Hungary, about 913,000 private septic tanks and about 6000 individual WWTP are registered, but many data are missing or incomplete. Similarly, in Poland, Czechia, and Slovakia, the number of private WWTP is estimated at about 295,400, 35,000, and 5000, respectively, while there are many more septic tanks.

One-third of the countries studied reported having national strategies to improve the connection of the population in small settlements to WWTP, which has also led to an improvement in connection in Hungary, Moldova, Slovakia, and Slovenia in the last decade [1]. In many countries (Czechia, Romania, Slovakia, Slovenia, Hungary, and others), there is also a legal obligation to connect households to the existing public water and wastewater system, if the technical and economic conditions allow it. A major obstacle to connecting the population to the sewage system is the low income of the rural population, who often refuse to connect to the nearby network or to install a private WWTP and instead continue to use the "traditional" leaky septic tanks and cesspools. However, most countries still do not have legislation or policies in place to connect residents of small settlements to WWTP. In addition, countries often do not have data or action plans based on strategies for how many residents will need to be connected to public or individual WWTP in the coming years. Water protection areas are also a special case, where free discharge of wastewater is highly undesirable and authorities therefore usually support projects that focus on centralizing water treatment.

Wastewater collection and treatment in settlements below 2000 PE and in individual systems has been identified by the EU as avoidable pollution [6]; therefore, the issue has been addressed in the revised UWWTD, which will require mandatory wastewater collection systems also for smaller agglomerations and will define individual systems in more detail. However, establishing effective and realistic legislation for wastewater treatment in small communities is a complex task that must take into account natural and demographic characteristics (sensitive areas, natural self-treatment capacity of the environment, relief, geology, population density), the financial feasibility of the various options (centralized or individual systems), and the potential for resource recovery (reuse of treated water and nutrients near wastewater generation). Tightening regulations without careful planning can only lead to unnecessary costs and ineffective systems.

3.2. Discharge Limits and Monitoring

The UWWTD sets common standards for countries for concentrations of organic matter (measured as biochemical oxygen demand during 5 days of incubation—BOD_5—and chemical oxygen demand—COD), suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) in discharges of treated urban wastewater, as well as the required monitoring frequency. To date, only agglomerations with populations greater than 2000 PE must comply with these standards. Since UWWTD does not set limits for wastewater generated in small settlements, countries have adopted national regulations regarding their demographic and natural characteristics. The discharge-limiting values vary considerably in the countries studied (Table 2). For small public WWTP, the limits for COD, BOD_5, and TSS are in the same or a slightly higher range than required by the UWWTD (125, 25, and 35 mg/L for COD, BOD_5, and TSS, respectively). For individual systems, the differences between countries are greater: from no discharge limits in Latvia, Bosnia and Herzegovina, and Moldova and only COD in Slovenia to very strict discharge requirements in Romania and Ukraine. In Romania, private WWTP must also comply with discharge limits for ammonia, nitrites, nitrates, and phosphates. In addition, limits are set for chlorides (500 mg/L), detergents (0.5 mg/L), phenols (0.3 mg/L), and sulphides (0.5 mg/L) (not listed in Table 2), which are not limited in any other country. Differences in discharge limits for small and individual systems may also result from differences in the sensitivity of aquatic environments in different countries and associated national or international guidelines, such as the recommendations of the Baltic Marine Environment Protection Commission (HELCOM) [23] for the treatment of urban wastewater discharged into the Baltic Sea basin. The document recommends the removal of nitrogen and phosphorus even for small wastewater treatment plants, which is reflected in the discharge regulations of Poland and Estonia (Table 2).

As with the requirements for the quality of treated wastewater, there are significant differences among the countries studied in the obligation to monitor small and individual WWTP and the frequency of monitoring. For WWTP between 50 and 2000 PE, only Bosnia and Herzegovina, Bulgaria, and Ukraine have not established monitoring requirements for these plants, while in Croatia, Czechia, Estonia, Hungary, Montenegro, Poland, Slovakia, and Slovenia, monitoring must be performed two, four, or six times per year by nationally accredited institutions. Latvia, Moldova, and Romania require monthly monitoring by accredited bodies.

For individual plants with less than 50 PE, there are no monitoring requirements in 8 of 14 countries. In Slovenia, such treatment plants should be inspected every three years, but in Croatia, Hungary, and Slovakia inspection must occur only once a year. In Czechia, the efficiency of small WWTP must either be tested once a year or the treatment plant must undergo a qualified inspection by a certified person. The strictest monitoring requirements for individual systems apply in Romania, where individual systems should be tested four times a year.

Table 2. Discharge limits in mg/L (or % where relevant) and CFU/100 mL (for *E. coli*) for wastewater treatment plants with less than 2000 PE in countries studied.

		COD	BOD	TSS	TN	NH_4-N	NO_3-N	NO_2-N	TP	PO_4-P	*E. coli*
BiH	PE < 2000	No limits below 2000 PE									
BG	All sizes	125	25	35							
HR	All sizes	125	25	35							
CZ	PE < 50	150	40	30	30						
	PE < 500	150–220	40–80	50–80							
	501 < PE < 2000	125–180	30–60	40–70		20–40					
EE	PE < 300	150	40	35			45 [a]	0.1 [a]			[b]
	300 < PE < 2000	125	25	35	60		45 [a]	0.1 [a]	2		[b]
HU	PE < 50	75–150 [c]				10–40 [c]					
	PE < 600	300	80	100							
	601 < PE < 2000	50–150 [c]	15–50 [c]	35–200 [c]	20–55 [c]	2–20 [c]			0.7–10 [c]		1
LV	PE < 50										
	50 < PE < 2000	50–70%	50–70%	<35							
MD	PE < 50										
	50 < PE < 2000	22	2.1–6.8	2–3	10	0.2–0.6	25	1	2		5×10^3
ME	PE < 50	125	25	60	15				2		
	50 < PE < 2000	125	25	60	15				2		
PL	PE < 50		20%	50%							
	50 < PE < 2000	150	40	50	30 [d]					5″	
RO	PE < 50	125	25	60		3	37	2		6	
	50 < PE < 2000	125	25	60		3	37	2		6	
SK	PE < 50 [e]	150-w	40–70	40–50-w	40-w	20–30-w			4-w		
	50 < PE < 500	150	40	50							
	500 < PE < 2000	135	30	30							
SI	PE < 50	200									
	50 < PE < 2000	150	30								
UA	PE < 50	15	80	15	0.39						
	50 < PE < 2000	15	80	15	0.39						

BiH—Bosnia and Herzegovina, BG—Bulgaria, HR—Croatia, CZ—Czechia, EE—Estonia, HU—Hungary, LV—Latvia, MD—Moldova, ME—Montenegro, PL—Poland, RO—Romania, SK—Slovakia, SI—Slovenia, UA—Ukraine; [a] in carstic regions/lakes; [b] can be set in the permit; [c] depending on the discharge point (soil or water); [d] values required only for wastewater introduced to lakes and their tributaries and directly to artificial water reservoirs situated in flowing waters. [e] There are five categories of WWTPs < 50 PE according to effluent requirements; w—without limits.

3.3. Technologies for Wastewater Treatment

The frequency of the different treatment technologies was estimated by the experts by indicating which technology has been used most often, frequently, rarely, or never. There was also an opportunity to add additional technologies. A total of 14 different treatment technologies were indicated as existing: sequencing batch reactor, moving bed biofilm reactors, membrane bioreactors, activated sludge system, up-flow anaerobic sludge blanket (UASB), sand filter, soil infiltration, evapotranspirative willow system, waste stabilization ponds, aerated/aerobic ponds, treatment wetlands (TW), sludge treatment reed beds, watertight septic tanks, and septic pits. Two additional nature-based treatment technologies were added (vermifilter and ecosan technology). Since there is no national registry of treatment technologies, the results are based on the knowledge of the experts and their familiarity with the situation in their respective countries.

3.3.1. Public Wastewater Treatment Plants in Small Settlements

The most common technology for wastewater treatment in small settlements (PE < 2000) is the sequencing batch reactor, which is mainly used in Czechia, Latvia, and Ukraine, as well as in Estonia, Hungary, Poland, and Romania. Other types of activated sludge treatment technology are also used in the region; classical activated sludge compact systems are most common in Slovakia and Estonia, membrane bioreactors in Romania, and moving bed biofilm reactors in Estonia, Poland, and Slovenia.

Following sequencing batch reactors and similar activated sludge processes, treatment wetlands are also commonly used, particularly in Croatia, Moldova, and Montenegro (Table 3). Accordingly, sludge drying reed beds are frequently used in Croatia and Montenegro to treat excess sludge from conventional activated sludge treatment plants.

Table 3. The presence of nature-based solutions (marked in green) as small wastewater treatment plants (<2000 PE) in Central and Eastern European countries. Where available, the (approximate) number of plants is also given.

	BiH	BG	HR	CZ	EE	HU	LV	MD	ME	PL	RO	SK	SI	UA	Total
Soil infiltration				>1000		12								300	>1312
Willow systems													1		>1
Waste stabilization ponds				100		3							2		>105
Aerated ponds													10		>10
Treatment wetlands	3		8	750				7	5	8000		150	180	80	>9183
Sludge treatment reed beds			8	10			10		4	1					>33
Vermifilter				1				1							2
Ecosan technology								>70							70
Total (this study, 2021)		n.a.	16		n.a.	>15	10	>78	9	8000	n.a.	>150	>193	380	
Total (Istenič et al., 2015) [1]		5			197	32	10			1000	6	10	80	1570	

Green cell —the technology is present in the country; BiH—Bosnia and Herzegovina, BG—Bulgaria, HR—Croatia, CZ—Czechia, EE—Estonia, HU—Hungary, LV—Latvia, MD—Moldova, ME—Montenegro, PL—Poland, RO—Romania, SK—Slovakia, SI—Slovenia, UA—Ukraine.

Sand filters are commonly used as robust and passive technology in Estonia, Moldova, and Romania, while soil infiltration is common in Moldova and Ukraine. In Czechia, sand filtration is mostly used for single households or tourist settlements, where it is often built as the main treatment step after pretreatment in a septic tank, as a septic tank alone is not recognized as sufficient treatment. Soil infiltration technologies require large areas of land, but are usually coupled with water reuse and biomass production; standard irrigation methods can distribute water to agricultural fields, pastures, or forested areas [9].

Despite the many different technologies available and used to treat wastewater from small settlements, septic tanks remain the most common solution. Only watertight septic tanks should be accepted as an appropriate solution. Septic tanks with outflow are considered unsuitable because they are often not designed and operated properly, i.e., they are not emptied regularly and the infiltration of the effluent water is not designed according to soil and site characteristics. This can lead to a threat to surface and groundwater quality [22]. Watertight septic tanks accumulate the total volume of wastewater and solids and, when full, are pumped out and transported to the central WWTP. For the end user, this is often the most expensive wastewater disposal solution and should only be used in areas where no other solution can be considered [24]. It also has to be noted that septic tanks are an important source of greenhouse gasses (GHG). For example, in Slovakia, 90% of GHG generated by the wastewater sector [25] and in Ireland, 90% of GHG generated by on-site wastewater treatment plants originate from septic tanks [26].

Waste stabilization ponds, aerobic ponds, UASB reactors, and willow systems are rarely used for small settlements in the region, with the exception of Estonia where aerated ponds are commonly used.

Comparing countries, the variety of treatment technologies used is mostly low: two in Latvia and Croatia, three in Poland, and four in Montenegro, Hungary, and Ukraine. In contrast, eight or nine different technologies are used in the Czechia, Estonia, and Slovenia. A small number of technologies leads to simpler operation and maintenance practices, as operators do not need to be familiar with many different technologies and can pay more attention to the selected solutions and deepen their knowledge. On the other hand, these selected technologies may not cover the peculiarities of some specific sites or applications and some additional benefits (ecosystem services, water reuse, nutrient and biomass recovery, etc.).

3.3.2. Private Wastewater Treatment Plants for Individual Settings

For individual plants, watertight septic tanks and septic tanks with outflow predominate and are common in Latvia and Poland, as well as in Czechia, Hungary, Moldova, Montenegro, Romania, and Slovenia. For Bosnia and Herzegovina, Croatia, and Ukraine, no data were provided on the technologies used in each country. As mentioned in the previous section, watertight septic tanks are not a sustainable solution. Moreover, although many septic tanks in rural areas are declared watertight, practical experience shows that there are often illegal discharges.

The second most common solution for individual settings is various activated sludge systems, with sequencing batch reactors and conventional activated sludge systems predominating. Sequencing batch reactors are also a common treatment technology in Western European countries; for example, they are reported to be the most common wastewater treatment system [27]. UASB reactors are commonly used in Romania and TW in Poland and Slovenia, while sand filters and soil infiltration are commonly used in Moldova and Romania. Waste stabilization ponds and aerobic ponds are rarely used in the region, with the exception of Estonia, where aerobic ponds are also commonly used for individual systems.

For both public and private WWTP, activated sludge technologies are more common that NBS in many countries. This pattern was found in countries that differ in terms of climate and relief (Estonia, Hungary, Latvia, Poland, Romania, Slovakia, Slovenia). However, TW are used in all countries studied, so geographic characteristics do not determine the pattern of use of the different technologies. A possible explanation could be the age and presence of different technologies on the market. Activated sludge technology was developed in the early 20th century [28], about 50 years before wetlands were first used for wastewater treatment [29]. In addition, national and international policies promoted so-called grey infrastructure in the 20th century which gave a boost to activated sludge systems, while nature-based solutions gained more policy attention in the last decade [30]. Another explanation for the dominance of activated sludge systems could be the low price and the large number of suppliers in the market. Moreover, activated sludge systems are prefabricated treatment plants that can also gain the CE label, while NBS have to be built on-site and the CE label can only be applied to individual system components.

The choice of treatment technology also affects the climate impact of wastewater management, e.g., the GHG emissions from different treatment technologies can differ significantly. Vertical subsurface flow TW have been shown to emit significantly less CO_2 equivalents compared to conventional activated sludge WWTP [31]; however, there are also significant differences in GHG emissions between different types of TW that must be considered [32–34].

3.4. Nature-Based Solutions

The survey offered a list of the six most common nature-based wastewater treatment technologies according to Cross et al. [9]: soil infiltration, evapotranspirative willow systems, waste stabilization ponds, aerated ponds, treatment wetlands, and sludge drying reed beds. In the survey, respondents also had the opportunity to indicate other NBS that are used in their countries. Activated sludge systems were excluded from the list, although they are sometimes referred to as NBS according to the EU-wide definition of NBS [35].

It is encouraging to note that all the listed NBS are present in the region, and two additional solutions have been added (Table 3). Data on the number of such systems were not always available, and when they were reported, the numbers were usually low. Additionally, the numbers of NBS systems should be interpreted with caution, e.g., 8 TW are reported in Croatia, but about 8000 in Poland. Despite the different numbers, the two countries indicate that TW are frequently (Croatia) or rarely (Poland) used. This is due to the very different size of the countries and the total number of WWTP so far applied for small settlements (about 80 in Croatia and more than 295,400 in Poland). Moreover, the number of NBS used for wastewater treatment differs significantly from the figures reported in a similar study a decade ago [1,21]. A difference due to methodology is less likely, since the question about the number of nature-based treatment systems was clear and unambiguous. A possible explanation is that both studies involved different experts, and in the absence of a national registry on treatment technologies and frequency, the answers are based on their knowledge and awareness. To obtain reliable data on NBS implementation, individual studies should be conducted in each country to map implemented systems based on data provided by water utilities, local communities, and practitioners.

Regarding the presence of various technologies, willow systems, sludge treatment reed beds, vermifilters, and ecosan technologies were not used a decade ago [21]. Moreover, soil infiltration systems were not used in Estonia, Hungary, and Slovenia at that time, but in this study they were indicated as applied solutions. Willow systems were reported from Hungary as short rotation biomass production plantations irrigated with wastewater and as a pilot system in Slovenia. Sludge treatment reed beds are gaining interest in the region as they are used to treat sludge from conventional activated sludge treatment plants in small- and medium-sized settlements (capacities from a few hundred to 15,000 PE). They are used mainly in Croatia and Latvia; in Croatia they are gaining attention due to the lack of a unified strategy for sewage sludge treatment. Sludge treatment reed beds can also be used to treat sludge and water accumulated in septic tanks. This is a technically simple and energy-efficient solution for rural areas that avoids transporting sludge to central treatment plants and generates treated sludge for agricultural use and leachate for irrigation of trees for energy production [36]; however, no such application was reported in this study.

TW were found to be the most widely used nature-based treatment system, as they comprise a well-established technology in Western Europe, supported by numerous freely available implementation and operation manuals and the scientific literature, e.g., [37,38]. TW are used in all the countries studied. In the cases of Bulgaria, Croatia, and Latvia, TW were not reported by the experts participating in the survey, but their presence was confirmed by a literature review [9,39,40]. This again shows that the number of nature-based treatment systems, let alone their performance and experience, is not well-known among stakeholders who are crucial for broader implementation and recognition of NBS. The number of TW has increased in Slovakia (from 5 to 150), Slovenia (from 80 to 180), and Ukraine (from 65 to 80) [21], but the increase over a 10-year period is not significant, although they are widely used in neighboring Western European countries. For example, Engstler et al. [27] report that TW comprise the second most commonly applied treatment technology for systems <50 PE, and in their study of the performance of about 14,000 WWTP, concluded that the most efficient treatment systems are technical WWTP, with vertical flow TW as the polishing stage, and single-stage vertical flow TW. TW also showed less variation in effluent concentrations compared to conventional solutions, which means that TW are a more robust solution.

The use of waste stabilization and aerated ponds has spread to other countries: in 2012 they were used in Estonia and Hungary, and now also in Bulgaria, Romania, and Slovenia. As with TW, pond treatment technologies are well documented and supported by experts and the scientific literature, e.g., [9,41], which has contributed to their spread.

Although the implementation rate of nature-based treatment systems in CEE is still low, the presence of various technologies in all the countries studied is a good basis for demonstrating their performance and promoting their further implementation throughout the region. To ensure high treatment performance of NBS, treatment systems should be designed by experts, operation and management plans and monitoring programs should be developed, and operators should be trained to work with nature-based treatment systems.

3.5. Barriers in Implementing NBS

In 2012, Bodik and co-authors [21] pointed out numerous regulatory and administrative barriers and lack of knowledge about nature-based treatment technologies. Since then, a large amount of the literature has been published in the EU [9,37,38] as well as in the CEE region (e.g., technical textbook by Rozkošný et al. [42]), which provides concrete guidance to practitioners on how to implement NBS for wastewater treatment. Accordingly, this study did not identify lack of technical knowledge as a major barrier to broader implementation of NBS, which is a significant improvement over the past decade. However, formal (institutional) training of designers is still largely lacking, which may lead to a lack of public confidence in the projects offered, as reported in Czechia.

Currently, the main challenges hindering wider adoption of nature-based treatment systems are the lack of acceptance of NBS by authorities, the lack of good case studies, and poor past experiences (mainly due to poorly designed systems and/or improper operation and management) (Table 4). Although NBS are recognized and supported by the EU, IUCN, UNEP, and other major international organizations, it is surprising that lack of awareness about nature-based treatment systems is still a major challenge for wider application. This was particularly noted in Bulgaria, Hungary, Poland, and Slovakia.

Table 4. A heatmap showing the main challenges for broader implementation of nature-based wastewater treatment (empty cell—no answer; 0—no challenge; 1—small challenge; 2—medium challenge; 3—large challenge). Croatia did not participate in this question and is therefore not included in the heatmap.

	Lack of Awareness	Negative Experiences	Lack of Land (Area)	Institutional Barriers	Natural Conditions	Lack of Legislation	Lack of Engineering
BiH *	3	1	1	3	1	3	3
Bulgaria	3	3	2	3	3	3	1
Czechia	2	2	1	2	0	2	1
Estonia	2	0	1	2	1	2	1
Hungary	3	3	3	3	3	0	2
Latvia	2	3	3	1	3	2	2
Moldova	2	1	1	3	1	1	2
Montenegro	2	1	3	2	1	1	2
Poland	3	3	0	0		2	2
Romania	2	2	3	2	3	3	2
Slovakia	3	3	2	2	2	2	2
Slovenia	2	1	3	1	2	1	1
Ukraine				3			

* BiH—Bosnia and Herzegovina. Cell colors correspond to the magnitude of the challenge: 0—no challenge; 1—small challenge; 2—medium challenge; 3—large challenge

Raising awareness of the solutions available, the efficiencies and benefits of NBS, and examples of good case studies is a way forward. Examples of good practices already exist in some countries: in Montenegro, TW have proven to be highly efficient, but ongoing efforts are needed to raise awareness of the benefits of NBS; Moldova is home to the largest TW in Europe with a capacity of 20,000 PE [43] and should be promoted for wider adoption of NBS. There are also good examples in Slovenia, where NBS is well accepted and implementation is slowly but surely increasing.

In addition, more qualified engineers and supportive legislation are needed; in Poland, for example, the use of TW as private treatment systems (<50 PE) is increasing because they can be built without building permits. In Montenegro, NBS have been included in the national strategy, which is in line with the political decision on environmentally friendly development of the country. In some countries, current legislation is not conducive to NBS or special requirements have to be met, e.g., strict discharge limits for all WWTP including individual systems, hinder the implementation of NBS in Romania and favour high-tech solutions with high CAPEX and OPEX. As a result, with the exception of some aerated ponds and pilot plants, there are almost no nature-based wastewater treatment systems in

Romania. In addition, some countries have specific requirements for NBS (e.g., in Hungary, wastewater can only be treated in NBS if a separated sewer system is used). Institutional barriers are a challenge in Bulgaria, Hungary, Moldova, and Ukraine. In Bulgaria, the Ministry of Environment and Water does not recognize NBS as a suitable solution for wastewater treatment.

Lack of land or available space for implementing NBS was cited as a major challenge in 5 of 12 countries. Indeed, nature-based treatment systems require larger areas of land compared to conventional treatment systems; however, in this study, we focused on rural areas rather than densely populated urban areas where land shortage is often cited as a problem in implementing NBS [44]. Lack of land was cited as a major challenge in countries where abundant flat land is available in rural areas (Hungary, Romania, Latvia) but competes with agriculture, as well as in smaller countries where scattered settlements occur due to diverse geographic conditions, and it can therefore be difficult to find a flat surface in a low-lying area of the settlement (Slovenia, Montenegro). Natural conditions have also been identified as a major obstacle in the same countries, with the exception of Slovenia, where NBS are well-known and have been adapted to this constraint by intensifying the treatment process and focusing on individual solutions and rural areas. Regarding the search for available space for NBS, numerous EU-supported research and innovation projects are developing new NBS with intensified processes (e.g., aerated TW) and considering walls and roofs of different buildings [9]. Regarding natural conditions, some experts expressed concern that nature-based treatment systems may not work in colder climates and at higher elevations. This suggests that more awareness and education is needed with regard to technical solutions, as many NBS have been shown to work efficiently in colder climates and at higher elevations [45].

In Estonia, there are no major challenges for the implementation of NBS. Nature-based treatment systems are mostly used as post-treatment or as individual systems. Guidelines and recommendations for installation are available. The country reports some operational issues, e.g., 60% of aerobic ponds lack a suitable sampling point for effluent water.

In addition to the obstacles listed in Table 4, other challenges may arise. Poor experiences, which have already been reported, are sometimes due to improper or neglected maintenance that can cause systems to malfunction over the years and, as a result, incur high remediation costs. In addition, public utilities should be empowered with competences to manage and operate NBS. Proper operation, maintenance, and training in these two areas have also been recognized by other authors as key factors for efficient performance [27,46]. Last but not least, the behavior of residents can affect the performance of the treatment system by introducing solid wastes and pollutants into the sewer system, which can clog the pretreatment settling basin or affect the microbial biomass and plants in the NBS.

3.6. Use of Reclaimed Water for Irrigation

Reuse of wastewater provides a valuable and constant source of water for areas with water scarcity. The use of reclaimed water is facilitated by the EU, which has adopted a regulation on minimum requirements for water reuse for agricultural irrigation [47], which will enter into force in June 2023, and guidelines to support its application [48]. Before the adoption of the regulation, the use of treated water for irrigation has been very different in the studied region: in Croatia, Czechia, Hungary, Latvia, Moldova, Poland, and Ukraine treated wastewater is allowed to be used for irrigation, while this practice has been prohibited in Bulgaria, Estonia, Montenegro, Romania, Slovakia, and Slovenia. The main reason for this is the risk of human health hazards from pathogens, metals, and contaminants of emerging concern. Moreover, in Latvia and Estonia, due to sufficient rainfall, irrigation with reclaimed water has not been foreseen so far. Not all countries where the use of reclaimed water for irrigation is practiced have specific national regulations; Hungary, Poland, and Ukraine have specific regulations, and Moldova refers to the limits given in the recommendations of WHO [49]. In Croatia, Czechia, and Latvia, there are no specific limits.

Although the use of treated water for irrigation is prohibited or not applied in many countries, there is indirect reuse of reclaimed water that is also practiced unintentionally (e.g., taking water for irrigation from a river downstream of a major inflow of treated water from WWTP). Although many experts oppose the reuse of water for irrigation, unintended reuse is generally overlooked and can be equally harmful [50].

Main Obstacles for Reuse of Reclaimed Water

The availability and low price of freshwater may hinder the use of reclaimed water; moreover, the market value of reclaimed water, which (when used for irrigation) should be considered a private good, is not established in many countries. Accordingly, Bulgaria and Estonia consider low water prices and water services as the main barrier to reclaimed water use.

Other countries are more concerned about health risks and expensive treatment technologies. Concerns about health risks are most likely in countries where legislation is absent or inadequate, because if treated water is not properly treated, it may contain pathogens, contaminants of emerging concern (pharmaceuticals, personal care products, plastics, endocrine disruptors, etc.), and heavy metals with various acute and chronic effects on human health. Expensive treatment technologies may be required to remove these contaminants. In addition, new infrastructures must be built to distribute reclaimed water from WWTP to the end users, causing additional costs and new interventions in the environment.

Moldova, Poland, Slovakia, and Slovenia indicate lack of relevant legislation and awareness. The latter is closely related to public acceptance. In general, people support reuse and environmental protection; however, the smaller the reuse cycle, the more reluctant the public reaction, which is why indirect reuse is much more readily accepted [51].

Adoption of the current EU regulation on minimum requirements for water reuse in agriculture [47] into national policy could increase the use of reclaimed water in the future; however, the regulation only refers to reuse in agriculture, which is important but not the only option for reuse. The use of reclaimed water for other purposes such as irrigation of lawns, hedges, and urban green spaces, drought mitigation, street-washing, or use as firefighting water is not regulated at the EU level, although these uses may be better accepted by the public because they are not related to food production.

4. Conclusions

Central and Eastern Europe is highly rural, with about one-third of the population living in small settlements. Settlements with less than 2000 PE are not specifically addressed in current European wastewater collection and treatment directive, so countries take different approaches to address this dispersed pollution. In the last decade, the connection of rural populations to public sewers and WWTP has increased from 9% to 19%, representing a significant increase in what is still a very low connection density. There is wide variation among countries in the proportion of the population connected, limits, and monitoring requirements; however, all countries use different types of nature-based treatment systems. NBS have proven to be efficient and robust treatment systems that can be applied in small communities and individual settings, so their widespread adoption could be the solution to promote the development of wastewater treatment in rural areas of the region. Prior to this, the enabling environment for nature-based treatment solutions and use of reclaimed water needs to be established, including the formalization of training on nature-based treatment technologies, the establishment of clear legal guidelines and monitoring programs, and, last but not least, capacity-building of decision-makers and practitioners. In this setting, showcasing best practices, establishing clear operation and maintenance guidelines, and knowledge sharing among local communities and countries are crucial. In this context, different online platforms, national and international networks, and pilot projects can be useful tools where experts, practitioners, decision-makers, and end users can share knowledge, ideas, doubts, or problems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15108145/s1, Supplementary File: Questionnaire on wastewater collection, treatment, and reuse in rural areas of CEE.

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