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Research Article

PRE-FEASIBILITY STUDY FOR TREATMENT WETLAND APPLICATION FOR WASTEWATER TREATMENT IN DISPERSED DEVELOPMENT

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ABSTRACT
The aim of the paper is to present the conducted analyses of pre-feasibility study of different approaches for wastewater management in a settlement of 180 persons. In the assessment both technical and economic aspects were analyzed. The costs were calculated for three different and, at the same time, most popular as well as possible technical solutions like: (i) construction of local wastewater treatment plant with gravitational and pressurized networks, (ii) construction of single family wastewater treatment plants, (iii) construction of sealed septic tanks. Carried out analyses of investment and maintenance costs revealed that at the stage of construction the most expensive is local sewer network with treatment plant, while the construction of a single family treatment plant has similar cost regardless of the technology used. When the long term operation and investment cost are accounted the most economical reasonable solution is the application of wetland treatment for household wastewater treatment.

Keywords: wastewater management in scattered development**,** conventional and natural treatment methods, economical cost, investment and maintenance costs

INTRODUCTION

The management of domestic wastewater in areas with dispersed development is a problem that not only individual households, but also municipal authorities have to face. Low population density and dispersed development make designing complex sewerage networks very difficult and, what is even more important, uneconomic. Rural households are supplied with water for different purposes partially from own wells and partially from water supply networks. Not every household in Poland has access to water supply system. For a total of 43 068 villages in Poland, around 87% are provided with full and 8% with partially water supply network. Many households still use water from their own, usually dug wells thus a problem with its quality still arises. Water from water supply system is constantly monitored and improved while water from dug wells is often of bad quality, meaning that is not potable (Staniszewska, 2013). According to research conducted by Polish Institute of Soil Science and Plant Cultivation, 44.8% of wells have water of bad quality, not suitable for drinking, with the concentration of NO_3^- above 50 mg/dm^3 which is the allowable limit value for the presence of nitrates in drinking water in Poland (Regulation of Minister of Health, 2007). Those results are the evidence that domestic wastewater management is of poor quality and appropriate actions should be taken. In Poland in the last few years one can see a significant increase in the number of investments in sanitary infrastructure. In the years 2007-2013 the length of the water supply network increased by 30 600 of kilometers, including over 23 thousand of kilometer built in the villages. The number of connections increased by more than 650 thousand, including approximately 418 thousand in the countryside. In the same period, sewerage network has increased by more than 43 400 of kilometers, of which almost 32 thousand kilometer network established in rural areas. This resulted in more than 797 thousand new sewer connections, of which over 465 thousand were established in rural areas [GUS, 2013, 2014].

Assuming the changes it could be noticed that in 2013 in Poland, the number of working wastewater treatment units was 2412 of which approximately 94% were septic tanks (with no major treatment unit). During last few years, the significant decrease of such units is observed while the number of individual sewage treatment plants increases. Due to high operation cost the amount of septic tanks has systematically decreased from about 2 433 thou. in 2009 to 2192 thou in 2014 (decrease about 9.9%). While at the same time the amount of single family wastewater treatment plants has increased about 191,9% (from 62 000 in 2009 to 181 000 in 2014) (GUS 2010, 2015). It is estimated that there is need to build another 700 thou. of facilities serving approx. 3.8 million inhabitants.

Single family wastewater treatment plants (SF WWTPs) are defined as those serving up to 50 inhabitants according to Polish Standards and maximum outflow from these facilities is 5 $m^3 \cdot day^{-1}$.

Requirements and policy for wastewater management in dispersed development

Understanding law regulations concerning water supplies, wastewater disposal and treatment are crucial in proper development and designing all facilities associated with these aspects.

For wastewater the most important for EU and, in consequence, for Poland is the Water Framework Directive (2000/60/EC) which established integrated policy and frame for water and wastewater management. The WFD includes the so called “daughter” or “sister” directives which are connected and important for water protection. Thus the quality of wastewater discharged to the recipients and the efficiency of municipal WWTPs is regulated by Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC). The reflection of this Directive is lately issued Regulation of Minister of Environment of 18 November 2014 concerning conditions of wastewater discharge into the water and soil, and also substances harmful particularly for water environment (Dz. U. 2014 poz. 1800). Treated domestic wastewater and wastewater from agricultural farms disposed into the water should not include pollutants in the amount exceeding the highest allowable norms for the agglomeration below 2 000 people (Figure 1).

This set of requirements could be assumed as ecological and environmental criterion for the selection adequate technology for wastewater management. Other criteria like economical, technical with the important issue of reliability could be assumed as an aspect of sustainable development. These aspects are partly released by the implementation of IPPC Directive (Integrated Prevention Pollution and Control) 96/61/EU from 24 September 1996. This Directive is indirectly connected to wastewater management in scattered development but it defines what is Best Available Technology (BAT). According to IPPC 96/61/EU BAT should ensure all the above mentioned criteria.

Assessment of types of facilities for domestic wastewater disposal

Small wastewater treatment plants are characterized by highly fluctuating inflow of wastewater and by a chemical composition that is significantly different from that encountered in typical municipal wastewater flowing into medium and large WWTPs (Gajewska & Obarska-Pempkowiak, 2011; Obarska-Pempkowiak et al., 2013). Therefore, the technology of wastewater treatment used in a single final WWTP should be chosen in such a way to ensure adequate ecological effects combined with low requirements relating to maintenance and with minimal costs of operation. The decision concerning the application of a specific technological solution for a single family WWTP should by based on the analysis of local conditions and the technological and environmental factors (Vymazal & Kröpfelová, 2008).

In the Table 1 the comparison as well as assessment of possible solution for single family treatment plant is presented.

Application of treatment wetlands have high investment cost in comparison to drainage system and sand filter although the operation cost are much lower in comparison to activated sludges or trickling filter but they ensure high efficiency of pollutants removal. Long term experience with application of treatment wetland for domestic wastewater treatment confirmed high applicability of this method, especially for scattered development (Gajewska & Obarska-

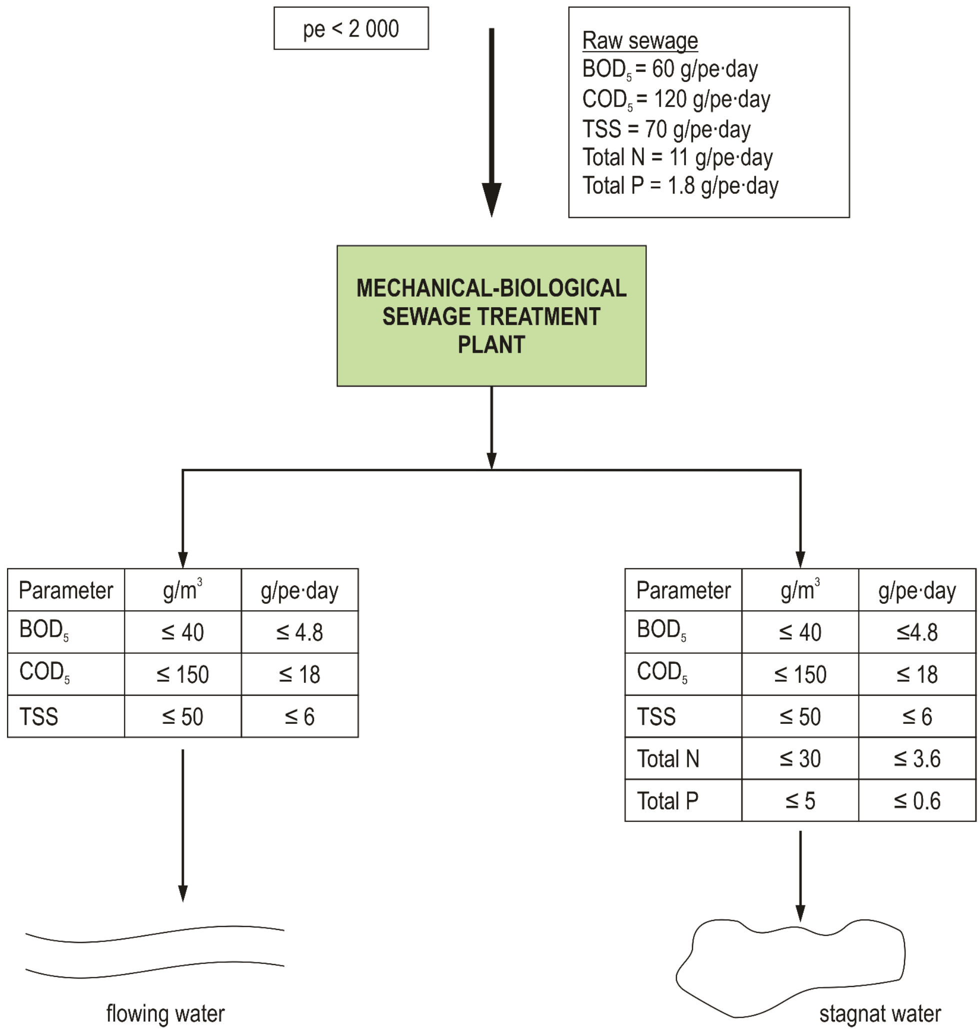

Figure 1. Schematic interpretation of the requirements for quality of treated wastewater disposed to surface waters, according to Regulation of Minister of Environment of 18 November 2014 (Bejnarowicz, 2015)

Pempkowiak, 2011; Obarska-Pempkowiak et all., 2012; Brix & Arias, 2005; Cooper, 2005; Langergraber et al, 2011; Puigagut et al, 2007). The newest technical solutions applied in this technology ensure stable and efficient removal of pollutants (organic matter and nitrogen as well as persistent organic pollutants) (Kadelc and Wallace, 2009). According to Langergraber et al., (2007), the effluents of one-stage vertical subsurface flow (VSSF) bed of a unit area equal to 4 m^2/pe and the organic matter loading equal to 20 g/m^2d, can meet rigorous Austrian outflow standards (below 90mg COD/l and 25 mg BOD_5/l), regardless of season of a year and air temperature. In Denmark very simple guidelines for designing TWs for less than 30 pe with single VSSF bed were introduced in 2005 (Brix and Arias, 2005). In France, two working sequentially VSSF beds have been successfully used for the treatment of raw sewage (without

Table 1. The comparison of single family wastewater treatment plants

Facility	Drainage system (DS)	Sand filter (SF)	Activated sludge (AC)	Trickling filter (TF)	Treatment wetland (TW)	Treatment wetland – French system
Investment costs	low	mean	high	high	high	high
Operation costs	low	low	high	high	low	low
The efficiency of pollutants removal	low	mean	high	high	high	high
Primary septic tank	+	+	+	+	+	-
Secondary septic tanks	-	-	+	+	-	-

primary mechanical treatment) for over 25 years (Molle et al., 2004). According to Molle et al. (2004) the unit area should be equal to 1.2 m²/pe for the first bed and only 1.0 m²/pe for the second bed. Such a configuration of VSSF beds allows for reducing pollutants concentrations to the following level: COD – 60 mg/l, TSS – 15 mg/l, TKN – 8.0 mg/l. It is strongly recommend not to exceeded hydraulic loading of 600 mm/d for the beds working in batches. Moreover, the so called "French" type of TWs for wastewater treatment could help in solving the problem of the rising amount of sewage sludge, which is generated in AC or TF technology (Table 1). By application of TWs in French technology generation of both type, primary and secondary sludge could be avoided (Molle et al., 2004; Chojnicka and Gajewska, 2014).

Thus, the economics is one of the most important aspects in the choice of wastewater treatment system. While organizing wastewater management in cities should be realized with network systems, whereas in rural areas dispersed settlement does not favor the implementation of network systems (small villages, dispersed development, long distances between buildings). This affects a significant increase in investment costs associated with the construction of sewerage system in the rural areas per capita. Economic criteria may be a major determinant way to solve the problem of sewage in the countryside. According to research, the estimated value of the investment of sewerage systems exceeds by far the financial capacity of municipalities the Baltic Sea Region in counters. The analysis, presented in the National Program of Municipal Wastewater Management (KPOŚK) in Poland, indicates that municipalities are not able to cover most on the investment costs.

THE EXAMPLE OF ECONOMIC ANALYSIS OF POSSIBLE SOLUTIONS OF WASTEWATER MANAGEMENT IN SETTLEMENTS – CASE STUDY

This economic analysis was made based on data obtained from the municipal office of Dębnica Kaszubska near Gdańsk, Poland as well as data from designers and constructors of wastewater treatment systems available in the specialist websites and literature, manufacturers of sewage treatment plants, as well as on the basis of sample reports available in the literature.

There are three possible solutions assumed for domestic wastewater treatment in the site of 180 pe (with 41 household):

- Option I – construction of local wastewater treatment plant with gravitational and pressurized networks.
- Option II – construction of single family wastewater treatment plants.
- Option III – construction of sealed septic tanks.

Option I – collective wastewater treatment plant

The choice of gravitational sewerage system is economically justified when it is associated with terrain conditions, i.e. when declines in the catchment area coincide with the direction of wastewater discharge – then it is profitable and reasonable. In the case of chosen settlement, landform favors the construction of gravity network, thus construction of a local treatment plant with gravitational and pressurized networks is a technically reasonable option. In Table 2, investment costs of a construction of local treatment plant with necessary connections in settlement

Table 2. Option I – investment costs

Physical data		Economic data		Investment costs [PLN]
Length of gravity network [m]	2 560	Cost of 1 m of gravity network [PLN/m]	300	768 000.00
Length of pressurized network [m]	500	Cost of 1 m of pressurized network [PLN/m]	100	50 000.00
Number of pumping stations	1	Average cost of construction of pumping station [PLN/piece]	5 000	5 000.00
Number of people connected to the WWTP	180	Index of construction costs [PLN/person]	1 300	234 000.00
Number of sewerage connections	41	Average cost of sewerage connection [PLN/piece]	2 500	102 500.00
		Total investment costs [PLN]		1 159 500.00
		Costs for one household [PLN]		28 280.49
		Cost for one person [PLN]		6 441.67

are presented. The length of gravitational, as well as pressurized connections were established on the basis of available maps and local vision. All unit prices are given taking into account such aspects as construction materials, permissions, labor or designing costs.

Total investment cost of building the local wastewater treatment plant for settlement seems to be very high (much more than one million PLN). The highest impact for this price has the length of the sewerage network. The reason is clear in chosen settlement there is very dispersed development which results in a necessity of building of long sewerage networks. Yearly total exploitation costs are presented in Table 3.

The choice of this option seems to be the most expensive solution for wastewater management in a settlement, because investment costs per one inhabitant is about 6442 PLN and exploitation cost per one year is also high – about 620 PLN. The cost of the treatment of 1m^3 of wastewater is about 22 PLN per year. The highest influence of exploitation cost has the annual depreciation (more than 52 000 PLN). Also, in the case of local wastewater treatment plant there is a need to employ specialized staff whose yearly cost is also high (for two workers is about 48 000 PLN).

Option II – individual wastewater treatment plants

The second option for domestic wastewater treatment in a settlement village is the construction of individual wastewater treatment plants for each household. As it is described in text books, there are several types of individual wastewater treatment plants and one should select the one which will be the most reasonable option for the settlement. That is why, general economic analysis is presented. The investment costs of this option are very difficult to determine because of a number of factors. Prices are set by producers individually, even within a single technology differences can be significant. The most influencing factors are the experience of producers, process technology and license fees for technology developers. The average cost of WWTP varies also according to the number of plants in a single investment. In addition, construction costs of a single family wastewater treatment plant specified in tenders are subject to significant changes, depending on the number of builders (with multiple builders the price of WWTP may be lower, and in the absence of competition in the building process the price may be even twice higher than the market value).

Table 3. Option l- exploitation costs per one year

Data		Local WWTP	Sewerage network
Capacity $Q_{average}$ [m^3/day]		14.4	
People equivalent		180	
Annual depreciation – 4.5% [PLN]		**52 177.50**	
Repairs and maintenance	Investment cost [PLN]	1 159 500.00	1 159 500.00
	Interest value of repair [%]	0.005	0.01
	Total cost [PLN/year]	5 797.50	11 595.00
Service	Number of workers	2	
	Monthly payment per person [PLN]	2000.00	
	Yearly payment per person [PLN]	24 000.00	
	Total cost [PLN]	48 000.00	
Energy	Amount of sewage per year [m^3/year]	5 256	5 256
	Unit consumption of energy [kW/m^3]	1.0	1.0
	Energy consumption per year [kWh/year]	5256	5256
	Unit cost [PLN/kWh]	0.45	0.45
	Total cost of energy [PLN/year]	2 365.20	2 365.20
Indirect costs	Amount of sewage per year [m^3/year]	5256	5256
	Unitary cost [PLN/m^3]	0.08	0.08
	Total costs [PLN/year]	**420.48**	**420.48**
Total exploitation costs of WWTP and networks [PLN]		**111 557.55**	
Unitary costs	Cost per one person [PLN]	619.77	
	Cost per 1 m^3 of treated wastewater [PLN]	21.23	

Table 4. Option II – investment costs

Type of WWTP	Investment cost for single household [PLN]	Investment cost for a whole village [PLN]	Investment cost per one inhabitant [PLN]
Septic tank + distribution drainage	9 500	389 500	2 164
WWTP with acivated sludge	14 000	574 000	3 189
WWTP with biological trickling filter	14 000	574 000	3 189
Constructed wetland	9 000	369 000	2 050

In Table 4 general costs of four different types of individual wastewater treatment plants proposed for households in settlement are presented.

On the basis of literature, data collected from the municipal office in Dębnica Kaszubska and local vision, the type of individual wastewater treatment plant can be selected. The most reasonable option for chosen settlement are constructed wetlands thus further economic analysis will be proposed for this type of technology. Among the types of constructed wetlands, vertical flow constructed wetland was chosen.

Nowadays vertical flow CW has a height of 1.0 m and is composed of three layers (mineral and organic). The total surface area of bed is 2 m^2 per pe. The bed is isolated from the ground with geomembrane with a thickness of 1 mm. The first layer from the bottom is gravel (diameter of 4–32 mm), followed by medium sand (with diameter of 0.5–2 mm). The last layer is made of a mixture of wood bark, sawdust and wood chips. The surface of the bed is planted with common reed. The last element is a receiver (pond) recessed in the ground to the depth of 0.7 m and partially isolated from the ground with geomembrane with thickness of 1 mm.

The exploitation costs are composed of two positions: transportation of sludge and energy consumption. Transportation of sludge should be carried out one per 2 years and yearly energy consumption is about 50 kWh. Additionally, annual depreciation cost should be included with the assumption that the wastewater treatment plant will be working through 15 year without modernization. Linear depreciation is assumed and value of 30% of investment cost which gives about 180 PLN per year. Exploitation cost are presented in Table 5.

The analysis of investment costs of individual WWTP in relation to particular types shows that solutions are cheaper than collective system, but also different from each other. Costs are formed depending on the technology, respectively: distribution drainage – 2164 PLN per one person, activated sludge and biological trickling filter – 3189 PLN per person and constructed wetland – 2050 PLN per one inhabitant. In contrast, operating costs are significantly differentiated. Depending on the technology, they range from 100 PLN even up to 2000 PLN per person per year (including depreciation). Typically, technology which is the most expensive in operation, is activated sludge because it requires large amount of electricity, what influences the total costs.

Option III – septic tanks

The last option to solve the problem of wastewater in chosen settlement which is subjected to the economic analysis is the option of construction of septic tanks for each household. In practice, this is not a complex system for wastewater treatment but system for its collection. Determining the real costs of the potential investment, one should include the construction of collective wastewater treatment plant where wastewater should be transported from septic tanks.

Table 5. Option II – exploitation costs per one year

Position	Unitary cost [PLN]	Total cost [PLN]
Transporation of sludge	75	3 075
Energy consumption	22.50	922.5
Depreciation	180	7380
Total costs per year [PLN]		11 377.50
Unitary costs	Cost per one pe [PLN]	63.21
	Cost per 1 m^3 of treated wastewater [PLN]	2.17

However, this is currently the most widely used method of wastewater management in rural areas in Poland and Baltic Sea Region (BSR) countries and for comparison purposes, the analysis of this solution is determined. From the investment site, the construction of septic tanks is not the cheapest option, because the average cost for one person is more than 2000PLN and it is comparable expense to the construction of individual wastewater treatment plant (Table 6). However, with regard to exploitation costs (Table 7), it is definitely the most expensive solution, because the collection of 1m^3 of wastewater accounts for about 28 PLN. What is more, it does not include costs of wastewater treatment. Thus, taking into account additional 5 PLN for 1 m^3 of wastewater (charge in conventional WWTP), the final cost of sewage treatment in this way is at the level of 33 PLN/m^3.

Summary of economic analysis

Table 8 presents the collective summary of investments as well as exploitation costs of all three proposed solutions of domestic wastewater treatment in a selected settlement.

The economic analysis of presented options clearly illustrates significant differences in terms of individual costs in reaction to the type of wastewater discharge and treatment. The highest rate of investment per capita has a network system (option I) which is 6441.67 PLN. The lowest investment costs are achieved in the Option II (2050 PLN per person). The analysis of operating cost shows that the highest costs of this type are associated with the construction of septic tanks, due to the nature of operation, which is confirmed in many engineering and scientific publications, unitary cost of collection of 1m^3 of wastewater is 28.51 PLN. The operation costs related to the construction of constructed wetlands are low and amounts to 2.17 PLN per 1 m^3 of wastewater.

CONCLUSIONS

The choice of method for wastewater treatment in scattered development should be based on the following criteria (i) environmental criteria (which is effect on the natural environment and aesthetics) (ii) technical criteria (simplicity of operation and maintenance as well as fail safety), (iii) economic criteria (costs of investment and operation), (iv) reliability of operation. In economic aspect of both investment and maintaining cost should be considered. Carried out detail economic analyses for settlement for 180 pe revealed that the best solution in long term is application of individual wastewater treatment plant working in treatment wetland technology, while the most expensive is the application of sealed septic tanks for each household.

Table 6. Option III – investment costs

Type	investment cost per one household [PLN]	Investment cost per whole village [PLN]	Investment cost per one inhabitant [PLN]
Septic tank	10 000	410 000	2 277.78

Table 7. Option III – exploitation costs per year

Type of cost	Unitary cost [PLN/m^3]	Total cost [PLN/m^3]
Transportation	25	131 400
Annual depreciation	450	18450
Total exploitation costs [PLN]		149 850
Unitary costs	Cost per one inhabitant [PLN]	832.50
	Cost per 1 m^3 of treated wastewater [PLN]	28.51

Table 8. The summary of investment and exploitation costs of three different solutions for wastewater treatment

Option	Investment cost per one inhabitant [PLN]	Investment cost per one household [PLN]	Exploitation cost per one inhabitant [PLN]	Exploitation cost per 1m^3 of wastewater [PLN]
Option I	6441.67	28 280.49	619.77	21.23
Option II	2 050–3 189	9 000–14 000	63.21	2.17
Option III	2 277.78	10 000.00	832.50	28.51

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