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ECONOMIC ANALYSES IN SEWAGE SYSTEM DESIGNING FOR RURAL SETTLEMENT – CASE STUDY

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Abstract

The paper presents application of multivariate economic analysis to decision making process of selection of the most economically suitable concept of sanitary sewage system for a selected rural settlement in Poland. Analysis covered Drelow, Lublin Voivodeship, settlement area with 121 households with 421 residents and several municipal services. Three variants of sewage removal and treatment were developed: unconventional gravity-pressure network, gravity-pressure network combined with local domestic wastewater treatment plants (WWTPs) and full pressure sewerage network. In all variants, the container wastewater treatment plant of daily capacity 450 m^3 day^{-1} was applied. Estimations of investment and exploitation costs for 30 years period operation were performed. Economic multivariate analysis was based on: Payback Period, Dynamic Generation Cost (DGC), Net Present Value (NPV) and Benefit-Cost Ratio (BCR). The obtained indicators were the input data for the weighted sum model allowing to select the most appropriate variant. Analysis showed that the most suitable was variant No 1. However, it was also noticed that all of the tested designs were ineffective economically.

Streszczenie

Praca przedstawia zastosowanie wariantowej analizy ekonomicznej w procesie decyzyjnym wyboru najkorzystniejszej koncepcji kanalizacji sanitarnej dla wybranej wiejskiej jednostki osadniczej. Analizami objęto Drelów, woj. lubelskie, jednostkę o 121 gospodarstwach i 421 mieszkańcach. Przeanalizowano trzy warianty odprowadzania i oczyszczania ścieków: sieć grawitacyjno-tłoczną, sieć grawitacyjną z odcinkami tłocznymi i oczyszczalniami przydomowymi oraz sieć ciśnieniową kanalizacji sanitarnej. We wszystkich wariantach zastosowano kontenerowe oczyszczalnie ścieków. Obliczenia ekonomiczne oparto o kosztorysy wstępne oraz oszacowane koszty eksploatacyjne dla okresu obejmującego 30 lat. W analizie wykorzystano wskaźniki: okres zwrotu, dynamiczny koszt jednostkowy (Dynamic Generation Cost), wartość bieżącą netto (Net Present Value) oraz wskaźnik kosztów i korzyści (Benefit-Cost Ratio). Wymienione wskaźniki stanowiły dane wejściowe do obliczenia sumy ważonej umożliwiającej wybór wariantu najodpowiedniejszego. Na podstawie przeprowadzonych obliczeń za najkorzystniejszy ekonomicznie uznano wariant pierwszy, niemniej jednak wykazano, iż wszytkie badane koncepcje są nieopłacalne ekonomicznie.

Keywords: **Rural sewage system; Economic multivariate analysis.**

1. INTRODUCTION

Despite the significant development of sewerage systems in rural countryside during the last decade, the access of rural population to sanitation is limited in Poland [1, 2].

According to official data reported regularly by the governmental office GUS, at the end of 2013 (latest available data) 25 047 629 residents of Poland had access to centralized sanitation (65.1% of population), of which 4 709 026 were the residents of rural settlements. Moreover, taking into account the rural population of Poland, only approx. 30.9% of countryside residents had in 2013 access to centralized systems of sewage removal and treatment. The mean density of sanitary sewerage systems in rural areas of Poland is equal to 26 km per 100 km^2, while in the less developed part of the country, in Lublin Voivodeship, sanitary sewage density from equal to 13 km per 100 km^2 was observed.

The remaining population of rural areas of Poland uses decentralized methods of sanitary sewerage transport and treatment such as individual treatment plants (154 944 reported in 2013 in the whole country), usually limited to drainage field, sewage septic tanks (2 256 572 septic tanks noted in Poland in 2013) of uncontrolled sealing quality and typical infiltration tanks. The risk for local surface water, groundwater and soil environment is obvious [3].

Insufficient sanitation of rural areas negatively influences the groundwater and surface water quality and significantly threats the health of rural population. Untreated or insufficiently treated sanitary sewerages pose potential and real source of environmental threats, due to which, application of centralized or local wastewater management systems seems to be reasonable and should have huge priority [1]. However, construction of centralized sewerage removal and treatment systems in rural areas, with dispersed building development, low population density, significant annual, monthly, weekly, daily and hourly irregularity of sewage discharge causes several serious technical problems, both, on the designing and operation stages. Additionally, economical aspect of the investment may also pose a serious problem. Nowadays, costs of construction and operation of sanitary wastewater systems are paid by the local governments, with the limited donation from the state governmental administration. Thus, designing, construction and operation of rural sewerage system may be treated as complicated engineering and economic task [4-7]. Taking the above into account and including possibility of significant refunds of the investment costs by e.g. EU funds, application of decision-making stage of conceptual design, supported by technical and economic multivariate analysis seems to be necessary [8-10].

Recently, investment decision-making and conceptual designing are frequently supported by various methods of economic efficiency assessment [11-13]. These methods, according to taking into account the influence of time, may be divided into simple, based on relations between costs and effects, and combined based on discount rate, inflation etc. etc. [14, 15]. Simple methods combine nonsimultaneous cash flows from different stages of investment life, so they should be used as preliminary tool, also to their simplicity, easy understanding and interpretation [11]. Contrary, combined, dynamic methods of investment financial efficiency are based on included time factor, resulting in possible change of money value. So, the assessment of investments' financial efficiency by simple methods performed on the decision-making stage of the design should be validated by combined methods, allowing to assess performance of the investments during their life time duration [11, 16]. Thus, methods of benefits and costs analyses are the important tools supporting decision-making, especially for capital investments [8, 9, 16-19].

2. MATERIALS AND METHODS

2.1. Object description

Rural settlement Drelow is located in Lublin Voivideship, county Bielsk and commune (*gmina*, in Polish) Drelow, east part of Poland, 150 km E from Warsaw, 15 km W from Biala Podlasaka and 90 km N from Lublin. Ground elevation levels in Drelow vary between 149.1 and 151.2 m above the sea level while groundwater level is located at depth of 0.5-3.5 m at green areas and approx. 10 meters below surface of arable soils. Hydrological network of surface water covers the Zelizna reservoir, the Wieprz-Krzna Chanel, and the rivers Krzna, Bialka, Rudka, Danowka and Dziegciarka as well as the system of drainage channels. Arable lands cover over 56% of Drelow commune area, with agriculture based on individual farms of 5-10 hectares area. Forests cover 37% of the commune area. Population of Drelow community in 2010 reached the level of 5762 residents of 1821 households. Number of households covered by our studies was equal to 121.

Water supply system in Drelow gmina covers approx. 41.2% of community population. Length of the exist-

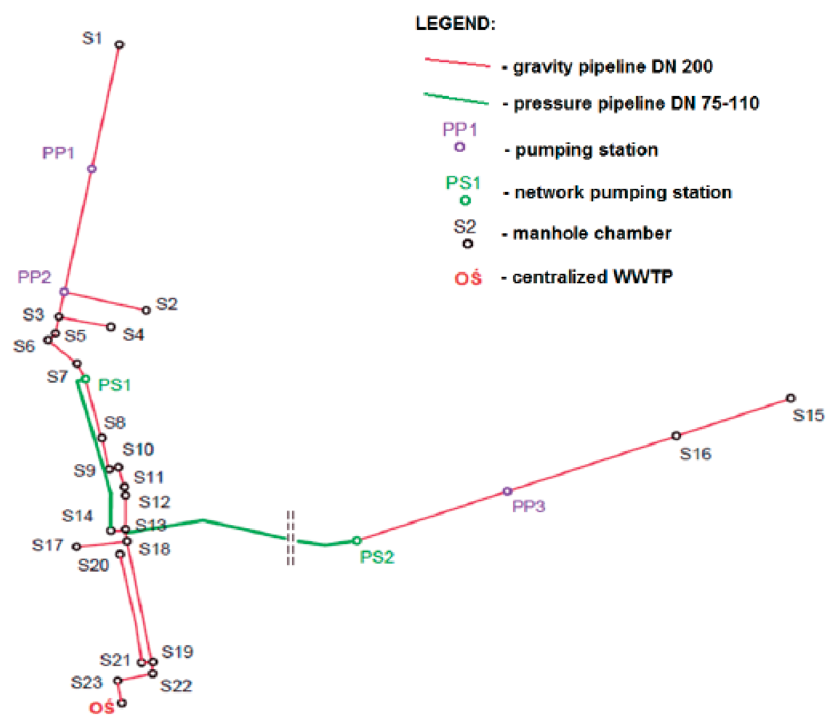

Figure 1.
Scheme of Variant I

ing water supply system was at the end of 2013, according to official data, equal to 106.7 km. Thus, the remaining population of Drelow uses water of unknown and questionable quality (possible high contents of iron and mangane) from individual water intakes. There is no centralized sewerage system operating in Drelow. According to official data of local government, population of the discussed community uses 650 holding septic tanks and 308 septic drainage fields. There are three wastewater treatment plants located in Drelow commune, of total daily capacity equal to 9.6 m^3 per day.

The following public objects are located in area covered by our studies: kindergarten, school (primary and secondary), culture and recreation center, library, social help, several groceries and other shops, bank, post office, pharmacy, council, florist's, health centre, bakery and printing office.

2.2. Variants of analysis

Our analyses were based on three different variants, covering variable possible systems of wastewater removal for selected part of Drelow community.

Variant I

The first variant assumes construction of gravity and pressure sewer system receiving sanitary sewage from 112 households, based on 9 household pumping stations, three network pumping station and one centralized wastewater treatment plant. The total length of gravity pipelines was equal to 4361 m while length of pressure pipelines was 2322 m. Gravity pipelines were designed as DN 200 PVC type S (SN8, SDR 34) with depth of range from 2.0 to 3.95 m. The self-purification velocity of sewage flow was not achieved on most of the gravity pipelines so flushing was advised. Pressure pipelines were designed as DN 75 and DN 100 PE100 SDR 17 (PN10), designed according to land surface inclination at the depth of 1.4 m. Sanitary pump stations were designed as equipped in Wilo – Drain MTS 40 E 20,13/11 and Wilo Drain MTS 40/21. In case of 9 distant households sewage management was designed as based on local WWTPs TRYBIO I and TYRBIO II. The main wastewater treatment plant was designed as container sewage treatment plant BIOBLOK by Biomech, Poland of capacity 400 m^3 per day.

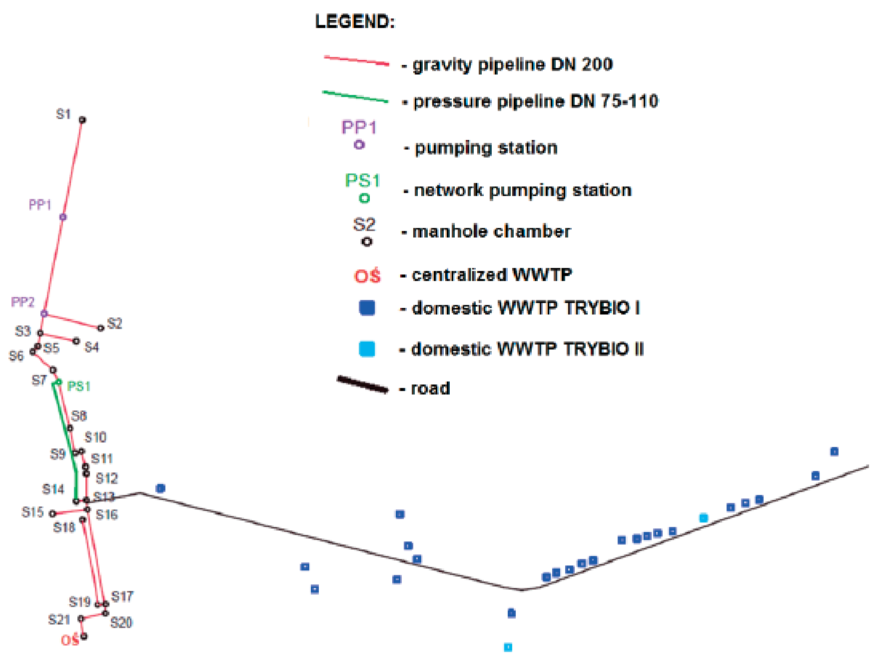

Figure 2.
Scheme of Variant II

Variant II

The second analyzed variant of sanitary sewage system for selected part of Drelow commune was designed as gravity and pressure sewer system receiving sanitary sewage from 95 households and local WWTPs for 26 households. The total length of gravity pipelines was equal to 3107 m while length of pressure pipelines was 476 m. Pipelines of both types, gravity and pressure were designed as in case of Variant I, as DN 200 PVC type S (SN8, SDR 34), DN 75 and DN 100 PE100 SDR 17 (PN10). Designed pumping stations were also equipped in Wilo – Drain MTS 40 E 20,13/11 and Wilo Drain MTS 40/21. Local WWTPs and main WWTP were designed as in Variant I, i.e. TRYBIO I&II, and container sewage treatment plant BIOBLOK by Biomech.

Variant III

The third variant of analyzed possible sewage management system for Drelow settlement covered pressure sewerage system receiving sewers from 121 households and 14 public buildings, supported by 135 household pump stations and 3 network pumping stations. The total length of designed pressure pipelines was equal to 5999 m (with additional 1177 m of pressure connections). Pressure pipelines were designed as DN 63, DN 90 and DN 110 PE80 SDR16 PN10. Designed sewage pumping stations were equipped with Wilo – Drain MTS 40/27. Sanitary sewage were delivered to container sewage treatment plant BIOBLOK by Biomech.

Assumed investment and operation and maintenance costs for all analyzed variants, evaluated in Euro, based on preliminary cost calculations and available unit maintenance cost of several similar investments, are presented in Table 1. The operation and maintenance costs for the each studied variant were based on studied numerous cases of financial reports and water and sewerage costs estimation by local goverments for comparable settlements and assumed type, size and materials of sewerage system. The source data for this estimation were freely available through Public Information Bulletin (BIP, Biuletyn Informacji Publicznej) for each self-governmental commune in Poland.

Table 1.
Investment costs and annual operation and maintenance costs for analyzed variants

Variant	Investment costs (Euro)	Annual operation and maintenance costs (Euro)
I	1 443 170	14 410
II	1 302 364	14 716
III	1 592 647	21 382

2.3. Methodology of studies

The performed multivariate economic analysis of the most suitable variant of sewage management for

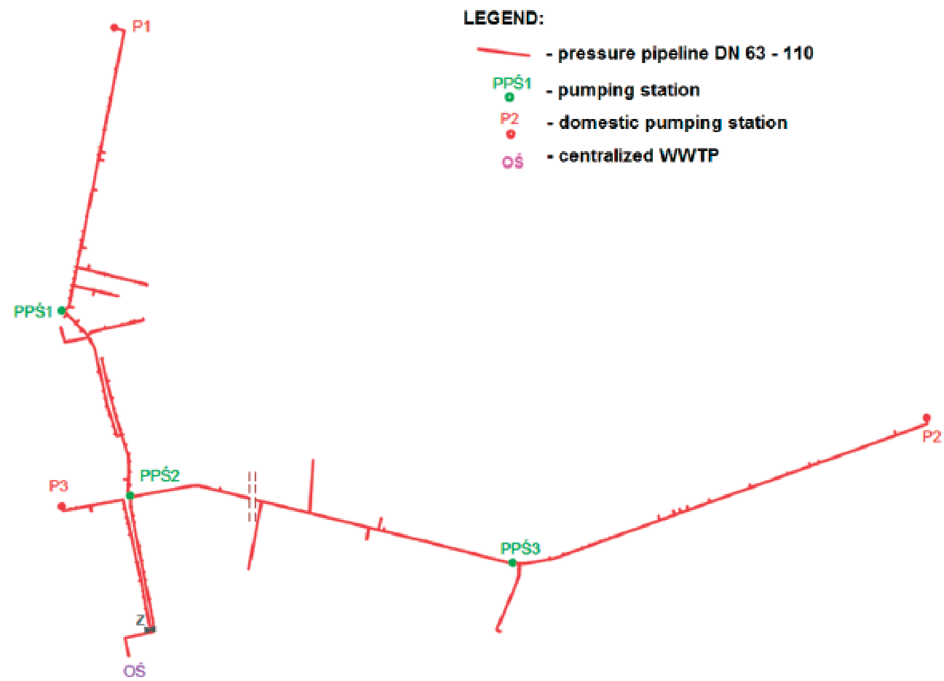

Figure 3.
Scheme of Variant III

selected part of Drelow rural settlement was based on four economic efficiency indicators, one simple and three dynamic: payback period, Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Dynamic Generation Cost (DGC).

The payback period, as the simplest indicator, allowing assessment of investment's economical efficiency was calculated as follows [20]:

$$PP = \frac{1}{RR} \tag{1}$$

where: PP – payback period, (year), RR – investment rate of return, (%).

The rate of return, understood as relation of annual net income and costs of depreciation to total investment costs may be calculated according to [20]:

$$RR = \frac{NI + IC \cdot d}{IC} \tag{2}$$

where: NI – annual net income, (Euro), IC – total investment costs, (Euro), d – depreciation rate, (%).

Net Present Value is a sum of discounted cash inflows and outflows (or benefits and costs) reduced by investment costs [21]. NPV (Euro) for life duration of investment n, including variable value of money (discount rate) may be calculated as follows [e.g. 20]:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \tag{3}$$

where: R_t – net cash flow for a given year (Euro), i – discount rate (%), t – year (-).

Net cash flow for a given year covers sum of investment financial effect, exploitation and investment costs. The positively assessed investment should present NPV value ≥ 0.

Dimentionless Benefit-Cost Rate presents ratio of the benefits of a project, related to its costs in given year.

$$BCR = \frac{PV_b}{PV_c} \tag{4}$$

where: PV_b – present value of benefits, (Euro), PV_c – present value of costs, (Euro).

BCR value of economically profitable investment should be BCR ≥ 1, which corresponds to the value of NPV ≥ 0.

The Dynamic Generation Cost (DGC) indicator presents the price allowing to obtain the discounted revenues equal to the discounted costs so DGC reflects the technical cost of ecological effect. In case of our studies covering sewerage networks the considered ecological effect may be applied as volume of transported/treated sewage, thus the unit of DGC will be Euro per m^{-3}. The DGC value may be calculated according to the following formula [e.g. 22]:

$$DGC = p_{EE} = \frac{\sum_{t=0}^{t=n} \frac{IC_t + EC_t}{(1+i)^t}}{\sum_{t=0}^{t=n} \frac{EE_t}{(1+i)^t}} \quad (5)$$

where: IC_t – investment cost in given year, (Euro), EC_t – exploitation cost in given year, (Euro), t – year of investment operational time from 0 to n, the last year of investment activity, i – discount rate, (%), p_{EE} – price of ecological effect unit, (Euro m^{-3}), EE_t – ecological effect in given year, (m^3).

The cost analysis based on DGC method applied covers the whole period of investment operation, so application of the different values of investment and operation and maintenance costs as well as ecological effects and generated incomes, in subsequent years is possible. The method is based on discounted costs so, the changes in value of money is reflected in the analysis. Thus, DGC method is easily intelligible for designers, decision makers and authorities or representatives of local societies/governments because it shows the technical costs of investments presented in the popular, easily understandable values and units. Application of DGC indicator to investment assessment is rather easy. The rule is obvious and simple: the lower value of DGC, the more acceptable economically investment is [23-27].

On the other hand, DGC does not reflect the actual price of service (water supply, sewage treatment, solid wastes disposal and management) and should not be used in productivity assessment of the assessed investment.

The above presented values of simple and combined economic efficiency indicators were applied to the simple and well known weighted sum model (WSM). The point values and criteria for all tested indicators were assumed, then the sum model was calculated according to the following formula [e.g. 28, 29]:

$$WSM = \sum_{i=1}^{k} w_i \cdot a_i \quad (6)$$

where: w_i – value of i criterion, a_i – performance point value for i criterion.

3. RESULTS

Table 2. presents calculated results of applied simple and combined economic efficiency for all three analyzed variants of sewage removal and management systems for rural settlement Drelow. It is visible that the payback period of all three variants is very long, comparable to assumed duration of analyzed period, i.e. 26.3-29.4 years. The calculated NPV value for all tested variants was lower than 0, thus the proposed variants of technically developed systems of sewage management were economically unprofitable. The same situation may be observed during analysis of BCR values, in all tested cases BCR were in range between 0.3 and 0.33, thus calculated BCR values were less then 1. The obtained DGC values showed that the lowest value of unit ecological effect was possible for the simplest Variant I. Thus, the more developed technically and technologically sewage removal and management system was proposed, the greater value of ecological effect cost was observed.

Table 2.
Values of economic indicators for 30 years of investment operation

Variant	Payback Period [yr]	NPV [Euro]	BCR [-]	DGC [Euro m^{-3}]
I	26.3	-1233545	0.33	5.41
II	27.5	-1177896	0.31	5.86
III	29.4	-1557511	0.30	5.89

The following performance points values were assumed for weighted sum model: 1 point – the less favorable variant; 2 points – intermediate variant; 3 points – the most favorable variant.

The required point value (used in our WSM analysis) for all considered economic variables are presented in Table 3.

Table 3.
Point values of economic variables assumed for calculation

Indicator	Criterion wage [%]
PP	20
NPV	20
BCR	20
DGC	40

The resultant matrix of point criterion values and weighted sum are presented in Table 4.

Table 4.
Matrix of point criterion values and weighted sum

Variant	Tested indicator point value				WSM
	PP	NPV	BCR	DGC	
I	3	2	3	3	**2.8**
II	2	3	2	2	2.2
III	1	1	1	1	1

Thus, according to results of Weighted Sum Model performed for the four applied simple and combined indicators of economic efficiency, the most suitable, among the three proposed, variant of sewage removal and management for Drelow settlement was Variant No I covering gravity and pressure sewer system supported by centralized wastewater treatment plant. This variant had the most favorable values of most of applied indicators, i.e. the shortest PP, the biggest BCR (the closest to 1.0) and the lowest DGC. Therefore, the differentiation of three tested variants of wastewater removal and management designed according to the actual engineering knowledge, using the up to date materials and technologies as well as offering the same ecological effect was possible. However, it should be strongly underlined that all of the tested designs were ineffective economically. So, construction and future operation may be a serious financial burden for a small rural community.

4. CONCLUSIONS

The performed analysis of economic efficiency of proposed three variants of sewage removal and treatment system of selected rural settlement (Drelow, Poland) allowed to present the following conclusions:

1. Each of applied indicators allows to assess, more or less accurate, economic efficiency of the tested investment, already at the designing stage.
2. Variant No I, covering gravity and pressure sewer system supported by centralized wastewater treatment plant, was assumed as the most accurate, according to results of WSM and the most favorable values of several tested indicators, including the lowest unit cost of ecological effect.
3. It was also noticed that none of the tested designs was effective economically.
4. In case of long-term investments, such as sewerage systems, combined indicators of economical efficiency, including variable value of money (discount rate), should be preferred to simple indicators.
5. Contrary, simple economic indicators may be useful in case of quick and preliminary assessment of the investment, without taking time into consideration.
6. Application of DGC method is reasonable in decision-making when selection of one, the most favorable variant from a larger group (at least two) is required.
7. Decision-making models, based on economic efficiency indicators, seems to be very useful in selection of the most favorable variant of environmental investment based on the similar level of technical development and offering comparable, or the same, ecological effect.

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